What Keeps Stablecoins Stable?

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First version: December 21, 2019 (posted SSRN)

This version: May 3, 2020

Abstract

We take this question to be isomorphic to, "What Keeps Fixed Exchange Rates Fixed?" and address it with analysis familiar in exchange-rate economics. Stablecoins solve the volatility problem by pegging to a national currency, typically the US dollar, and are used as vehicles for exchanging national currencies into non-stable cryptocurrencies, with some stablecoins having a ratio of trading volume to outstanding supply exceeding one daily. Using a rich dataset of signed trades and order books on multiple exchanges, we examine how peg-sustaining arbitrage stabilizes the price of the largest stablecoin, Tether. We find that stablecoin issuance, the closest analogue to central-bank intervention, plays only a limited role in stabilization, pointing instead to stabilizing forces on the demand side. Following Tether's introduction to the Ethereum blockchain in 2019, we find increased investor access to arbitrage trades, and a decline in arbitrage spreads from 70 to 30 basis points. We also pin down which fundamentals drive the two-sided distribution of peg-price deviations: Premiums are due to stablecoins' role as a safe haven, exhibiting, for example, premiums greater than 100 basis points during the COVID-19 crisis of March 2020; discounts derive from liquidity effects and collateral concerns.

Keywords: Cryptocurrency, stablecoins, fixed exchange rates, monetary policy, intervention

JEL Classifications: E5, F3, F4, G15, G18

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Introduction and Motivation

Benefits of cryptocurrencies include ubiquitous ledgers and transparent updating, where payments are verified and recorded without need for centralized settlement. A major drawback is their volatility, with Bitcoin (BTC) volatility relative to the US dollar (USD) being roughly 10 times that between the major national currencies (Yermack, 2015). This led to the introduction of stablecoins, most of which peg to the USD. By maintaining a collateralized peg, this category of cryptocurrency is much less volatile, and is used as a store of value and medium of exchange in the digital-asset economy. The role of stablecoins has risen dramatically in the last two years, with estimates of total trading volume between Bitcoin and Tether, the stablecoin in largest supply, exceeding the trading volume of Bitcoin/USD in 2019.[1]

At first glance, it is not clear why there is so much demand for stablecoins as a vehicle currency given that the dollar itself could serve directly for rebalancing portfolios. There are institutional features, however, that induce investors to use stablecoins. The first is added intermediation costs when trading cryptocurrencies for dollars. On some exchanges, for example, there are longer processing lags for dollar withdrawals. Fees are also often imposed when dollar withdrawals are frequent or large.[2] A second institutional feature favoring stablecoins is their usability across a greater cross-section of crypto exchanges: Of the exchanges that have "trusted volume" according to a report filed with the SEC, two of them, Binance and Poloniex, do not provide investors with any on-ramp for trading dollars, and only accept stablecoins as a medium of exchange.[3]

Exchange-rate pegs have a long history both in practice and in exchange-rate economics. A example is the Hong Kong dollar (HKD) peg to the USD managed through a currency-board system since 1983 by the Hong Kong Monetary Authority. The large literature on national-currency pegs addresses whether they are vulnerable to attack depending on, for example, macroeconomic fundamentals such as interest rates and inflation, and whether the peg is sufficiently backed by reserves.[4] A key lesson in this literature is the importance of the institutional/policy regime for ensuring credibility, in part through management of foreign exchange

[1]https://econ.st/2NSR5Q6.

[2]For more information, refer to the following announcements by Bitfinex: https://bit.ly/2NEzITW and https://www.bitfinex.com/posts/311. Bitfinex states it takes investors 7 to 15 days to make dollar withdrawals from their platform in order to comply with intermediation procedures. Bitfinex has also introduced a transaction cost of 3% for investors who make more than two dollar withdrawals a month, or for withdrawals of more than $1 million in a given month.

[3]For a report on trusted exchanges, see https://www.sec.gov/comments/sr-nysearca-2019-01/srnysearca201901-5164833-183434.pdf.

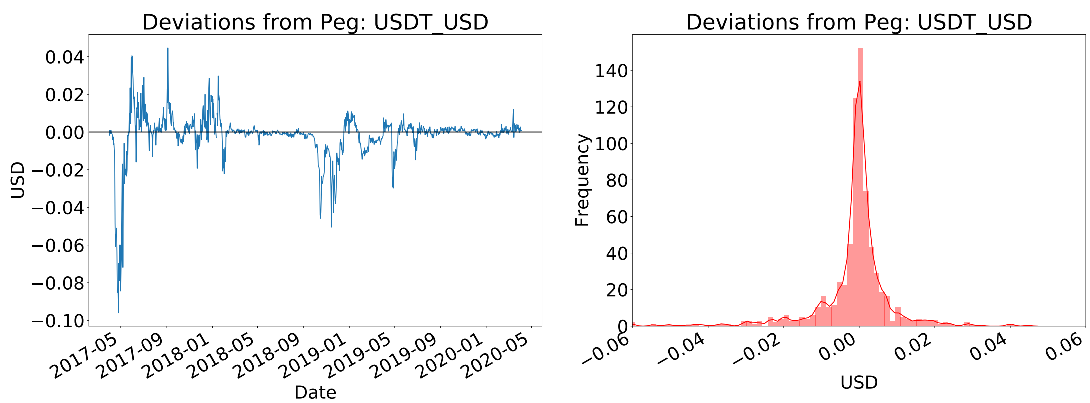
[4]Note our use of the adjective "national-currency" rather than "fiat." We dislike the term fiat for describing national currencies when contrasting them with cryptocurrencies. Wikipedia, for example, offers a two-part definition of a fiat currency as being i) without intrinsic value and ii) established as money often by government decree. Bitcoin is certainly fiat with respect to the first of these defining dimensions, so calling the USD fiat and BTC not fiat is misleading.

reserves.

There are currently two types of stablecoin depending on the backing collateral: national-currency backed and cryptocurrency backed.[5] The two types employ different systems for maintaining the peg. Here we focus on the design of national-currency-backed stablecoins, and focus specifically on Tether (USDT), the most liquid and heavily traded of the stablecoins, with a market cap of $4.1 billion in late 2019, accounting for nearly 80 percent of the total market cap of the stablecoin market.

A key difference between a national-currency peg and a stablecoin peg is that the distribution of stablecoin price deviations is two-sided (Figure 1).[6] While typically national currencies pegged to the dollar trade at a discount due to the risk of mismanagement by the central bank, it is more difficult to rationalize why stablecoins so frequently trade at a premium.

Figure 1: Tether/USD Deviations from Peg and Histogram of Deviations



Note: Figure plots the deviations of the Tether/USD price from parity (left panel). A positive deviation indicates Tether/USD trades at a premium. The right panel indicates a histogram of deviations of the Tether/USD peg. Data from Coinapi. Sample is April 2017 to March 2020.

We develop a model of stablecoin prices that generates a two-sided distribution and examine its other testable implications. In the framework, an investor chooses to invest in a risky cryptoasset using dollars, stablecoins, or both. The investor's relative demand for each vehicle currency is dependent on the relative ease with which they can transact in cryptocurrency. By imposing an increased intermediation cost for using dollars, the model describes how the stablecoin trades at a premium due to its relative benefit as a vehicle. The model also includes arbitrageurs who trade against peg deviations, which in turn stabilizes prices around the peg. For example, if the stablecoin trades at a premium then they have an incentive to buy stablecoins from the primary-market issuer at parity, and sell them in the secondary market for a profit.

[5]A third type is not backed at all by collateral. We omit this type from our analysis – they are viewed skeptically by academics and industry analysts alike; see Eichengreen (2019) for more details.

[6]Plots of peg-price deviations for other major stablecoins are provided in the appendix C.

We then test the model predictions empirically. The first question we answer is how national-currency-based stablecoins maintain stability of the peg. In a conventional fixed-exchange-rate regime, a central bank stands ready to use its foreign reserves to exchange for domestic currency in the event there are persistent deviations from the peg. When the domestic currency's value trades below the peg, the central bank reduces the supply of domestic currency by selling foreign reserves. The stability mechanism is thus supply driven in the case of a central-bank-managed peg. Empirically, we do not find evidence of this stabilizing mechanism on the supply side; it is the demand side instead, the trades of apparent arbitrageurs, that stabilizes price around the peg.

In the case of Tether, each unit is purportedly backed fully by USD reserves.[7] In the event of a mass Tether liquidation, the Tether Treasury would be able in principle to draw down its reserves and still maintain the peg. Under this system, Tether supply would be dependent on investor demands, with supply increasing when investors decide to deposit USD with Tether Inc, and falling when investors reclaim dollar deposits, which withdraws Tether from circulation. To illustrate how arbitrage trading maintains the peg, suppose the Tether/USD price in the market falls below the peg at 1. Private investors can buy Tether at that price and sell those Tether to the Tether Treasury at the rate of 1 Tether/USD. Both legs of this arbitrage put endogenous, upward pressure on the Tether price toward the one-to-one parity. (The selling of Tether to the Treasury is a reduction of the supply in circulation.) If alternatively the Tether price of USD rises above 1, private investors can sell USD to the Tether Treasury, obtaining in return Tether at one-to-one, which they then sell into the market at the prevailing higher rate. Again, both legs put pressure on the market price toward parity, in this case downward. For stablecoins to remain stable, they depend on these mechanisms to operate when the market rate deviates from the target peg.

We test these mechanisms in two ways. First, to obtain data on Tether issuance we use data from the two platforms Omni Explorer and Etherscan, which contain an entire history of transactions, and classify transactions between senders and recipients of Tether. Transactions are classified as "simple send" (transactions between two wallets), "grants" (creation of new tokens)," or "revokes" (redemptions of tokens). We use this to construct net flows from the Tether Treasury to the secondary market. The second dataset is Coinapi, which provides transaction and order-book data on stablecoin currency pairs with respect to the USD for multiple crypto exchanges. This dataset provides the timestamp of each trade, together with the price and amount of the underlying Tether in each trade, and a true-or-false variable *taker side sell* which we use to sign each transaction according to the direction of the trade's initiator. Using this rich dataset, we construct issuance flow using recorded trades between the Tether

[7] This is similar to the operation of the Hong Kong Currency Board, in which the central bank maintains dollar reserves to match every Hong Kong dollar in circulation.

Treasury and investors.

To test our hypothesis of investor-driven flows stabilizing the peg, we exploit a pseudo natural experiment: The April 2019 introduction of Tether on the Ethereum blockchain. This resulted in a large increase in investor access to the Tether Treasury, made possible by the reduced transaction costs of operating on the Ethereum blockchain.[8] Following this event, we do observe a significant increase in the number of unique addresses transacting with the Tether Treasury. Consistent with our hypothesis, we also find a significant decline in the size of price deviations of the peg and a decline in the half-life of deviations from 6 days to 3 days. We then construct estimates of arbitrage spreads and imputed profits of investors that deposit dollars with the Tether Treasury. We find that Tether's introduction to the Ethereum blockchain coincides with a decrease in the average size of arbitrage trades from $7 to $4 million, and a decline in arbitrage spreads from 70 to 30 basis points. We also find that arbitrage flows to the secondary market have a stabilizing impact on the Tether price, with a one standard deviation change in net flows causing a decline in the deviation of Tether's price from the peg by up to 10 basis points.

We then test hypotheses regarding which fundamentals drive peg deviations. This follows a literature on national-currency pegs, e.g. Eichengreen et al. (1994), in which deviations of pegs are due to either macroeconomic fundamentals (such as interest rates misalignments, current account deficits, government deficits, or high inflation) or insufficient reserves. Analogously, we can test which fundamentals impact pricing of stablecoins. The first (proximate) fundamental we examine is order flow, which is the net of buyer-initiated trades less seller-initiated trades in the Tether-Dollar pair in the secondary market.[9] We use order-book data across multiple crypto exchanges, and find evidence that order flow is significant for price discovery in the secondary market, with a positive shock to net buyer-initiated flows to the secondary market causing an increase in the dollar price of Tether: One percent change in price per roughly $40 million in net order flows. We then examine fundamentals such as the intensity of trading of Bitcoin. We find that on average an increase in the volatility of Bitcoin trading has a positive effect on the Tether price. This is evidence that Tether, and other stablecoins, serve as safe havens in the domain of cryptoassets. This effect is particularly pronounced in turbulent periods. For example, when the price of Bitcoin crashed in January of 2018, the Tether price averaged a premium of 5 cents. Investors rebalanced their portfolios by liquidating their Bitcoin holdings into Tether during this period. In another example, Bitcoin crashed by 40% overnight during the COVID-19 economic shock. As investors rebalanced their portfolios toward a store of value,

[8]For more information on the event, we refer readers to https://www.prnewswire.com/news-releases/huobi-global-offers-deposit--withdrawal-in-tether-erc20-300803113.html.

[9]Identifying the direction of a trade's initiation is crucial for getting the information economics right: all trades have a buyer and a seller – the informational "news" is in the direction of the initiator/aggressor.

we find increases in stablecoin premiums during this period as well.

Finally, we conclude with a case study of a speculative attack on Tether in October of 2018. In this episode, speculators were uncertain whether Tether was fully collateralized, due to a move by its partner exchange Bitfinex to suspend convertibility of dollar deposits. The Bitfinex exchange is responsible for investing the majority of USD deposits with the Tether Treasury. A risk of the Treasury being under-collateralized poses a systemic risk to the Bitfinex exchange. In response to this event, we find a decline in the USD price of Tether, a rise in the volatility of trading volume in Tether, and a rise in bid-ask spreads.

Turning to related literature, there are many studies of how fundamentals determine fixed exchange rates, such as relative money supplies and interest rates, capital flows, financial frictions, and commodity prices (Eichengreen et al., 1994; Engel and West, 2005; Gabaix and Maggiori, 2015; Itskhoki and Mukhin, 2017; Chen and Rogoff, 2003). Eichengreen et al. (1994), for example, show that macroeconomic factors such as insufficient reserves of the central bank, interest-rate differentials, current-account and sovereign deficits, and high inflation can result in a currency trading at prices discounted from the pegged value. In this setting a peg can collapse due to macroeconomic fundamentals that are sufficiently weak. With stablecoins, standard macroeconomic fundamentals need not apply in the same way, and certainly do not when considering the fundamentals of the currency-issuing entity (not a country). A second line of macroeconomic modeling of fixed rates focuses on the collapse of fixed exchange rates due to inadequate central bank reserves (Krugman, 1979; Flood and Hodrick, 1986; Obstfeld, 1984). This has led to so-called "2nd generation" models, where currency crises arise from speculative attacks that are potentially self-fulfilling (Eichengreen et al., 1995; Morris and Shin, 1998; Chamley, 2003; Cukierman et al., 2004). In these models, there is generally an equilibrium under which the peg is sustainable, and another under which the peg can be broken if speculation is sufficiently intense.

Our paper also relates to the role of central-bank intervention in maintaining pegs (Fratzscher et al., 2019a,b; Sarno and Taylor, 2001; Ferreira et al., 2019; Flood and Jeanne, 2005; Vitale, 1999) and a theoretical literature on target zones (Krugman, 1991; Svensson, 1992). Empirical evidence in Fratzscher et al. (2019b) shows that central banks typically "lean against the wind" by actively counteracting the private forex buy/sell trades of market participants, which has a stabilising effect on the exchange rate. A theoretical prediction of the target-zone models is the so-called "honeymoon" effect: That the currency price under a credible peg tends to cluster toward the middle of the target zone due to the expectation of a central bank intervention that leans against the wind near the edges. With national-currency-based stablecoins, there is generally no equivalent of a central bank actively participating in the market to stabilize the peg. Instead, most stablecoin systems generate price stabilization through demand-driven flows to arbitrage differences between the official peg and the rate in the secondary market, akin to the mechanism that keeps exchange-traded funds trading at prices close to their net asset values.[10]

The literature on cryptocurrencies is relatively new, with many papers focusing on how Bitcoin and other prices are determined (Abadi and Brunnermeier, 2018; Biais et al., 2019; Catalini and Gans, 2016; Chiu and Koeppl, 2017; Easley et al., 2019; Schilling and Uhlig, 2019; Raskin and Yermack, 2018; Zimmerman, 2020; Sockin and Xiong, 2020), initial coin offerings (ICOs) (Catalini and Gans, 2018; Howell et al., 2018; Goldstein et al., 2019; Florysiak and Schandlbauer, 2019), and central-bank digital currencies (Bordo and Levin, 2017; Benigno et al., 2019; Bindseil, 2020; Brunnermeier et al., 2019; Fernández-Villaverde et al., 2020; Kumhof and Noone, 2018; Raskin and Yermack, 2018; Skeie, n.d.). Topics include: Bitcoin having a dual role as a medium of exchange and speculative investment, the pricing of fees for mining, and the interaction of digital-currency deposits with monetary policy and central banking. In our paper, we abstract from the process of Bitcoin price determination and base our model on Bitcoin (or other non-stable cryptocurrency) as a predominantly speculative investment, focusing instead on the investor's decision whether to use dollars or stablecoins as the vehicle to finance their speculative investment.

The cryptocurrency research most closely related to our paper focuses on market efficiency. Much attention has been paid to the potential for market manipulation, with evidence of pump and dump schemes (Gandal et al., 2018; Li et al., 2018; Dhawan and Putnins, 2020), opportunities for speculation and arbitrage on crypto exchanges (Makarov and Schoar, 2019, 2020; Hale et al., 2018) and determining a set of factors to explain cryptocurrency returns (Liu and Tsyvinski, 2018; Bhambhwani et al., 2019). There is a recent and growing literature investigating properties of stablecoins (Berentsen and Schär, 2019; Bullmann et al., 2019; BIS, 2019; Eichengreen, 2019). For example Eichengreen (2019) comments on stablecoins being backed by either national currencies or cryptocurrencies, and highlights that systems can be vulnerable to speculative attack if there is perception that the peg is under-collateralized. Griffin and Shams (2020) document the role of Tether as a vehicle currency, and how it has been used potentially to manipulate Bitcoin prices during 2017 and 2018.[11] There is also recent work that looks at intraday price changes to support the role of stablecoins as safe havens (Baur and Hoang, 2020, in press). We extend existing work on stablecoins in several ways. Most broadly,

[10]There are other differences between the decentralized structure of stablecoins and forex interventions by a central bank. For example, a central bank is typically concerned with macroeconomic fundamentals like preserving low interest rates and inflation, and is targeting an exchange rate that is based on a set of macroeconomic fundamentals. A stablecoin issuer has no equivalent policy function. Secondly, investors can often deposit dollars directly with the stablecoin issuer. In contrast, investors cannot typically initiate trades, or directly deposit currency, with the central bank.

[11]As of October 2019, there is a class-action suit against Tether that claims: (i) Tether is not backed one-for-one by dollar reserves and (ii) Bitfinex increased Tether issuance during 2017 to manipulate Bitcoin markets. Plaintiff-estimated damages amount to roughly 1.4 trillion USD. For more details, see *The Economist*: `https://econ.st/2WPQjXX`.

we push beyond past work focusing on prices only and address quantities, in particular signed order flow. This allows many new avenues of analysis, e.g., quantifying the effects on prices of bearing the risk that safe havens help avoid (by estimating the negative loadings of stablecoin prices on a crypto risk factor). We also present an optimizing model that clarifies why dollar prices of Tether should at times trade above the parity of 1.0, as noted above.

The remainder of the paper is structured as follows. In section 1 we summarize the properties and performance of the major stablecoins. In section 2 we introduce the model of stablecoin prices, and use it to illustrate potential mechanisms that produce a distribution of peg deviations that is two-sided. In section 3, we illustrate mechanisms through which arbitrage flows from investors can stabilize deviations of market prices from parity. In section 4 we test hypotheses about which fundamentals drive parity deviations, and provide a discussion of factors contributing to why Tether trades at a premium, such as its role as a safe-haven asset in periods of increased risk, and why Tether trades at a discount, such as the amount of collateral and trading volatility. Section 5 concludes.

1 Stablecoins: Properties and Performance

The collateral systems adopted by the six largest stablecoins by market capitalization are presented in Table 1.[12] Stablecoins are typically backed by either dollar collateral or crypto collateral. Of the top six coins by market cap, five are backed by dollar deposits, the exception being DAI, which is backed by Ethereum.[13] The methods of how dollar collateral itself is backed includes a central issuer in the case of Tether, which acts analogously to the Hong Kong Currency Board. The second-largest stablecoin, USDC, has a more decentralized system of governance, with multiple issuers that have a license to provide USDC tokens. The other three stablecoins managed by dollar collateral, Binance USD Coin, Paxos, and TrueUSD, focus on concerns over the risk of issuer default: In the case of Binance USD coin and Paxos, dollar collateral is backed by FDIC-insured banks, whereas TrueUSD dollar collateral is backed by escrow accounts.[14]

The sixth largest coin, DAI, is different from the other coins in that it is a crypto-collateral-

[12] The top six coins by market share in April 2020 capture over 95% of the stablecoin market.

[13] Since November 16, 2019, investors holding single-collateral DAI have transferred their holdings to multi-collateral DAI. For the purposes of our analysis, we address single-collateral DAI as it has a longer time series. Multi-collateral DAI is also based on Ethereum collateral at present, with a view to extend to different types of collateral in the future. In the market, the ticker DAI now refers to the multi-collateral version; the original single-collateral version now has the ticker DAI.

[14] Escrow accounts offer a novel security design. For example, suppose an investor wants to deposit one USD for one TrueUSD token. They first deposit their dollar in a protected escrow account. TrueUSD then provides the escrow account 1 token. Only upon receipt of the token, and once the token is sent to the investor, the escrow account transfers the dollar deposit to TrueUSD. This system minimises settlement risk on both sides of the transaction.

based coin. Under this system, investors deposit Ethereum into a collateralized position that allows them to borrow DAI. The number of DAI they can borrow is limited by a smart (i.e., auto-executing) contract. The contract liquidates underlying Ethereum collateral if the value of that collateral is less than 150% of the corresponding DAI-borrowing value. Agents therefore have an incentive to scale back borrowing by redeeming DAI when Ethereum prices fall in order to prevent their collateral from breaching the 150% level.

A technical difference among the stablecoins is their choice of stabilizing mechanism. For stablecoins backed by dollar collateral, this works through investor arbitrage flows. When the USD price of the stablecoin rises above parity, investors have an incentive to deposit dollars to create new stablecoin tokens, and sell them in the secondary market. For a coin backed by Ethereum, an investor has to take into account expectations of the future value of Ethereum, so there is no risk-free arbitrage opportunity in this case.[15] DAI also has by design a monetary-policy tool at its disposal: Through a voting procedure on DAI's platform MAKER DAO, holders of the currency have a right to vote on a "stability fee". This is a fee for borrowing DAI, analogous to a central bank setting the interest rate on borrowed money. All else equal, in a period when DAI is trading at a discount, a rise in the stability fee induces an increase in DAI redemptions, shrinking supply in order to restore parity.

An equally important institutional detail is how these coins' collateral is audited. Tether publishes its balance sheet daily,[16] which provides a breakdown of the value of its assets (dollar deposits) and liabilities (Tether in circulation on blockchain platforms). While Tether liabilities are accounted for based on the record of transactions on the blockchain, there is a need to audit issuers to verify that the holdings of dollar deposits are secure. For full solvency, the dollar value of assets held in the issuer's accounts must at least equal the dollar value of its liabilities. Audit reports for these top coins assert that they are sufficiently collateralized. We review audit accountability and transparency measures in Appendix B.

[15] For example, suppose DAI trades at a premium in the secondary market. The value of Ethereum collateral is subject to uncertainty, so if an investor believes the value of Ethereum is expected to fall, they may choose not to add Ethereum collateral in order to borrow DAI to sell in the secondary market.

[16] See https://wallet.tether.to/transparencyformoredetails.

Table 1: Top 6 Stablecoins – System of Collateral

Coin	Symbol	Blockchain	System of Collateral
Tether	USDT	Omni and Ethereum	100% USD Deposits held in centralized Tether Treasury
USD Coin	USDC	Ethereum	100% USD Deposits in decentralized (private) accounts.
Paxos Standard	PAX	Ethereum	100% USD Deposits held by FDIC-insured banks
Binance USD Coin	BUSD	Ethereum	100% USD Deposits held by FDIC-insured banks
True USD	TUSD	Ethereum	100% USD Deposits held in escrow accounts
Multi Collateral DAI	DAI	Ethereum	Ethereum held in CDO with value of >150% DAI borrowed

The table lists properties of the top-six stablecoins by market capitalization as of April 2020. Blockchain refers to the platform on which the history of transactions is recorded. System refers to method of collateral; for dollar-collateral-based systems this means there is, as a stated principle, 100% backing of dollar deposits.

Table 2 presents summary statistics on the deviations from peg prices as of March 2020. (For details on the source of price data, see the data appendix A.) The first observation is the high ratio of total reported trading volume to the market capitalization, also referred to as the daily velocity of stablecoins in circulation.[17] This daily ratio is typically over five for Tether, the largest coin, and is similarly above one for other national-currency-backed coins Paxos (PAX) and TrueUSD (TUSD). For perspective, the daily turnover in spot foreign exchange markets involving the USD as one leg of the transaction is $1.7 trillion over the period 2016-2019, compared to a total supply in circulation of approximately $15 trillion. This implies a daily USD velocity of one tenth, an order of magnitude smaller than stablecoin velocities. A takeaway is that stablecoins derive significant use in cryptocurrency markets as vehicle currencies.

[17] The reported 24H Volume in Coinmarketcap and other vendors includes all transactions verified on the blockchain. The volume of trading on exchanges trusted by the SEC is less likely to be inflated for the purpose of feigning activity and liquidity.

Table 2: Top 6 Stablecoins – Peg Price Deviations

Sample	Symbol	Market Cap	24H Volume	Mean	SD	Min	Max	Half-Life (days)
04/17-03/20	USDT	$6,400M	$40,000M	-20.5	128.9	-960	571	6.4
01/20-03/20	USDC	$705M	$692M	6.9	25.0	-21	100	0.8
01/19-03/20	PAX	$245M	$911M	7.8	29.6	-100	200	0.5
10/10-03/20	BUSD	$187M	$49M	1.4	6.1	-10	50	0.3
06/18-03/20	TUSD	$136M	$466M	6.7	59.2	-170	990	0.4
04/18-03/20	DAI	$79M	$12M	42.5	128.7	-391	800	4.7

Note: Market capitalization for all coins is based on total value of stablecoins in circulation; 24H Volume is total reported trading volume, from Cryptoslate (as of April 10th 2020, `https://cryptoslate.com/cryptos/stablecoin/`). Summary statistics for price deviations from the parity peg are expressed in basis points (100 basis points equals 1 percent, which here equals 1 US cent). Half-Life is in days. Price data are sourced from Coinapi, which reports data from trusted exchanges Bitfinex, Bittrex and Kraken.

Examining the summary statistics in Table 2, we observe that stablecoins typically have two-sided distributions, with maximum deviations both below and above the one-to-one parity exceeding 500 basis points (five percent) for Tether (USDT), and of similar magnitudes for the other coins. We also observe deviation persistence, measured by the half-life of price departures from the peg. The half-lives for all coins range from 1 to 10 days.[18] Persistence of deviations is evidence that the stabilizing mechanisms of these coins are not without frictions or risk.

Our hypothesis and model below includes three possible explanations for the existence of the deviations' two-sided distribution and persistence. The first is liquidity, for example, affecting the price impact of arbitrage-trade flows. The second explanation is a speculative channel and includes concern over whether the stablecoin peg is in fact sustainable. The third explanation depends on the fundamentals of intermediation costs. For example, because stablecoins use blockchains for settlement, they remove the need for certain intermediation fees and processing in contrast to dollar transactions, leading potentially to premiums when crypto investors want to liquidate into a less risky asset.

2 Model of Stablecoin Prices

Our model serves three purposes, all of which present testable implications. First, we want to generate in an optimizing setting the two-sided distribution of stablecoin prices around their pegs. While a pegged currency trading at a discount can be explained by issuer mismanagement, a lack of collateral, or speculation against the peg, it is puzzling given past findings in exchange-

[18] To measure the half-life, we run an auto-regressive process of order 1 on the deviations, $\Delta = \rho\Delta_{t-1} + u_t$. The half-life, or the time it takes for a shock to dissipate by 50%, is $T = -\frac{\rho}{log(0.5)}$.

rate economics why stablecoins sometimes trade at a substantial premium.

Second, we want to understand more fully how stablecoins serve as a vehicle currency. We find in the model's equilibrium that pressure for stablecoins to trade at a premium operate through three channels. The first is an intermediation premium that arises from added costs of using dollars as a vehicle to buy the model's risky asset (think of the model's risky asset as a cryptoasset traded on a crypto exchange, some of which accept only stablecoins for purchases). The second channel is a safety premium: stablecoins can trade at a premium due to its role as as safe haven. The third channel is a "latency" premium tied to the relative variance of risky-asset returns in dollars versus stablecoins (think of using the dollar as a vehicle as taking more time).

Third, we want to understand the mechanism by which stablecoin prices move back toward their pegs. Here, we model a representative investor/arbitrageur reallocating dollar wealth toward stablecoins when the stablecoin trades at a premium, and toward the dollar when the stablecoin trades at a discount. In the former case, they deposit dollars with the stablecoin issuer, draw stablecoins at par (avoiding the premium), and use these coins to purchase the model's risky asset; this increase in the relative supply of stablecoins leads to a decline in the secondary-market price of stablecoins toward the peg.

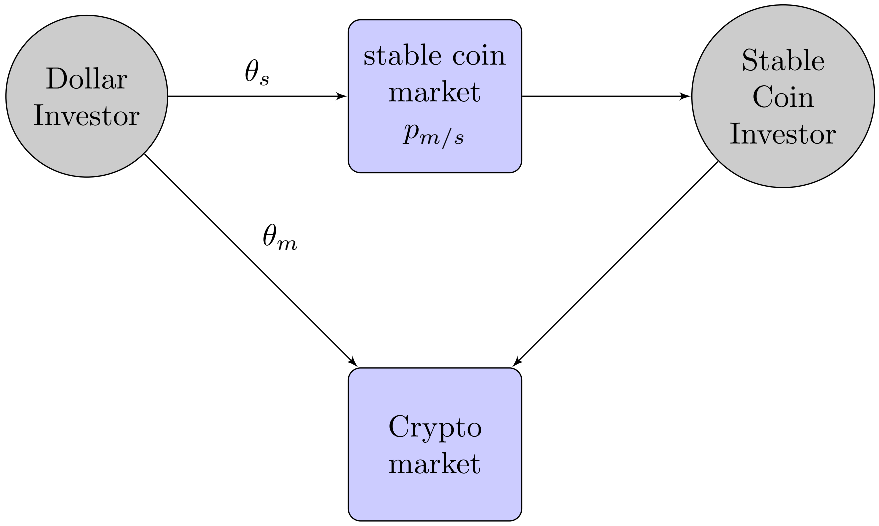
The model has two periods. A representative investor decides in period 1 the optimal choice for investing in a combination of the risk-free asset and the risky asset (e.g., Bitcoin or other non-stable cryptoasset). They have two alternatives for the risk-free asset, the dollar or a stablecoin. Which risk-free asset is chosen determines which is used for investing in the risky asset.

Investors face a cost to rebalancing their portfolio when holding the dollar. The intuition is that liquidating risky cryptoassets incurs greater intermediation costs when converting into dollars (e.g., conversion into stablecoins is faster and incurs lower transaction costs). This assumption will affect the point at which an investor is indifferent between choosing the dollar versus the stablecoin as the risk-free asset. We illustrate both methods in Figure 2.

1. **If dollar is chosen**: Invest a fraction $\theta_{m,1}$ of wealth in a combination of the dollar as the risk-free asset and the risky portfolio C.

2. **If stablecoin is chosen**: Convert the fraction $1 - \theta_{m,1}$ of wealth into stablecoin S at the prevailing exchange rate $p_{m/s}$ and uses those stablecoins to invest in the risky asset C.

Figure 2: Investor decision to use dollars or the stablecoin as vehicle currency



Note: This figure illustrates the choice of a representative investor to adopt dollars versus stablecoins as a vehicle currency, with shares $\theta_{m,1}$ and $\theta_{s,1}$ respectively.

Dollar Chosen Case

Wealth is allocated to the risky cryptoasset and the risk-free asset, in this case the dollar. The cryptoasset has a final return in dollars of $R_m \sim N(E[R_m], \sigma_m^2)$. The risk-free dollar asset has a non-negative return R_f. The investor has CARA utility over wealth, which yields mean-variance preferences. We can represent the dollar-investor problem by maximising equation (1) subject to the period 1 and period 2 budget constraints. Expressing the investor's wealth W in dollars, they purchase the cryptoasset C up to a share of their wealth $\theta_{m,1}$ at the dollar price $p_{m/s}$.

$$\max_{C_{m,1}} \qquad L = E[\theta_{m,1} W_2] - \frac{1}{2}\gamma Var(\theta_{m,1} W_2) \tag{1}$$

subject to:

$$\theta_{m,1} W_1 = p_{m/s,1} C_{m,1} + M_1 \tag{2}$$

$$\theta_{m,1} W_2 = R_m C_{m,1} + R_f M_1 - \phi(C_{m,1}) \tag{3}$$

In period 1 the dollar investor chooses between the risk-free dollar asset M and the risky asset C. In period 2, returns are realized, and the investor incurs a dollar portfolio rebalancing cost $\phi(.)$ that is an increasing function of C, with $\phi'(.) > 0$ a constant marginal cost of transacting in the dollar/cryptocurrency market.[19]

Solving for optimal investment in the risky cryptoasset in period 1 yields equation (4). This

[19] The intermediation cost is technically a function of the *change* in holdings of the cryptoasset. Given period 1 constitutes the first period in which cryptoassets are held, the intermediation cost is $\phi(C_{m,1})$.

level of cryptoassets depends positively on the expected return, and negatively on the risk of the portfolio. In particular, the intermediation cost $\phi'(C_m)$ has a negative effect on the optimal holdings of the cryptoasset.

$$C_{m,1} = \frac{E[R_m] - \phi'(C_{m,1})}{\gamma\sigma^2} \tag{4}$$

Stablecoin Chosen Case

The representative investor converts the remaining fraction of their period-1 wealth into the stablecoin at the exchange rate $p_{m/s,1}$ units of dollars per stablecoin. With CARA utility, we can represent the stablecoin investor problem by maximising equation (5) subject to the period 1 and period 2 budget constraint. The cryptoasset now has a final return in stablecoins of $R_s \sim N(E[R_s], \sigma_s^2)$. Note that we express the allocations of wealth, cryptoasset and the risk-free asset in stablecoins. In contrast to using dollars, there is a zero risk-free rate on holding stablecoins, and so if the investor decides to use stablecoins as the vehicle currency, all stablecoins will be used to purchase the cryptoasset in period 1.

$$\max_{C_{s,1}} \qquad L = E[\frac{\theta_{s,1}W_2}{p_{m/s,1}}] - \frac{1}{2}\gamma Var(\frac{\theta_{s,1}W_2}{p_{m/s,1}}) \tag{5}$$

subject to:

$$\frac{\theta_{s,1}W_1}{p_{m/s,1}} = C_{s,1} \tag{6}$$

$$\frac{\theta_{s,1}W_2}{p_{m/s,1}} = R_s C_{s,1} \tag{7}$$

Solving for the optimal cryptoassets in period 1 yields equation 8. As before, the optimal level of cryptoassets depends positively on the expected return, and negatively on the risk of the portfolio.

$$C_{s,1} = \frac{E[R_s]}{\gamma\sigma_s^2} \tag{8}$$

Equilibrium allocation of dollar and stablecoin portfolio shares

To choose an optimal weight $\theta_{m,1}$ of wealth to invest as the dollar investment and $\theta_{s,1} = 1 - \theta_{m,1}$ as a stablecoin investment, the representative investor equates the value of investment in dollars with the value of investment in stablecoins. We normalise the investments by the shares $\theta_{m,1}$ and $\theta_{s,1}$ to effectively equate the investment value per unit wealth invested. The fraction $\frac{E_1[p_{m/s,2}]}{p_{m/s,1}}$ measures the valuation effect of stablecoins over the investment horizon of the investor.

$$\frac{C_{m,1}}{\theta_{m,1}} = \frac{C_{s,1}}{\theta_{s,1}} \frac{E_1[p_{m/s,2}]}{p_{m/s,1}} \tag{9}$$

In the optimal allocation, the investor is indifferent between both methods. This yields the condition in equation (10), which is analogous to an uncovered interest-rate parity condition in foreign exchange markets. The expected return per unit invested using dollars and stablecoins are equalised after taking into account exchange rate changes. On the left hand side, we define the return per dollar of wealth invested in the dollar portfolio. An investment of $\frac{1}{\theta_{m,1}}$ dollars makes an expected return equal to $E[R_m] - \phi'(C_m)$. On the right hand side, we convert one dollar into stablecoins at the rate $p_{m/s,1}$. The expected return on stablecoin investment is equal to $E[R_s]$, and this is reconverted back to dollars at the future expected price of stablecoins $E_1[p_{m/s,2}]$.

$$\frac{E[R_m] - \phi'(C_{m,1})}{\theta_{m,1}\sigma_m^2} = \frac{E_1[p_{m/s,2}]}{p_{m/s,1}} \frac{E[R_s]}{\theta_{s,1}\sigma_s^2} \tag{10}$$

We can then solve for the dollar price of the stablecoin, $p_{m/s}$, which yields equation (11):

$$p_{m/s,1} = E_1[p_{m/s,2}] \frac{1-\theta_{s,1}}{\theta_{s,1}} \frac{E[R_s]}{E[R_m] - \phi'(C_{m,1})} \frac{\sigma_m^2}{\sigma_s^2} \tag{11}$$

The relative price of stablecoins is a function of three ratios. The first ratio, $\frac{1-\theta_{s,1}}{\theta_{s,1}}$, captures the relative market share of the stablecoin. All else equal, a higher share of representative-investor wealth invested in stablecoins leads to a lower stablecoin price. This is intuitive, as a rise in $\theta_{s,1}$ is equivalent to an increase in the supply of stablecoins in circulation (and conversely a relative decline in the supply of dollars). Equilibrium in the stablecoin/USD market requires the stablecoin price to fall to clear the market. The second ratio, $\frac{E[R]}{E[R]-\phi'(c)}$, measures the role of intermediation costs $\phi'(C_m)$. This measures the relative advantage of stablecoins in that it incurs lower intermediation costs than using the dollar to buy the risky asset. Added intermediation costs in dollars leads to a reduction in the return an investor can get when using dollars as the vehicle currency. By the UIP condition, this causes an appreciation of the stablecoin's exchange rate. The third ratio reflects differences in the volatility of the risky asset in dollars versus stablecoins. We discuss immediately below a potential channel through which practical differences in the time needed to transact in stablecoins versus dollars can change the uncertainty investors face.

Safety and latency premium

We elaborate on the UIP condition in two ways. The first is the role of risk premia in driving a wedge between the risky-asset return as a stablecoin versus a dollar investor. More formally, define the relationship between the risky-asset return in dollars, R_m, and in stablecoins R_s:

$$R_m = R_s \frac{p_{m/s,2}}{p_{m/s,1}} \tag{12}$$

Taking expectations,

$$E[R_m] = E[R_s]E\left[\frac{p_{m/s,2}}{p_{m/s,1}}\right] + cov\left(R_s, \frac{p_{m/s,2}}{p_{m/s,1}}\right) \tag{13}$$

The latter term $cov(R_s, \frac{p_{m/s,2}}{p_{m/s,1}})$ can be interpreted as a safety premium of the stablecoin: If stablecoins appreciate in periods of low risky-asset returns, then $cov(R_s, \frac{p_{m/s,2}}{p_{m/s,1}}) < 0$. This increases the relative return on using stablecoins as a vehicle currency.

A different premium relating to the safety premium arises as a practical matter – i.e., not directly in the model – due to a differential in time needed to transact when using the dollar as a vehicle versus the stablecoin. The variance of cryptocurrency returns depends on the latency time of the transaction. For dollars, this latency time can be quite high if the transaction involves intermediation costs.[20] Formally, let us define the standard deviation of risky-asset returns $\sigma(T)$, where T is the latency time, and $\sigma(T)$ is an increasing function in T, $\sigma'(.) > 0$.

Therefore, assuming the latency time for dollar transactions exceeds that for stablecoin transactions, $T_m > T_s$, the ratio of volatility of cryptocurrency returns in dollars relative to stablecoins is greater than one. This causes a stablecoin premium due to latency time of transactions, which we dub the "latency premium," and can work in tandem with the safety premium if investors decide to liquidate cryptocurrency into a store of value in bad times. Given it takes more time in actual crypto markets to convert a non-stable cryptocurrency into dollars, investors prefer to use stablecoins as a way to rebalance their portfolios, causing a relative increase in the price of stablecoins. We document the latency premium and safety premium in equation 14.

$$p_{m/s,1} = E_1[p_{m/s,2}] \frac{1-\theta_{s,1}}{\theta_{s,1}} \frac{E[R_s]}{E[R_s] + cov\left(R_s, \frac{p_{m/s,2}}{p_{m/s,1}}\right) - \phi'(C_m)} \frac{\sigma^2(T_m)}{\sigma^2(T_s)} \tag{14}$$

While we have established a relationship between $p_{m/s,1}$ and $\theta_{s,1}$, we need another relation to close the model. We now turn to arbitrage flows as a stabilising mechanism.

Arbitrage flows

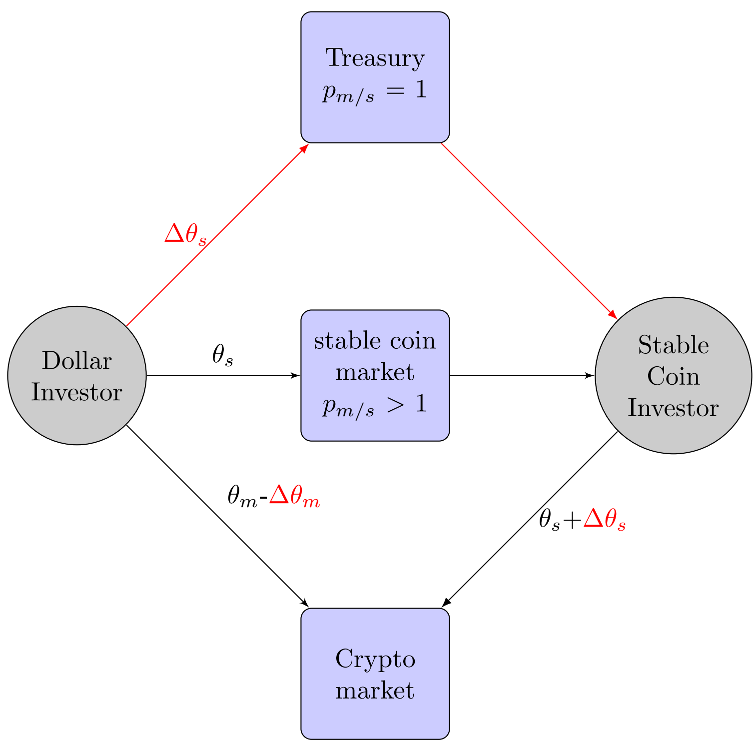
The primary-market issuer is willing to supply stablecoins at a 1:1 exchange rate. This means departures of the stablecoin price from the peg result in incentives for arbitrage, and will cause endogenous investor flows. For example, if what we will call the "secondary-market

[20]For example, cryptocurrency exchange Bitfinex states that there can be a delay of up to two weeks for a bank wire of dollar deposits to be useable to buy cryptocurrency.

price" $p_{m/s,1} > 1$, investors will buy stablecoins from the primary-market issuer with dollars at par. Conversely, investors will sell stablecoins to the primary-market issuer for dollars at par when the secondary-market price $p_{m/s,1} < 1$. Therefore the representative investor using stablecoins as the vehicle currency will, through arbitrage flows, cause $\theta_{s,1}$ to be a positive function of deviations from the peg. We illustrate this in equation 15. The change in the representative investor's share of wealth using the stablecoin as the vehicle, $\Delta\theta_s = \theta_{s,2} - \theta_{s,1}$ is positively related to deviations from the peg, $p_{m/s,1} - 1$. The constant of proportionality is ω and measures the half-life of the peg. The speed of convergence parameter ω depends on the ability of private investors to transact with the stablecoin issuer directly via depositing dollars, obtaining an equivalent number of stablecoin tokens, and then selling them in the secondary market at $p_{m/s,1}$. In a highly efficient market, investors can arbitrage deviations quickly, and this is represented by a high ω. Conversely, frictions in arbitrage, for example by limiting the agents' ability to transact with the primary issuer of the stablecoin, will result in a low ω.

$$\Delta\theta_s = \omega(p_{m/s,1} - 1) \tag{15}$$

Figure 3: Dollar holdings reallocate toward stablecoins when in the secondary market $p_{m/s} > 1$



Note: This figure illustrates the endogeneity of investor arbitrage flows. In response to a secondary-market price of stablecoins trading above the peg, an investor reallocates their portfolio away from dollars (share $\Delta\theta_{m,1}$) and toward stablecoins (share $\Delta\theta_{s,1}$).

We illustrate arbitrage flows in Figure 3. The dollar investor reallocates a share $\Delta\theta_m$ of dollars and deposits them in the stablecoin Treasury. In return, they obtain stablecoin tokens which they then use to purchase the risky asset. Therefore the share allocated to the stablecoin increases by $\Delta\theta_s$. The increase in the stablecoin share of wealth will cause the gap between the primary- and secondary-market rate to narrow, until the secondary market trades at parity (the new steady state equilibrium).

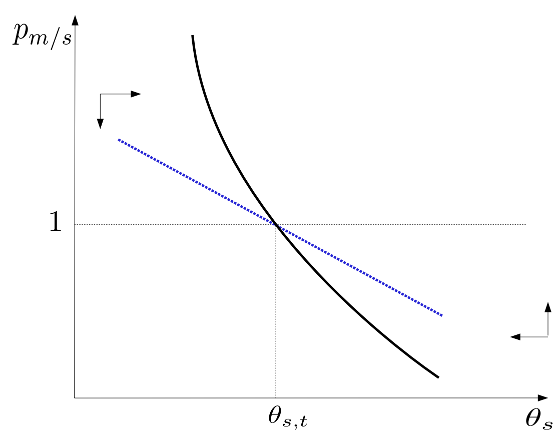
Equilibrium: Phase Diagram

The equilibrium is characterised by the following two equations 16 and 17. In characterising our equilibrium, we extend the two-period model to a multi-period model in continuous time to illustrate the dynamics of arbitrage flows in stabilizing the peg. The first equation represents the price that leads to a representative investor making an optimal allocation between dollars and stablecoins as a vehicle currency. The second equation represents the investor's incentive to arbitrage deviations from the peg, by increasing the relative share of stablecoin use when the secondary market trades at a premium to the peg. The equilibrium can be represented through a phase diagram, plotted in Figure 4.

$$p_{m/s,t} = E_t[p_{m/s,t+1}]\frac{1-\theta_{s,t}}{\theta_{s,t}}\frac{E[R_s]}{E[R_m]-\phi'(C_m)} \tag{16}$$

$$\dot{\theta}_{s,t} = \omega(p_{m/s,t}-1) \tag{17}$$

Figure 4: Phase Diagram of Equilibrium



Note: This phase diagram illustrates equilibrium, which in steady state will always be where $p_{m/s} = 1$, eliminating the incentive for arbitrage flows.

The model yields two key predictions.

Prediction 1: Stablecoin premiums

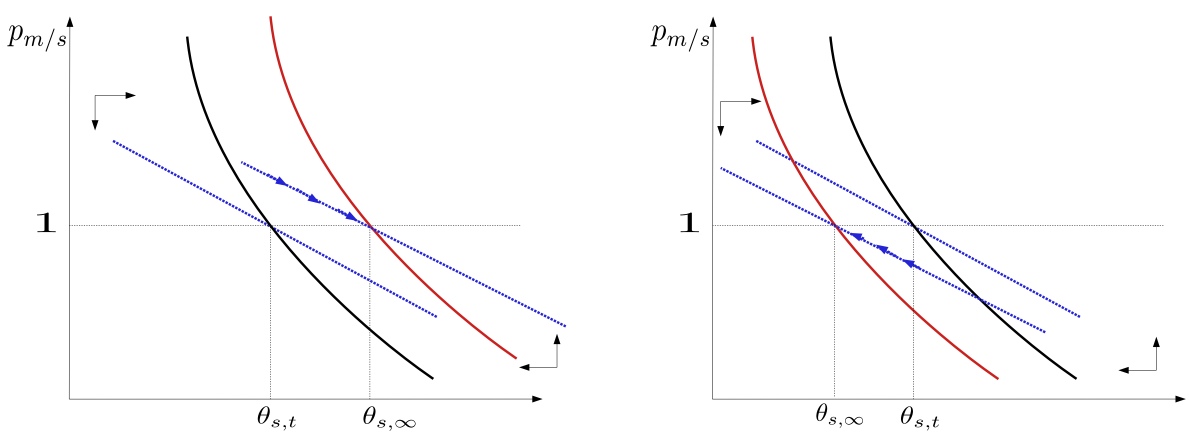
An increase in intermediation costs $\phi'(C)$, and an increase in the latency time T_m for dollar transactions, increases the price $p_{m/s,t} > 1$, all else equal. Logic: The representative investor reallocates their portfolio toward stablecoins ($\theta_{m,t} \downarrow$ and $\theta_{s,t} \uparrow$) by depositing dollars with the stablecoin issuer, obtaining stablecoins at a 1:1 rate, and uses stablecoins to buy the risky cryptoasset. This causes the price $p_{m/s}$ to gradually return to its equilibrium pegged value of one as $t \to \infty$.

Prediction 2: Stablecoin discounts

A decrease in the expected future spot price, $E_t[p_{m/s,t+1}]$, decreases the current spot price $p_{m/s,t} < 1$, all else equal. Logic: One economic rationale for an investor expecting the peg to trade at a discount is insufficient collateral. The representative investor reallocates their portfolio toward dollars ($\theta_{m,t} \uparrow$ and $\theta_{s,t} \downarrow$) by withdrawing their dollar deposits with the stablecoin issuer, and using those dollars to buy the risky cryptoasset. This causes the price $p_{m/s}$ to gradually return to its equilibrium pegged value of one as $t \to \infty$.

We document both channels in Figure 5. The first is the effect of a positive shock to intermediation cost $\phi'(C)$. All else equal, the relative return of a unit of cryptoasset purchased via a stablecoin is higher. This causes a contemporaneous increase in the price of the stablecoin $p_{m/s}$. This is represented as a shift upward of $p_{m/s}$ until it reaches the new saddle path, indicated in Figure 5, left.

Figure 5: Left panel: Shock to intermediation cost $\phi'(C)$; Right panel: Speculative attack



Note: The left panel shows the transition dynamics for a shock to intermediation costs of using dollars as a vehicle. This results in a temporary stablecoin price $p_{m/s} > 1$, and causes arbitrage flows to the secondary market, $\theta_{s,t} \uparrow$, to restore parity. The right panel shows the impact of an unsuccessful speculative attack (i.e., one that does not break the peg), which results in a decline in $E[p_{m/s}]$, and redemptions of stablecoins, $\theta_{s,t} \downarrow$, to restore parity.

Consequently, the representative investor decides to sell a fraction of their wealth in \$ and buy stablecoins from the primary-market issuer. This is mathematically represented by $\dot{\theta}_{s,t} = \omega(p_{m/s,t} - 1) > 0$. Movement along the saddle path will occur until the price of stablecoins reaches a new long-run equilibrium at $p_{m/s} = 1$, and a higher vehicle-currency share for stablecoins, $\theta_s \uparrow$.

The second key prediction is the effect of a speculative attack. In our model this most closely corresponds to 2nd-generation currency-crisis models (e.g., Morris and Shin (1998)), which show how fixed exchange rates can be vulnerable to self-fulfilling attack from speculators who believe the currency is overvalued. Under this theory, we would expect deviations from the peg to be one-sided. For example, suppose speculators believe there is some positive probability $P > 0$ that the stablecoin will collapse. This necessarily implies that the expected value of the stablecoin price trades at a discount to the peg, $E_t[p_{m/s,t+1}] = P \times 0 + (1 - P) \times 1 < 1$. The low secondary market price of the stablecoin will cause the representative investor to redeem their stablecoins and withdraw dollar deposits from the primary-market issuer, causing a decline in the stablecoin share of wealth, $\dot{\theta}_{s,t} = \omega(p_{m/s,t} - 1) < 0$. Movement along the saddle path will occur until the price of stablecoins reaches a new long-run equilibrium at $p_{m/s} = 1$, and a lower vehicle-currency share for stablecoins, $\theta_s \downarrow$.We illustrate the dynamics in Figure 5, right.

3 Empirical Evidence: Stabilising Mechanisms

We examine now how deviations from stablecoin pegs are arbitraged, which is fundamental to how they dissipate. As an analogy, consider first the setting of a national currency and a fixed exchange-rate peg managed by a central bank. The central bank is committed to maintaining the peg by buying the domestic currency and selling foreign-currency reserves when the domestic-currency value falls below the peg level, and conversely selling domestic currency when the domestic-currency value rises above the peg level.[21]

While forex intervention can work in theory, central banks typically face societal pressures when the domestic currency is overvalued relative to economic fundamentals. These fundamentals include high inflation, current account and sovereign deficits, and high interest rates. Many currency crises, most famously the peso crises of Argentina, among others, have occurred when a central bank has insufficient foreign reserves to defend the peg, or insufficient resolve to keep short-term interest rates high, making the peg vulnerable to a speculative attack.

[21]The literature emphasizes whether this central-bank intervention is sterilized versus unsterilized. When unsterilized, the simpler case, the central bank action either removes or adds to the domestic money supply when exchanging for foreign currency. Sterilizing the effect of the intervention on the domestic money supply is achieved by conducting a parallel, offsetting open market operation – buying or selling domestic-currency bonds from the public and thereby injecting/absorbing an offsetting amount of domestic money. Unsterilized intervention is the more potent due to its direct effects on money supply and, especially, short-term interest rates. See Sarno and Taylor (2001) for details on the forex intervention literature.

In contrast to conventional exchange rate pegs, stablecoins are not managed by a national central bank. The issuer of Tether has formally stated that it does not intervene in secondary markets to stabilise the market rate. In a statement released on its website, Tether Inc states:[22]

Tether does not purport to be a central bank, and it is false to suggest that Tether is like a central bank for a number of reasons:

1. *Tether does not represent a country or oversee a banking system*
2. *The USDT supply is dictated by consumer demand (all issued USDT has been bought by a consumer at a 1:1 ratio)*
3. *Tether does not set or manage any interest rates anywhere*
4. *Tether does not oversee – and is not responsible for – a banking or exchange sector, and does not claim to do so, and no serious person is under the impression that we do so.*

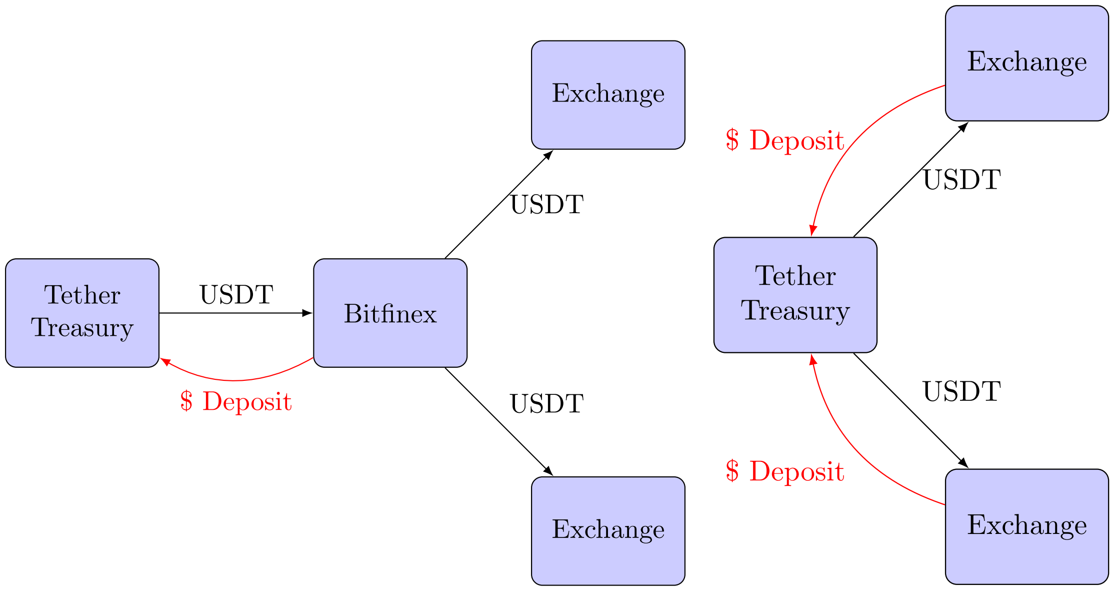
In the absence of intervention, we posit a mechanism driven by demand-side arbitrage. We test whether arbitrage flows accommodated by the Tether Treasury to the exchanges act to stabilise deviations from the peg. While our analysis in this section focuses on Tether, as it represents approximately 90% of the stablecoin market, our analysis applies more generally to the class of national-currency-backed stablecoins. We provide similar analysis for other national-currency-backed coins in Appendix C, and provide a brief discussion of alternative stability mechanisms for cryptocurrency-collateralized stablecoins in Appendix D.

Tether Balance Sheet

Tether is collateralized with a national currency, the USD. Analogous to a currency board, every Tether issued is in principle backed by a dollar deposit, so that in the event of a run, all investors could redeem their Tether for an equivalent amount in dollars at the exchange. Tether tokens are created through Tether grants, which occur when an investor or exchange deposits USD in Tether's account, creating an equivalent supply of Tether introduced in circulation. Conversely, a revoke is when Tether is redeemed for dollar deposits and withdrawn from circulation.

[22] For full reference, see `https://tether.to/a-commentary-on-tether-chainalysis/`.

Figure 6: Left – Distribution of Tether to Secondary Market via Bitfinex; Right – Distribution of Tether directly to Crypto Exchanges



Note: Left figure illustrates the creation of Tether "grants" prior to April 2019. Bitfinex, a crypto exchange, deposits dollars into the Tether Treasury. The Tether Treasury then issues a number of Tether tokens at parity (1:1 exchange rate). The newly created Tether tokens are then distributed to other investors and exchanges in the secondary market. Right figure illustrates the creation of Tether starting in April 2019 – when investors and other exchanges began getting direct access to the Tether Treasury on the Ethereum blockchain. Exchanges directly deposit dollars with the Tether Treasury to create newly minted Tether tokens.

Figure 6 describes the creation and subsequent distribution of Tether from the Treasury to the secondary market. Prior to April 2019, Bitfinex, an active cryptocurrency exchange, first deposits dollars with the Tether Treasury. The Treasury transfers newly created Tether tokens to Bitfinex, which then distributes them to a set of other exchanges and investors for trading in the secondary market. While we use Bitfinex as an example of an investor, we stress that Tether, in its white paper, states that currently any investor is allowed to deposit dollars directly in order to obtain Tether tokens at the 1:1 pegged rate (Tetherinc. (2016)). This corresponds to distribution of Tether where crypto exchanges directly deposit dollars with the Tether Treasury in order to create newly minted Tether tokens (Figure 6, right). To construct the balance sheet of Tether, including the size and timestamp of grants and revokes, we use three databases, Omniexplorer, Etherscan, and Tron.[23] These are platforms on which the blockchain – the entire history of on-chain transactions involving transfers of Tether, is recorded.[24] These platforms contain an api that allows users to access an entire history of transactions in Tether. Transactions are classified as "simple send," "grants," or "revokes." These transactions are then

[23]These are the three largest blockchain platforms on which Tether is traded, and account for over 99% of Tether in circulation as of April, 2020.

[24]Off-chain transactions, such as transactions within a cryptocurrency exchange, are not recorded.

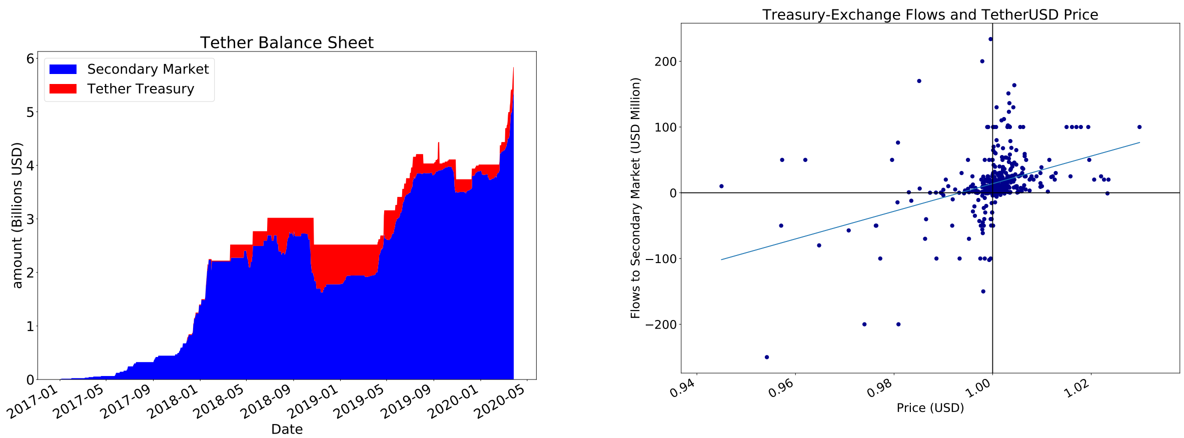
recorded in a series of blocks, and can be retrieved using the Omniexplorer and Etherscan api. For more detail on the databases, including how the flows are constructed from the addresses of the issuer, see data appendix A.

Prior to 2018, nearly all Tether created in grants is distributed to Bitfinex and the other exchanges for trading in the secondary market. However, since 2018 this is no longer the case: The Tether Treasury now holds a fraction of total Tether in circulation. To obtain the balance at the Tether Treasury, we use the Omniexplorer api to receive all transactions and Etherscan api of the Tether Treasury address. In the left panel of Figure 7, we document the total Tether in circulation, which changes due to grants and revokes, as well as the division of total Tether held by the Treasury and the secondary market, which included balances held at crypto exchanges, retail investors, and institutional investors. While balances held at the Treasury are typically a small fraction of total Tether in circulation, they reached almost $1B USD in 2018, which equates to 25% of total Tether in circulation. While the Tether Treasury holds one of the largest balances of Tether, other accounts are typically held by cryptocurrency exchanges. The usefulness of the Treasury's reserves can be seen as analogous to the accumulation of foreign exchange reserves by a central bank. This provides the stablecoin issuer a one-sided potency against stablecoin premiums; in the event of a secondary market price above one USD, the Tether Treasury can sell its Tether reserves in the secondary market to restore parity of the peg. This provides an alternative to endogenous investor flows as a stability mechanism.[25]

While Tether grants occur at a low frequency, there are continuous flows of Tether from the Treasury to the secondary market. In the right panel of Figure 7 we plot daily flows between the Treasury and the secondary market against the Tether price. Flows from the Treasury to the secondary market typically coincide with periods in which the price is above the peg. Conversely, when Tether trades at a discount to the dollar, there are net flows from the secondary market to the Treasury. This is suggestive evidence that flows between the Tether Treasury and the secondary market are key to the stabilising mechanism that maintains the Tether/USD peg. For details on the balance sheets of other national-currency-backed stablecoins, see Appendix C.

[25] The accumulation of Tether reserves helps guard against stablecoin premiums, but not stablecoin discounts. For example, if Tether trades at a discount, then the Tether Treasury would require investors to redeem their dollar deposits and withdraw Tether from circulation.

Figure 7: Left is Tether/USD Balance Sheet – Tether held by the Treasury and Other Accounts (exchanges); Right is Scatter Plot of Daily Flows from the Tether Treasury to the Secondary Market, and the Tether/USD peg



Note: Left figure plots total Tether in circulation, divided into holdings in the secondary market (by investors and exchanges) and holdings by the Tether Treasury as reserves. Right figure illustrates scatter plot of flows of Tether to the secondary market, and the corresponding Tether/USD price, measured using daily data on secondary-market flows from Omni and Etherscan. Price data are from Coinapi, and uses transaction data from trusted crypto exchanges Bitfinex, Bittrex, and Kraken. Sample is April 2017 to March 2020.

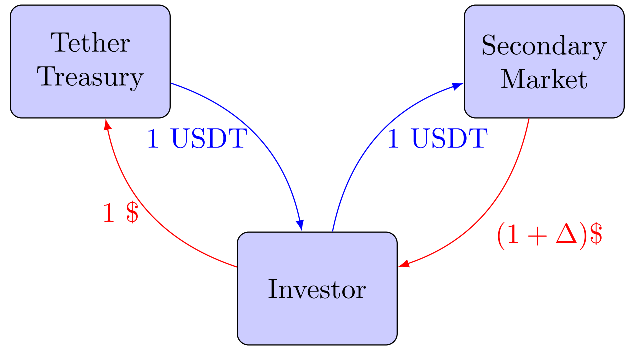
Arbitrage Mechanism

An investor can make money from gaps between the market rate on exchanges and the rate the Tether Treasury buys and sells Tether, which is parity. Consider the case in which the dollar price of Tether in the market is above parity, illustrated in Figure 8. In this instance, an investor can buy Tether from the Treasury at a one-for-one rate, and sell Tether at the prevailing market rate to profit. This arbitrage results in a flow of Tether from the Treasury to the secondary market.[26] Stability of the Tether/USD peg is thus maintained through the actions of investors seeking to arbitrage differences between the pegged rate and the secondary-market rate. Arbitrage by secondary market participants offers a decentralized solution to exchange-rate stability.[27]

[26] Conversely, when the dollar price of Tether is below 1, an investor can buy Tether at the exchange and sell to the Tether Treasury, resulting in a flow in the opposite direction – from the secondary market to the Tether Treasury.

[27] The arbitrage mechanism we outline is taking advantage of a law-of-one-price deviation in currency markets, and follows a line of reasoning similar to arbitrage conditions in foreign exchange markets such as covered interest-rate parity arbitrage (Akram et al., 2008) and triangular arbitrage of cross-rates in forex (Foucault et al., 2017).

Figure 8: Arbitrage Flows when Tether Price in Secondary Market is Trading at a Premium



Note: Schematic illustrates an arbitrage trade where the secondary-market price of Tether trades at a premium. An investor makes a dollar deposit with the Tether Treasury, obtains a Tether token (at exchange rate 1 Tether per 1 USD), and then sells Tether tokens in the secondary market for a round-trip profit of Δ.

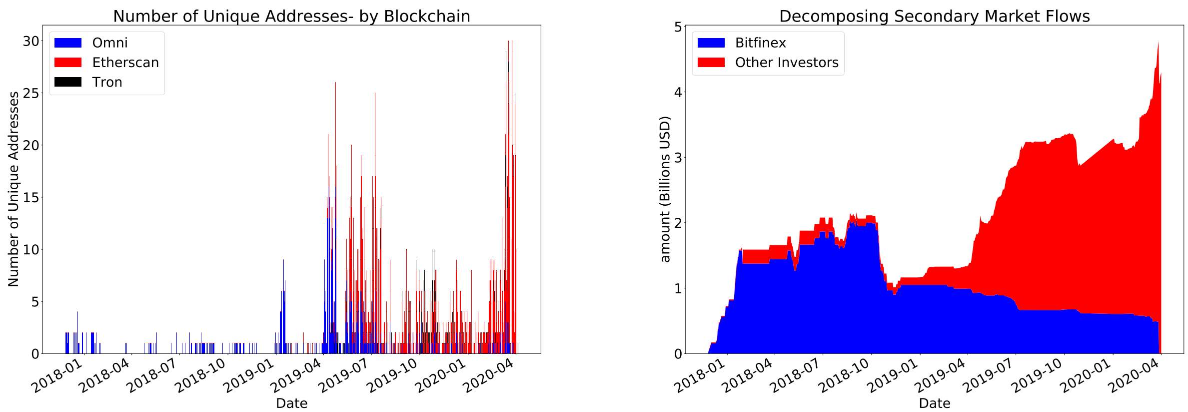
For the arbitrage mechanism to work, at least some investors must be able to deposit dollars with the primary-market issuer when the secondary-market price trades at a premium, and conversely to be able to redeem their dollar deposits when the market price trades at a discount. To test the arbitrage mechanism we have identified, we exploit a particular event: The migration of Tether from the Omni to the Ethereum blockchain in 2019. By operating on the Ethereum blockchain, Tether could now be used more directly as a vehicle currency for a large number of cryptocurrency investors that use the Ethereum blockchain. Tether circulating on the Ethereum blockchain has faster deposit/withdrawal features, enabling higher-frequency arbitrage.[28]

Increased direct access of investors for depositing dollars with the Tether Treasury is coincident with the introduction of Tether in circulation on the Ethereum Blockchain, which occurred in April, 2019 (Figure 9, left). Figure 9 shows that prior to 2019, there was typically only one unique address transacting with the Tether Treasury, and that is the Bitfinex exchange. We decompose total flows to the secondary market into flows from the Tether Treasury to Bitfinex versus flows to other investors (equation 18). Consistent with the increased number of unique addresses since April 2019, there is a strong shift in flows toward other investors (Figure 9, right).

$$Flow_{T \to EX} = Flow_{T \to \text{Bitfinex}} + Flow_{T \to \text{Investors}} \tag{18}$$

[28] For more on the benefits of migrating to the Ethereum blockchain, see https://www.prnewswire.com/news-releases/huobi-global-offers-deposit--withdrawal-in-tether-erc20-300803113.html. The Ethereum blockchain processes 15 transactions per second, in contrast to the Omni blockchain (based on Bitcoin) at about 4 transactions per second.

Figure 9: Left – Number of Unique Addresses on Omni, Ethereum and Tron Blockchains; Right – Decomposing cumulative flows to the Secondary Market to Bitfinex and other investors.



Note: Left plots the daily number of unique investor addresses transacting with the Tether Treasury. Right plot decomposes cumulative flows from Treasury to Bitfinex and other investors/exchanges. Data from Etherscan, Omniexplorer, and Tron Blockchains. Sample is January 2018 through March 2020.

We hypothesize that the introduction of Tether transactions on the Ethereum blockchain, and the subsequent access of other investors to the primary market, should translate to an increased effectiveness of the arbitrage mechanism in sustaining the peg. For example, if Bitfinex is the only investor that has access to the primary market, then this will impair the ability of private investors to arbitrage peg deviations.[29] We test this mechanism, by first partitioning our sample of Tether prices into the pre and post periods according to the date that investors are first able to deposit dollars directly with the Tether Treasury on the Ethereum blockchain, which we identify as April 9th, 2019.[30] Table 3 presents summary statistics. We find a significant difference in the average size of peg deviations, and in particular, note a significantly lower half-life of deviations, measuring 6.5 days in the pre Ethereum blockchain sample, versus 3.3 days in the post period.

We compute an upper bound for the size of arbitrage profits. To do so we match the timestamp of investor Treasury deposits with the secondary-market price of Tether based on minute-frequency price data from trusted exchanges Bitfinex, Bittrex, and Kraken, three of the most liquid exchanges in the Tether/Dollar market. We assume an arbitrage sequence where an investor deposits dollars with the Tether Treasury, and contemporaneously sells Tether in the secondary market. The arbitrage spread is then defined, in USD, as the difference $p_{USDT} - 1$, where p_{USDT} is the dollar price of Tether at the exchange. In constructing the arbitrage spread, we assume the transaction sequence is contemporaneous, and there are no

[29] This is particularly relevant given allegations that Bitfinex colluded with Tether to manipulate the market as outlined in Griffin and Shams (2020).

[30] For details on the dataset covering Tether Treasury transactions, see data appendix A.

Table 3: Summary Statistics of Tether/USD Deviations, pre and post introduction of Tether on the Ethereum Blockchain

Period	Mean	SD	Min	Max	Half-Life (days)
Pre Ethereum Blockchain	-28.2	97.2	-505	298	6.5
Post Ethereum Blockchain	-0.9	47.2	-298	119	3.3

Note: Summary statistics for deviations from the peg are expressed in basis points (100 basis points = 1 US cent). Secondary-market price is based on daily data that averages prices from the Bitfinex, Bittrex, and Kraken exchanges, all three being trusted exchanges, sourced from Coinapi. Sample is divided into 04/17-04/19 in the pre period, and 04/19-03/20 in the post period. The post period corresponds to when investors can directly transact with the Tether Treasury on the Ethereum blockchain.

delays in the processing of each transaction due to queuing or latency time of transactions. Second, the arbitrage profit is also an upper bound due to our implicit assumption that the investor's selling of Tether in the secondary market does not have immediate price impact. The resulting profit we calculate, on a per-trade basis, is the amount deposited with the Tether Treasury multiplied by the arbitrage spread. We summarise the statistics of arbitrage profits, deposits and spread in Table 4.

Based on our calculations of arbitrage spreads and profit, the majority of deposits of investors, both on the Omni and Ethereum blockchains, earn positive profits, with 92% and 87% of deposits with the Tether Treasury coinciding with a secondary market price above the peg. There are two takeaways from Table 4. First, the introduction of Tether to the Ethereum blockchain increased investor access: more Treasury transactions are executed, rising from 16 per month on average in the pre period to 92 in the post period, with the average size of these trades falling from 7.0 to 4.0 USD Million. Second, arbitrage spreads shrink from an average of 69 basis points on Omni to 27 basis points on Ethereum. Increased investor access has reduced the extent of arbitrage opportunities. We can also do a back-of-the-envelope calculation of the amount of arbitrage profit in total. On the Omni platform, 394 deposits, with an average arbitrage profit of 0.03 Million USD, comes to a total arbitrage of $394 \times 0.03 \approx 12$ Million USD. The total arbitrage profit made on the Ethereum blockchain is $1098 \times 0.01 \approx 11$ Million USD.

We test now more directly whether arbitrage flows stabilize price around the peg. This follows a large literature on measuring the effects of forex intervention. Specifically, we test whether there is a price impact from arbitrage flows that is stabilizing. We conduct local projections (based on Jordà (2005)) of the value of net inflows from the Treasury to the secondary market on the level of deviations from Tether's parity peg. We denote $Flow_{T \to EX,h}$ as total flows from the Treasury to the secondary market, measured at a daily frequency.[31] The change

[31] A positive flow to the secondary market is equivalent to a net positive deposit of dollars with the Tether Treasury, aggregated at a daily frequency.

Table 4: Summary Statistics of Arbitrage spreads on the Omni and Ethereum Blockchains

			Omni	Blockchain				
Variable	Count	Mean	Std	Min	25%	50%	75%	Max
Deposit (USD Million)	394	6.991	32.37	0.002	0.528	1.442	3.396	400
Spread (Basis Points)	394	69.42	81.95	-303.50	28.18	51.00	95.00	437
Profit (USD Million)	394	0.031	0.309	-2.320	0.002	0.007	0.018	3.78
			Ethereum	Blockchain				
Variable	Count	Mean	Std	Min	25%	50%	75%	Max
Deposit (USD Million)	1098	3.84	13.11	0.000	0.544	1.798	4.183	300
Spread (Basis Points)	1098	27.16	35.67	-157.77	12.00	25.00	38.50	483.75
Profit (USD Million)	1098	0.01	0.024	-0.079	0.001	0.003	0.011	0.383

Note: Table records statistics on Tether Treasury deposit size, arbitrage spread, and profit (calculated as arbitrage spread times deposit size, trade-by-trade). Spread, measured in basis points, is the difference between the secondary-market price of Tether and the pegged rate of 1. Secondary-market price is based on minute-frequency data that averages prices from the Bitfinex, Bittrex, and Kraken exchanges, sourced from Coinapi. Sample is April 2017 to March 2020.

in the Tether dollar price, $P_{t+h} - P_{t-1}$, is projected on the level of arbitrage flows of investors in equation (19), allowing for feedback effects using lagged price and flows as controls. We hypothesize a negative coefficient β_h, which suggests that positive flows to the secondary market have a stabilizing impact on price. We present the results of the local projections in Figure 10, with a baseline specification of 4 lags.[32]

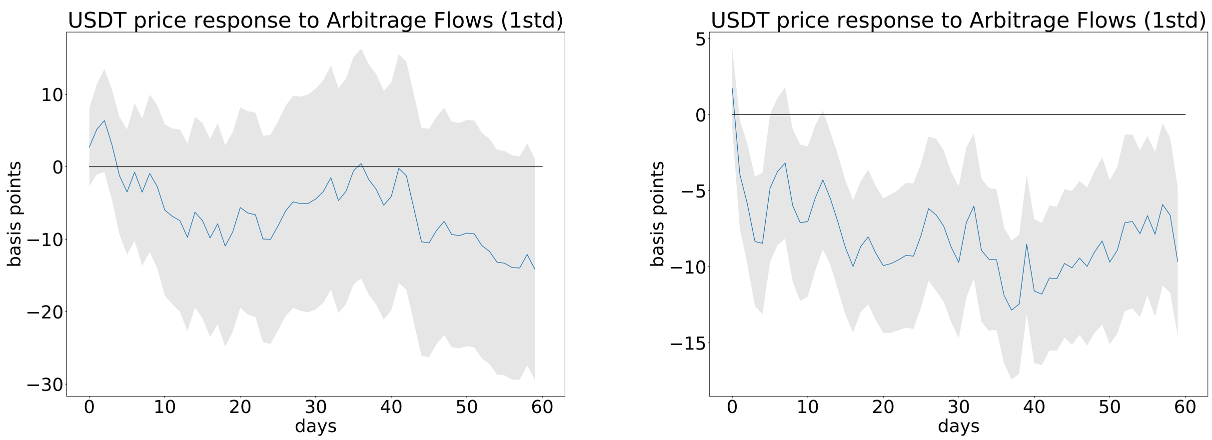
$$P_{t+h} - P_{t-1} = \alpha + \beta_h Flow_{T \to \text{EX}} + \sum_{k=1}^{4} \delta_k Flow_{T \to EX, t-k} + \sum_{k=1}^{4} \gamma_k (P_{t-k-1} - P_{t-k-2}) + u_t \qquad h = 0, 1, 2, ... \quad (19)$$

Consistent with our hypothesis, arbitrage flows from investors have a stabilizing effect on the Tether/USD price (Figure 10). After dividing our sample based on the introduction of Tether to the Ethereum blockchain, we find a significant price impact of arbitrage flows in the post period, confirming that increased direct access of investors to the Tether Treasury supports the arbitrage mechanism. In the period since April 2019, a price impact of between 5 and 10 basis

[32] An alternative specification for equation 19 is a structural VAR. By using the method of local projections, we do not impose restrictions on the timing of the model's flow shocks; however we still control for endogeneity through lagged prices and lagged flows in our specification.

points results from one standard-deviation shock in secondary-market flows (approximately 30 Million USD daily). The largest deposit in Table 4 is 300 Million USD, which yields based on our estimates up to a maximum 100 basis-point movement in the USDT back toward the peg. These effects tend to dissipate over longer horizons, which may be due to the underlying "wind the arbitrage is leaning against" being persistent. In the case of stablecoins collateralized by cryptocurrency, such as DAI, the arbitrage mechanism is not exactly the same; we explore the stability mechanism used in that case in Appendix D.

Figure 10: Response of Tether/USD price to 1 standard deviation shock in flows to the secondary market; Left panel – Pre Ethereum blockchain; Right panel – Post Ethereum blockchain



Note: Figure documents the effect of a 1 standard-deviation shock to net secondary-market flows on the price of Tether/USD. Left and Right panels are for different sample periods based on the introduction of Tether to the Ethereum blockchain. Data for secondary-market flows are from Omniexplorer and Etherscan. Price data are from Coinapi, and takes an average of trade-price data from three trusted exchanges: Bitfinex, Bittrex, and Kraken. Sample is April 2017 to March 2019 in left panel, and April 2019 to March 2020 in right panel. Gray area denotes two-standard-error bands for statistical significance at the five-percent level.

Stablecoin's role as a vehicle currency: Effect on cryptoasset prices

The previous section on Tether established that there are self-stabilizing mechanisms in place, principally through arbitrage, to maintain the stablecoin peg. A recent paper by Griffin and Shams (2020) suggests that Tether plays an additional role via intervention/manipulation in currency markets. If stablecoins are managed by a single issuer, analogous to a central bank, then the issuer could in principle strategically change stablecoin supply if, for example, such an action would affect the prices of other cryptoassets (e.g., Bitcoin). Even if this action were public information, it could still have important distributional effects. To the extent it is not public information, additional distortions would arise. These possibilities depart from central banks in that for central banks, if well functioning, goals are clear and social-welfare based, and actions are public.

Under a null hypothesis that stablecoins are passive with respect to intervention in crypto markets, and are used purely to satisfy transaction demand by investors, then one should find no systematic effect of stablecoin issuance on, for example, the price of Bitcoin. Under this null the coin's use would depend on other factors, for example, the coin's role in reducing intermediation costs, its role in restoring parity in the stablecoin vs USD market, its use as a risk-free asset in crypto investors portfolios, and technological advances in crypto markets.

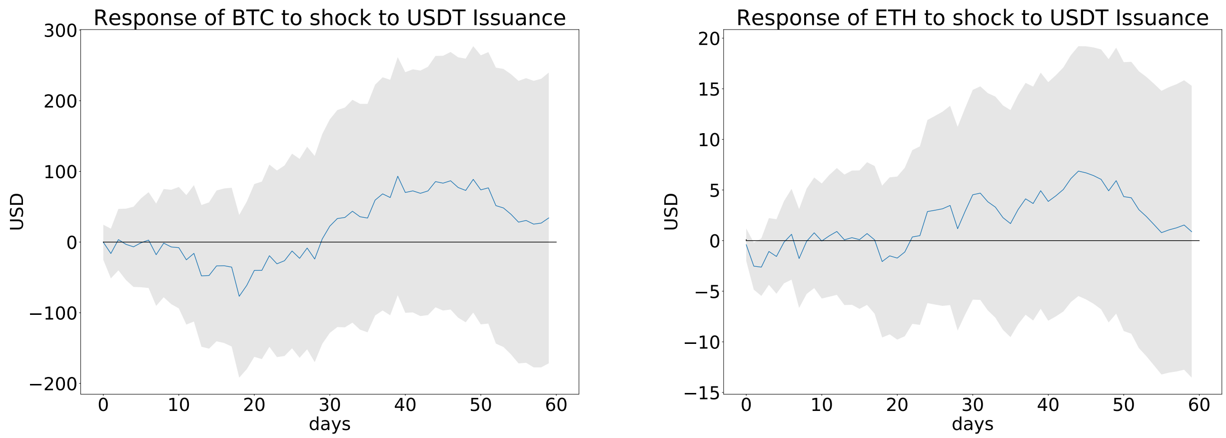
Our first test is to measure the effect of shocks to Tether supply on Bitcoin price, after controlling for past movements in supply and Bitcoin price (to control, for example, for two-way feedback and for lagged effects). The regression specification is outlined in equation 20. The outcome variable measures the price change in Bitcoin, regressed on the measure of total flows of Tether to the secondary market. A similar specification can be conducted for other non-stable cryptocurrencies such as Ethereum. Controls include lagged price changes of Bitcoin and lagged measures of secondary-market issuances. We also include controls for the daily change in the hash rate $Hash_t$ (a measure of BTC-miner computing power) and the daily change in the number of unique addresses, Adr_t, which proxies the outcome-variable's network value. This is based on work in Bhambhwani et al. (2019) that finds a cointegrating relationship between Bitcoin price, the hash rate, and the number of unique addresses. We find no significant effect on the prices of Bitcoin and Ethereum: These prices are not responding to Tether flows to the secondary market (Figure 11).[33]

Our results do not discount the possibility that price manipulation can occur, as discussed in (Griffin and Shams, 2020). Based on aggregate issuance data, however, there is no systematic effect. This supports the notion that stablecoins operate at the top level as decentralized systems of exchange-rate pegs, without intervention effects on prices in other non-stable cryptocurrency markets.

$$P_{BTC,t+h} - P_{BTC,t-1} = \alpha + \beta_h Flow_{T\to \mathrm{EX}} + \sum_{k=1}^{4} \delta_k Flow_{T\to EX,t-k} + \sum_{k=1}^{4} \gamma_k (P_{BTC,t-k} - P_{BTC,t-k-1}) + \sum_{k=1}^{4} \psi_k (Hash_{t-k} - Hash_{t-k-1}) + \sum_{k=1}^{4} \theta_k (Adr_{t-k} - Adr_{t-k-1}) + u_t \qquad h = 0, 1, 2, ... \quad (20)$$

[33]Our analysis here is limited to aggregate issuance data, and is robust to the choice of sample period, finding qualitatively similar results by restricting our sample from March 2017 to March 2018, the period of analysis in ?. That no effect arises in the overall data is, in our judgment, material. One finding in Griffin and Shams (2020) is that flows of Tether were apparently directed to a particular wallet, which then proceeded to invest in Bitcoin. Aggregate flows to the secondary market do not capture these microeconomic flows.

Figure 11: Response of Bitcoin and Ethereum prices to issuance flows in USDT



Note: Figure documents local projections of a change in secondary-market issuance on the prices for Bitcoin and Ethereum. Data for secondary-market flows are from Tether transactions on Omni, Etherscan, and Tron Blockchains. Price data are from Cryptocompare. Controls include lagged price changes and changes in cryptocurrency fundamentals such as hash rate and the number of unique addresses of the network, based on Bhambhwani et al. (2019). 4 lags are included in the baseline specification. Sample period is from April 2017 to March 2020. Gray area denotes two-standard-error bands for statistical significance at the five-percent level.

4 Empirical Evidence: Fundamentals of Peg Deviations

In this section we test channels through which stablecoins trade at a premium or discount. We present evidence that premiums arise in times of increased volatility in non-stable cryptocurrency markets. Notable examples include the crash of Bitcoin in early 2018 and the COVID-19 crisis of 2020. This supports our model predictions of stablecoin premia due to the three channels of safety, latency time, and intermediation cost differences. This section also addresses a second prediction of the model that centered on the effects of speculative attacks. We document an example of speculation on Tether in October 2018, when Bitfinex temporarily suspended convertibility of dollar deposits. This signalled to investors that Tether may not have been fully collateralized, and Tether traded at a discount of approximately 500 basis points, with significant increases in bid-ask spreads. All data used in this section, including transaction data used to construct order flow, are discussed further in the data appendix A.

Liquidity Fundamentals

We quantify factors that determine pricing in the Tether/USD market. We identify two such factors, order flow, which is a measure of net buying pressure, and cryptocurrency price volatility. Determinants of Tether's value are difficult to model in traditional ways with macroeconomic fundamentals such as inflation and interest-rate differentials. We draw instead from the medium-of-exchange role in monetary theory to posit that the price of Tether is driven by factors connected to Bitcoin- and Tether-market liquidity.

Order Flow

The first determinant of Tether returns we examine is order flow. Order flow is a measure of net buying pressure in the secondary market and, viewed through the lens of information models in microstructure theory, is the primary means through which dispersed information in the market is expressed and aggregated in price-setting.

We construct a measure of order flow using transaction data provided by cryptocurrency vendor Coinapi. This includes a history of trades from a series of exchanges that trade in the Tether/USD pair.[34] This dataset provides the timestamp of each trade, together with the amount of underlying Tether in each trade, and a true-or-false variable *taker side sell* which we use to construct the sign of the transaction.

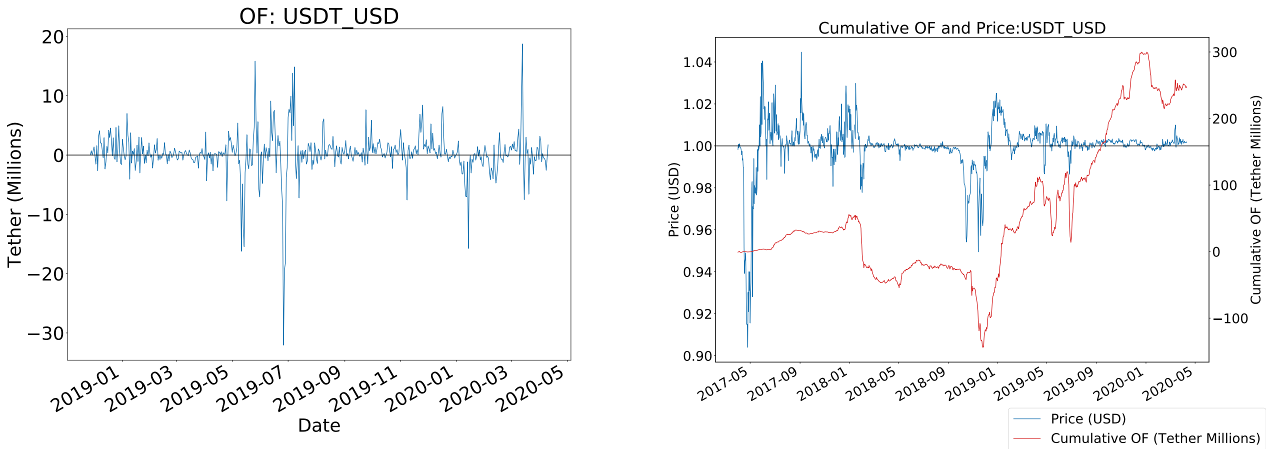
The exchange follows a maker-taker structure. The marketmaker is the provider of liquidity, and typically submits limit orders to the exchange with a specified bid and ask price. The takers are typically private investors who submit market orders for Tether, and are the aggressor of the transaction. When the *taker side sell* column reads true, this signifies that the taker is selling Tether and buying USD. The price they are willing to sell Tether is the bid price offered by the marketmaker. Conversely, when *taker side sell* is false, the taker is buying Tether and selling USD. They buy Tether at the ask price offered by the marketmaker. Using this signing convention we can construct a measure of order flow as the difference between buyer- and seller-initiated transactions, expressed in the following equation where T_k is the transaction, B indicates it is buyer-initiated and S indicates it is seller-initiated, and V_{T_k} is the amount of the transaction.

$$OF_t^{vol} = \sum_{k=t_0}^{k=t} V_{T_k} \left(\mathbb{1}[T_k = B] - \mathbb{1}[T_k = S] \right) \tag{21}$$

Figure 12 plots daily order flow on the left. We observe that order flow is stationary and mean-reverting towards zero. This is consistent with marketmakers in crypto exchanges being averse to holding inventory and net positions in Tether. We also observe a strong correlation between cumulative order flow and the price level of Tether in Figure 12, right. This suggests that order flow may convey significant information for price dynamics in the market. In particular, we observe a sharp positive correlation between order flow and price changes in October 2018, when Tether was trading at a steep discount.

[34]Exchanges that trade significantly in Tether/USD are Bitfinex and Kraken. For the baseline results we use the Kraken exchange as it has the highest volume of trades, and the earliest history (starting in April 2017).

Figure 12: Cumulative Order Flow and Price in Tether/USD



Note: Figure plots order flow of Tether/USD (left panel), and price and cumulative order flow (right panel). Transaction price and volume data are from Coinapi. Sample is April 2017 to March 2020.

Volatility of Cryptocurrency Markets

We construct measure of volatility in the BTC/USDT market based on a 10-day rolling standard deviation of the BTC/USDT price. This fundamental captures the safety premium of Tether; in times of high uncertainty in the Bitcoin price, investors want to liquidate to a store of value. Stablecoins have lower intermediation costs and lower latency time of transactions, with bank wires taking significantly longer than a transaction executed on the blockchain. We hypothesize that this results in investors choosing to liquidate unstable cryptocurrencies to stablecoins, as opposed to dollars, causing Tether to trade at a premium in times of increased risk in cryptocurrency markets.

Price discovery and determinants of Tether premiums and discounts

Following Evans and Lyons (2002), we first report regressions of price discovery on order flow. We estimate equation (22), where $\Delta p_t = p_t - p_{t-1}$ measures the difference between the closing dollar price of Tether today and the prior day. OF_t measures the net of buyer-initiated trades for Tether over the concurrent 24 hours.

$$\Delta p_t = \alpha + \beta OF_t + u_t \tag{22}$$

We find that order flow conveys significant information relevant to price-discovery (Table 5). A one standard-deviation change in order flow (which we measure as \$3.8 million based on our estimation period for combined trading in the Bitfinex, Bittrex, and Kraken exchanges) leads to an approximately 10 basis-point increase in the dollar price of Tether, where 100 basis points is \$0.01. Alternatively, a 100 basis-point move in the dollar price of Tether then requires an approximate $40 million change in net trading. We then condition the order-flow equation on subsets of the sample. In specification 2, we condition on the USDT price being within 1 standard deviation of parity. In specifications 3 and 4, we condition on the price being less than 1 standard deviation, and greater than 1 standard deviation respectively.

The estimated elasticity of price changes to order flow is significantly higher than estimates for national currencies in Evans and Lyons (2002). The authors find net trading of $1 billion in the USD/Deutschemark market in 1995 led to a 50 basis point change in the exchange rate. Our estimates are significantly higher likely due to the relative differences in liquidity between the stablecoin and national-currency forex markets.[35] The high elasticity of price to net trading in the stablecoin market is also due to the role of private investors in arbitraging deviations from parity.[36] When Tether trades at a discount, the price impact of order flow is insignificant. We reason that speculation and liquidity fundamentals explain periods when Tether trades at a large discount to the Dollar. In these periods, order flow is likely to be more noisy and aggregate less information than in periods of relative stability in the peg. Finally, we show that order flow has much larger price impact when Tether trades at significant premiums in column 4. In this case, flows from the Tether Treasury to the secondary market begin to occur as a potential stabilizing mechanism. To the extent these arbitrage flows impact the order book in a systematic way, this explains the increased price impact of order flow. For example, in response to Tether trading at a premium, an investor deposits dollars with the Treasury, obtains an equivalent amount of Tether at a price of 1.0, and sells it at the higher secondary-market price via a market order at the best bid. This results in an increase in seller-initiated transactions, meaning negative order flow, and price stabilizing toward the peg.[37]

[35] Daily trading volume in USD markets in 1995 is approximately $1 trillion according to BIS figures. In our sample, the daily average trading in the Kraken exchange is approximately $5 million.

[36] Another related paper on order flow in fixed exchange rate regimes is (Killeen et al., 2006), which analyses the transition from fixed to floating of the currencies under the European Monetary System (EMS). They propose that under fixed exchange rates, the sensitivity of order flow goes to zero under a perfectly credible regime because the central bank stands ready to offset any private-sector order flow. Therefore order imbalances have zero price impact. Alternatively, in our setting, stablecoin issuers are passive, and so even under a perfectly credible regime, private investors are required to initiate trades in the market to arbitrage peg deviations.

[37] If the investor is also a marketmaker (such as a crypto exchange), they could alternatively post competitive limit-order offers to sell. This action could have an opposing effect on measured order flow since it can trigger buyer-initiated trades.

Table 5: Price Discovery and Signed Order Flow

	I	II	III	IV
	Δp	Δp	Δp	Δp
OF	9.49***	9.19***	11.97	35.07***
	(1.73)	(1.34)	(11.60)	(11.07)
Intercept	-0.69	0.44	28.00*	-53.74***
	(1.73)	(1.31)	(15.81)	(9.79)
R-squared	0.03	0.05	0.01	0.13
No. observations	1104	956	78	70
Full Sample	Y	N	N	N
$\lvert p_{t-1} - 1\rvert < 1sd$	N	Y	N	N
$p_{t-1} - 1 < -1sd$	N	N	Y	N
$p_{t-1} - 1 > 1sd$	N	N	N	Y

Note: Table presents regressions of the daily change in the USD price of Tether on a measure of daily order flow. Order flow is constructed as the net of buyer-initiated transactions for the Tether/USD pair, where a buy transaction is reported as +1 when the buyer of Tether is the aggressor. Order flow and trade price data are from Coinapi. Sample period is April 2017 to March 2020, and consolidates trade data from three trusted exchanges: Bitfinex, Bittrex, and Kraken. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

We now regress the deviation of the Tether price from the peg, $p_t - 1$, on signed order flow OF_t, as well as a ten-day rolling window of Bitcoin price volatility, $\sigma_{BTC,t}$, as expressed in equation 23.

$$p_t - 1 = \alpha + \beta_1 OF_t + \beta_2 \sigma_{BTC,t} + u_t \tag{23}$$

Table 6 provides evidence that liquidity fundamentals have an important role in explaining deviations from the peg. In specification 1, we present the results of regression 23 for the full sample. We then condition on subsets of the sample in specifications 2, 3, and 4. In column 2, we condition on the USDT price being within 1 standard deviation of parity. In columns 3 and 4 we condition on price being more than 1 standard deviation below parity, and greater than 1 standard deviation above parity respectively.

We find positive effects of an increase in Bitcoin volatility on the Tether price. Based on specification 1, the volatility of trading volume in Bitcoin has a positive effect on Tether premiums, with a 1 percent increase in BTC price volatility increasing the price of Tether by

Table 6: Determinants of Tether/USD Price – Liquidity Fundamentals

	I	II	III	IV
	$p_t - 1$	$p_t - 1$	$p_t - 1$	$p_t - 1$
OF	21.85***	13.60***	23.45	19.36*
	(3.79)	(1.84)	(19.63)	(11.54)
σ_{BTC}	30.90***	6.07***	115.10***	-5.63
	(4.15)	(2.06)	(24.30)	(9.53)
Intercept	-178.55***	-26.01**	-903.42***	183.64***
	(23.34)	(11.64)	(121.54)	(53.66)
R-squared	0.07	0.06	0.24	0.05
No. observations	1091	942	77	70
Full Sample	Y	N	N	N
$\lvert p_{t-1} - 1 \rvert < 1sd$	N	Y	N	N
$p_{t-1} - 1 < -1sd$	N	N	Y	N
$p_{t-1} - 1 > 1sd$	N	N	N	Y

Note: Table presents regressions of the deviation from parity in the USD price of Tether on variables capturing liquidity in the Tether/USD and BTC market. OF measures order flow and is constructed as the net of buyer-initiated transactions for the Tether/USD pair, where a buy transaction is reported as +1 when the buyer of Tether is the aggressor. σ_{BTC} is the log standard deviation of the BTC/USDT trading price sourced from Cryptocompare. Standard deviations are measured using a rolling window of 10 days. Sample is April 2017 to March 2020, and consolidates trade data from three trusted exchanges: Bitfinex, Bittrex, and Kraken. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.

approximately 0.4 basis points.[38] This suggests a potential risk-hedging motive for holding Tether in periods of extreme Bitcoin-price volatility. One of Tether's features is its store-of-value function for crypto investors. This analysis is suggestive evidence that Tether acts as a safe haven, however two questions remain. To what extent is the role of Tether a safe haven to the entire class of non-stable cryptocurrencies? And does the behaviour of Tether generalize to other stablecoins as well? We address both questions in the following section, which provides more evidence on the role of the safety premium and latency time in giving rise to stablecoin premiums.

Stablecoin premiums: Safety and latency premium

To test the role of stablecoins as a safe asset in the domain of cryptoassets, we conduct a factor analysis of the returns of the five largest non-stable cryptocurrencies by market capi-

[38] Our result on the effects of BTC price volatility is robust to using a trading-volume measure to construct our volatility variable.

talization (BTC, ETH, XRP, BCH, LC), together with each stablecoin separately. The factor analysis suggests a first factor that explains a cumulative 55 per cent of covariance between asset returns. Critically, all non-stable cryptocurrencies load positively on this risk factor, and Tether (USDT) loads negatively on this risk factor (Table 7). We conduct a similar analysis for other major stablecoins, and tabulate the loadings of the first factor on the stablecoin. We find negative loadings on other stablecoins as well, suggesting stablecoin returns comove negatively with a crypto risk factor.

Why do Tether and other stablecoins exhibit safe-haven properties? In periods of risk, investors need to liquidate into a store of value. Portfolio rebalancing toward Tether and other stablecoins provide this function with minimal intermediation costs. As noted, on some exchanges for example, there are long processing lags for dollar withdrawals to comply with intermediation procedures. Fees are also often imposed when dollar withdrawals are frequent or large.[39]

Table 7: Factor analysis of crypto returns and stablecoins show stablecoins have a negative loading with respect to a crypto risk factor

	F1		F1		F1		F1
BTC	0.80	BTC	1.00	BTC	0.89	BTC	0.85
ETH	0.94	ETH	0.85	ETH	0.92	ETH	0.83
XRP	0.72	XRP	0.73	XRP	0.83	XRP	0.57
BCH	0.66	BCH	0.78	BCH	0.86	BCH	0.83
LTC	0.87	LTC	0.79	LTC	0.88	LTC	0.83
USDT	**-0.02**	**USDC**	**-0.02**	**PAX**	**-0.002**	**TUSD**	**-0.02**

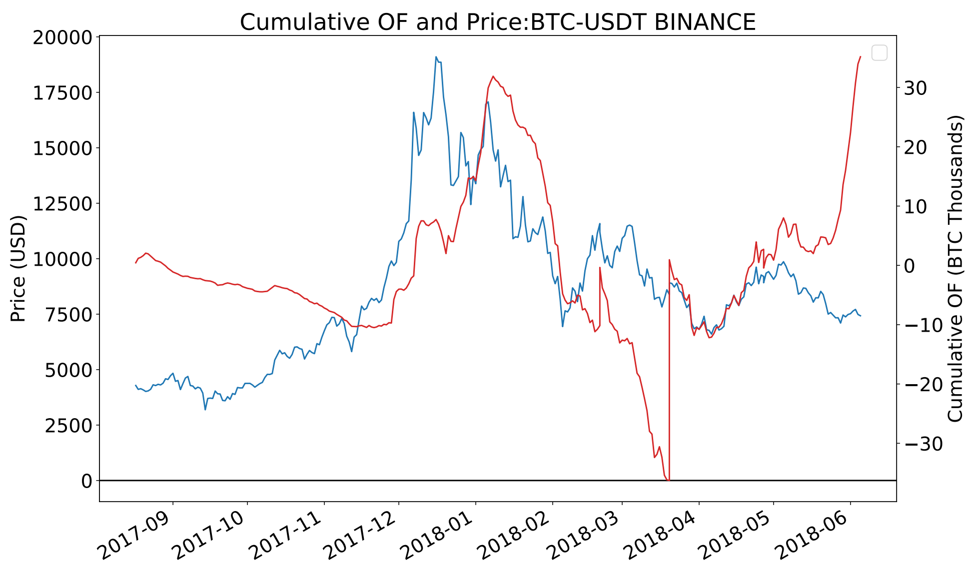
Note: Table reports correlations of the first factor with returns on a set of 5 largest crypto currencies (by market cap), and a stablecoin. The factor analysis is based on a model with 2 factors, and the loadings on the stablecoin are illustrated in the last row of the table. Price data are from Cryptocompare for major cryptocurrencies, and Coinapi for the stablecoins. Sample for each coin is based on available price data of daily close prices from Bitfinex, Bittrex, and Kraken exchanges. For details on sample period refer to appendix A.

To provide evidence of the safe-haven demand during the period from January 6 to February 6, 2018, we first note that there was a decline of up to 65 percent in the price of Bitcoin. While this necessarily implies a relative portfolio shift from Bitcoin to dollars purely from the valuation effect, we observe a similar rebalancing toward Tether during this period. We use trade data on BTC-USDT sourced from Coinapi for the Binance exchange. This covers a sample from August 2017 to June 2018. We see clearly a decline in cumulative order flow for BTC during

[39]For more information, see announcements by Bitfinex: https://bit.ly/2NEzITW and https://www.bitfinex.com/posts/311. Bitfinex states it will take investors 7 to 15 days to make dollar withdrawals from their platform in order to comply with intermediation procedures. Bitfinex has also introduced transaction costs of a 3% fee for investors who make more than two dollar withdrawals a month, or for withdrawals larger than $1 million in a given month.

the period of January-February 2018 in Figure 13. Liquidation into Tether is intuitive given Tether is pegged to the dollar, and provides a natural hedge for crypto investors, and proxies as a risk-free cryptoasset. Liquidation into Tether is also the only option for exchanges such as Binance which do not allow conversion into national currencies directly.

Figure 13: Cumulative Order Flow and Price in BTC/USDT



Note: Figure plots cumulative order flow in the BTC-Tether market (red line) against the BTC-Tether price (blue line). Data from Coinapi, which provides trade data for BTC-USDT pair on Binance exchange.

Stablecoins During the COVID-19 Panic

The COVID-19 economic crisis resulted in a collapse of the BTC market of approximately 40%, as it fell from approximately $8,000 to $5,000 from March 12th to 13th. Amidst the widespread sell-off in cryptocurrency markets, there were clear efforts by investors to liquidate into a store of value. To gauge investors incentive to liquidate into a store of value quickly, we use the Ether Network's gas prices. Gas is a measure of the amount of ether (ETH) a user pays to perform a given activity, or batch of activities, on the Ethereum network. These transaction costs are analogous to commissions on exchanges, however these costs are paid to the miners who authenticate the transactions on the Ethereum blockchain. These prices are denominated in GWEI which is equivalent to one-billionth of one ETH, and they are typically an average of 10 GWEI per transaction. Critically, these units of GWEI provide a proxy for transactions' latency time. For example, on March 29th, 2020, the Ether gas station states that there is transaction cost of 8 units of GWEI for a transaction time less than 2 minutes, 5 units of GWEI for a transaction time less than 5 minutes, and 3 units of GWEI for a transaction time less than 30 minutes.[40]

On March 12th, the average gas prices temporarily spiked to over 100 GWEI per transaction from the 10 GWEI average seen just one day prior. There was congestion on the Ethereum blockchain as investors wanted to liquidate unstable cryptocurrencies into stablecoins. The rise in gas costs reflected the cost of latency time; investors were willing to pay more gas costs to liquidate faster.[41]

We plot in Figure 14 the price response of the six largest coins by market cap, based on data in March 2020. Shaded areas indicate the period in which the price of Bitcoin fell by 50%. In all cases, we see a rise in the price of stablecoins of approximately 500 basis points. The largest increase is for BinanceUSD coin, the stablecoin issued by the Binance cryptocurrency exchange. A potential reason why BinanceUSD trades at a premium to the dollar is because Binance platforms do not allow conversion to national currencies directly. Therefore, for investors on the Binance exchange, converting to BinanceUSD is a good option for reducing latency time.

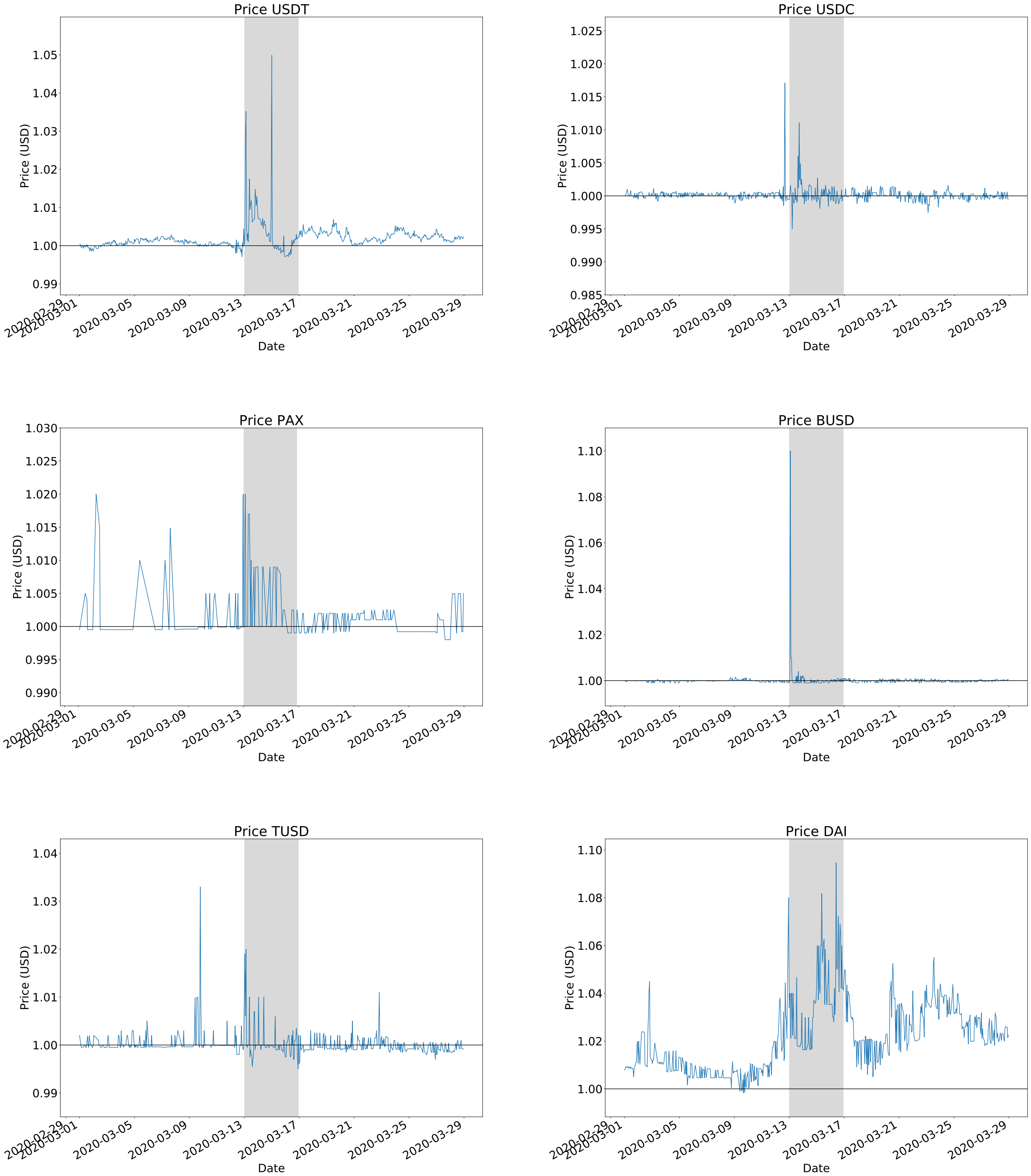
We finish our analysis on the latency premium with Figure 15, which plots cumulative order flow and price of BTC in terms of stablecoins for the five largest market-cap currencies. There is a significant sell-off of BTC during March 12th. For example, on the Binance exchange, there was an approximate 30,000 unit net selling pressure of BTC on March 12th. Similar trends of a decline in cumulative order flow for BTC in other stablecoin markets is evident. For the crypto-collateralized coin DAI, we examine the ETH/DAI market, and a similar trend collapse of the Ether price and decline in cumulative order flow on March 12th is evident; it is not as pronounced, however, as for the national-currency-backed coins.[42]

[40] Gas prices, as well as daily amounts of Ether Gas used, are provided in `https://ethgasstation.info/`.

[41] For more information see `https://blockonomi.com/ethereum-gas-prices-surged/`.

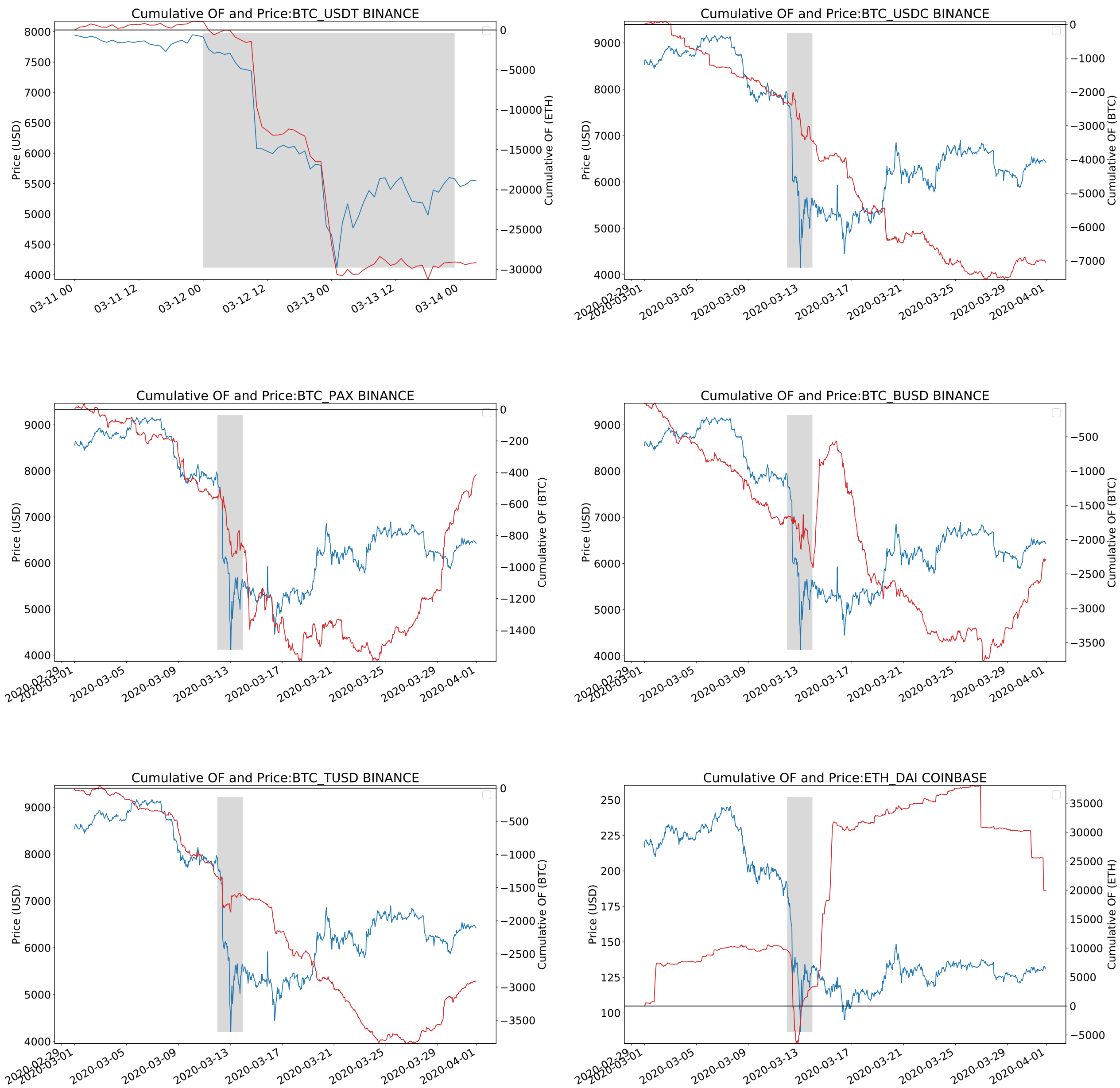
[42] We reason that as DAI is crypto-collateralized, investors use it more as a speculative investment. Therefore, investors that liquidate ETH into DAI will return to longer Ethereum positions once there is a greater expectation of rising Ethereum prices in the future; we do see a quick turnaround in order flow once the Ethereum price reaches its low.

Figure 14: Response of stablecoin prices to negative price shock of Bitcoin in March, 2020



Note: Price (in USD) of 6 largest stablecoins by market cap during March 2020. Price data are from Coinapi and are hourly, available on cryptocurrency exchanges Binance, Bitfinex, Bittrex, and Kraken. Shaded areas indicate the period when the price of Bitcoin fell approximately 50% from March 12th to March 13th.

Figure 15: Response of Bitcoin prices and order flow in BTC/Stablecoin markets in March, 2020

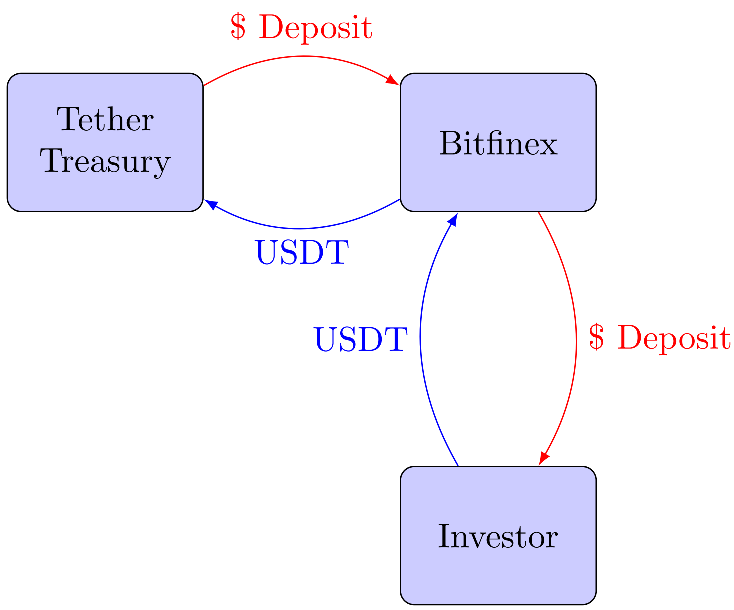


Note: Blue line indicates BTC price (in terms of stablecoin), and red line indicates cumulative order flow in BTC. Trade data for BTC/Stablecoin are from Coinapi and is hourly, available on cryptocurrency exchanges Binance, for the national-currency-backed coins USDT, USDC, PAX, BUSD, and TUSD. For crypto-collateralized DAI, we plot the Ethereum price and cumulative order flow in ETH/DAI market on the Coinbase exchange. Shaded areas indicate the period when the price of Bitcoin fell approximately 50% from March 12th to March 13th.

Stablecoin Discounts: Speculative Attacks

The event we consider is a classic example of a 2nd-generation currency crisis, in which a perceived risk of the Tether Treasury not being fully backed leads to a sell-off on Tether as investors perceive a non-zero probability that Tether may be devalued. The setting is an announcement on 11th October, 2018, by the exchange Bitfinex. On that day, Bitfinex decided to temporarily pause national-currency deposits (USD, GBP, EUR, JPY) for certain customer accounts in the face of processing complications.[43] This exchange is the first point of contact for the Tether Treasury, so an announcement suppressing investors' ability to redeem for US dollars can signal that Tether is not fully collateralized.

Figure 16: Flow of Dollar Deposits and USDT in a Speculative Attack



Note: Schematic illustrates the dynamics of a speculative attack. Investors have expectations that Tether is not fully backed by dollar reserves. In response, an investor redeems dollar deposits with Bitfinex. In turn, Bitfinex redeems its dollar deposits with the Tether Treasury, withdrawing Tether tokens from circulation.

Figure 16 helps understand the motive for Bitfinex suspending conversion to dollars. Suppose the Tether Treasury is not fully collateralized, and contains a level of dollar deposits that is less than the amount of Tether in circulation. If investors believe the USDT peg is unstable, they will redeem their Tether for dollar deposits at Bitfinex. Bitfinex will in turn want to redeem their Tether for dollar deposits from the Tether Treasury. If the Tether Treasury suspends Bitfinex's conversion to dollar deposits, then this poses a systemic risk to Bitfinex. This suggests that Bitfinex is susceptible to a liquidity crisis in the event that Tether is not fully collateralized. Hence, the suspension of dollar convertibility in Bitfinex serves as a signal

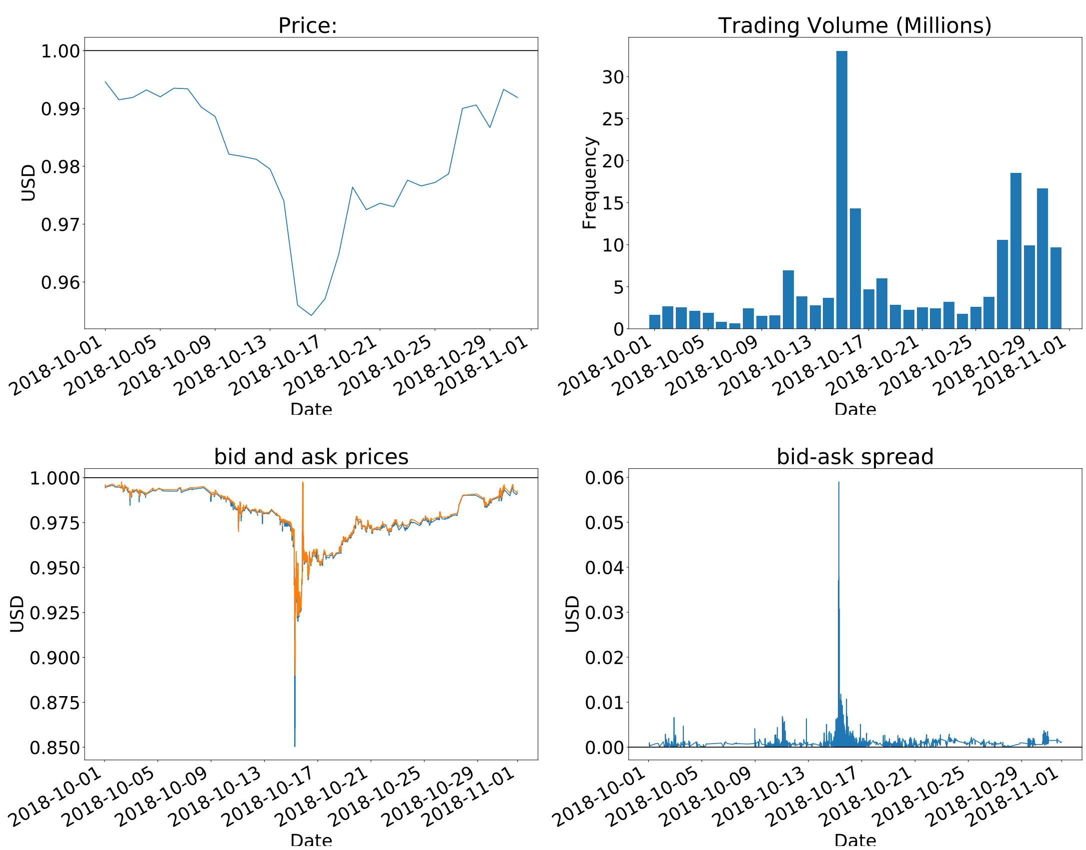
[43]See https://medium.com/bitfinex/fiat-deposit-update-october-15th-2018-18ddd276c3fd.

to investors that Tether may not be fully collateralized.

We can see the unfolding of this event on Tether's dollar price, and on measures of liquidity, in Figure 17. Tether prices fall to a discount of 95 cents on October 15th. Similarly, liquidity fundamentals such as volatility of USDT tell a similar story. There is a sharp rise in Tether trading volume, and a corresponding decline in network transaction value, around the Bitfinex announcement. This is consistent with a relative increase in return volatility as buyers and sellers of Tether are unsure of the fundamental trading price.

Bid-ask spreads rise significantly, with bid prices in the limit order book falling to 85 cents, indicating a lack of buyers. While the whole-sample average bid-ask spread is between 0.1 and 0.15 of a cent, with a standard deviation of 0.2 cents, there are evident spikes in bid-ask spreads, suggesting an information asymmetry in response to speculative events. In particular, the sharp fall in bid and ask prices corresponds to a spike in the width of the spread of 6 cents (600 basis points).

Figure 17: Tether/USD price, Trading Volume, Cumulative Order Flow, and Bid-Ask Spreads



Note: Schematic illustrates the movement in Tether/USD price, bid-ask prices, spreads, and trading volume during October 2018. Transaction, bid, and ask prices from Coinapi trade and order-book data. Volume data are from Cryptocompare. Sample period October 2018.

5 Conclusion

This paper examined the efficiency and mechanisms of how stablecoins work in the digital-asset economy. Two fundamental questions were addressed. First, how does price stabilization function in the case of stablecoins and does this process differ from the supply-driven (i.e., central-bank-intervention-driven) process that applies when national currencies are pegged to one another? Second, what fundamentals account empirically for the premiums and discounts that open up in Tether and other stablecoin markets?

We develop a model both to clarify the channels through which stablecoin premiums and discounts can arise and to provide other testable implications. A representative investor can use dollars, stablecoins, or both as vehicle currencies through which they invest in a non-stable cryptoasset (e.g., Bitcoin). Stable-coin premiums can arise in the model due to relatively low intermediation costs, which accords with actual market conditions since stablecoins use blockchains. Stablecoin premiums can also arise in the model by providing a hedge for non-stable cryptoassets. An arbitrage mechanism stabilizes the stablecoin price around the peg: in response to a deviation from the peg, the investor has an incentive to buy (sell) Tether from the primary market issuer at a one-for-one rate and sell (buy) Tether in the secondary market when that price trades above (below) parity. These endogenous investor flows drive the price of stablecoins toward its pegged value.

Empirically, we find that stablecoin issuance, the closest analogue to central-bank intervention, plays only a limited role in stabilization, pointing instead to the demand side as providing the fundamental stabilizing forces, consistent with our model. In explaining deviations from the peg, we find that stablecoin premiums are due to coins' uniqueness as a safe-haven asset within the digital-asset economy, citing evidence of significant premiums during the crash in non-stable cryptocurrencies in early 2018 and during the COVID-19 crisis, whereas stablecoin discounts derive from both liquidity effects and collateral concerns.

Looking to the future, Facebook announced in 2019 its intention to launch Libra, a global stablecoin. Our analysis sheds light on the mechanisms by which a global stablecoin like Libra can maintain its peg, in that case to a basket of currencies. Our findings indicate that a decentralized system of pegs can work well even when the primary issuer remains passive and depends on demand-driven arbitrage to stabilize price around the peg. As stablecoins become even more widely used, new mechanisms for stabilizing price around the peg will inevitably arise. Introductions of forward and futures markets on stablecoins, for example, will attract arbitrage capital from regulated financial institutions, inducing still greater stability, so long as the pegs remain fully credible and collateralized.

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Appendices

A Data Appendix

We have four sources, each supporting a different aspect of our analysis.

1. **Coinapi**: Online subscription with access to open, high, low, close, and volume (OHLCV) trade data and order book data from multiple crypto exchanges.

2. **Omniexplorer and Etherscan**: Blockchain explorers that contain transaction data of individual wallets, used to obtain new issuance/redemptions of stablecoin tokens to compute flows of these tokens to the secondary market.

3. **Cryptocompare**: Price and trading volume data for currencies (based on a representative list of crypto exchanges).

4. **Coinmetrics**: Provides fundamentals data on the network value, computing power of cryptocurrency mining, and number of unique addresses.

Coinapi

Coinapi offers a monthly subscription with access to their data api which gives historical cryptocurrency OHLCV, trade, and order book data. We outline in Table 8 the specific trading pairs, coin symbols, and types of data that we employ. To use the api, we followed `https://github.com/coinapi/coinapi-sdk`, which gives sample code for querying the api.[44] The trade data are used to construct order-flow data, as it has a boolean "taker_side_sell" variable that is a seller-initiated transaction if True, and buyer-initiated if False. Orderbook data for exchanges are also provided, useful for bid and ask prices. To construct bid-ask spreads, we take the highest bid and the lowest ask out of a set of 20 quotes for a specific time period, which gives us a lower bound for the bid-ask spread at any given point in time.

[44] Modifications were made to customize results; api requests are limited to 100,000 data points per day.

Table 8: Coinapi Data

Data Type	Coin Symbol	Exchange	Sample Period
OHLCV, Trade and Order Book Data	USDT_USD	Kraken	04/17-03/20
OHLCV, Trade and Order Book Data	USDT_USD	Bitfinex	12/18-03/20
OHLCV, Trade and Order Book Data	USDT_USD	Bittrex	05/18-03/20
OHLCV	USDC_USD	Kraken	01/20-03/20
OHLCV	PAX_USD	Bittrex	01/19-03/20
OHLCV	BUSD_USD	Binance	10/19-03/20
OHLCV	TUSD_USD	Bittrex	06/18-03/20
OHLCV	DAI_USD	Bitfinex	04/18-03/20
OHLCV and Trade Data	BTC_USDT	Binance	08/17-03/20
OHLCV and Trade Data	BTC_USDC	Binance	12/18-03/20
OHLCV and Trade Data	BTC_PAX	Binance	11/18-03/20
OHLCV and Trade Data	BTC_BUSD	Binance	09/19-03/20
OHLCV and Trade Data	ETH_DAI	Coinbase	05/19-03/20

Where multiple cryptocurrency exchanges offer the same data, we choose the exchange that (i) has the longest time series and (ii) is one of ten exchanges that has "trusted volume" according to a report filed by the SEC.[45] The report tests exchanges for fraudulent activities (e.g., suspicious variability in bid-ask spreads, systematic patterns in histograms of transaction size) and finds that the exchanges listed in Table 9 do not have the telltale patterns in trading volume or spreads. We note that of the ten exchanges, two do not offer an onramp for trading national currencies, Binance and Poloniex. Similarly, two platforms, Itbit and Bitflyer, only accepted national currencies at the time the SEC report was written.

[45]See https://www.sec.gov/comments/sr-nysearca-2019-01/srnysearca201901-5164833-183434.pdf.

Table 9: Trusted Exchanges According to SEC Report

Exchange	National Currencies	Stablecoins
Binance	N	Y
Bitfinex	Y	Y
Bitstamp	Y	Y
Bittrex	Y	Y
Bitflyer	Y	N
Coinbase	Y	Y
Gemini	Y	Y
Itbit	Y	N
Kraken	Y	Y
Poloniex	N	Y

Omniexplorer and Etherscan

We use this dataset to construct net flows from the stablecoin issuer to the secondary market. The addresses of the issuers are listed in Table 12. We follow Wei (2018) in obtaining transactions of Tether grants (creation of new tokens) and revokes (redemptions) from the Omniexplorer api. Tether's id is 31, and using the api call in Table 11, we retrieve the entire history of Grants and Revokes.[46] Etherscan is an explorer of all transactions recorded on the Ethereum blockchain, available at `https://etherscan.io/`. This includes transactions for Tether and other national-currency-backed coins. The history of token grants and revokes is exportable to a data-readable format.

For Etherscan, we first need the contract address of each coin, which one can find by searching the ticker id of the coin (USDT, USDC, PAX and TUSD) in the search portal on `https://etherscan.io/`. The contract addresses are listed in Table 10. To find the Etherscan address, you need the contract address of the coin, followed by the wallet address to get the entire history of transactions for a given wallet. For example, the contract address for USDC is 0xa0b86991c6218b36c1d19d4a2e9eb0ce3606eb48, and the wallet address for Tether grants is 0x0000000000000000000000000000000000000000. Therefore, the Etherscan url for USDC grants is given by: `https://etherscan.io/token/0xa0b86991c6218b36c1d19d4a2e9eb0ce3606eb48?a=0x0000000000000000000000000000000000000000`. The addresses for Tether Grants/Revokes of tokens are listed in Table 11, and the Treasury addresses of four coins are listed in Table 12. (The only national-currency-backed coin that does not have a Treasury listed is TrueUSD.) We note that the addresses for Tether Grants for USDC, PAX, and TUSD are identical; when

[46] Please refer to `https://api.omniexplorer.info/` on how to obtain transaction histories.

searching for transactions of the grant address, each coin has a different contract address and so it is a unique identifier. Using the following data, we compute net changes in Tether in circulation to the secondary market as the level of token grants less redemptions. Similarly, we measure net flows in and out of the Tether Treasury wallet. Subtracing net flows into Treasury from the net of grants and revokes of tokens gives a measure of total flows to the secondary market.

Table 10: Stablecoin Contract Addresses

Coin	Blockchain	Contract Address
USDT	Etherscan	0xdac17f958d2ee523a2206206994597c13d831ec7
USDC	Etherscan	0xa0b86991c6218b36c1d19d4a2e9eb0ce3606eb48
PAX	Etherscan	0x8e870d67f660d95d5be530380d0ec0bd388289e1
TUSD	Etherscan	0x97A9F6F941b54c373cec38b8Dc7565CcDBbE75C6

Table 11: Stablecoin Issuer Wallet Addresses

Coin	Blockchain	Wallet Address
USDT	Omni Explorer	https://api.omniexplorer.info/v1/properties/gethistory/31
USDT	Etherscan	0xc6cde7c39eb2f0f0095f41570af89efc2c1ea828
USDC	Etherscan	0x0000000000000000000000000000000000000000
PAX	Etherscan	0x0000000000000000000000000000000000000000
TUSD	Etherscan	0x0000000000000000000000000000000000000000

Table 12: Stablecoin Issuer Wallet Addresses

Coin	Blockchain	Wallet Address
USDT	Omni Explorer	1NTMakcgVwQpMdGxRQnFKyb3G1FAJysSfz
USDT	Etherscan	0x5754284f345afc66a98fbb0a0afe71e0f007b949
USDC	Etherscan	0x55fe002aeff02f77364de339a1292923a15844b8
PAX	Etherscan	0x5195427ca88df768c298721da791b93ad11eca65
TUSD	Etherscan	N/A

Cryptocompare

Cryptocompare provides public access to price and volume data based on volume-weighted averages of price quotes and trades from 150 cryptocurrency exchanges, available via their api https://min-api.cryptocompare.com/.[47] We use this resource to measure total traded volume in the Tether/USD and BTC/USD pairs. We also use cryptcompare to determine the daily closing price of non-stable cryptocurrencies BTC, ETH, XRP, BCH, and LTC.

Coinmetrics

We use coinmetrics for the following series, based on the data dictionary available at https://coinmetrics.io/data-downloads, using the tickers listed in Table 13.

Hash Rate: The mean rate at which miners are solving hashes in a give time interval. Hash rate is the speed at which computations are being completed across all miners in the network. The unit of measurement varies depending on the protocol.

Number of Unique Addresses: The sum count of unique addresses that were active in the network (either as a recipient or originator of a ledger change) in that time interval. All parties in a ledger change-action (recipients and originators) are counted. Individual addresses are not double-counted if previously active.

Following Bhambhwani et al. (2019), we use the hash rate and number of unique addresses as fundamentals to model price determination of non-stable cryptocurrencies such as BTC and ETH.

Table 13: Coinmetrics Indicators

Variable	Ticker	Pairs
Hash Rate	HashRate	BTC, ETH
Number of Unique Addresses	AdrActCnt	BTC, ETH

[47]For more detail on how quotes and traded volume are calculated, see: https://www.cryptocompare.com/media/27010937/cccagg_methodology_2018-02-26.pdf.

B Governance and Transparency Measures

We provide here more institutional detail on the transparency measures undertaken by stablecoins. Tether inc. acknowledges in its white paper that there are potential problems with the security of its dollar deposits. It lists the following five points (Tetherinc., 2016):

1. *We (Tether inc.) could go bankrupt*
2. *Our bank could go insolvent*
3. *Our bank could freeze or confiscate the funds*
4. *We could abscond with the reserve funds*
5. *Recentralization of risk to a single point of failure*

Of the following points, Tether claims dollar deposits are still redeemable if Tether inc. goes bankrupt or becomes insolvent. For the third and fourth point, they state that their bank is familiar with holding cryptocurrency deposits, and that absconding with funds is unlikely due to its public charter. The fifth point is the biggest issue with Tether, and that is, while Tether in circulation is using a decentralized system of exchange by being on the blockchain, all dollar deposits are held in a centralized issuer. There is settlement risk if the dollar deposits are vulnerable to attack from an outside party. One way for Tether to mitigate the central point of failure is by having sufficient reserves in its balance sheet. This point is tackled differently by newer stablecoins, e.g., Paxos, which has FDIC-insured deposits, and USDC tokens via decentralization of the issuer with multiple licenses to create tokens, and finally by protecting counterparty risk through the use of escrow accounts.

The main transparency measure undertaken by Tether is the publication of its daily balance sheet. As stated in the Tether White Paper (Tetherinc., 2016), Tether follows a "proof of reserves" process in which they account for all liabilities (Tether in circulation) on the blockchain. This includes all platforms Tether currently trades on, the three main platforms being Omni explorer, Ethereum, and Tron according to its balance sheet in April, 2020. Every Tether in circulation is backed, in principle, by a dollar deposit. Tether inc. releases a daily balance sheet reporting their total dollar deposits. For example, on April 2nd, 2020, their balance sheet, according to `https://wallet.tether.to/transparency`, says the Total Assets, which is the bank deposits, is equal to \$6,480,678,611.74, and total Tether in circulation is given by \$6,349,160,932.47. The excess of assets over liabilities is \$131,517,679.27. As a percentage of total assets, that is approximately 2%. We note that this matches very roughly what a risk-free rate would yield annually on fixed-income instruments.[48]

[48] While not explicit about their interest-bearing assets, the following article documents that Tether does earn interest on its dollar deposits: `https://cryptobriefing.com/tether-interest-stablecoins/`.

Audit Reports

Similar to Tether, we have monthly auditing reports for TrueUSD and USDC that are managed by accounting firms Cohen & Co and Grant Thornton respectively. For example, a typical audit report on TrueUSD, from the December 2019 statement, states the following: *"The issued and collateralized TrueUSD...do not exceed the balance of the escrow accounts reported above. The supply of TUSD tokens can be reconciled to transactions within the escrow accounts..."*.

Similarly, a statement on USDC's accounting firm Grant Thornton, December 2019 statement, states the following: *"USD Coin (USDC) tokens issued and outstanding = $519,628,995 USDC US Dollars held in custody accounts = $520,537,729...the issued and outstanding USDC tokens do not exceed the balance of the US Dollars held in custody accounts."*

Statements confirm that total assets exceed total liabilities and that the stablecoins are at least 100% collateralized.

Crypto-Collateralized Coins

The above discussion accounts for national-currency-backed coins; a different set of rules of transparency and accountability apply to the crypto-collateralized coin DAI. DAI is encoded on the Ethereum blockchain using a smart contract. This is a set of protocols that are enforced by computer code. In the case of DAI, the smart contract is designed to enforce liquidation of the collateral if the collateral ratio goes below 150% (the ratio of Ethereum collateral to total value of DAI borrowings), and will impose a liquidation penalty to the borrower. In contrast to national-currency-backed coins, there is no centralized risk of the issuer absconding with funds, as the smart contract means any Ethereum collateral deposited by the investors is locked in the contract.

Due to the nature of the Ethereum collateral, this currency requires additional features for stability of the secondary market price. One such tool is the DAI borrowing rate, which controls the level of borrowings of DAI, and by extension flows of DAI into the secondary market. This feature is controlled through a continuous voting process where voters can choose a DAI stability rate, with the weight of votes given by their share of total DAI borrowings in the economy. While the system consults all users on the stability rate, there are occasions where a "whale", an investor with significant market power, can manipulate the stability rate.[49]

C Data on Other National-Currency-Backed Stablecoins

We provide here supplementary evidence on other national-currency-backed stablecoins. USDC, Paxos, and TrueUSD are among the largest 5 coins by market cap as of March, 2020,

[49]See https://bit.ly/2WoJRXY for more details.

and are national-currency-backed like Tether. They differ from Tether: USDC decentralises the primary issuer to have multiple issuers with licenses to create USDC tokens; Paxos dollar deposits are insured by FDIC banks; and TrueUSD uses a system of escrow accounts in transactions between investors and the stablecoin issuer. All of these systems claim to be 100% backed by US dollar collateral.

We subdivide this section into the following:

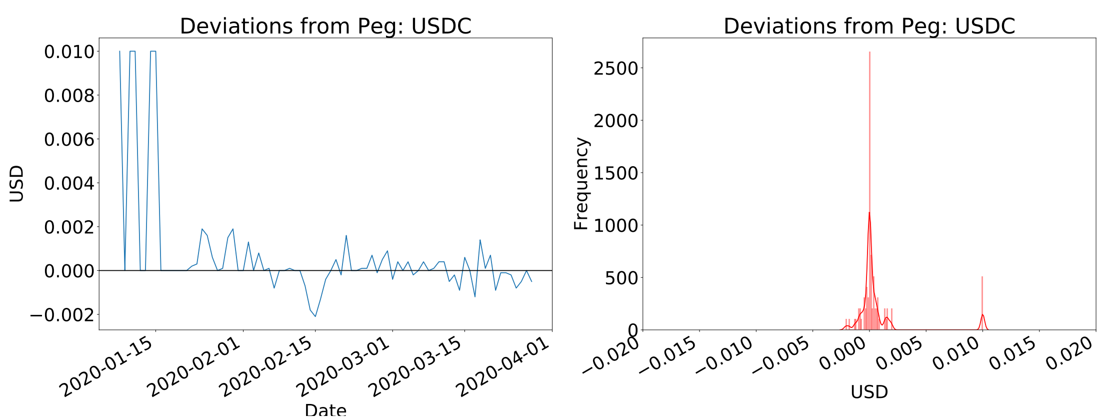
1. Transaction prices and histograms showing a two-sided distribution of deviations.

2. Balance sheets and secondary market flows.

Transaction Price and Histogram of Deviations

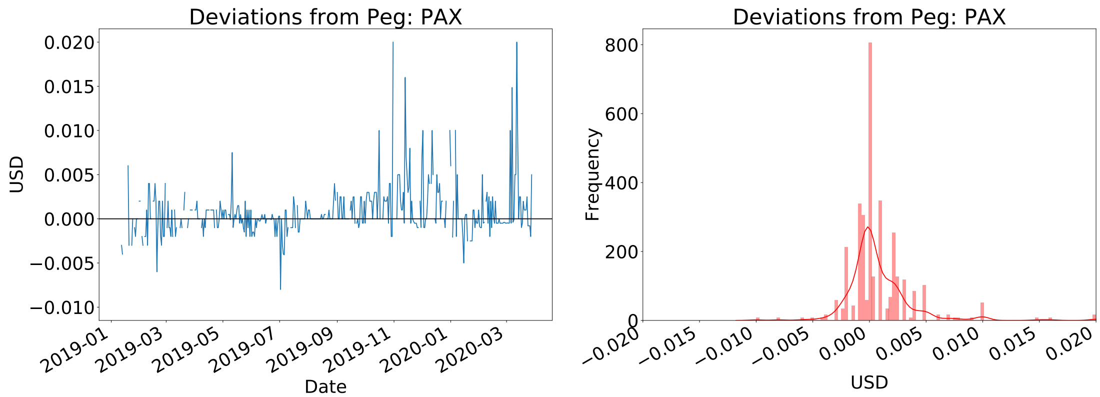
We plot transaction-price deviations from the peg for USDC, Paxos, and TrueUSD. Data are from Coinapi for all coins. We make two general observations based on the following Figures 18, 19, and 20. The first is that deviations are two-sided – these stablecoins trade at both a premium and a discount to the dollar parity peg. The second observation is that deviations are typically persistent, and as indicated in section 1, we note a half-life of deviations that ranges from 5 to 10 days for most coins.

Figure 18: USDC/USD Deviations from Peg and Histogram of Deviations



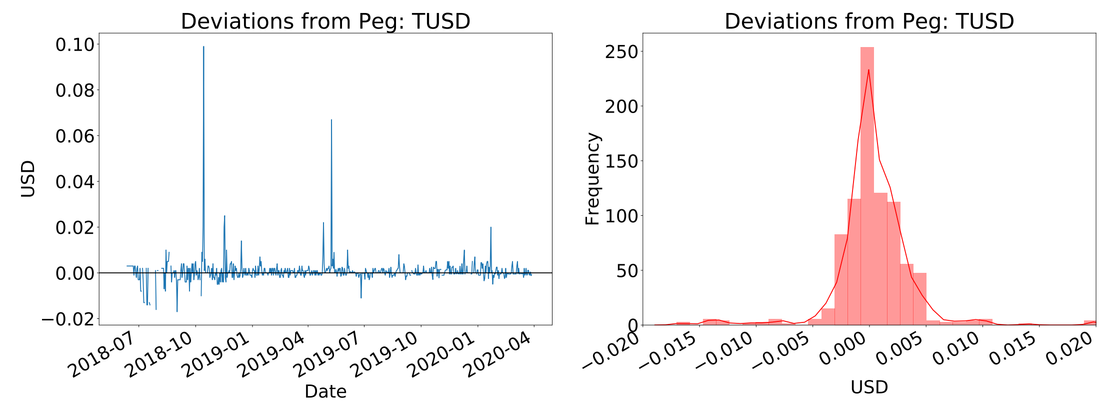
Note: Figure plots deviations of the USDC peg from parity (left panel). A positive deviation indicates USDC trades at a premium. Right panel is a histogram of deviations of the USDC peg. Data from Coinapi. Sample is January 2020 to March 2020.

Figure 19: PAX/USD Deviations from Peg and Histogram of Deviations



Note: Figure plots the Paxos deviations of the peg from parity (left panel). A positive deviation indicates Paxos trades at a premium. Right panel is a histogram of deviations of the Paxos peg. Data from Coinapi. Sample is January 2019 to March 2020.

Figure 20: TUSD/USD Deviations from Peg and Histogram of Deviations

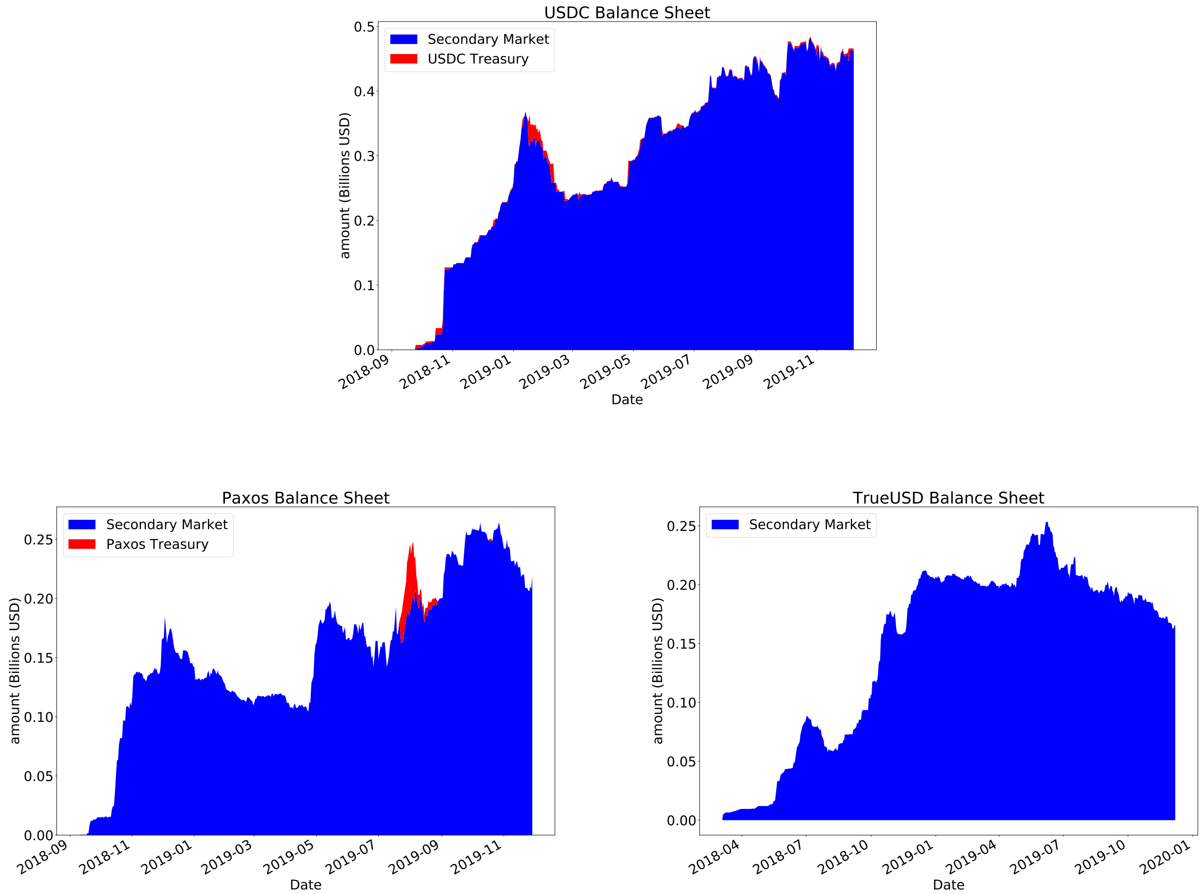


Note: Figure plots the deviations of the TrueUSD peg from parity (left panel). A positive deviation indicates TrueUSD trades at a premium. Right panel is a histogram of deviations of the TrueUSD peg. Data from Coinapi. Sample is June 2018 to March 2020.

Balance Sheets of Other Stablecoins

We plot here the balance sheets of other major stablecoins. The data platform we use is Etherscan, which records the entire set of transactions of a given stablecoin on the blockchain. To use Etherscan, we identify the wallet address of the issuer, and the wallet address of the Treasury (where applicable). We can then use the api to extract a set of transactions of a given wallet. Transactions are classified as a "from" or "to". The underlying assumption is that for the set of transactions involving the primary issuer, if the issuer is "from" this indicates a flow from the issuer to the secondary market. Conversely, "to" indicates redemptions and a withdrawal of stablecoin tokens from circulation. Sample period is from introduction of a given coin to Etherscan to November 2019.

Figure 21: Balance Sheet for USDC, Paxos, and TrueUSD



Note: Figure plots the balance sheet of USDC, Paxos, and TrueUSD. Balance-sheet data from Etherscan.

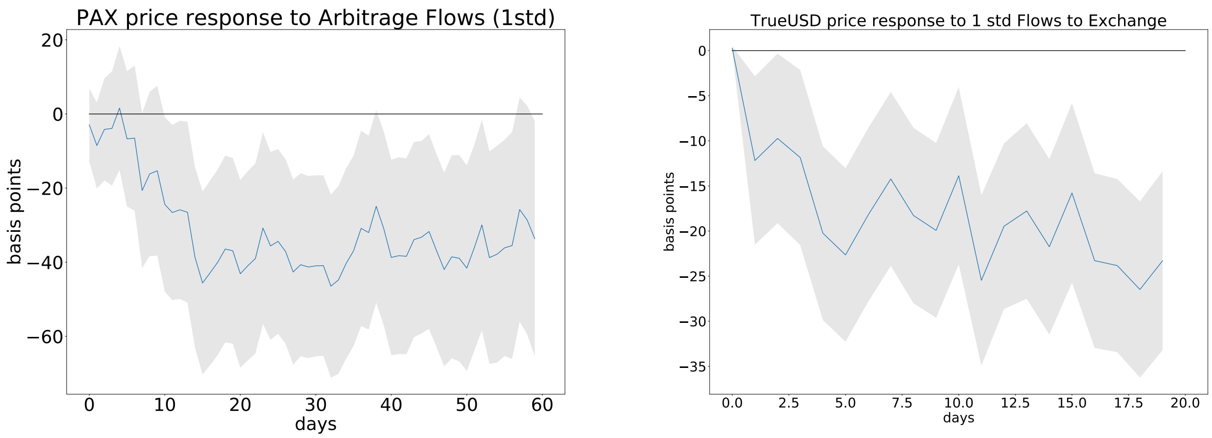
Arbitrage Flows

We estimate the following regression in equation 24 (h equals 0,1,2, ...) to test the stabilizing effect of arbitrage flows on the pegs. The results for Paxos and TrueUSD in Figure 22 suggest a stabilizing effect, on the order of 40 basis points for Paxos and 20 basis points for TrueUSD (for a one-standard-deviation shock in order flow).[50]

$$P_{t+h} - P_{t-1} = \alpha + \beta_h Flow_{T\to \mathrm{EX}} + \sum_{k=1}^{4} \delta_k Flow_{T\to EX,t-k} + \sum_{k=1}^{4} \gamma_k (P_{t-k-1} - P_{t-k-2}) + u_t \quad (24)$$

[50] We do not report results for USDC as our price data currently do not go back far enough, unlike the other two coins.

Figure 22: Response of Paxos (left panel) and TrueUSD (right panel) Prices to a Unit Standard Deviation of Flows to the Secondary Market

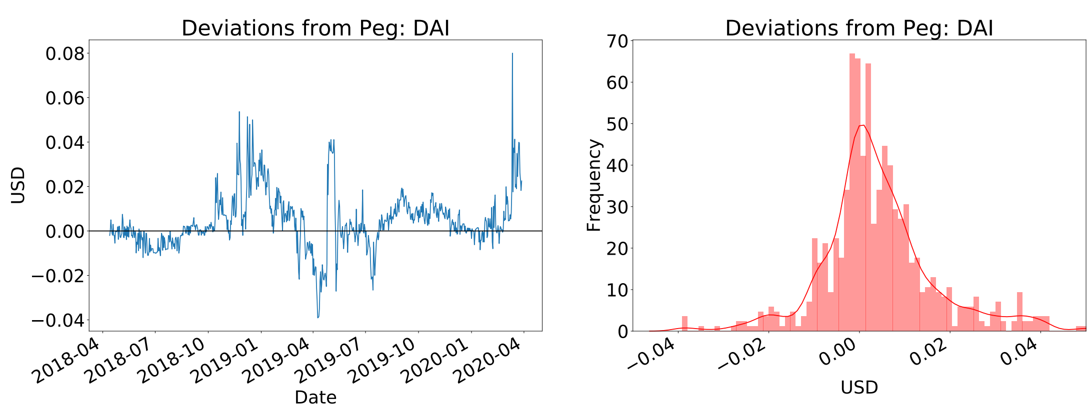


Note: Figure documents the effect of a 1 standard deviation shock to net secondary market flows on the price of Paxos and TrueUSD. Data for secondary-market flows from Etherscan. Price data from Coinapi. Sample is January 2019 to March 2020 in left panel, and June 2018 to March 2020 in right panel. Gray area denotes two-standard-error bands for statistical significance at the five-percent level.

D Crypto-Collateralized Stablecoins

In this section we detail the stability mechanisms of DAI, a stablecoin backed by Ethereum collateral. Similar to other national-currency-backed coins, DAI exhibits a two-sided distribution of stablecoin prices, illustrated in Figure 23.

Figure 23: DAI/USD Deviations from Peg and Histogram of Deviations



Note: Figure plots the deviations of the DAI/USD peg from parity (left panel). A positive deviation indicates DAI/USD trades at a premium. Right panel presents a histogram of deviations of the DAI/USD peg. Data are Coinapi. Sample is April 2018 to March 2020.

The steps that increase DAI supply involve depositing a set amount of Ethereum collateral into a collateralized debt position. Based on the value of Ethereum collateral, the investor can borrow a fraction of their collateral as DAI tokens. There is a limit on how much DAI one can borrow. The safe ratio of collateral is considered by many market practitioners to be 300%. The minimum collateral ratio required is 150%. If the collateral ratio falls below 150%, the smart contract will trigger a liquidation.[51] In this event, the investor is required to repay the debt of DAI tokens using their remaining collateral, as well as pay a liquidation penalty. In general, investors are incentivized to maintain a stable collateral ratio of 300%. If the value of Ethereum prices fall, then an investor can either inject more Ethereum collateral, or alternatively redeem DAI, in order to maintain their level of collateral.

These incentives of the liquidation system and enforcement of smart contracts make it less likely that extreme price events in Ethereum will cause significant deviations from DAI/USD parity. An equally central question for stabilisation is what tools can be used when a coin like DAI trades systematically above or below parity. For national-currency-backed coins there is an arbitrage motive for investors in the event of a difference between the peg and the secondary market rate. However, in the case of DAI there is no similar arbitrage motive because the real-time value of the underlying collateral that would be released or absorbed is uncertain.

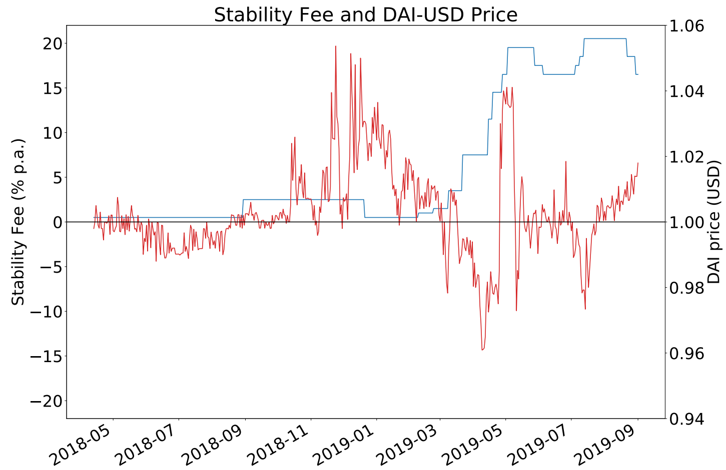
For example, suppose DAI trades at a dollar price above 1. If an investor buys Ethereum for dollars, then deposits that Ethereum as collateral and borrows DAI, then sells DAI in the secondary market for dollars, and finally closes out their position (by buying back DAI and exchanging that for their Ethereum collateral), they could lose money if the market value of Ethereum in dollars has fallen over the latency period. Given the market price of Ethereum against the USD exhibits considerable volatility, valuation losses on their Ethereum can easily dwarf deviations of the DAI secondary-market price from the peg.

Accordingly, crypto-collateralized coins use additional tools to maintain the peg. One tool that is used is the stability fee. Implemented by the MAKER DAO protocol, the stability fee is managed by the issuer of DAI tokens, and is effectively an interest rate on borrowing DAI tokens. This is analogous to a central bank managing interest rates. We document plots of the stability fee and the DAI/USD price in Figure 24. A critical difference from a national central bank is the voting structure. While central banks typically have a centralised arrangement for setting rates, DAI has a decentralised, continuous-voting procedure for approval of a stability-fee (i.e., rate) change. Voters can choose from a range of options for the stability rate, and if the number of votes surpasses the number of votes for the prior decision, the stability rate will change.[52]

[51] A smart contract is a set of instructions in computer code that defines the conditions of the contract for each counterparty under different scenarios (default etc.). Being managed by computer code and visible on the blockchain, it can be verified publicly by all nodes on the blockchain.

[52] Voting can be influenced by whales, i.e. voters with market power. A recent stability-rate change in October 28, 2019, was influenced largely by one voter with a significant holding of DAI, and had a near 50% share of the total number of votes.

Figure 24: DAI Stability Fee (blue) and DAI/USD Price (red)



Note: Figure illustrates the stability fee (blue) and the DAI/USD price (red). Stability fee is expressed as a rate on borrowing DAI, sourced from Maker DAO api. DAI/USD data are from Coinapi. Sample is April 2018 to September 2019.

Given a higher DAI stability rate raises the cost of borrowing DAI, the intention of the stability rate is to reduce growth of DAI in circulation. This will be a combination of redemptions of existing DAI borrowed, and reductions in future growth of new Ethereum collateral by investors when generating DAI tokens. By reducing supply, all else equal, this will lead to a rise in the price of DAI.

On November 16th, 2019, MakerDAO introduced a multi-collateral DAI as well as retaining the single-collateral version (which has been renamed SAI and is planned to phase out by the end of 2020). Now investors can choose to diversify their basket of collateral to reduce idiosyncratic risk of a single cryptoasset, such as Ethereum. This is a natural direction for evolution in crypto-collateralization as future coins like Facebook's Libra consider pegging to currency baskets rather than a single currency such as the US dollar.