Currency Stability Using Blockchain Technology

Bryan Routledge
Tepper School of Business
Carnegie Mellon University

Ariel Zetlin-Jones
Tepper School of Business
Carnegie Mellon University

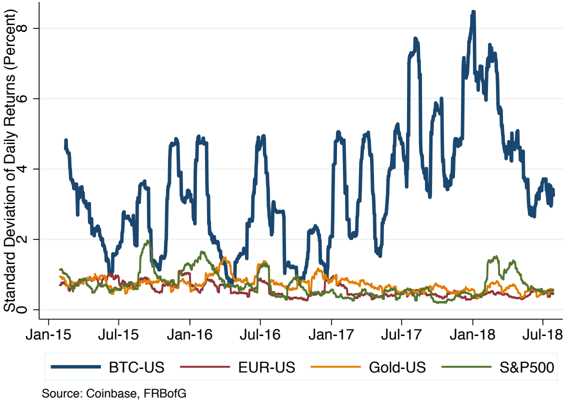
August 10, 2018

Motivation

- Tokens used a means of payment central component of most blockchain technologies
  - Bitcoin: means of payment primary purpose
  - Many others: “utility token” used to perform transactions on the blockchain
- To date, existing crypto-currencies too volatile to be effective medium of exchange or store of value

Price Instability with Current Cypto-Currencies

- Crypto-currencies have been too volatile to be used as money



- BTC order of magnitude more volatile than *EUR*, Gold, SP500

This Paper

- Currency stability challenging, even with exchange rate peg
  - If not 100% backed, peg vulnerable to self-fulfilling attacks
  - Exchange rate pegs admit multiple equilibria as in Obstfeld (1996)
- We develop new theory of pegs with less than 100% backing
  - Show optimal exchange rate policy necessarily dynamic
  - Exchange rate adjusts (optimally) to trade requests
  - Optimal, gradual exchange capture much of stability of traditional peg, but immune to speculative attacks
    - Ex post exchange rate depreciations (under pressure) unwind ex ante incentives to speculate (as reduced convertibility in Green and Lin (2003) eliminates ex ante incentives to run)

Why Blockchain Matters

- Theory is agnostic to the currency involved
  - Applies equally well to government issued fiat as to blockchain crypto-currency
  - Theory shows how to resolve Obstfeld (1996) multiplicity "problem"
- Blockchain important primarily for implementation
  - Optimal policy depends on real-time currency demand
  - Specifying/communicating such a policy difficult (moral hazard)
  - We use "smart contracts"—rich, state-contingent contracts verified and credibly enforced by an irreversible distributed ledger blockchain—to implement the optimal exchange rate policy (in progress)

Related Literature

Exchange Rate Stability

- Krugman (1979), Obstfeld (1996), Morris and Shin (1998), Chang and Velasco (2000)

Suspension of Convertibility

- Diamond and Dybvig (1983), Green and Lin (2003), many others

Existing Crypto-currency Stable-Coins (and white papers)

- Tether, TrueUSD, Bridgecoin, Dai, NuBits, Nomin, Basecoin, Carbon, USD Fragments, AAA Reserve Currency

▸ More on Stablecoins

Example: Using State Contingent Policy to Eliminate Speculative Attacks

Model Environment

- Two periods, $t = 0, 1$
- Continuum (measure 1) of traders each own 1 Crypto-Peso
- Each trader is of type $\theta \in \{C, F\}$ (*Crypto, Foreign*)
  - *Crypto* traders care about period 1 consumption in (mostly) Crypto-Peso currency goods
    - Crypto traders are potential *speculators*
  - *Foreign* traders care about period 0 consumption in foreign currency goods
  - $Prob(\theta = C) = \mu_C$, i.i.d. across traders
- Let e_t denote the period t USD price of Cypto-Pesos

Actions and Payoffs

- **Foreign** traders' action set in period 0: $\{attack\}$

- Attacking yields utility: $u(e_0)$

- Foreign traders, endowed with 1 crypto-peso, require immediate conversion into foreign reserves

Actions and Payoffs

- **Crypto** traders' action set in period 0: $\{wait, attack\}$
- Waiting yields utility: $u\left((1-\lambda)e_1+\lambda\right)$
  - $\lambda \equiv$ exogenous fraction of period 1 pesos spent on on foreign goods
- Attacking yields utility

$$u\left(\underbrace{[(1-\lambda)e_1+\lambda]}_{\text{Consump. per Crypto-Peso}}\underbrace{\left[\frac{e_0}{e_1}-t\right]}_{\text{Spec. Profit}}\right)$$

  - Convert Crypto-Peso to USD in period 0 at rate e_0
  - Convert USD back into Crypto-Pesos in period 1 at rate e_1
  - Fixed, round-trip transaction cost $t > 0$

The Currency Board and Obstfeld Policies

- Currency board sets policy with initial USD reserves R_0

Definition (Limited Contingency Policies)

A *limited contingency policy* converts crypto-pesos to USD at a fixed rate e_0 as long as feasible. When not feasible, converts fraction of demand uniformly at e_0.

- Restrict attention to *limited contigency* policies (Obstfeld (1996)):
  - If total conversion demand, x satisfies $xe_0 < R_0$, convert at e_0
  - If $xe_0 > R_0$, convert as much as feasible uniformly, allow exchange rate to float at e_f after
    - Implies each of x demand convert $y = R_0/(xe_0)$ at e_0
    - Think of e_f as small implying Crypto-peso "overvalued"
    - Can think of e_f as priced by abitrageurs

Optimal Limited Contingency Policy

- Currency board using limited contingency policies solves

$$\max_{e^0,e^1}(1-\mu_C)u(e_0)+\mu_C u((1-\lambda)e_1+\lambda)$$

subject to

$$\begin{aligned}(1-\mu_C)e_0 &\leq R_0\\ (1-\mu_C)e_0+\mu_C(1-\lambda)e_1 &\leq R_0\end{aligned}$$

and the no-speculation incentive constraint,

$$u\left((1-\lambda)e_1+\lambda\right)\geq u\left(\underbrace{[(1-\lambda)e_1+\lambda]}_{\text{Cons. per Crypto-Peso}}\underbrace{\left[\frac{e_0}{e_1}-t\right]}_{\text{Spec. Profit}}\right)$$

Optimal Obstfeld Policy

- Since currency board exhausts reserves in period 1, if incentive constraint slack, then optimal e_0 satisfies

$$u'(e_0) = u'\left(\frac{R_0 - (1-\mu_C)e_0}{\mu_C} + \lambda\right)$$

or

$$e_0^* = R_0 + \mu_C \lambda$$

- This policy is incentive-feasible if $(1-\mu_C)e_0^* \leq R_0$ and

$$(1-\lambda)e_1^* + \lambda \geq [(1-\lambda)e_1^* + \lambda]\left[\frac{e_0^*}{e_1^*} - t\right]$$

or

$$\frac{e_0^*}{e_1^*} \leq 1 + t.$$

Obstfeld Policies and Multiplicity

Proposition (Optimal Obstfeld Policies and Multiplicity)

If $(1-\mu_C)\lambda \leq R_0$ and λ sufficiently close to 1, then the optimal, incentive-feasible Obstfeld policy satisfies

$$e_0^* = R_0 + \mu_C\lambda, \quad e_1^* = \frac{R_0 - (1-\mu_C)\lambda}{1-\lambda}.$$

Moreover, if e_f sufficiently small, then this policy admits another equilibrium where all crypto traders speculate.

Proof of multiplicity:

- Conjecture equilibrium where all crypto traders demand conversion
- Since $e_0^* > R_0$, currency board will run out of reserves and exchange rate will float
- Consumption from speculating:

$$\left[(1-\lambda)e_f + \lambda\right]\left[\frac{e_0^*}{e_f}y + 1 - y - t\right], \text{ where } y = R_0/e_0^*$$

- For e_f sufficiently small, speculation is worthwhile

Optimal, Contingent Policies

- Consider next *fully contingent* policies:
  - Let x denote total demand for USD in period 0
  - A *contingent policy* is $e_t(x)$
- An obvious policy that is immune to speculative attacks:

$$e_0(x) = \begin{cases} e_0^* & \text{if } x = (1-\mu_C) \\ e_f & \text{if } x \neq (1-\mu_C) \end{cases}, \quad e_1(x) = \begin{cases} e_1^* & \text{if } x = (1-\mu_C) \\ e_f & \text{if } x \neq (1-\mu_C) \end{cases}$$

Contingent Policies

Proposition (Contingent Policies and Uniqueness)

There exist contingent policies that uniquely implement the efficient exchange rate policy.

Example very stylized

- Assumes total demand observed before setting exchange rates
- No sequential service constraints (not in Obstfeld (1996) either)
- Assumes no risk in foreign vs crypto currency demand; too stark for crypto-currencies
- Next, relax these assumptions

Efficient, History-Contingent Exchange Rate Protocols

A Finite Trader Economy

Two model modifications:

- Finitely many traders, J
  - $d_0^j \equiv$ report of trader j ($d_0^i = 1$ implies foreign)
  - $D_0^j = (d_0^1, \ldots, d_0^j)$
- Policies respect sequential service:
  - $e_0^j(D_0^J) \equiv$ history-contingent exchange rate offered to trader j
  - Sequential service: $e_0^j(D_0^J)$ measurable with respect to D_0^j
- These changes imply model is subject to aggregate risk
  - Interpret this risk as aggregate shock to demand for crypto-pesos
  - Risk indistinguishable (for currency board) from speculative attack

Policies and Objectives

Optimal policy solves

$$\max \mathbb{E} \sum_{j=1}^{J} \left[d_0^j u(e_0^j(D_0^j)) + (1 - d_0^j) u\left((1-\lambda) e_1(D_0^J) + \lambda \right) \right]$$

subject to the reserve transition equations

$$R_0^j(D_0^j) = R_0^{j-1}(D_0^{j-1}) - d_0^j e_0^j(D_0^j)$$

the feasibility constraints

$$\forall j \in \{1, \ldots, J\} \text{ and } D_0^{j-1}, \quad e_0^j(D_0^j) \leq R_0^{j-1}(D_0^{j-1})$$

$$\forall D_0^J, \quad (1-\lambda) e_1(D_0^J) \sum_{j=1}^{J} (1 - d_0^j) \leq R_0 - \sum_{j=1}^{J} d_0^j e_0^j(D_0^j)$$

and the incentive constraints

$$\forall D_0^j, \quad \mathbb{E}\left[u\left((1-\lambda) e_1(D_0^J) + \lambda \right) \middle| D_0^j \right] \geq \mathbb{E}\left[u\left(\left[(1-\lambda) e_1(\hat{D}_0^J) + \lambda \right] \left[\frac{e_0^j(\hat{D}_0^j)}{e_1(\hat{D}_0^J)} - t \right] \right) \middle| D_0^j \right]$$

Finding Optimal Policies

- Conjecture (and later verify) incentive constraints are slack
- Policy determined as solution to straightforward dynamic programming problem
- State variables:
  - $\Theta \equiv$ sum of previous "crypto" reports
  - $R \equiv$ remaining reserves
- Period 1:

$$W(\Theta; R) = \max_{e \leq R/[\Theta(1-\lambda)]} \Theta u\left((1-\lambda)e + \lambda\right) = \Theta u\left(\frac{R}{\Theta} + \lambda\right)$$

- Period 0, trader j:

$$V_0^j(\Theta; R) = \max_{e \leq R}(1-\mu_C)\left[u(e) + V_0^{j+1}(\Theta; R-e)\right] + \mu_C V_0^{j+1}(\Theta+1; R)$$

where $V_0^{J+1}(\Theta; R) = W(\Theta; R)$

An Analytically Tractable Case

A Tractable Case

- Suppose $J = 3$ and $u(x) = -\exp(-\alpha x)$

- Straightforward to solve (by hand) dynamic program assuming incentive constraints slack

- Will show:
  - As $\lambda \to 1$ and $\mu_C \to 1$, not speculating a *dominant* strategy
  - Implies optimal policy admits a unique (no speculation) equilibrium

- Key feature of optimal policy for proof:
  - Government retains reserves if any traders report they are crypto
  - Period 1 exchange rate satsfies:

$$e_1(\Theta; R) = \begin{cases} \frac{R}{\Theta(1-\lambda)} & \text{if } \Theta \geq 1 \text{ \& } \frac{R}{\Theta(1-\lambda)} \geq e_f \\ e_f & \text{otherwise} \end{cases}$$

  - Implies as $\lambda \to 1$, traders expect large *appreciation* unless government out of reserves

Incentive Compatibility

- Incentives for Trader 3 require

$$(1-\lambda)e_1(\Theta+1;R)+\lambda \geq \underbrace{\left[(1-\lambda)e_1(\Theta;R-e_0^3(\Theta;R))+\lambda\right]}_{\text{Consump. per Crypto-Peso}} \underbrace{\left[\frac{e_0^3(\Theta;R)}{e_1(\Theta;R-e_0^3(\Theta;R))}-t\right]}_{\text{Spec. Profit}}.$$

- When $\Theta \geq 1$, last trader knows government will retain reserves to period 1
- $\lambda \to 1 \Rightarrow$ trader expects *appreciation* $\Rightarrow$ speculation not profitable
- If e_f not too small, speculation also not profitable when $\Theta = 0$
- Implies independent of previous players strategies, not speculating dominant strategy for Trader 3
- Also implies can use objective probability Trader 3 is crypto to evaluate incentives for Trader 2

Incentive Compatibility

- In case $\Theta = 0$ (interesting case), incentives for Trader 2 require

$$(1-\mu_C)u\left((1-\lambda)e_1(1;R_1-e_0^3(1;R_1))+\lambda\right)+\mu_C u\left((1-\lambda)e_1(2;R_1)+\lambda\right)$$
$$\geq (1-\mu_C)u\left(\left[(1-\lambda)e_f+\lambda\right]\left[\frac{e_0^2(0;R_1)}{e_f}-t\right]\right)$$
$$+\mu_C u\left(\left[(1-\lambda)e_1(1;R_3)+\lambda\right]\left[\frac{e_0^2(0;R_1)}{e_1(1;R_3)}-t\right]\right)$$

where $R_3 = R_1 - e_0^2(0;R_1)$

- As $\lambda \to 1$, if trader 3 is crypto, trader 2 expects *appreciation*
- But if trader 3 is foreign, trader 2 expects *depreciation* (e_f small)
- As $\mu_C \to 1$, Pr(exchange rate floats) $\to 0$
- As $\lambda \to 1$ and $\mu_C \to 1$, truth-telling dominant for trader 2 (similar idea for trader 1)

Optimal Policy Admits Unique Equilibrium

Proposition (Finite Complex Policies and Uniqueness)

For λ and μ_C in a neighborhood of $\lambda = \mu_C = 1$ and $1 + t \geq R_0[\frac{1}{e_f} - 1]$, the efficient exchange rate policy is incentive compatible. Moreover, truth-telling, or no speculation is the unique equilibrium.

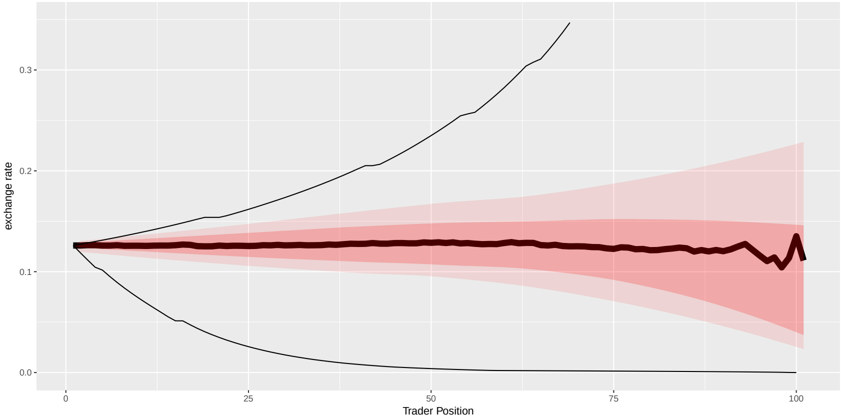
- Have shown optimal exchange rate resembles a peg
- Optimal policy is immune to (purely) speculative attacks
- Optimal policy tolerates some currency appreciation or depreciation

Optimal Policy in Large Economies

Policy in Large Economies

- Model emphasizes speculative motives between e_0^j and e_1
- Our aim is implementation via blockchain $\Rightarrow$ real-time dynamics (e.g. e_0^j vs e_0^{j+1}) interesting
- Today:
  - Solve optimal policy in large economies
  - Explore key features of optimal policy:
    - When to appreciate/depreciate? how much?
    - Dynamic incentives? (in progress)
  - Parameterization:
    - $J = 100, \mu_C = 0.85, \lambda = 0.98, t = 0.01, R_0 = 2$
    - Generates mild depreciation in Period 1

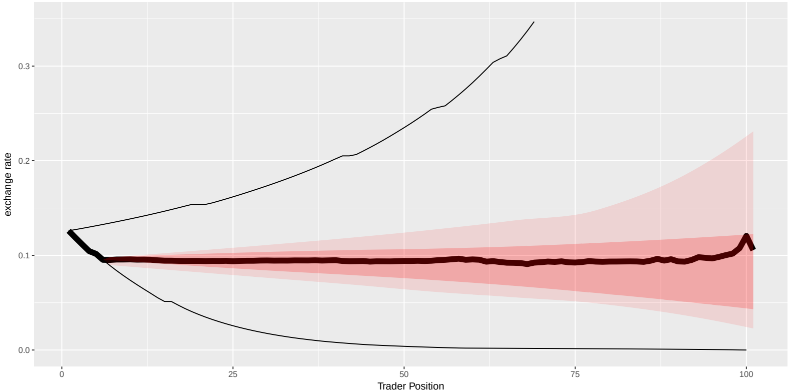
Optimal Exchange Rate Policy



- Mean policy resembles an exchange rate peg

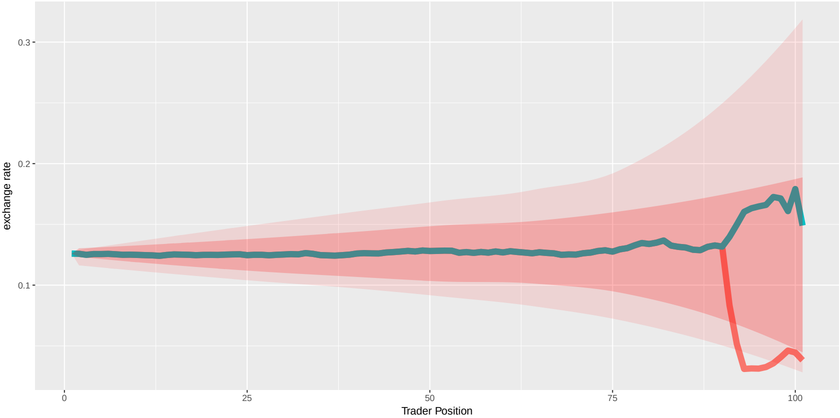
Optimal Exchange Rate Policy

- Policy is incentive compatible (via same backwards induction argument)



- Policy eliminates speculative equilibria (additional volatility)
- Outcomes independent of floating rate, e_f (within a window)
- Policy successfully eliminates additional sources of volatility

Optimal Exchange Rate Policy: Comparative Statics



- Consider impact of “rare” event: Traders 90-92 all report $\theta = F$
- Use of reserves induces depreciation of the currency Policy reacts more aggressively to late “shocks”

Next Steps

- Check dynamic incentives *within* period 0
- Simulation on Ethereum's test network (in progress)
  - Policy and traders' strategies easy to implement as smart contracts
  - Smart contracts: software code (solidity) that implements state-contingent transfers of crypto-currency based on publicly observable (and defined) states
- Simulate transaction costs associated with complex, history-contingent policies
  - More complicated smart contracts require more "gas"/transaction costs to implement
  - Simulations useful to benchmark costs of averting speculative attacks
- Explore implementation without centralized control of reserves

Conclusions

- Developing protocol to issue to stable USD price crypto-currency with limited USD reserves
- Protocol requires history contingent USD reserve exchange policy
- Such policies implementable in transparent manner on blockchain ledger with smart contracts (as on Ethereum's network)

Appendix Slides

Existing Stable Coins

Currently, three classes of stable (cyprto)-coins

- 100% USD Reserve backed coins (Tether, TrueUSD)
  - Costly way to implement stability
- Protocol coins without redemption (Bridgecoin, Dai, NuBits, Nomin)
  - Users post collateral in exchange for stablecoin
  - If price of stable-coin were to fluctuate, users incentivized to redeem collateral or sell stable-coins
  - Requires over-collateralization to avoid margin risks
- Protocol coins with redemption in floating-rate crypto-currencies (Basecoin, Carbon, USD Fragments)
  - Stability dependent on stability of floating-rate coin

Back to Literature