# The Trilemma of Stablecoin

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**Abstract.** We propose a theoretical framework to understand the price stability mechanism of stablecoins. With the model, we identify three sources of price instability that form a trilemma. The trilemma suggests that any stablecoin design can avoid at most two of all the following risks: (1) downward price instability due to moral hazards of the operating entity, (2) downward price instability when the entity is exposed to external market risk and has a poor financial performance, and (3) upward price instability caused by limited coin supply. When evaluated using our theoretical framework, many existing stablecoins are found to suffer from the trilemma as predicted by our theory. We further conduct a large-scale global survey of 17,550 individuals from 34 countries to see how the general public perceives the risks of the trilemma. The survey finds that heterogeneity exists across countries and that most people perceive the potential price instabilities influenced by moral hazards and financial risks are larger than the upward price instability. Our study uncovers a fundamental principle of the price stability mechanism in stablecoins, identifying a critical choice for stablecoin issuers and justifying regulatory interventions.

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## 1 Introduction

Digital currencies can facilitate more efficient and transparent transactions using blockchain technology. Further, their easy accessibility, which does not require traditional financial infrastructure, has the potential to help approximately 2 billion unbanked people worldwide [1]. However, many of the existing digital currencies such as Bitcoin have been criticized for their high price volatility, which makes it difficult for them to function as money. Aimed at providing a stable value, a privately issued digital currency called stablecoin has emerged, and its growth has been remarkably rapid. As of August 2021, Tether, one of the most popular stablecoins, has a market cap of about $62 billion USD, increasing nine-fold within a year. Moreover, many major companies such as Facebook, Amazon, Walmart, and JPMorgan Chase have started creating their own stablecoin or have shown interest in a currency project to expand their businesses to the payment industry [2, 3, 4, 5, 6, 7]. Governments and regulatory institutions worldwide are also planning new regulations to prepare for the advent of stablecoins [8, 9].

Despite high expectations and considerable interest in stablecoins, there are no clearly stated fundamental principles explaining how stablecoins should operate to achieve price stability [10, 11, 12]. Moreover, many of the existing stablecoins are often criticized for the inherent risks in their design [11, 12]. For example, since Facebook announced its plan to launch their currency, Diem (formerly known as Libra), its model has been dogged by criticisms from many experts because its stability depends on the credibility of the central organization established by Facebook [13, 14]. In addition, as a paper [15] pointed out, many existing stablecoins suffer from imperfect price stability (see Figure 1). Concerned over inherent risks involved in stablecoins, regulators have been seeking ways to mitigate those risks. For example, the US lawmakers recently proposed a bill to regulate stablecoins, which encountered a strong backlash from the currency developers [16].

In this paper, we discover the fundamental principle of stablecoins in stabilizing the price, which is necessary to propose a better design that can manage the inherent risks more efficiently and to make systematic regulation guidelines for stablecoins. In particular, we identify three sources of price instability in stablecoins and theoretically prove that there is a trilemma among the three. The trilemma indicates that any stablecoin can eliminate at most two of the following price instability elements: (1) downward price instability from the tar-

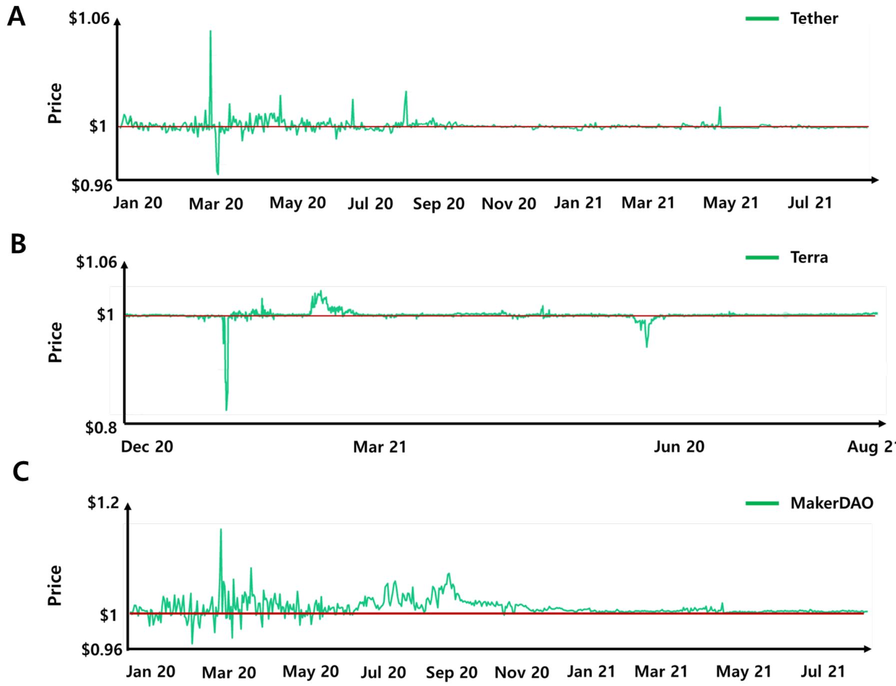


**Fig. 1. Price charts of stablecoins.** We can see limited price stability of some existing stablecoins. The price data is retrieved from CoinMarketCap (`https://coinmarketcap.com/`). Here, note that we could get the price data of the Terra stablecoin from Dec. 2020 as it is a relatively nascent currency.

get value after moral hazards of the operating entity[5] occur, (2) downward price instability from the target value when the entity is exposed to external market risk and has a poor financial performance, and (3) upward price instability from the target value caused by limited coin supply. Therefore, any stablecoin design bears some price instability risk, meaning that regulations are vital to manage these risks.

To derive the trilemma, we start by considering system requirements to guarantee downward price stability. For the price recovery from below the target value, the system needs to incentivize users to increase the market demand (buy more coins) or to decrease the market supply (sell fewer coins). These demand and supply controls can be costly, requiring the system to maintain sufficient

[5] The operating entity can refer to an institution representing the stablecoin system, and it can also be an algorithm of a stablecoin system if the system is run algorithmically.

reserves per coin in circulation. This reserve requirement can be achieved either by maintaining a high value of reserves or limiting the total number of coins in circulation. The trilemma occurs when choosing between keeping a high value of reserves and limiting new coin issuance.

Among the three price instability elements of the trilemma, the first two arise when the system decides to hold a high value of reserves. Here, which of the two price instability elements the system bears depends on whether the reserves are stored in the target assets (e.g., a national currency) or non-target assets. When reserves are in the form of the target assets, it bears the moral hazard risk of the operating entity because transactions of the target asset, such as a national currency, cannot always be transparent. On the other hand, when the system decides to store reserves in non-target assets, it can avoid the moral hazard risk by employing blockchain-based digital assets. While it enables transparent reserve operations, the downside is that the value of reserves consisting of non-target assets can fluctuate so that the system has to replenish the reserves. This brings another risk as the system may fail to meet the reserve requirement when it does not have enough cash flow due to the external market risk or its own poor financial performance.

Lastly, to avoid these risks, the system should limit the coin supply. However, with a limited supply, the system cannot freely increase the market supply of stablecoins to meet the market demand, thereby failing to lower the price. This brings upward price instability, which the third element of the trilemma describes.

The three types of price instability risk in the trilemma, although separately, have already been noted and studied in the existing literature. For example, papers [11] and [17] discuss the importance of the counterparty risk, which corresponds to our first type of price instability. Another paper [18] addresses the risks related to the reserve management, specifically the volatility of the reserve assets and death spiral, which belongs to the second price instability element of the trilemma. Lastly, the literature [19] show concerns for the third type of risks, considering a popular real-world stablecoin, MakerDAO. Our novel contribution puts these three elements of risk together and proves that they form the trilemma.

Next, we examine the price mechanisms of several existing stablecoins through the lens of our theoretical model. The analysis shows that the existing stablecoins bear at least one of the three price instability elements of the trilemma, as predicted in our theory.

The trilemma suggests that there is always an unavoidable risk. The next step would then be to investigate how we can manage or reduce the risks. From that perspective, we conducted a large-scale global survey to investigate how (potential) users perceive each type of risk in the trilemma. The survey was executed in 34 countries covering six continents, with a total of 17,550 respondents. Our survey results indicate that most people perceive that potential downward price instability due to the operating entity's moral hazards or financial risks are greater than the upward price instability, which global companies may have overlooked. Further, the choices were significantly different at the country level, suggesting that a stablecoin design can be customized. These findings not only help issuers design a stablecoin, but it also indicates that commitment to business ethics and monitoring of financial risks should be much more strengthened.

Recent theoretical studies provide insights into how stablecoin systems can be better designed and managed. A paper [11] categorized stablecoin designs according to how the reserves are managed and discussed the risks involved in each design; they also make a theoretical contribution by applying capital structure models from the traditional finance literature to analyze core market players' choices in a non-custodial stablecoin market. Specifically, they propose optimization problems of market players such as the operating entity and coin users with or without governance or collusion attacks. Another paper [20] also provides a theoretical model for stablecoin prices to examine whether price stabilization of Tether depended more on the supply-side (coin issuance) or demand-side (arbitrage trading).

Closer to ours is the recent line of theoretical literature that sheds light on the price instability of stablecoins. A paper [21] developed a dynamic market microstructure model to analyze the potential price instability of popular non-custodial stablecoins such as MakerDAO. Their model predicts a vicious cycle of price drop when the reserve value declines. In addition, another study [22] built a micro-founded model to identify the optimal strategy for an operating entity to maximize its profit in a stablecoin system that fills reserves through earned transaction fees. They present another possible vicious cycle of price drops if the reserves suffer from negative external shocks. These theoretical models illustrate that it is difficult to build a stablecoin without substantial risks, consistent with the main message that our trilemma delivers. Moreover, the technical reports of Terra and Celo, two popular stablecoins, also acknowledge that the price peg can break in their models of price stability mechanisms [23, 24].

Our theoretical model adds to this nascent literature on stablecoins by taking a more aggregated and general approach for analyzing the fundamental price stability mechanism of the stablecoin, using a semi-game-theoretical model. While previous papers provide a theoretical lens to the stablecoin market by modeling some of the popular stablecoin systems, we aim to provide a more unified perspective and theoretical tools to understand the stablecoin market in general. Our novel contribution is the discovery of the trilemma, an essential principle of the price stability mechanism in stablecoins, identifying a crucial choice facing stablecoin issuers. Moreover, the existence of the trilemma justifies regulatory interventions on stablecoins. It also points to how the risks can be managed from the perspective of both currency issuers and policymakers.

The rest of this paper is organized as follows: We first model a stablecoin system in Section 2; we then prove that there is a trilemma of a stablecoin design in Section 3. Section 4 examines some existing stablecoins using our theoretical framework. Section 5 reports the findings of our global survey. Finally, Section 6 discusses the implications of our findings, and Section 7 concludes.

## 2 Model

In this section, we first describe a stablecoin system, introduce parameters (Table 1) used throughout this paper, and define a stablecoin.

### 2.1 System

A stablecoin is a coin whose value is fixed or pegged at other assets for high price stability, which we will formally define in the next subsection. Let $a^T$ denote the target asset. In this study, we focus on the case where $a^T$ is a national currency that is used as a standard of value in each country. Indeed, whether one can use a stablecoin as popular currency depends on the target asset $a^T$. For example, if $a^T$ is Bitcoin, we would not be able to use the stablecoin as money because of the high price volatility of Bitcoin. Many stablecoins currently select national currencies such as the US dollar and Euro as the target.

There are two types of players in a stablecoin system: an operating entity[6] $\mathcal{O}$ and a set of users $\mathcal{U}$. First, $\mathcal{O}$ needs to stabilize a price. We assume that users are rational and choose an action resulting in the greatest expected gain. They can trade coins with each other in a market and also directly buy/sell a coin from/to $\mathcal{O}$. The quantity of coins that a user $i$ holds is denoted by $c^i$, and thus, the quantity of coins in circulation can be expressed as $\sum_{i \in \mathcal{U}} c^i$.

A stablecoin system stores the reserves as a set of assets, denoted by set $\mathcal{A}$. For example, if the system stores US dollars as reserves, the US dollar belongs to $\mathcal{A}$. Alternatively, if the system stores gold as reserves, $\mathcal{A}$ would contain gold.

[6] The operating entity $\mathcal{O}$ can be an algorithm if the system is algorithmically operated.

Note that $\mathcal{A}$ can contain multiple assets. Note that the system can spend its reserves to control the supply and demand of the coins in the market for price stability.

The price $p$ of a stablecoin is determined by the supply and demand in the market. We assume that the downward sloping demand curve and the upward sloping supply curve are given exogenously. Moreover, there could be a buy-sell spread in the system due to transaction costs (fees $f$ that users need to pay to the system when conducting transactions). Therefore, the actual price that a seller receives or a buyer pays can be different from the price $p$. The actual selling price ($p^s$) is generally lower than the actual buying price ($p^b$), and the system earns the difference between them. The fee $f\,(\geq 0)$[7] determines the difference between $p^s$ and $p^b$. When $f = 0$, the selling price and buying price are the same, and we denote the price by $p^0$. Lastly, we use superscript $t$ to denote time $t$.

As described above, one of the main goals for the operating entity $\mathcal{O}$ is maintaining high price stability. To this end, $\mathcal{O}$ can issue and burn stablecoins to control the market supply and demand similar to the central bank. Further, it can change the transaction fee $f$ and spend some of its reserves to incentivize users to hold, sell off, or buy coins in the market. Moreover, $\mathcal{O}$ could directly trade coins with users, where the traded price may be set differently from the market price. In the coin transaction between users and $\mathcal{O}$, the actual payment from $\mathcal{O}$ may occur some time before or after the coin trade: for example, $\mathcal{O}$ can pay a 1-year bond to a user in return for buying coins from the user. Lastly, we assume that $\mathcal{O}$ cannot arbitrarily block trades between users in the market.

The parameters mentioned above are listed in Table 1.

**Table 1.** List of model notations.

| **Notation** | **Definition** |
|---|---|
| $a^T$ | Target asset of a stablecoin |
| $\mathcal{O}$ | Operating entity that can issue and burn stablecoins |
| $\mathcal{U}$ | Set of all users |
| $c_t^i$ | Coin quantity that user $i$ holds at time $t$ |
| $\mathcal{A}$ | Set of assets stored in the system |
| $p_t^s$ | Selling price at time $t$ |
| $p_t^b\,(=p_t^s + f_t)$ | Buying price at time $t$ |
| $f_t$ | Transaction fee at time $t$ |
| $p_t^0$ | Price with zero fee at time $t$ |

[7] In fact, even if $f$ is allowed to be negative, our results still apply.

### 2.2 Definition of a Stablecoin

In this section, we will formally define a stablecoin. To this end, we first present the definition of pegging at the target value $T$, which is in the unit of $a^T$.

**Definition 1 ($\varepsilon$-Pegging at $T$).** *We state that a coin is* $\boldsymbol{\varepsilon}$***−pegged*** *($\varepsilon \geq 0$) at target $T$ if the following are satisfied for any time $t$ and duration $\Delta\,(> 0)$:*

$$\begin{aligned} \min_{x\in[T-\varepsilon,T+\varepsilon]} |p_t^s - x| &> \min_{x\in[T-\varepsilon,T+\varepsilon]} \left|p_{t+\Delta}^s - x\right| \quad \textit{if} \min_{\substack{x\in[T-\varepsilon,T+\varepsilon]\\0\leq\delta\leq\Delta}} \left|p_{t+\delta}^s - x\right| > 0, \\ \min_{x\in[T-\varepsilon,T+\varepsilon]} \left|p_t^b - x\right| &> \min_{x\in[T-\varepsilon,T+\varepsilon]} \left|p_{t+\Delta}^b - x\right| \quad \textit{if} \min_{\substack{x\in[T-\varepsilon,T+\varepsilon],\\0\leq\delta\leq\Delta}} \left|p_{t+\delta}^b - x\right| > 0. \end{aligned} \tag{1}$$

Pegging is used to force the price of a coin, including the transaction cost, into a target price range for high price stability. According to Definition 1, $\varepsilon-$pegging at target $T$ implies making the buying and selling prices return to the range between $T - \varepsilon$ and $T + \varepsilon$ when they go out of the range due to unexpected factors, such as external shocks. Below we describe the first equation of Eq. (1), which is the pegging condition for the selling price. First, $\min_{x\in[T-\varepsilon,T+\varepsilon]} |p_t^s - x|$ represents the distance between the selling price $p_t^s$ and the range of $[T-\varepsilon, T+\varepsilon]$. Its nonzero value indicates that the selling price is out of the range. Thus, the inequality indicates that the distance between the selling price and the range gradually decreases until the price reaches the target range. A low value of $\varepsilon$ indicates high price stability and low fees. Note that when $\varepsilon$ is 0, the coin price is fixed at $T$ with $f = 0$, and the price stability would be the highest.

Now, we present the definition of stablecoin.

**Definition 2 ($(T, \varepsilon)$-Stablecoin).** *We define* $\boldsymbol{(T, \varepsilon)}$***-stablecoin*** *as a coin satisfying the following conditions:*

*C1. The coin is $\varepsilon-$pegged at target $T$.*

*C2. The quantity of coins that a user possesses should not change unless the user executes coin transactions.*

*In addition, if a coin satisfies Eq. (2) below for any time $t$ and duration $\Delta\,(> 0)$ instead of C1, it is referred to as* $\boldsymbol{(T, \varepsilon)}$***-downward stablecoin*** *and regarded as* $\boldsymbol{(T, \varepsilon)}$***-downward stable****.*

$$\begin{aligned} p_t^s &< p_{t+\Delta}^s \quad \textit{if} \max_{0\leq\delta\leq\Delta} p_{t+\delta}^s < T - \varepsilon, \\ p_t^b &< p_{t+\Delta}^b \quad \textit{if} \max_{0\leq\delta\leq\Delta} p_{t+\delta}^b < T - \varepsilon. \end{aligned} \tag{2}$$

*If a coin satisfies Eq.* (3) *below for any time* $t$ *and duration* $\Delta\,(>0)$ *instead of C1, it is referred to as* $\boldsymbol{(T,\varepsilon)}$***-upward stablecoin*** *and regarded as* $\boldsymbol{(T,\varepsilon)}$***-upward stable****.*

$$
\begin{aligned}
p_t^s > p_{t+\Delta}^s \quad & \textit{if} \min_{0\le\delta\le\Delta} p_{t+\delta}^s > T+\varepsilon, \\
p_t^b > p_{t+\Delta}^b \quad & \textit{if} \min_{0\le\delta\le\Delta} p_{t+\delta}^b > T+\varepsilon.
\end{aligned}
\tag{3}
$$

In Definition 2, the first condition (C1) is for price stability, and the second condition (C2) prevents the fluctuations in coin quantities except the change caused by coin transactions.[8]

We require condition C2 because pegging alone is not sufficient for a coin to be regarded as a stable asset. It is feasible for a system to change the quantity of digital coins that a user has even if they do not transact coins.[9] When the quantity of coins owned by a user fluctuates regardless of the transaction volume of the user, the coin cannot be considered a stable asset even if the price of the coin is fixed; this approach abandons the stability of asset value for the sake of price stability.

We define $(T,\varepsilon)$-downward stablecoin and $(T,\varepsilon)$-upward stablecoin, which we will use later to prove the trilemma. Eq. (2) indicates that a price stability mechanism should increase the selling and buying prices above ($\geq$) $T-\varepsilon$ if they drop below $T-\varepsilon$ due to unexpected factors such as external shocks. That is, a *downward stablecoin* prevents its price from staying below a certain value. Meanwhile, Eq. (3) indicates that a price mechanism decreases the selling and buying prices to reach below ($\leq$) $T+\varepsilon$ if they surged above $T+\varepsilon$ due to unexpected factors such as external shocks. Therefore, an *upward stablecoin* prevents the price from continuing to rise above a certain value. Note that $(T,\varepsilon)$-stablecoin should satisfy all conditions of $(T,\varepsilon)$-downward stablecoin and $(T,\varepsilon)$-upward stablecoin.

## 3 Trilemma

Now, we present a trilemma in designing a stablecoin. The trilemma states that a stablecoin can completely eliminate at most two of the following elements of instability, all with regard to the target value: (1) downward price instability after moral hazards of the operating entity[5] occur, (2) downward price instability when the entity is exposed to external market risk and has a poor financial

[8] We can also relax C2 to allow coin quantities to fluctuate within some range (i.e., a quantity change up to $\pm\gamma\%$), which will not affect our main theoretical results.

[9] Such a coin exists in reality (e.g., Ampleforth [25]).

performance, and (3) upward price instability due to a limited coin supply. In this section, we first give an intuition for how stablecoin systems should operate for price stability, and then theoretically analyze system requirements of $(T, \varepsilon)$-downward stablecoins and $(T, \varepsilon)$-upward stablecoins. Lastly, we derive the trilemma from the requirements.

### 3.1 Overview of Stablecoin System Operation for Price Stability

Now, we provide an intuitive explanation of how $(T, \varepsilon)$-downward stablecoin and $(T, \varepsilon)$-upward stablecoin should operate. Its formal analysis will be presented in Section 3.2. Here, for simplicity, we consider the case where $T$ is \$1 USD and $\varepsilon$ is 0.

**$(T, \varepsilon)$-Downward Stablecoin: When the Market Price Is Less Than \$1.** According to Definition 2, a downward stablecoin system should increase the price when it drops below \$1. Based on the law of supply and demand, the system should incentivize users to sell fewer coins in the market to reduce supply and to buy more coins in the market to increase demand.

To motivate users to sell fewer coins in the market, it should be more profitable for the users to sell coins to $\mathcal{O}$ or hold them, compared to selling them in the market immediately. First, to make it more profitable for users to sell their coins to $\mathcal{O}$ rather than to the market, $\mathcal{O}$ should buy the coins from the users at a higher price. For example, if the market price is \$0.90, $\mathcal{O}$ can consider buying the users' coins at \$1. Thus, $\mathcal{O}$ needs to maintain sufficient reserves for these purchases. Second, to make it more profitable for users to hold coins, $\mathcal{O}$ should provide a reward per coin to the users who hold coins for a specific period from now, which also requires $\mathcal{O}$ to maintain a high value of reserves. The reward is to compensate for the possible loss during the holding period. Therefore, if the market price increases over time, $\mathcal{O}$ will not need to pay a reward. On the other hand, if the market price continues to decrease, $\mathcal{O}$ should give funds equal to the loss to the user who has held the coins until then (e.g., giving a higher interest rate when a user deposits stablecoins into the system).[10] As a result, these holders would not be at a loss even if the value of the coin drops.

The system operation to incentivize users to buy more coins in the market is similar, and therefore, we omit the description of the mechanism here. For a full formal analysis, please refer to Theorem 1.

**$(T, \varepsilon)$-Upward Stablecoin: When the Market Price Is Greater Than \$1.** An upward stablecoin system should decrease the price if it is greater than \$1. That is, if the market price is greater than \$1, then according to the law of

[10] In other words, the operating entity gives users contingent claims as a reward.

supply and demand, the system should incentivize users to buy fewer coins in the market to decrease demand and to sell more coins in the market to increase supply.

To motivate users to buy fewer coins in the market, it should be more profitable to buy coins from $\mathcal{O}$ or buy them in the market later than buying them in the market immediately. First, to encourage users to buy coins from $\mathcal{O}$ instead of the market, $\mathcal{O}$ should sell the coins at a cheaper price than the market. For example, if the market price is \$1.10, $\mathcal{O}$ can consider selling coins to users at \$1. Second, to encourage users to wait to buy coins (buy them in the market later), $\mathcal{O}$ should give a reward per coin to users who will have waited a certain period of time to buy coins. The reward is to compensate for the possible loss while they wait. Note that if the market price decreases over time, $\mathcal{O}$ will not need to pay a reward. On the other hand, if the value of the coin continues to increase, $\mathcal{O}$ should provide a subsidy to the users who have waited to buy coins until then (e.g., giving a higher interest rate when a user deposits USD into the system). This can make it more profitable for users to wait and buy coins in the market later, at the expense of $\mathcal{O}$'s reserves.

The system operation to incentivize users to sell more coins in the market is similar, and therefore, we omit the description of the mechanism here. For a full formal analysis, please refer to Theorem 2.

### 3.2 Theoretical Analyses of Stablecoin System Requirements

Next, we formally present the system requirements for price stability through Theorems 1 and 2. Theorem 1 shows that $(T, \varepsilon)$-downward stablecoin should maintain sufficient reserves, by finding a lower bound of reserves that the system needs to possess to recover a price above $T - \varepsilon$. Theorem 2 shows that a new coin supply (i.e., the quantity of new coins issued by $\mathcal{O}$) or a reserve value that the system spends should be large in $(T, \varepsilon)$-upward stablecoin, to recover a price below $T + \varepsilon$.

**Theorem 1 (Reserve Lower Bound for $(T, \varepsilon)$-Downward Stablecoin).** *In any $(T, \varepsilon)$-downward stablecoin, the expected present value of reserves that the operating entity $\mathcal{O}$ spends to control the coin price should satisfy the following* *inequality for some $g_t$, $G$, and $G'$:*

$$\sum_{\substack{i\in\mathcal{U}\\ \Delta\in G\\ a\in\mathcal{A}}} E_t^i\left(v_{t+\Delta}^{i,a}\right)\cdot d_\Delta > \sum_{i\in\mathcal{U}} c_t^i \cdot \sum_{\substack{j\in\mathcal{U}\\ \Delta'\in G'}} \left\{g_t(j,\Delta')\cdot\left(\min\{p_t^b,p_t^s\} - h_{\Delta'}\big(E_t^j\left(p_{t+\Delta'}^s\right)\big)\cdot d_{\Delta'}\right)\right\}$$
$$= \sum_{i\in\mathcal{U}} c_t^i \cdot \sum_{\substack{j\in\mathcal{U}\\ \Delta'\in G'}} \left\{g_t(j,\Delta')\cdot\left(p_t^s - h_{\Delta'}\big(E_t^j\left(p_{t+\Delta'}^s\right)\big)\cdot d_{\Delta'}\right)\right\} \quad \text{if } p_t^0 < T-\varepsilon, \tag{4}$$

*where*

1. *$E_t^i(x)$ indicates the expected value of $x$ by user $i$ at time $t$.*
2. *$v_t^{i,a}$ denotes the value of an asset $a$ in reserves (denominated in $a^T$) that the operating entity $\mathcal{O}$ spends on user $i$ at time $t$ to control the coin price.*
3. *$G$ and $G'$ represent the sets of periods including 0.*
4. *$g_t(i,\Delta)$ for user $i$ and period $\Delta$ is non-negative, and $\sum_{\substack{i\in\mathcal{U}\\ \Delta\in G'}} g_t(i,\Delta) = 1$ for any time $t$. Moreover, $g_t(i,\Delta)$ is 0 for any $\Delta \notin G'$.*
5. *$d_\Delta$ indicates a discount factor for period $\Delta$.*
6. *$h_\Delta(x)$ is defined as follows:*

$$h_\Delta(x) \coloneqq \begin{cases} x & \text{if } \Delta > 0,\\ 0 & \text{else.}\end{cases}$$

The left-hand side (LHS) of Eq. (4) represents the sum of the asset values that $\mathcal{O}$ spends to control a coin price after each period in $G$. Note that the discount factor $d_\Delta$ is multiplied to obtain the present value. Therefore, the right-hand side (RHS) of Eq. (4) indicates the lower bound for the reserves that $\mathcal{O}$ should maintain. First, on the RHS, $\sum_{i\in\mathcal{U}} c_t^i$ denotes the coin quantity in circulation. What follows after this term represents the minimum reserve requirement for the average incentive payment per coin from $\mathcal{O}$ to the users. Recall that the downward stablecoin system should incentivize users not to sell coins in the market now, and therefore, it should motivate the users to sell coins to $\mathcal{O}$ or to sell them in the market later, as described in Section 3.1. Therefore, we find the function $g_t$ by setting it as follows: The value of $g_t(i,0)$ is set to the share of coins out of the total coins in circulation that $\mathcal{O}$ buys from user $i$ at a price greater than the market price. Further, the value of $g_t(i,\Delta')$ is set to the share of coins out of the total coins in circulation that user $i$ is motivated to sell in the market after time $t+\Delta'$. $G'$ denotes the set of all periods $\Delta'$ such that $\Delta' = 0$ or $g_t(i,\Delta')$ is positive for some $i\in\mathcal{U}$. For the share $g_t(i,0)$ of coins, the minimum required expected incentive is $p_t^s$. For the share $g_t(i,\Delta)$ of coins, the minimum required expected incentive is $p_t^s - E_t^i(p_{t+\Delta'}^s)\cdot d_{\Delta'}$. Note that the maximum possible value of the RHS is $\sum_{i\in\mathcal{U}} c_t^i \cdot p^s$.[11] In sum, Theorem 1 suggests that the $(T,\varepsilon)$-downward stablecoin system should have sufficient reserves (i.e., > RHS) to increase market demand or decrease market supply when the coin price is less than $T-\varepsilon$. The proof of Theorem 1 is provided in Section 1.1 of the Appendix.

Although Theorem 1 finds the reserve lower bound for $(T,\varepsilon)$-downward stablecoin, satisfying Eq. (4) does not guarantee that $\mathcal{O}$ recovers the price from below $T-\varepsilon$. That is, the existence of downward stablecoins is not guaranteed by Eq. (4). Therefore, we present Corollary 1, which shows the existence of $(T,\varepsilon)$-downward stablecoin. In other words, if $\mathcal{O}$ has sufficient reserves to satisfy Eq. (5), it can guarantee the increase in price back to $T-\varepsilon$.

**Corollary 1.** *There exists $(T,\varepsilon)$-downward stablecoin with $g_t$, $G$, and $G'$ satisfying the following inequality.*

$$\begin{aligned}\sum_{\substack{i\in\mathcal{U}\\ \Delta\in G\\ a\in\mathcal{A}}} E_t^i\left(v_{t+\Delta}^{i,a}\right)\cdot d_\Delta &> \sum_{i\in\mathcal{U}} c_t^i \cdot \sum_{\substack{j\in\mathcal{U}\\ \Delta'\in G'}} \left\{ g_t(j,\Delta')\cdot\left(\max\{p_t^b,p_t^s\} - h_{\Delta'}\big(E_t^j\left(p_{t+\Delta'}^s\right)\big)\cdot d_{\Delta'}\right)\right\}\\ &= \sum_{i\in\mathcal{U}} c_t^i \cdot \sum_{\substack{j\in\mathcal{U}\\ \Delta'\in G'}} \left\{ g_t(j,\Delta')\cdot\left(p_t^b - h_{\Delta'}\big(E_t^j\left(p_{t+\Delta'}^s\right)\big)\cdot d_{\Delta'}\right)\right\} \qquad \text{if } p_t^0 < T-\varepsilon \end{aligned} \tag{5}$$

Note that, in Eq. (5), $\min\{p_t^b,p_t^s\}$ of Eq. (4) is substituted with $\max\{p_t^b,p_t^s\}$. The proof of Corollary 1 is presented in Section 1.2 of the Appendix.

The smaller the RHS of Eqs. (4) and (5), the smaller the value of reserves that $\mathcal{O}$ should prepare. For example, if the RHS of Eqs. (4) and (5) are less than 0, the system does not require any reserves for price recovery. This corresponds to the case where the price increases at time $t$ even without a specific mechanism. Note that RHS is less than 0 when $g_t(j,\Delta')$ is positive only for some users $j$ and periods $\Delta'(>0)$ such that $p_t^b$ and $p_t^s$ are less than $h_{\Delta'}\big(E_t^j\left(p_{t+\Delta'}^s\right)\big)\cdot d_{\Delta'}$ $(= E_t^j\left(p_{t+\Delta'}^s\right)\cdot d_{\Delta'})$. This implies that the system does not need to spend its reserves to recover the price if many believe that the price will increase later. Otherwise, the system needs to have sufficient reserve assets.

**Examples of $(T,\varepsilon)$-downward stablecoin.** For clarity, we present several possible mechanisms by which a $(T,\varepsilon)$-downward stablecoin can recover the price

[11] The requirement that the value of reserves should be greater than $\sum_{i\in\mathcal{U}} c_t^i\cdot p^s$ is called full asset backing.

to a range above $T - \varepsilon$. In the following examples, we assume that $T$ is 1 USD and $\varepsilon$ is 0 for simplicity.

(i) Let us first consider a downward stablecoin that sets $\sum_{i \in \mathcal{U}} g_t(i, 0) = 1$ and $g_t(i, \Delta') = 0$ for any $i \in \mathcal{U}$ and $\Delta' \in G' \backslash \{0\}$. In this case, users sell all their coins to $\mathcal{O}$ at a higher price than the market when the market price is less than \$1. Therefore, this downward stablecoin system should hold sufficient assets to buy all coins at a price greater than the market price.

(ii) The second example is a downward stablecoin that sets $\sum_{i \in \mathcal{U}} g_t(i, 0) = 0$ and $\sum_{i \in \mathcal{U}} g_t(i, 1\text{yr}) = 1$. In this case, all users are incentivized to hold their coins in the market for 1 year if the market price at time $t$ is less than \$1; for example, users could earn high interest or a reward from the system. Note that the system does not need to reward users if the coin price increases after 1 year.

(iii) The third downward stablecoin is a case where $\sum_{i \in \mathcal{U}} g_t(i, 0) = 0.5$, $\sum_{i \in \mathcal{U}} g_t(i, 1\text{yr}) = 0.3$, and $\sum_{i \in \mathcal{U}} g_t(i, 2\text{yr}) = 0.2$. This is a combination of the above two cases. In this case, $\mathcal{O}$ buys coins from some users at a higher price and provides incentives to other users who hold their coins for 1 or 2 years.

Next, we present a theorem for $(T, \varepsilon)$-upward stablecoin.

**Theorem 2. (Requirement of New Coin Supply and Asset Value for $(T, \varepsilon)$-Upward Stablecoin).** *In any $(T, \varepsilon)$-upward stablecoin, for any $x$ $(\geq 0)$, $\mathcal{O}$ should ensure that there exists a subset of users $\mathcal{U}'$ that holds a total value $x$ of non-stablecoin assets at time $t$ and satisfies the following inequality for some $G$ and $x^i_\Delta$:*

$$\sum_{\substack{i \in \mathcal{U}' \\ \Delta \in G}} \left( E^i_t\big(s^i_{t,t+\Delta}(x^i)\big) + E^i_t \left( \frac{o^i_{t,t+\Delta}(x^i_\Delta)}{p^b_{t+\Delta}} \right) \right) \cdot d_\Delta > \frac{x}{\max\{p^b_t, p^s_t\}} = \frac{x}{p^b_t} \quad \textit{if } p^0_t > T + \varepsilon, \tag{6}$$

*where*

1. *$E^i_t(y)$ indicates the expected value of $y$ by user $i$ at time $t$.*
2. *$s^i_{t,t+\Delta}(x^i)$ denotes the quantity of stablecoins newly issued by $\mathcal{O}$, which user $i$ can get at time $t + \Delta$ by using the non-stablecoin assets whose value is $x^i$ at time $t$.*
3. *$o^i_{t,t+\Delta}(x^i_\Delta)$ represents a value of non-stablecoin assets in an asset portfolio that user $i$ can possess at time $t + \Delta$, where the portfolio is evolved from the non-stablecoin assets whose value is $x^i_\Delta$ at time $t$ and can change over time by the investment decisions of the users.*

4. $x^i_\Delta$ *is non-negative, its value is 0 except for some finite set of periods* $\Delta\,(>0)$*, and* $\sum_{(x^i_\Delta>0)} x^i_\Delta = x^i$*. Moreover, according to the condition for* $\mathcal{U}'$*,* $\sum_{i\in\mathcal{U}'} x^i = x$*.*
5. $G$ *denotes a set of periods, which is defined as*

$$G = \{\Delta \,|\, E^i_t(s^i_{t,t+\Delta}(x^i)) > 0 \text{ or } E^i_t(o^i_{t,t+\Delta}(x^i_\Delta)) > 0 \text{ for some } i \in \mathcal{U}\}.$$

In the RHS of Eq. (6), $x/p^b_t$ indicates the quantity of stablecoins that users can buy in the market using some non-stablecoin assets with value $x$ that they held at time $t$. The LHS of Eq. (6) represents the total expected quantity of stablecoins that users can either buy from $\mathcal{O}$ at any time or buy in the market after time $t$. In particular, $E^i_t\big(s^i_{t,t+\Delta}(x^i)\big)$ is the expected coin quantity that user $i$ can buy using non-stablecoin assets, which the user held at time $t$, from $\mathcal{O}$ at time $t+\Delta\,(\geq t)$, and $E^i_t\left(o^i_{t,t+\Delta}(x^i_\Delta)/p^b_{t+\Delta}\right)$ is the expected coin quantity that the user can buy using non-stablecoin assets, which the user held at time $t$, in the market at time $t+\Delta\,(>t)$. Here, the discount factor $d_\Delta$ is multiplied to obtain the present value. As described in Section 3.1, an upward stablecoin system needs to ensure that it is more profitable for users to buy coins from $\mathcal{O}$ or to buy coins in the market later when compared to buying coins in the market now in order to decrease the market demand, for a price recovery below $T+\varepsilon$. This is exactly what Theorem 2 states. The system requirement to increase the market supply is similar to that for decreasing the market demand. This case corresponds to when RHS of Eq. (6) is $x/p^s_t$. The proof of Theorem 2 is provided in Section 1.3 of the Appendix.

As mentioned when introducing Corollary 1, although Theorem 2 finds a requirement for $(T,\varepsilon)$-upward stablecoin, satisfying Eq. (6) does not mean that $\mathcal{O}$ can always recover the price from above $T+\varepsilon$. That is, Theorem 2 does not guarantee the existence of upward stablecoins. Therefore, we present below Corollary 2 that shows the existence of $(T,\varepsilon)$-upward stablecoin.

**Corollary 2.** *There exists* $(T,\varepsilon)$*-upward stablecoin satisfying the following inequality for any* $x\,(\geq 0)$*:*

$$\sum_{\substack{i\in\mathcal{U}'\\ \Delta\in G}} \left( E^i_t\big(s^i_{t,t+\Delta}(x^i)\big) + E^i_t\left(\frac{o^i_{t,t+\Delta}(x^i_\Delta)}{p^b_{t+\Delta}}\right)\right)\cdot d_\Delta > \frac{x}{\min\{p^b_t, p^s_t\}} = \frac{x}{p^s_t} \quad \text{if } p^0_t > T+\varepsilon, \quad \text{for some } G \text{ and } x_\Delta. \tag{7}$$

If $\mathcal{O}$ satisfies Eq. (7), it can guarantee to decrease the coin price from above $T+\varepsilon$. Note that Eq. (7) replaces the term of $\max\{p_t^b, p_t^s\}$ in Eq. (6) with $\min\{p_t^b, p_t^s\}$. The proof of Corollary 2 is presented in Section 1.4 of the Appendix.

Eqs. (6) and (7) show that a high value of $E_t^i(s_{t,t+\Delta}^i(x^i))$ or $E_t^i\big(o_{t,t+\Delta}^i(x_\Delta^i)/p_{t+\Delta}^b\big)$ is required to reduce the price below $T+\varepsilon$. Here, for $E_t^i(s_{t,t+\Delta}^i(x^i))$ to have a large value, the $(T,\varepsilon)$-upward stablecoin system needs to issue a sufficient quantity of coins. On the other hand, for a high value of $E_t^i\big(o_{t,t+\Delta}^i(x_\Delta^i)/p_{t+\Delta}^b\big)$, $p_{t+\Delta}^b$ should be low or $o_{t,t+\Delta}^i(x_\Delta^i)$ should be high. When users believe that the market price will decrease soon (i.e., $E_t^i(p_{t+\Delta}^b) < p_t^s\,(= \min\{p_t^b, p_t^s\})$), $E_t^i\big(o_{t,t+\Delta}^i(x_\Delta^i)/p_{t+\Delta}^b\big)$ can become sufficiently high. In this case, rational users should not buy coins in the market at time $t$ because they can earn safely at least $x^i/d_\Delta$ at time $t+\Delta$ (e.g., make a deposit in a bank instead of buying stablecoins in the market at time $t$). Technically, $o_{t,t+\Delta}^i(x_\Delta^i) \geq x_\Delta^i/d_\Delta$, where $x_\Delta^i = x^i$, and Eq. (6) is naturally met. Therefore, this belongs to when the price of the coin can decrease even without any mechanism. Lastly, for a value of $o_{t,t+\Delta}^i(x_\Delta^i)$ to be high, we can consider the case when high returns are expected in some non-stablecoin assets. In this case, users would earn higher profits by investing in such assets instead of buying coins in the market, and therefore, the coin price would decrease even without a certain mechanism. In contrast, if there are no such non-stablecoin assets preferred by many users, $\mathcal{O}$ should spend its reserves to reward users who did not buy or sold coins in the market at time $t$. As a result, upward stablecoin systems should be ready to issue enough coins or spend its reserves if the price is greater than $T+\varepsilon$.

**Example of $(T,\varepsilon)$-Upward Stablecoin.** Here, we describe several mechanisms that cause the coin price to return to the range below $T+\varepsilon$. In these examples, we assume that $T$ is 1 USD, and $\varepsilon$ is 0 for simplicity.

(i) Let us first consider an upward stablecoin that sets $s_{t,t}^i(x^i)$ (i.e., $\Delta = 0$) to be high so that Eq. (6) is satisfied. Then, in this system, a user can buy coins at a cheaper price from $\mathcal{O}$ at time $t$, which implies that enough coins should be issued by $\mathcal{O}$.

(ii) The second example is an upward stablecoin system that guarantees high $o_{t,t+1\mathrm{yr}}^i(x_{1\mathrm{yr}}^i)$. To keep $o_{t,t+1\mathrm{yr}}^i(x_{1\mathrm{yr}}^i)$ high, the system can give user $i$ high interest after 1 year when they deposit a value $x_{1\mathrm{yr}}^i$ of non-stablecoin assets to the system at time $t$. Here, the system should spend its reserves to provide users with high interest.

(iii) As the final example, we consider a system where the two examples above are combined: the system leverages both new coin issuance and asset value guarantees to control the price. In the system, $s_{t+1\mathrm{yr}}^i(x^i)$ and $o_{t+1\mathrm{yr}}^i(x_{1\mathrm{yr}}^i)$

have positive values. Then, users can simultaneously earn high interest and buy coins at a cheaper price from the system after 1 year when depositing non-stablecoin assets to the system.

### 3.3 Trilemma From Theorems 1 and 2

Now, we derive a trilemma in designing a stablecoin using Theorems 1 and 2.

**Theorem 3 (The Trilemma of Stablecoin).** *For any $(T,\varepsilon)$-stablecoin, if the transactions of $a^T$ are not always transparent for everyone, it can eliminate only at most two of the following items simultaneously:*

1. ***(Downward price instability due to moral hazards)*** *It is not $(T,\varepsilon)$-downward stable when $\mathcal{O}$ does not maintain its reserves at least as much as $\sum_{\substack{i\in\mathcal{U}\\ \Delta\in G\\ a\in\mathcal{A}}} E_t^i\left(v_{t+\Delta}^{i,a}\right)\cdot d_\Delta$ satisfying Eq. (4) as promised.*
2. ***(Downward price instability due to financial risks)*** *It is not $(T,\varepsilon)$-downward stable when $\mathcal{O}$ cannot maintain its reserves at least as much as $\sum_{\substack{i\in\mathcal{U}\\ \Delta\in G\\ a\in\mathcal{A}}} E_t^i\left(v_{t+\Delta}^{i,a}\right)\cdot d_\Delta$ satisfying Eq. (4) due to external market risk and $\mathcal{O}$'s poor financial performance.*
3. ***(Upward price instability due to limited coin supply)*** *It is not $(T,\varepsilon)$-upward stable when Eq. (6) is not satisfied because the new coin supply $\sum_{i\in\mathcal{U}'} s_{t,t+\Delta}^i(x^i)$ should be limited.*

*Proof.* All $(T,\varepsilon)$-stablecoins should satisfy Eq. (4) and Eq. (6) because they must be both $(T,\varepsilon)$-downward stable and $(T,\varepsilon)$-upward stable. We first consider Eq. (4) in Theorem 1, which provides the lower bound of reserves that $\mathcal{O}$ should spend to increase the price. This inequality can be rewritten by decomposing $\mathcal{A}$ in LHS into $a^T$ and $\mathcal{A}\backslash\{a^T\}$ as:

$$\sum_{\substack{i\in\mathcal{U}\\ \Delta\in G}} E_t^i\left(v_{t+\Delta}^{i,a^T} + \sum_{a\in\mathcal{A}\backslash\{a^T\}} v_{t+\Delta}^{i,a}\right)\cdot d_\Delta > \sum_{i\in\mathcal{U}} c_t^i \cdot \sum_{\substack{j\in\mathcal{U}\\ \Delta'\in G'}} \left\{ g_t(j,\Delta')\cdot\left(p_t^s - h_{\Delta'}\left(E_t^j\left(p_{t+\Delta'}^s\right)\right)\cdot d_{\Delta'}\right)\right\} \quad \text{if } p_t^0 < T-\varepsilon, \tag{8}$$

To satisfy Eq. (8), the stablecoin system can adjust time paths of allocations of the reserve spendings $\left\{v_{t+\Delta}^{i,a^T}\right\}_{\substack{i\in\mathcal{U}\\ \Delta\in G}}$ and $\left\{\sum_{a\in\mathcal{A}\backslash\{a^T\}} v_{t+\Delta}^{i,a}\right\}_{\substack{i\in\mathcal{U}\\ \Delta\in G}}$, $\sum_{i\in\mathcal{U}} c_t^i$, $g_t$, and $p_{t+\Delta'}^s$. However, adjusting only $g_t$ does not affect the RHS of Eq. (8) significantly because the sum of $g_t(i,\Delta)$ for all $i\in\mathcal{U}$ and $\Delta\geq 0$ is 1. In addition, to adjust the future price, Eq. (8) should be satisfied again, which is recursive. As a result, the system needs to adjust either of the following three: $\left\{v_{t+\Delta}^{i,a^T}\right\}_{\substack{i\in\mathcal{U}\\ \Delta\in G}}$, $\left\{\sum_{a\in\mathcal{A}\setminus\{a^T\}} v_{t+\Delta}^{i,a}\right\}_{\substack{i\in\mathcal{U}\\ \Delta\in G}}$, or $\sum_{i\in\mathcal{U}} c_t^i$. Considering $\sum_{i\in\mathcal{U}} v_{t+\Delta}^{i,a^T}$, Eq. (8) can be met if the system stores sufficiently large reserves in $a^T$, which is the target asset. However, this entails the risk of moral hazard because the transactions of the target asset are not always transparent: $\mathcal{O}$ can betray the trust of its users for its own interest. For example, $\mathcal{O}$ could steal the reserves or invest them in risky assets. Although audits exist to prevent this dishonesty, there is still a risk of collusion or the audit risk [26]. Therefore, price recovery to above $T-\varepsilon$ may not be guaranteed when controlling $\sum_{i\in\mathcal{U}} v_{t+\Delta}^{i,a^T}$. As a result, we obtain the following: ***(1) the stablecoin system may not be $(T,\varepsilon)$-downward stable if $\mathcal{O}$ acts dishonestly while managing its reserves.***

Second, we consider that $\sum_{i\in\mathcal{U},a\in\mathcal{A}\setminus\{a^T\}} v_{t+\Delta}^{i,a}$ is sufficiently large so that Eq. (8) is satisfied. That is, the system maintains sufficient reserves in non-target assets. This allows the system to hold reserves in assets whose transactions can be traced by everyone such that $\mathcal{O}$ cannot arbitrarily misappropriate the reserves. For example, an operating entity could use digital assets with blockchain technology to store the reserves,[12] allowing transparent reserve management and preventing the operating entity from misappropriating reserves [11]. However, values of non-target assets can fluctuate due to external shocks even if the asset portfolio is diversified to minimize risk. Thus, there may be times when $\mathcal{O}$ should fill in its reserves to cover the loss and maintain a high value of $\sum_{i\in\mathcal{U},a\in\mathcal{A}\setminus\{a^T\}} v_{t+\Delta}^{i,a}$ if the value of reserves comprising non-target assets decreases. To this end, $\mathcal{O}$ has several economic options to take inside or outside of the stablecoin system, such as providing financial services, investing assets, and running a separate business. However, whether $\mathcal{O}$ can replenish the reserves depends on its financial performance. This leads to the second element of the trilemma: ***(2) the stablecoin system may not be $(T,\varepsilon)$-downward stable if the operating entity is exposed to external market risks and has a poor financial performance.***

Lastly, to satisfy Eq. (8), we consider controlling the coin quantity in circulation $\sum_{i\in\mathcal{U}} c_t^i$ without adjusting the value of reserves to avoid the first two elements of the trilemma. Note that, to satisfy Eq. (8), the stablecoin system cannot change $\sum_{i\in\mathcal{U}} c_t^i$ regardless of users' transactions according to C2 in Definition 2. Therefore, to satisfy Eq. (8) by controlling $\sum_{i\in\mathcal{U}} c_t^i$, the system should

[12] This type of currency is usually referred to as a *decentralized or non-custodial stablecoin* applying blockchain technology.

limit issuing coins. However, recall that the new coin issuance should satisfy Eq. (6), which suggests that the system should issue more than a certain number of stablecoins to recover the price from above the target value if it were not to spend reserves. Thus, Eq. (6) can be violated while limiting issuing coins to satisfy Eq. (8). For example, let us consider a case in which the coin price jumps very high. Then, the system can satisfy Eq. (6) even with a small value of $\sum_{i\in\mathcal{U}'} s^i_{t,t+\Delta}(x^i)$ (i.e., a quantity of stablecoins that the system should issue) to drop the price because the RHS of the inequality is low. However, while the coin price gradually drops, the system may not be able to maintain a small value of $\sum_{i\in\mathcal{U}'} s^i_{t,t+\Delta}(x^i)$ at some point of time because the RHS of Eq. (6) gradually increases. This implies that the system may not lower the price any further while maintaining a small value of $\sum_{i\in\mathcal{U}} c^i_t$. As a result, the system will not be able to guarantee that the price returns to below $T+\varepsilon$ owing to a limited coin supply, which leads to the last element of the trilemma: ***(3) the stablecoin system may not be*** $(T,\varepsilon)$***-upward stable because it cannot lower the price below a certain value (***$> T+\varepsilon$***) due to the limited coin supply.***

Remember that the system needs to adjust either of the following three terms to satisfy Eq. (8): $\left\{v^{i,a^T}_{t+\Delta}\right\}_{\substack{i\in\mathcal{U}\\ \Delta\in G}}$, $\left\{\sum_{a\in\mathcal{A}\setminus\{a^T\}} v^{i,a}_{t+\Delta}\right\}_{\substack{i\in\mathcal{U}\\ \Delta\in G}}$, and $\sum_{i\in\mathcal{U}} c^i_t$. We showed above that controlling each of the three terms leads to the three price instability elements of the trilemma. Thus, the system should not control the corresponding term in Eq. (8) to rule out one price instability element of the trilemma. As a result, we can eliminate at most two price instability elements of the trilemma because the system should control at least one of the three terms in Eq. (8). This completes the proof of Theorem 3.

The trilemma is derived because we assume that the transactions of the target asset are not always traceable. In other words, if the target asset is traceable, the first two elements of the trilemma can be eliminated, thereby freeing the stablecoin system from the trilemma. For example, when the target asset is Bitcoin, $\mathcal{O}$ can store all the reserves in Bitcoin. In this case, because it can be implemented for the reserves to be traced by anyone, we can prevent the operating entity from misappropriating the reserves. In addition, the value of the reserves remains stable because reserves are stored in the target asset itself (i.e., Bitcoin). Thus, the operating entity does not need to cover a loss to maintain a high value of reserves. As a result, the system can guarantee price stability relative to Bitcoin without encountering the trilemma. However, such a stablecoin cannot yet function as popular money because its target itself currently suffers from high price volatility.

In summary, a trilemma exists in designing a stablecoin. The trilemma states that any stablecoin bears at least one of the following types of potential price instabilities: (1) downward price instability due to moral hazards of the operating entity, (2) downward price instability when the entity is exposed to external market risks and has a poor financial performance, and (3) upward price instability due to the limited coin supply.

## 4 The Trilemma Found in Existing Stablecoins

In this section, we examine some existing stablecoins using our theoretical framework to see which price instability element of the trilemma they bear.

**Stablecoins With Price Instability Due to Moral Hazard.** Currently, most stablecoins including Diem (formerly known as Libra)[13], Tether[14], and TrueUSD[15] are designed to maintain sufficient reserves with fiat currencies for high price stability. Their operating entities intend to achieve this by maintaining a high value of reserves stored with $a^T$, which corresponds to satisfying Eq. (4) in Theorem 1. However, this implies that they may suffer from a price drop because of the moral hazard of the operating entity, as indicated in previous research [11, 17]. For example, Tether, which has the highest market cap among the launched stablecoins at the time of writing, broke their promise to store sufficient reserves in cash, which caused many people to worry and criticize the coin [17, 27, 28].

Another example is Diem, developed by Facebook. Diem has been facing considerable backlash and criticism by experts [13, 14]. One of the main concerns is that its design requires users' trust in Facebook, although Facebook claims that the company is just one equal member of the Diem Association, which consists of 27 institutions. Nevertheless, many people seem to believe that trust in Facebook is one of the main factors required to use Diem [29, 30]. For example, Forbes contributor Enrique Dans says that their "malign philosophy is contagious" and that it will eventually drag all members of the association "down to its murky levels" [30]. Moreover, even if we grant Facebook's claim, the price stability of Diem may not be guaranteed if the moral hazard of the Diem Association occurs. As such, in the existing stablecoins, we observe many concerns related to the first price instability element of the trilemma.

**Stablecoins With Price Instability Due To Financial Risk.** Some stablecoins maintain reserves with digital assets that can be managed and traced

[13] The Diem website. `https://www.diem.com/en-us/`, [Online; accessed 10-May-2021].
[14] The Tether website. `https://tether.to/`, [Online; accessed 10-May-2021].
[15] The TrueUSD website. `https://www.trueusd.com/`, [Online; accessed 10-May-2021].

transparently to avoid the first element of the trilemma. Since the value of the reserves consisting of assets other than the target asset can fluctuate, the stablecoins employ various mechanisms to address this issue. We first consider Terra[16] to see how it handles the problem. The Terra company operates both Terra stablecoins and Luna, another cryptocurrency; Terra stablecoins use Luna as reserves. Therefore, the operating entity can maintain a high value of reserves and satisfy Eq. (4) in Theorem 1 by minting more Luna tokens. However, even so, it may not be always possible to keep replenishing reserves sufficiently because increasing Luna supply further lowers the price of Luna, creating a vicious cycle. Here, how long and how deep the cycle will persist may depend on how well the company operates Luna. If the company cannot efficiently run the Luna business thereby losing the control of the Luna price, it will not be able to replenish the reserves, which Terra also acknowledges [24]. As another example, some stablecoins such as Basis [31] use a form of bond for their stablecoin as reserves: the bond token promises to provide Basis stablecoins in the future when a certain condition is satisfied. Similar to the Terra system, its operation of the bond market would affect whether the price of Basis can be stabilized. Therefore, the price stability of stablecoins such as Terra and Basis depends on the financial performance of the operating entity, which corresponds to the second element of the trilemma.

**Stablecoins With Price Instability Due to Limited Coin Supply.** There are stablecoin systems that issue stablecoins only when users pay or deposit assets with a sufficiently high value, where the deposited assets can be spent as part of reserves to satisfy Eq. (4) in Theorem 1. MakerDAO[17] is the most popular, ranked by market capitalization, among the stablecoins that employ this mechanism. In MakerDAO, the target of which is the US dollar, users need to deposit some digital assets with a value greater than $1.5 \times c$ USD into the system to issue $c$ stablecoins. The users can rollback the transaction by returning $c$ stablecoins to the system. This can be deemed a loan mechanism, wherein the asset the users deposit and the issued coins are regarded as collateral and loans, respectively. Clearly, a high collateralization ratio[18] (e.g., 150% in MakerDAO) can result in a high ratio of reserves to the coin supply.

To achieve downward price stability, the MakerDAO system uses a process called Emergency Shutdown. The system initiates the process if the price cannot

[16] The Terra website. `https://www.terra.money/`, [Online; accessed 10-May-2021].

[17] The MakerDAO website. `https://makerdao.com/en/`, [Online; accessed 8-Aug-2021].

[18] A collateralization ratio is defined as the ratio between the collateral assets and loans

recover to \$1 for a while, and it collects back all the coins by spending the reserves including the collaterals to pay \$1 per a coin to all holders. Through this method, the system can satisfy Eq. (4), and MakerDAO becomes downward stable according to Theorem 1.

However, there are cases where Eq. (6) of Theorem 2 is not satisfied for MakerDAO, making it difficult to guarantee the price recovery from above the target value. Consider a case where the market price is \$1.10, and a user collateralizes an asset with a value of \$150 to borrow 100 coins. Here, because the user would anticipate high future profits for the collateral compared to buying coins with a value of \$150 in the market, they take out a loan despite the lower number of coins. For example, we can imagine the case in which many speculate that the collateral value will considerably increase or the market price of coins will decrease; technically, Eq. (6) can be satisfied because of a high value of $E_t^i(o_{t,t+\Delta}^i(x_\Delta^i))$ or a low value of $E_t^i(p_{t+\Delta}^b)$. In contrast, when many speculate that its collateral value will decrease (low $E_t^i(o_{t,t+\Delta}^i(\$150))$) or the coin price will increase (high $E_t^i(p_{t+\Delta}^b)$), Eq. (6) cannot be satisfied, where the new coin issuance is limited to $s_{t,t}^i(\$150) = 100$ and $s_{t,t+\Delta}^i(\$150) = -100$ for some $\Delta > 0$ in the MakerDAO system.[19] This implies that a price recovery from above \$1 may not be guaranteed, and the market price can go up to \$1.50.[20] This result is consistent with previous research, which warned that price appreciation could occur [19, 32]. A research team [32] states that the loan mechanism does not always guarantee price recovery to \$1, and thus, MakerDAO "lacks strong price stabilization mechanisms" because of the limited coin supply. Furthermore, its price actually went up to \$1.1264 on Mar 12, 2020, when Ethereum used as collateral in the MakerDAO system experienced a sharp drop in price [33]. This price increase coming with the price drop of the underlying digital asset, while predicted by our theory, can be counterintuitive, as noted by a paper [19]. Figure 1C shows that the price of MakerDAO is often placed above \$1.[21] In sum, MakerDAO suffers from the third price instability element of the trilemma.

[19] The case where $s_{t,t+\Delta}^i(\$150) = -100$ indicates that users return 100 stablecoins to the system.

[20] Note that the higher the upper bound of the range in which the market price of this type can change above the target, the more likely it is to eliminate the first and second elements of the trilemma. This is because lower supply limits (eliminating the first two elements) increase the extent to which the price can rise.

[21] Note that the fact there are cases where the MakerDAO price is less than \$1 does not mean that the system is not downward stable. Downward price stability indicates that the price can "recover" from below \$1.

**Others.** It is also possible for a stablecoin to suffer from more than one source of price instability. For example, Synths[22] and Sweetbridge[23] bear both the second and third elements of the trilemma. They have the same collateralization mechanism as MakerDAO, so they may experience upward price instability. Although Synths attempts to address the issue by distributing some fraction of its profit from transaction fees to those who use the loan service (i.e., increasing $o^i_{t,t+\Delta}(x^i_\Delta)$ to satisfy Eq. (6)), upward instability could still occur depending on the size of the profit.

The second price instability element in these coins comes from the following factors. Above all, they do not employ any process of price control that spends reserves consisting of collaterals according to Theorem 1 (e.g., MakerDAO's Emergency Shutdown).[24] Therefore, they may not successfully achieve downward stability by limiting coin supply. This implies that they need to raise funds that they can spend according to Theorem 1. However, they do not run any business or take economic actions to do so. As a result, it seems that the systems bear the second price instability element. However, if there is a method similar to Emergency Shutdown in these systems, they would be able to remove the second element.

Augmint is another example of a currency that can experience both upward price instability caused by limited coin supply and downward price instability caused by their poor financial performance. Upward price instability due to the limited coin supply comes from the fact that Augmint operates a collateralization mechanism for newly issued coins, which requires a high collateralization ratio for some fraction of new coin issuance.[25] Augmint can also allow users to take out a loan for newly issued coins with a lower collateralization ratio if they pay interests. In addition to users' interest payments, the system earns transaction fees from users to maintain the high value of reserves. Therefore, Augmint can suffer from downward price instability when the operating entity is unable to replenish the reserves from their business performance. Note that the system bearing two sources of price instability does not necessarily mean that it has a higher risk than other stablecoins.

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[22] The Synthetix (Havven) website. `https://synthetix.io/`, [Online; accessed 10-May-2021].

[23] The Sweetbridge website. `https://sweetbridge.com/`, [Online; accessed 10-May-2021].

[24] We could not find such a process in their white papers.

[25] The Augmint website. `https://www.augmint.org/`, [Online; accessed 10-May-2021].

In addition, there are digital currencies that are conventionally called stablecoins but do not fit our criteria of a stablecoin. For example, Ampleforth changes the quantity of stablecoins owned by users to achieve price stability [25]. In the system, if a user holds 100 coins and the market price is \$0.80, the system gradually changes the coin quantity from 100 to 80 to increase the price from \$0.80 to \$1. Additionally, a recent stablecoin mechanism employs both limiting the supply of coins and changing the coin quantities that users own [34]. These price mechanisms violate C2 in Definition 2.

Table 2 summarizes the classification of several existing stablecoins according to the trilemma.

**Table 2.** Mapping existing stablecoins to the trilemma

<table>
<tr><th>Moral Hazard</th><th>Financial Risk</th><th>Limited Coin Supply</th></tr>
<tr><td rowspan="2">Diem, Tether, USDC, TrueUSD, Stably, Stasis, AAA Reserve, Stronghold USD, Gemini Dollar</td><td>Terra, Basis, Celo</td><td>MakerDAO</td></tr>
<tr><td colspan="2">Augmint, Synths, Sweetbridge</td></tr>
</table>

## 5 Global Survey

The trilemma suggests that stablecoin issuers should choose to carry at least one of three sources of price instability. Here, we present a global survey to explore which choice the general public thinks is most stable. It is important for issuers and policymakers to be cognizant of public opinion regarding the price stability of stablecoins. Stablecoin issuers who want to pursue high popularity may consider adopting a stablecoin design that the public perceives as the most stable. Policymakers and regulators can also refer to public preference when introducing regulations for stablecoins.

We conducted a global online survey using Pollfish[26] between October 2020 and December 2020. The survey was conducted in 34 countries in 10 languages; at least 500 individuals participated from each country. The ratio of real stablecoin users to the total survey participants for each country ranged from 12%–49%,

[26] A study [35] shows that survey results from Pollfish are comparable to traditional surveys such as the General Social Survey (GSS) and the Pew Research Center surveys.

which suggests that our samples consist of people who are relatively enthusiastic about digital currencies compared to the general population [36, 37].

In the survey, we present three currencies, each of which bears a different price instability element of the trilemma. That is, these stablecoins cannot completely eliminate the first, second, and third price instability element of the trilemma, respectively. We refer to the fictional currencies as moral hazard (MH), poor financial performance (PFP), and limited supply (LS). We assume that the currencies' target is a national currency for each country. Therefore, in the survey conducted in the US, the price of MH is fixed at $1 but drops if the operating entity misappropriates the reserves.

The price of PFP is fixed at $1 but drops if the operating entity faces financial difficulties. The price of LS can be unstable between $1 and $1.50 following MakerDAO.[27] That is, it may not be possible to lower the price of LS within this range due to the limited coin supply, while downward price stability from $1 is guaranteed.

We asked participants to choose which stablecoins they consider more stable for all possible pairs of the three stablecoins (i.e., MH versus PFP, MH versus LS, and PFP versus LS) operated by the same issuing company. Facebook and Google were presented as an issuing company in all 34 countries, and we repeated the questions for the two companies.[28] For a detailed survey methodology, please refer to Section 2 in the Appendix.

Based on the respondents' choices for a given pair of currencies, we identified the currency that respondents thought was most stable (MH, PFP, or LS) for each country. Then, we calculated the average result for Facebook and Google, which is presented in Fig. 2A.[29] First of all, we observe distinct cross-country differences in the choice of the most stable currency. Interestingly, only in Venezuela was PFP perceived to be the most stable currency, whereas other countries perceived MH or LS to be the most stable. The most stable currency was chosen

[27] Recall that the MakerDAO system requires users to deposit collateral, the value of which is at least 1.50 USD $\times$ the amount of the stablecoins that they intend to get from the system.

[28] We considered six global companies (Amazon, Facebook, Google, JPMorgan Chase, Netflix, and Walmart) as stablecoin issuers. Only participants in the US were asked about all six companies; in the surveys conducted in other countries, only two (Facebook and Google) or three companies (Amazon, Facebook, and Google) were provided. For more detailed criteria of company selection, please refer to Section 2.1 in the Appendix.

[29] The results did not differ much whether Facebook or Google was assumed to be the issuing company.

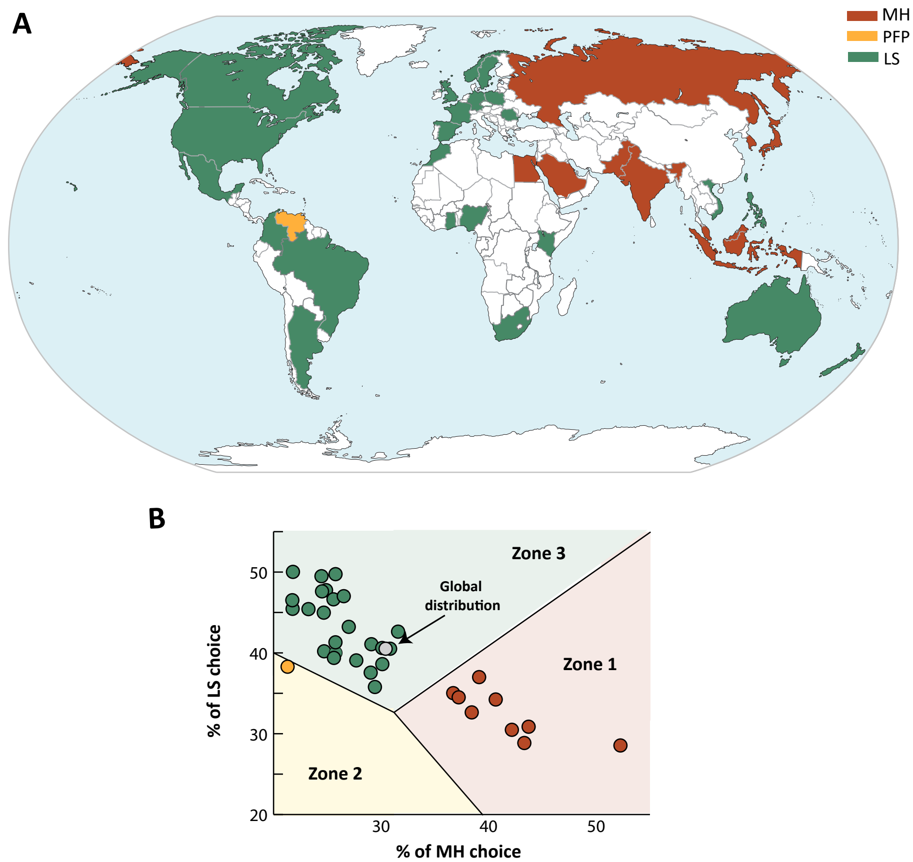


**Fig. 2. Public preference on the trilemma.** (**A**) A world map showing the choices of the most stable currency across surveyed countries, given the currency issuers as Facebook and Google. Countries colored red, yellow, and green chose MH, PFP, and LS as the most stable currency, respectively. (**B**) Choice distributions over MH, PFP, and LS. MH, PFP, and LS are chosen to be the most stable currency if a point is located in the zone marked red (Zone 1), yellow (Zone 2), and green (Zone 3), respectively. The grey colored circle shows a distribution of the entire sample covering all 34 countries. Note that the percentage of votes for PFP can be inferred from the summation of the coordinates: 100%−(% of the MH choice + % of the LS choice).

by a sizable margin in many countries (Fig. 2B). In the Online Appendix, we provide correlation analyses to show what economic, political, and cultural characteristics of a country are associated with the cross-country differences in the choice of the most stable currency.

In addition, the distribution of the choices of the entire samples is shown in the grey point, which suggests that LS was perceived as the most stable currency at the global level. That is, most people thought that the currency with the third element of the trilemma is the most stable when compared to the others.

## 6 Discussion

In this paper, we have identified three sources of price instability and theoretically proved that they form a trilemma. The trilemma states that it is impossible to design a stablecoin that completely eliminates all three sources of price instability, so a stablecoin should bear at least one of the following, all with respect to the target value: (1) downward price instability after moral hazards of the operating entity[5] occur, (2) downward price instability when the entity suffers from financial risks, and (3) upward price instability due to limited coin supply. The three elements of the trilemma might pose a tangible threat; in particular, for the first two elements that rely on the operating entity, considering that only less than 3% of US citizens would trust the stablecoin developed by Facebook [29]. Meanwhile, the operating entities may have underestimated the first two sources of risk.

One key practical application of our theory is to examine existing stablecoins through the lens of our theoretical framework. We showed that existing stablecoins are indeed facing the trilemma, thereby carrying at least one source of price instability. In fact, they are often criticized for reasons associated with the trilemma [10, 14, 32]. The trilemma also suggests that there can be various designs for stablecoins depending on which type of price instability they carry; it is difficult to weigh one type of risk's superiority over the others. This fact recalls the status quo of the stablecoin market: existing stablecoins vary in their design, some touting their excellency over others.

In addition, we conducted a large-scale global survey to discover public preferences on the trilemma, which can further provide an assessment of the current stablecoin market based on the global preference. Our survey indicates that, currently, most people think that a currency with upward price instability is more stable than currencies with limited price stability due to moral hazards or financial risk, which may have been overlooked by global companies [18]. Furthermore, we observed that the stability preference is distinctly different across countries, suggesting that it may be challenging to implement a globally unified stablecoin; each country may need a different design that suits the preferences of its public. However, the current stablecoin market is moving away from the global preference; for example, global companies such as Facebook and Walmart are planning to create currencies that can be affected by moral hazard [5, 6, 7].

Although the trilemma implies that stablecoins have limited price stability, it is still possible to improve the stability. First, for a currency with downward price instability caused by moral hazards, to diversify the risk of moral hazards, an association consisting of independent entities (e.g., the Diem association established by Facebook) can be constructed to issue a stablecoin [38]. However, there are doubts whether this can effectively improve the stability of stablecoins [29, 30, 39]. For the second and third price instability elements of the trilemma, we can decrease the instability by finding or creating relatively stable digital assets to use as reserves. For example, one may consider finding or developing a digital asset, which is in the form of digital currencies, vouchers for blockchain-based services, or digital products developed by a company. Note that stablecoins facing either of the last two elements store reserves with digital assets different from the target to avoid the moral hazard risk, and their price stability is related to the price volatility of the digital assets. However, as of now, finding such digital assets may be challenging, and the technical costs of creating a new one may be high. Future research is required to investigate the extent to which the price instability of stablecoins can be alleviated through a union of several independent entities or through different digital assets.

Regulation is another way to achieve higher price stability. For example, policymakers can introduce institutional devices such as auditing, systematic monitoring, requirements for market entry, and safety nets to reduce moral hazards or financial risks. Moreover, to decrease price instability due to limited coin supply, governments may consider limiting stablecoin trade upon a sudden price shock through a policy like a trading halt.

Although these efforts to improve the price stability of stablecoins are constructive, measurement should be first preceded to understand how much of each type of risk the current stablecoin market bears. Even though it is challenging at this point, future work may attempt to employ an empirical analysis of the price history of each type of existing stablecoins.[30] Assessing currency issuers in their commitment to business ethics or financial performance would also be important to quantify risk. Once we estimate the size of each risk, we can then

[30] The paper [15] proposed a rigorous statistical method and applied it to price history to empirically analyze the price volatility of stablecoins depending on their design.

think about how to optimally combine the three elements of the trilemma; we can solve a portfolio optimization problem with the three types of stablecoins. Furthermore, expert interviews can complement our survey of public preference on the trilemma. Finally, we note that this work does not intend to imply that there are only three sources of price instability. For example, if there is an attack on a system and the reserves are lost, price stability can be threatened by not satisfying the system requirements described in Section 3.2 [11]. As a result, we would need to explore more sources of price instability and determine how to manage them.

## 7 Conclusion

Ultimately, our trilemma suggests that it is impossible for stablecoins to achieve perfect stability. The theoretical framework provided in this paper can serve as a fundamental tool to examine the current status of the stablecoin market. Indeed, as described here, we found that existing stablecoins face the trilemma. Furthermore, our theory has policy implications validating the necessity of regulatory interventions in the stablecoin market because there are fundamental risks that cannot be resolved technically. However, the fact that any stablecoin cannot avoid the trilemma does not necessarily predict a bleak future for stablecoins. Instead, we would like to point to the importance of better managing the risk that stablecoins bear. Our global survey, whose results can be referred to by currency issuers and policymakers, aligns with such a view. With a novel theoretical framework and large-scale survey, we believe that this work provides insight into the factors weighing the stablecoin market from the perspectives of both currency issuers and regulators.

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# Supplementary Information

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Supplementary Information proceeds as follows. Section 1 presents the full formal proof of the trilemma. Section 2 describes additional materials and methods for the global survey. Section 3 presents the additional analysis of survey results. Lastly, figures are attached at the end of the document.

## 1 Proofs of Theorems and Corollaries

### 1.1 Proof of Theorem 1

In this section, we present the proof of Theorem 1. When $p_t^0$ is less than $T-\varepsilon$, $p_t^s$ is less than $T-\varepsilon$ for any fee $f_t$, as shown in Fig. S1. Therefore, according to Definition 2, $(T,\varepsilon)$-downward stablecoin should increase the coin price ($p_t^b$ or $p_t^s$) when $p_t^0$ is less than $T-\varepsilon$. To increase the price of the coin, the system should change the demand and supply curves to achieve a higher equilibrium price. Specifically, $\mathcal{O}$ should either shift the downward sloping demand curve $D_t(p)$ to the right or shift the upward sloping supply curve $S_t(p)$ to the left, thereby moving to a new equilibrium point with a higher price. The new equilibrium price is higher than $p_t^0$ if and only if $D_t'(p_t^0) - S_t'(p_t^0)$, the difference between the new market demand and supply at price $p_t^0$, is greater than 0 after an instantaneous transition, where $D_t'(\cdot)$ and $S_t'(\cdot)$ are new demand and supply curves after the transition, respectively. To create a condition that $D_t'(p_t^0) > S_t'(p_t^0)$, the system should ensure that at most $D_t'(p_t^0)$ coins are supplied to the market right after time $t$, while at least $S_t'(p_t^0)$ coins should be in demand in the market right after time $t$. This is equivalent to that users should be incentivized not to sell at least $\sum_i c_t^i - D_t'(p_t^0)$ coins and to buy at least $S_t'(p_t^0)$ coins in the market at time $t$. In light of this observation, we can see that $\mathcal{O}$ needs a mechanism that incentivizes users not to sell or to buy coins in the market now, if the actions

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are not profitable. Therefore, we will first find the requirements to incentivize users not to sell or to buy coins in the market at time $t$.

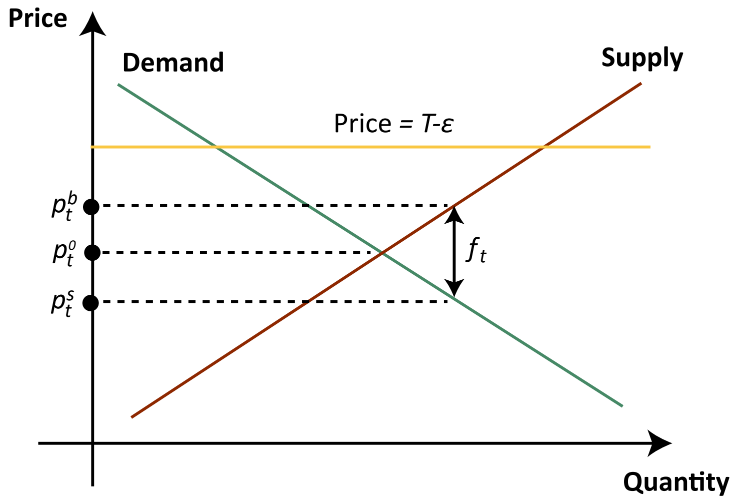


**Fig. S1. Supply and demand curves.** It shows that $p_t^s$ is always less than $T-\varepsilon$ for any $f_t$ in the case where $p_t^0$ is less than $T-\varepsilon$.

**(Supply Control) Incentives Not to Sell:** We now focus on the incentive not to sell coins and later describe the incentive to buy coins, because the incentive to buy coins is easily derived from the incentive not to sell coins. Incentivizing users not to sell coins in the market at time $t$ can be achieved in two ways: encouraging users to sell their coins to operating entity $\mathcal{O}$ and not to the market, and encouraging users to sell it in the market later (i.e., after time $t$), not now. Note that there are a total of three actions: selling coins in the market at time $t$, selling coins to $\mathcal{O}$ at any time, and selling coins in the market later. Therefore, if the second or third action is more profitable than the first action, users would not sell their coins in the market now. We present two lemmas for incentivizing the second and third actions below, respectively. On the other hand, the case where the two lemmas are not applied indicates that the first action is the most profitable and so users would sell coins in the market now.

**Lemma S1.** *To incentivize a user $i$ to prefer selling their coins $c$ to the operating entity $\mathcal{O}$ over selling $c$ in the market now, the system should satisfy the* *following for a certain set G.*

$$\sum_{\Delta \in G} \sum_{a \in \mathcal{A}} E_t^i(v_{t+\Delta}^{i,a}) \cdot d_\Delta > c \cdot p_t^s \tag{1}$$

*Proof.* If user $i$ sells $c$ coins in the market at time $t$, they would earn $c \cdot p_t^s$ in return. On the other hand, if the user sells the coins to $\mathcal{O}$ at time $t$, they would expect to earn $E_t^i(v_t^{i,a})$. Therefore, to incentivize users to sell their coins to $\mathcal{O}$, not to the market, $E_t^i(v_t^{i,a})$ should be greater than $c \cdot p_t^s$. In other words, the minimum reserves that the system needs at time $t$ would be $c \cdot p_t^s$.

When considering that the system gives a user certain assets after a specific time has elapsed in return for getting a stablecoin, the expected present value that the system gives to the user should be greater than $c \cdot p_t^s$. Let $G$ be the set of period, where the system gives the user the value after every period in $G$. Then, $\sum_{\Delta \in G} \sum_{a \in \mathcal{A}} E_t^i(v_{t+\Delta}^{i,a}) \cdot d_\Delta$, the total expected present value that the system gives the user after each period in set $G$, should be greater than $c \cdot p_t^s$. Therefore, we attain Eq. (1).

**Lemma S2.** *To incentivize a user $i$ to prefer holding their coins $c$ at time $t$ and then selling them in the market at time $t + \Delta'$ over selling $c$ in the market at time $t$, the system should satisfy the following for a certain set $G$.*

$$\sum_{\Delta \in G} \sum_{a \in \mathcal{A}} E_t^i(v_{t+\Delta}^{i,a}) \cdot d_\Delta > c \cdot \Big(p_t^s - E_t^i(p_{t+\Delta'}^s) \cdot d_{\Delta'}\Big)^+. \tag{2}$$

*Proof.* To incentivize this, a user should expect a higher gain than $\frac{p_t^s}{d_{\Delta'}}$ per coin when selling coins in the market after an period $\Delta'$ (e.g., holding coins during the period $\Delta'$ and then selling them). If the expected gain per coin is less than $\frac{p_t^s}{d_{\Delta'}}$, they should sell their coins in the market immediately (i.e., at time $t$) without waiting for time period $\Delta'$.

When user $i$ sells their coins at the market after time period $\Delta'(> 0)$, its expected gain would be $E_t^i(p_{t+\Delta'}^s)$ per coin. Let us denote $r_i$ the reward per coin that the user $i$ expect from the system if they sell the coins in the market after time period $\Delta'(> 0)$. Then, when user $i$ decides to sell their coins in the market at time $t + \Delta$, the total expected gain would be $E_t^i(p_{t+\Delta'}^s) + E_t^i(r_i)$. As a result, $E_t^i(p_{t+\Delta'}^s) + E_t^i(r_i)$ should be greater than $\frac{p_t^s}{d_{\Delta'}}$.

We let $G$ be a set of period, where the system can give user $i$ the reward after every period in $G$. Then, the total present value that the user $i$ expect from the system, aggregated over all elements of the set $G$ should be greater than

$$c \times \left(p_t^s - E_t^i(p_{t+\Delta'}^s) \cdot d_{\Delta'}\right)^+$$

As a result, the following inequality should be satisfied.

$$\sum_{\Delta \in G} \sum_{a \in \mathcal{A}} E_t^i(v_{t+\Delta}^{i,a}) \cdot d_\Delta > c \cdot \left(p_t^s - E_t^i(p_{t+\Delta'}^s) \cdot d_{\Delta'}\right)^+$$

**(Demand Control) Incentives to Buy:** To incentivize users to buy coins from the market at time $t$, $\mathcal{O}$ should guarantee a gain. Here, after users buy coins from the market, they have the following two choices: selling the coins to $\mathcal{O}$ or remaining in the market. If the users decide to sell coins to $\mathcal{O}$, the entity should pay a higher price than $p_t^b$. This repeats Lemma S1 by substituting $p_t^s$ with $p_t^b$. On the other hand, if the users decide to remain in the market and the price drops, the entity should compensate for the loss, which is similar to Lemma S2. As a result, we attain the following lemmas to give user $i$ incentives to buy $c$ coins in the market at time $t$.

**Lemma S3.** *To encourage a user $i$ to buy $c$ coins in the market at time $t$ through gains earned by reselling the coins to $\mathcal{O}$, the system should satisfy the following.*

$$\sum_{\Delta \in G} \sum_{a \in \mathcal{A}} E_t^i(v_{t+\Delta}^{i,a}) \cdot d_\Delta > c \cdot p_t^b, \tag{3}$$

**Lemma S4.** *To encourage a user $i$ to buy $c$ coins in the market at time $t$ through gains earned by remaining in the market, the system should satisfy the following.*

$$\sum_{\Delta \in G} \sum_{a \in \mathcal{A}} E_t^i(v_{t+\Delta}^{i,a}) \cdot d_\Delta > c \cdot \left(p_t^b - E_t^i(p_{t+\Delta'}^s) \cdot d_{\Delta'}\right)^+ \tag{4}$$

We omit the proofs of Lemmas S3 and S4 because they are similar to that for Lemmas S1 and S2, respectively.

**Finding Function $\mathbf{g_t}$:** Now we find function $g_t$ that satisfies Eq. (4), using the four lemmas. First, remember that, to increase a price, $D_t'(p_t^0) - S_t'(p_t^0)$ should be greater than 0. Moreover, users are being incentivized not to sell $\sum_i c_t^i - S_t'(p_t^0)$ coins and to buy $D_t'(p_t^0)$ coins in the market at time $t$. In fact, because $\sum_i c_t^i - S_t'(p_t^0) + D_t'(p_t^0)$ is greater than $\sum_i c_t^i$, it implies that there should be incentives not to sell or to buy for all coins.

To consider the case in which there are incentives not to sell or to buy for each coin, we first let $\mathcal{C}_t$ denote the set of all coins at time $t$. Here note that $|\mathcal{C}_t| = \sum_i c_t^i$. We partition the set $\mathcal{C}_t$ into a family of sets $\left\{\mathcal{C}_t^{i,\Delta}\right\}_{i\in\mathcal{U},\Delta\in G'}$ for some set of periods $G'$ including 0 so that $\bigcup_{i\in\mathcal{U},\Delta\in G'} \mathcal{C}_t^{i,\Delta} = \mathcal{C}_t$ and $\mathcal{C}_t^{i,\Delta} \bigcap \mathcal{C}_t^{j,\Delta'} = \emptyset$ for any $(i,\Delta)$ and $(j,\Delta')$ ($i \neq j$ or $\Delta \neq \Delta'$). Here, let us assume that for $\Delta > 0$, among the partition sets, $\mathcal{C}_t^{i,\Delta}$ is

$$
\begin{aligned}
&\{\text{coin } x \,|\, \text{Coin } x \text{ is incentivized to be held at time } t \text{ and then sold by user } i \text{ at time } t+\Delta\} \\
&\bigcup \{\text{coin } x \,|\, \text{Coin } x \text{ is incentivized to be bought by user } i \text{ in the market} \\
&\qquad\qquad \text{through gains earned by selling coin } x \text{ in the market at time } t+\Delta\}.
\end{aligned}
$$

Moreover, for $\Delta = 0$, among the partition sets, let $\mathcal{C}_t^{i,\Delta}$ be

$$
\begin{aligned}
&\{\text{coin } x \,|\, \text{Coin } x \text{ is incentivized to be sold to } \mathcal{O}, \text{ not in the market, by user } i\} \\
&\bigcup \{\text{coin } x \,|\, \text{Coin } x \text{ is incentivized to be bought by user } i \text{ in the market} \\
&\qquad\qquad \text{through gains earned by selling coin } x \text{ to } \mathcal{O}\}.
\end{aligned}
$$

In other words, $\mathcal{C}_t^{i,\Delta}$ is the set of coins that are incentivized to be sold in the market at time $t+\Delta$ when $\Delta > 0$, and we use $\Delta = 0$ to refer to the set of coins that are incentivized to be sold to $\mathcal{O}$ at any time.

Then, we set $g_t(i,\Delta)$ as follows:

$$
g_t(i,\Delta) := \begin{cases} \frac{|\mathcal{C}_t^{i,\Delta}|}{|\mathcal{C}_t|} & \text{if } \Delta \in G', \\ 0 & \text{otherwise} \end{cases}
$$

According to the above equation, the following are met: $\sum_{i\in\mathcal{U},\Delta\in G'} g_t(i,\Delta) = 1$, and $g_t(i,\Delta) \geq 0$ for any $t$. These accord with the conditions of $g_t(i,\Delta)$ stated in Theorem 1.

Next, we should check whether our function of $g_t(i,\Delta)$ satisfies Eq. (4). Note that there should be incentives not to sell or to buy for all coins in $\mathcal{C}_t$. That is, such incentives should exist for all partition sets $\left\{\mathcal{C}_t^{i,\Delta}\right\}_{i\in\mathcal{U},\Delta\in G'}$. To derive requirements to guarantee incentives for the coins in $\bigcup_{i\in\mathcal{U}} C_t^{i,\Delta=0}$, Lemmas S1 and S3, which find reserve requirements to incentivize user $i$ to sell $c$ coins to $\mathcal{O}$, should be aggregated for the set of coins $\bigcup_{i\in\mathcal{U}} C_t^{i,\Delta=0}$. Then we can easily derive the following inequality:

$$
\sum_{\substack{i\in\mathcal{U}\\ \Delta'\in G\\ a\in\mathcal{A}}} E_t^i\left(v_{t+\Delta'}^{i,a}\right)\cdot d_{\Delta'} > \sum_{j\in\mathcal{U}} g_t(j,0)\cdot\sum_{i\in\mathcal{U}} c_t^i \cdot \min\{p_t^b, p_t^s\} \tag{5}
$$

Note that $h_{\Delta=0}\big(\min\{p^b_t, p^s_t\}\big)$ is 0. For $\bigcup_{i\in\mathcal{U}} C^{i,\Delta>0}_t$, we use Lemmas S2 and S4, which find reserve requirements to incentivize user $i$ to sell $c$ coins to the market at time $t+\Delta$, should be aggregated for the set of coins $\bigcup_{i\in\mathcal{U}} C^{i,\Delta>0}_t$. Then the following inequality is derived:

$$\sum_{\substack{i\in\mathcal{U}\\ \Delta'\in G\\ a\in\mathcal{A}}} E^i_t\left(v^{i,a}_{t+\Delta'}\right)\cdot d_{\Delta'} \quad > \sum_{i\in\mathcal{U}} c^i_t \cdot \sum_{j\in\mathcal{U}} \Big\{ g_t(j,\Delta)\cdot\Big(\min\{p^b_t, p^s_t\} - E^j_t\left(p^s_{t,t+\Delta}\right)\cdot d_\Delta\Big)^+\Big\}. \tag{6}$$

According to the definition of function $h_\Delta$, Eqs. (5) and (6) can be expressed as follows:

$$\sum_{\substack{i\in\mathcal{U}\\ \Delta'\in G\\ a\in\mathcal{A}}} E^i_t\left(v^{i,a}_{t+\Delta'}\right)\cdot d_{\Delta'} \quad > \sum_{i\in\mathcal{U}} c^i_t \cdot \sum_{j\in\mathcal{U}} \Big\{ g_t(j,\Delta)\cdot\Big(p^s_t - h_\Delta\Big(E^j_t\left(p^s_{t,t+\Delta}\right)\Big)\cdot d_\Delta\Big)^+\Big\}. \tag{7}$$

To consider all partitions in $\left\{\mathcal{C}^{i,\Delta}_t\right\}_{i\in\mathcal{U},\Delta\in G'}$, we aggregate the right-hand side of Eq. (7) for $\forall\Delta\in G'$, which derives Eq. (4). As a result, for arbitrary $(T,\varepsilon)$-downward stablecoin, we found the function $g_t(i,\Delta)$ and two sets of period $G$ and $G'$ that satisfy Eq. (4). This completes the proof of Theorem 1.

### 1.2 Proof of Corollary 1

To be $(T,\varepsilon)$-downward stablecoin, the price should increase when $p^0_t$ is less than $T-\varepsilon$. As described in the proof of Theorem 1, the system should make $D'_t(p^0_t) - S'_t(p^0_t)$ positive by the law of supply and demand. Also, we already showed that it is equivalent to the case where there are incentives for users not to sell or to buy in the market for all coins. To guarantee these incentives for each coin, we should consider the maximum of Eqs. (S1) and (S2) and the maximum of Eqs. (S3) and (S4). Note that, in the proof of Theorem 1, we considered the minimum values instead of the maximum values because our goal was to find the lower bound there. As a result, we can derive the following:

$$\sum_{\substack{i\in\mathcal{U}\\ \Delta\in G\\ a\in\mathcal{A}}} E^i_t\left(v^{i,a}_{t+\Delta}\right)\cdot d_\Delta > \sum_{i\in\mathcal{U}} c^i_t \cdot \sum_{\substack{j\in\mathcal{U}\\ \Delta'\in G'}} \Big\{ g_t(j,\Delta')\cdot\Big(\max\{p^b_t, p^s_t\} - h_{\Delta'}\big(E^j_t\left(p^s_{t+\Delta'}\right)\big)\cdot d_{\Delta'}\Big)^+\Big\}$$

$$\text{if } p^0_t < T-\varepsilon$$

This suggests that there are $(T,\varepsilon)$-downward stablecoin that satisfies the above equation. This completes the proof of Corollary 1.

### 1.3 Proof of Theorem 2

If $p_t^0$ is greater than $T+\varepsilon$, $p_t^b$ would be always greater than $T+\varepsilon$ for any fee $f_t$. Therefore, in this case, the price should decrease according to the definition of $(T,\varepsilon)$-upward stablecoin. By the law of supply and demand, to achieve a lower equilibrium price, the system should adjust downward sloping demand curve $D_t(p)$ and the upward sloping supply curve $S_t(p)$. Specifically, the system should satisfy that $D_t'(p_t^0) - S_t'(p_t^0)$, the difference between the new market demand and supply at price $p_t^0$, is less than 0 after an instantaneous transition. Here, $D_t'(\cdot)$ and $S_t'(\cdot)$ denote new demand and supply curves after the transition, respectively. To create a condition that $D_t'(p_t^0) < S_t'(p_t^0)$, the system should ensure that at most $S_t'(p_t^0)$ coins are in demand in the market right after time $t$, while at least $D_t'(p_t^0)$ coins are supplied in the market. This corresponds to that users should be incentivized not to buy at least $Q - S_t'(p_t^0)$ coins and to sell at least $D_t'(p_t^0)$ coins in the market at time $t$, where $Q$ is the maximum quantity of coins that can be purchased with all non-stablecoin assets that users hold at time $t$. In light of this observation, we can see that $\mathcal{O}$ needs a mechanism that incentivizes users not to buy or to sell coins in the market now, if the actions are not profitable.

Among the two, we now focus on incentivizing users not to buy coins in the market at time $t$. To motivate users not to buy coins in the market now, the system should encourage them to buy coins from $\mathcal{O}$, not from the market, or to buy coins in the market later, not now, for a higher profit. Note that there are a total of three actions that a user can take in terms of coin purchases: buying coins in the market now, buying coins from $\mathcal{O}$ at any time, and buying coins in the market later. Therefore, if the second or third action is more profitable than the first action, users would not buy their coins in the market now. Otherwise, if the first action is the most profitable, users would sell coins in the market now. Below we will look at how the second or third action can become more profitable than the first action.

We first consider that the system incentivizes a user to prefer buying coins from $\mathcal{O}$ over buying them from the market now. If a user buys coins with their assets worth as much as $x$ in the market at time $t$, the quantity of coins would be $x/p_t^b$. Therefore, to incentivize buying coins from $\mathcal{O}$ instead of the market, the expected coin quantity that the user can buy from $\mathcal{O}$ by spending the asset value $x$ should be greater than $x/p_t^b$. Here, we let $s_{t,t+\Delta}^i(x^i)$ denote the quantity of stablecoins issued by $\mathcal{O}$ that user $i$ can have at time $t+\Delta$ by using non-stablecoin assets whose the value is $x^i$ at time $t$. Then, considering the definition of $s_{t,t+\Delta}^i(x^i)$, the expected present value of the coin quantity that the user can buy from $\mathcal{O}$ by spending the asset value $x$ is $\sum_{\Delta\in G_1} E_t^i\left(s_{t,t+\Delta}^i(x)\right)\cdot d_\Delta$, where

$G_1$ denotes a set of all period $\Delta$ such that $\mathcal{O}$ gives the user the newly issued coins at time $t+\Delta$. Note that getting $c$ stablecoins at time $t$ has the same value as getting $c/d_\Delta$ stablecoins at time $t+\Delta$. As a result, we attain the condition below that $\mathcal{O}$ should satisfy to incentivize users to buy coins from $\mathcal{O}$ instead of the market.

$$\sum_{\Delta \in G_1} E_t^i \left( s_{t,t+\Delta}^i(x) \right) \cdot d_\Delta > \frac{x}{p_t^b} \tag{8}$$

Second, we consider that a user is incentivized to prefer buying coins in the market later over buying them in the market now. Remember that when a user buys coins with their assets worth as much as $x$ in the market at time $t$, the quantity of purchased coins is $x/p_t^b$. Therefore, to incentivize buying coins in the market at time $t+\Delta$ instead of time $t$, the expected coin quantity that the user can buy in the market at time $t+\Delta$ should be greater than $\frac{x}{p_t^b \cdot d_\Delta}$. Recall that $o_{t,t+\Delta}^i(x_\Delta^i)$ is a value of non-stablecoin assets in an asset portfolio that users can possess at time $t+\Delta$, where the value is $x_\Delta^i$ at time $t$ and the portfolio can change over time by users' investment decisions. Then, the following should be satisfied to incentivize users to buy coins in the market at time $t+\Delta$ instead of now:

$$E_t^i \left( \frac{o_{t,t+\Delta}^i(x)}{p_{t+\Delta}^b} \right) > \frac{x}{p_t^b \cdot d_\Delta}.$$

If $G_2$ denotes the set of all periods $\Delta$ such that users are incentivized to buy coins in the market at time $t+\Delta$ instead of time $t$, the following inequality can be easily derived:

$$\sum_{\Delta \in G_2} E_t^i \left( \frac{o_{t,t+\Delta}^i(x_\Delta)}{p_{t+\Delta}^b} \right) \cdot d_\Delta > \frac{x}{p_t^b}, \tag{9}$$

where $\sum_{\Delta \in G_2} x_\Delta = x$. Here, note that we can set $x_\Delta = 0$ for all $\Delta \notin G_2$. Therefore, $x_\Delta$ can be seen as a partition of $x$ over set $G_2$. As a result, $x_\Delta$ satisfies the two conditions stated in Theorem 2: $x_\Delta$ is 0 except for some finite set of periods $\Delta\,(\geq 0)$, and $\sum_{(x_\Delta > 0)} x_\Delta = x$.

We then combine the two cases described above. That is, it should be more profitable for a user to buy some newly issued coins from $\mathcal{O}$ while buying some coins in the market later than buying coins in the market at time $t$. Therefore, the expected total quantity of coins that users can get from $\mathcal{O}$ after every period in $G_1$ and can buy from the market after every period in $G_2$ should be greater than $x/p_t^b$. Considering this, we can easily derive the following inequality:

$$\sum_{\Delta \in G_1} E_t^i(s_{t,t+\Delta}^i(x)) \cdot d_\Delta + \sum_{\Delta' \in G_2} E_t^i \left( \frac{o_{t,t+\Delta'}(x_{\Delta'})}{p_{t+\Delta'}^b} \right) \cdot d_{\Delta'} > \frac{x}{p_t^b}$$

Assuming that $G = G_1 \cup G_2$, the above equation can be expressed as Eq. (10) below because $E_t^i(s_{t,t+\Delta}^i(x^i)) = 0$ for $\Delta \notin G_1$, $x_{\Delta'} = 0$ for $\Delta' \notin G_2$, and $E_t^i(o_{t,t+\Delta}^i(x_\Delta)/p_{t+\Delta}^b) = 0$ for $x_\Delta = 0$.

$$\sum_{\Delta \in G} \left( E_t^i(s_{t,t+\Delta}^i(x)) + E_t^i\left(\frac{o_{t,t+\Delta}^i(x_\Delta)}{p_{t+\Delta}^b}\right)\right) \cdot d_\Delta > \frac{x}{p_t^b} \tag{10}$$

One can see that Eqs. (8) and (9) are the same as Eq. (10) when $o_{t,t+\Delta}^i(\cdot) = 0$ and $s_{t,t+\Delta}^i(\cdot) = 0$, respectively.

Up to this point, we focused on the incentives to not buy coins in the market at time $t$. We now move on to the incentives to sell coins in the market at time $t$. If a user holds coins whose a total value is $x$ at time $t$, the coin quantity that they own would be $x/p_t^s$. Therefore, there should be a way to increase their asset value when compared to holding coins, using $x$'s worth of non-stablecoin assets earned by selling the coins in the market at time $t$. As a result, we can repeat the above steps of the demand control by substituting $x/p_t^b$ with $x/p_t^s$, which derives the following from Eq. (10).

$$\sum_{\Delta \in G} \left( E_t^i\left(s_{t,t+\Delta}^i(x)\right) + E_t^i\left(\frac{o_{t,t+\Delta}^i(x_\Delta)}{p_{t+\Delta}^b}\right)\right) \cdot d_\Delta > \frac{x}{p_t^s} \tag{11}$$

Remember that, to decrease the price, $D_t'(p_t^0) - S_t'(p_t^0)$ should be less than 0. In addition, there are incentives to not buy $Q - D_t'(p_t^0)$ coins and to sell $S_t'(p_t^0)$ coins in the market at time $t$. Because $Q - D_t'(p_t^0) + S_t'(p_t^0)$ is greater than $Q$, either Eq. (10) or Eq. (11) (or both) should be satisfied for all non-stablecoin assets that users hold at time $t$. As a result, for any $x$, there should exist a subset of users $\mathcal{U}'$ that satisfies Eq. (6) for some $G$ and $x_\Delta^i$, which completes the proof.

### 1.4 Proof of Corollary 2

We show that there is $(T, \varepsilon)$-upward stablecoin satisfying Eq. (7). As described in the proof of Theorem 2, $D_t'(p_t^0) - S_t'(p_t^0)$ should be negative to decrease the price according to the law of supply and demand. Moreover, in the above proof, we showed that this is equivalent to the case where either Eq. (10) or Eq. (11) should be satisfied for all non-stablecoin assets that users hold at time $t$. To guarantee this, we should consider the maximum of Eqs. (10) and (11). Note that, in the proof of Theorem 2, we considered the minimum value instead of the maximum value. As a result, we can derive the following:

$$\sum_{\substack{i \in \mathcal{U}' \\ \Delta \in G}} \left( E_t^i\left(s_{t,t+\Delta}^i(x)\right) + E_t^i\left(\frac{o_{t,t+\Delta}^i(x_\Delta)}{p_{t+\Delta}^b}\right)\right) \cdot d_\Delta > \frac{x}{\min\{p_t^b, p_t^s\}}$$

This implies that there exists $(T, \varepsilon)$-upward stablecoin where, for any $x$, users in $\mathcal{U}'$ can expect to earn $E_t^i\left(s_{t,t+\Delta}^i(x^i)\right)$ and $E_t^i\left(o_{t,t+\Delta}^i(x_\Delta^i)\right)$ satisfying Eq. (7) for some $G$ and $x_\Delta^i$. This completes the proof of Corollary 2.

## 2 Survey Methodology

We conducted a global online survey to discover public preferences for the three options of the trilemma. We collected decisions on the trilemma by presenting three currencies MH, PFP, and LS to 17,550 individuals in 34 countries between Oct. 2020 and Dec. 2020.

### 2.1 Selection of Companies

We selected the top global companies that are currently interested in the currency project and are regarded as potential currency issuers by experts [1, 2]. Another criterion for selecting the currency issuers presented in the survey is whether it is well-known to the general public worldwide. Therefore, the following companies were selected: Amazon, Facebook, Google, JPMorgan Chase, Netflix, and Walmart.

The set of companies given as a currency issuer varies across the sample countries because it is important for respondents to be familiar with the given company to reduce bias. More specifically, we included Facebook and Google for all 34 countries, Amazon for 12 countries, and JPMorgan Chase, Netflix, and Walmart only for the US. For Amazon, we surveyed only countries where it is considered among the top five e-commerce sites. For JPMorgan Chase, Netflix, and Walmart, we added a screening question asking whether the respondent knows each company because JPMorgan Chase and Walmart do have relatively small businesses in some states [3, 4], and Netflix is relatively small compared to the other online platforms in the survey, Amazon, Facebook, and Google [5]. Table S1 lists companies included in the survey conducted in each country.

### 2.2 Selection of Countries

We choose sample countries to cover all six continents, thereby featuring political, cultural, and economic diversity, to determine the global preference. Note that we excluded countries in which the service of Facebook or Google, given as a currency issuer in our survey, is currently banned (e.g., China, Iran, and North Korea). Table S1 lists a total of 34 selected countries and each national currency.

### 2.3 Translation

The survey was provided in ten languages: Chinese, English, French, German, Japanese, Korean, Polish, Portuguese, Spanish, and Vietnamese. This helped reach more representative samples in non-native English-speaking countries. The survey was first drafted both in English and Korean. For languages besides English and Korean, we used the professional services of a translation agency currently in charge of many projects of global companies and public institutions. Table S1 presents languages in which the survey was translated for each country.

### 2.4 Recruiting Participants

Our survey was administered through Pollfish[5], which is an online survey platform with approximately one billion potential respondents worldwide. It currently partners with 140 thousand app publishers and sends surveys over mobile apps. When encountering a survey, app users have a non-cash incentive to participate. For example, users can participate in a survey to read a premium article in a news app. To ensure random sampling, Pollfish adopts random device engagement (RDE) that randomly chooses device numbers and then sends a survey. This allowed us to reach a representative sample of the global internet population. Moreover, Pollfish applies AI fraud detection to eliminate fraudulent responses that could threaten data quality. Previous work showed that Pollfish results are significantly well-aligned with those conducted by professional institutions such as GSS and Pew [6]. Through Pollfish, we gathered at least 500 participants over 18 years old in each country. Table S1 lists the sample size for each country.

### 2.5 Survey Questions

In the survey, the respondents rated companies given as currency issuers in terms of reputation on ethics and future financial conditions and also rated the price stability of various currencies constructed through a combination of the three currency types (i.e., MH, PFP, and LS) and issuing companies. The three currencies – MH, PFP, and LS – were given to respondents as A, B, and C, respectively. Then, they stated which currency they believed is more stable when given two currencies issued by the same company. Each respondent answered for two or three companies. In addition, we measured individual risk aversion. Below, we present our survey questions for US in which we asked questions regarding the three companies (Amazon, Google, and Facebook).

[5] The Pollfish website. `https://www.pollfish.com/`, [Online; accessed 20-Apr-2021].

**Table S1.** Sample overview

| Country | Language | National Currency | Companies | Sample Size |
|---|---|---|---|---|
| Argentina | Spanish | ARS | Google, Facebook | 500 |
| Australia | English | AUD | Google, Facebook, Amazon | 500 |
| Brazil | Portuguese | BRL | Google, Facebook, Amazon | 500 |
| Canada | English | CAD | Google, Facebook, Amazon | 500 |
| Colombia | Spanish | COP | Google, Facebook, Amazon | 500 |
| Egypt | English | EGP | Google, Facebook | 500 |
| France | French | EUR | Google, Facebook, Amazon | 500 |
| Germany | German | EUR | Google, Facebook, Amazon | 500 |
| Ghana | English | GHS | Google, Facebook | 500 |
| India | English | INR | Google, Facebook, Amazon | 500 |
| Indonesia | English | IDR | Google, Facebook | 500 |
| Japan | Japanese | JPY | Google, Facebook, Amazon | 500 |
| Kenya | English | KES | Google, Facebook | 550 |
| South Korea | Korean | KRW | Google, Facebook | 500 |
| Malaysia | English | MYR | Google, Facebook | 500 |
| Mexico | Spanish | MXN | Google, Facebook, Amazon | 500 |
| Morocco | French | MAD | Google, Facebook | 500 |
| New Zealand | English | NZD | Google, Facebook | 500 |
| Nigeria | English | NGN | Google, Facebook | 500 |
| Norway | English | NOK | Google, Facebook | 500 |
| Pakistan | English | PKR | Google, Facebook | 500 |
| Philippines | English | PHP | Google, Facebook | 500 |
| Poland | Polish | PLN | Google, Facebook | 500 |
| Romania | English | RON | Google, Facebook | 500 |
| Russia | English | RUB | Google, Facebook | 500 |
| Saudi Arabia | English | SAR | Google, Facebook | 500 |
| South Africa | English | ZAR | Google, Facebook | 500 |
| Spain | Spanish | EUR | Google, Facebook, Amazon | 500 |
| Sweden | English | SEK | Google, Facebook | 500 |
| Taiwan | Chinese | TWD | Google, Facebook | 500 |
| UK | English | GBP | Google, Facebook, Amazon | 500 |
| USA | English | USD | Google, Facebook, Amazon, JPMorgan Chase, Walmart, Netflix | 1000 |
| Venezuela | Spanish | VES | Google, Facebook | 500 |
| Vietnam | Vietnamese | VND | Google, Facebook | 500 |

### 2.5.1 Assessment of Companies

For each company among Amazon, Facebook, and Google, we asked respondents to rate the company in terms of ethical behaviors and future financial conditions using a 7-point Likert scale as follows.

- Do you think that the following companies are honest?
- Do you think the following companies will make large profits over the next 10 years?

### 2.5.2 Perceived Price Stability of Currencies

For Amazon, Facebook, and Google, we asked respondents to answer the following questions on their perception of the price stability of currencies A and B issued by the company using a 7-point Likert scale.

- Currency A is fixed at 1 dollar, but if the company steals funds, then A's value can drop from 1 dollar. How stable do you think this currency would be if made by the companies below?
- Currency B is fixed at 1 dollar, but if the company can't make a lot of money, then B's value can drop from 1 dollar. How stable do you think this currency would be if made by the companies below?

We also asked respondents to answer the following question on their perception of the price stability of currency C using a 7-point Likert scale.

- Currency C's value is guaranteed in the range of 1∼1.5 USD, but it can be unstable within the range. For example, if the price drops from 1.2 to 1 USD, you can lose money. How stable do you think Currency C is?

### 2.5.3 Currency Preferences

We conducted paired comparisons to identify the preference on the trilemma. Three different pairs picked out of the three types of currencies were provided for each company. Depending on the number of companies that were assigned as a currency issuer in the survey, a total of 6 or 9 items were asked in random order. Below we present the questions when Google was assumed to be the currency issuer.

- Which A or B do you think is a more stable currency? (Google)

☐ A: If Google steals funds, A's value drops, otherwise it's fixed at $1.

☐ B: If Google can't make a lot of money, B's value drops, otherwise it's fixed at $1.

– Which A or C do you think is a more stable currency? (Google) (Please consider stability, not profitability!)

☐ A: If Google steals funds, A's value drops, otherwise it's fixed at \$1.
☐ C: Guaranteed in the range of \$1∼1.5 but unstable within the range.

– Which B or C do you think is a more stable currency? (Google) (Please consider stability, not profitability!)

☐ B: If Google can't make a lot of money, B's value drops, otherwise it's fixed at \$1.
☐ C: Guaranteed in the range of \$1∼1.5 but unstable within the range.

#### 2.5.4 Knowledge Regarding the Stablecoin

To determine if a respondent has knowledge regarding stablecoins, we administered the following quiz question on the stablecoin. In the third choice below, "USD" is replaced with other national currencies for countries other than the US.

– Do you know what a stablecoin is?

☐ Never heard about it (or Don't know)
☐ It's a cryptocurrency that has a fixed value
☐ It's the USD
☐ It's a stable service provided by a company

#### 2.5.5 Risk Aversion

We also measured the degree of risk aversion in both losses and gains. To this end, we modified the Sabater-Grande and Georgantzis lottery panel task [7]. Five options in which respondents lose \$1,000 on an average are given to measure the level of risk aversion in losses. In contrast, five options in which \$1,000 can be earned on an average are given to measure the level of risk aversion in gains. The further down respondents choose, the more averse they are to risk. For each country, the values are converted into the national currency.

– What would you prefer? (Loss)

☐ a 10% chance to lose \$10,000
☐ a 20% chance to lose \$5,000
☐ a 50% chance to lose \$2,000
☐ a 80% chance to lose \$1,250
☐ a \$1,000 loss for sure

– What would you prefer? (Gain)

☐ a 10% chance to gain $10,000
☐ a 20% chance to gain $5,000
☐ a 50% chance to gain $2,000
☐ a 80% chance to gain $1,250
☐ a $1,000 gain for sure

### 2.6 Additional Demographic and Socioeconomic Factors

Pollfish provided us with some individual demographic and socioeconomic factors, which are described below.

- *Gender*: Female, male, and others are coded as 0, 1, and 2, respectively.
- *Age*: Age is measured on a 6-point scale: 18-24, 25-34, 35-44, 45-54, 55-64, 65+.
- *Income*: Income ranges are given by the following groups: <$25,000; $25,000∼$49,999; $50,000∼$74,999; $75,000∼$99,999; $100,000∼$124,999; $125,000∼$149,999; >$150,000. The 7-point scale is assigned to these income ranges in which the highest income group is coded as 7 and the lowest income group is coded as 1.
- *Education level*: If a respondent has a college degree or higher, the education level is coded as 1. Otherwise, it is coded as 0.
- *Finance-related professions*: This is coded as 1 if a respondent works in the following fields: finance and insurance, market research, and real estate. Otherwise, it is coded as 0.
- *Computer-related professions*: This is coded as 1 if a respondent works in the following fields: manufacturing computer, electronics, and software. Otherwise, it is coded as 0.

### 2.7 Country-Level Variables

In later analyses, we investigated whether the perceived stability and currency choices are correlated with the following variables.

- *Corruption Perception Index (CPI)*: The index is measured by Transparency International and is retrieved from its website (`https://www.transparency.org/en/cpi/2020/index/nzl`). This index indicates the perceived level of public sector corruption in each country, where corruption is defined as “the abuse of entrusted power for private gain".[6] This ranges between 0 and 100, where lower values indicate more corrupt countries.

– GDP per capita: GDP per capita for 2019 (in USD) is obtained from the World Bank.

– *World Index of Moral Freedom (WIMF)*: This is estimated by the Foundation for the Advancement of Liberty and taken from the WIMF 2020 report (`https://www.fundalib.org/wp-content/uploads/2020/07/WIMF-2020.pdf`). This index indicates the freedom level in each country in terms of five categories: religious freedom, bioethical freedom, drugs freedom, sexual freedom, and family and gender freedom. The index ranges between 0 and 100, where higher values indicate higher moral freedom.

– *Press Freedom Index*: This is published by Reporters Without Borders and is taken from its website (`https://rsf.org/en/ranking`). We used the index for 2020. This index is constructed based on experts' assessment regarding the following seven criteria: pluralism, media independence, environment and self-censorship, legislative framework, transparency, infrastructure, and abuses and violence against journalists. The index ranges between 0 and 100, where higher values indicate lower press freedom.

– *Freedom in the World*: This index is annually measured by the Freedom House and is taken from its website (`https://freedomhouse.org/explore-the-map?type=fiw&year=2020`). The index indicates the level of civil liberties and political rights. This ranges between 0 and 100, where higher values indicate higher civil and political rights.

– *Human Freedom Index*: This index is measured by the Cato Institute and Fraser Institute and is taken from the Human Freedom Index 2020 report (`https://www.cato.org/human-freedom-index/2020`). The index indicates personal, civil, and economic freedom. The index varies between 0 and 10, where a higher value indicates higher human freedom.

– *Power Distance*: This is one of Hofstede's cultural dimensions[7], which represents how much people can tolerate inequality and a power hierarchy. This is taken from the website: `https://www.hofstede-insights.com/product/`

[6] Transparency International (2021) WHAT IS CORRUPTION? `https://www.transparency.org/en/what-is-corruption`, [Online; accessed 8-Aug-2021].

[7] There are six Hofstede's cultural dimensions [8]: Power distance, individualism, masculinity, uncertainty avoidance, long-term orientation, and indulgence. Among them, we chose two dimensions related to relying on a society, organizations, and groups: power distance and individualism.

`compare-countries/`. This ranges between 0 and 100, where a high value indicates a high degree of acceptance for inequity and power differences.

– *Individualism*: This is also one of Hofstede's cultural dimensions. This is taken from the website: `https://www.hofstede-insights.com/product/compare-countries/`. It reflects the extent to which individuals can integrate into groups, depend on groups, etc. This ranges between 0 and 100, where a high value indicates strong individualism.

– *Unbanked rate*: This indicates an unbanked rate in each country. The data were taken from World Bank.

### 2.8 Statistical Analysis

We conducted correlation analyses both for the perceived stability and currency preference at the country level. The analyses were performed for currencies issued by Facebook and Google, which were given to participants in all countries. In this analysis, we used an average for each variable that asked about Facebook and Google.

## 3 Survey Results

The trilemma highlights the importance of understanding public preferences. Here, we look at how the perceived stability of currencies and currency choices differ depending on various companies and countries.

### 3.1 Summary Statistics and Demographics

Table S2 presents the summary statistics of our survey. As shown in the table, one can see that our sample covers a wide range of demographics. However, our sample may not be representative of the global population. For example, over 80% participants were younger than 45, and approximately half obtained a college or post-graduate education. Therefore, our sample can underrepresent the old and relatively uneducated.

This discrepancy between the survey sample and population can be attributed to the biased demographics of Internet users and people with high interests in economic or currency issues. However, we believe that our large data covering a wide range of demographics can help us gain significant insights to discover currency choices for the potential users.

### 3.2 Perceived Stability of Currencies

We now investigate whether each of the following country characteristics is correlated with the perceived stability of the three currencies. Here, we illustrate several findings from the correlation analyses.

**Table S2.** Summary statistics.

| Variable | Mean | Std. Dev. | Min. | Max. | N |
|---|---|---|---|---|---|
| *Outcome measures*: | | | | | |
| Perceived stab. of MH | 1.1027 | 1.6342 | -3 | 3 | 41,600 |
| Perceived stab. of PFP | 1.2965 | 1.5006 | -3 | 3 | 41,600 |
| Perceived stab. of LS | 0.6140 | 1.5064 | -3 | 3 | 17,500 |
| PFP more stable than MH | 0.5476 | 0.4977 | 0 | 1 | 41,600 |
| LS more stable than MH | 0.5548 | 0.4970 | 0 | 1 | 41,600 |
| LS more stable than PFP | 0.4917 | 0.4999 | 0 | 1 | 41,600 |
| *Others*: | | | | | |
| Reputation on firm ethics | 1.4820 | 1.4856 | -3 | 3 | 41,600 |
| Expected financial condition | 2.1550 | 1.1529 | -3 | 3 | 41,600 |
| Risk aversion (gain) | 0.2717 | 1.5367 | -2 | 2 | 17,550 |
| Risk aversion (loss) | -0.5151 | 1.5858 | -2 | 2 | 17,550 |
| Male | 0.5162 | 0.4997 | 0 | 1 | 17,550 |
| Age (18-24) | 0.2640 | 0.4408 | 0 | 1 | 17,550 |
| Age (25-34) | 0.3234 | 0.4678 | 0 | 1 | 17,550 |
| Age (35-44) | 0.2306 | 0.4212 | 0 | 1 | 17,550 |
| Age (45-54) | 0.1045 | 0.3059 | 0 | 1 | 17,550 |
| Age (55-64) | 0.0488 | 0.2155 | 0 | 1 | 17,550 |
| Age (65+) | 0.0287 | 0.1669 | 0 | 1 | 17,550 |
| Income | 2.8356 | 1.8669 | 1 | 7 | 12,545 |
| Education level | 0.5546 | 0.4970 | 0 | 1 | 17,550 |
| Finance-related prof. | 0.0599 | 0.2373 | 0 | 1 | 17,550 |
| Computer-related prof. | 0.0405 | 0.1970 | 0 | 1 | 17,550 |
| Knowledge of a stablecoin | 0.3921 | 0.4882 | 0 | 1 | 17,550 |

**Risk Aversion.** Fig. S2 shows that the perceived stability of currencies is significantly and negatively correlated with risk aversion at the country level. In addition, risk aversion under the gain condition is more associated with the perceived stability of currencies than the risk aversion for the loss condition.

**Reputation of Companies.** Fig. S3 shows that the perceived stability of MH and PFP is significantly and positively associated with the reputation of the issuing company at the country level. Moreover, reputation on firm ethics has a higher correlation with the perceived stability of currencies compared to the expected financial conditions.

**Corruption.** Next, we examine whether the perceived stability of a currency is associated with the level of corruption in a nation. This is especially relevant for the currency MH, which can be affected by the prevalence of unethical and illicit behaviors in the nation. Fig. S4A shows that the perceived stability of MH is significantly and negatively associated with the corruption level measured by the Corruption Perception Index (CPI). This implies that the more corrupt the country is, the more stable its people will feel MH is. This is interesting because one may argue that people who are exposed to high corruption should feel that MH is more unstable because they think it is highly likely that price drops will occur due to a moral hazard of the operating entities. Note that the currencies presented in the survey were not assumed to be operated by domestic companies. Therefore, this result may be due to a higher trust on global companies than that on domestic companies in a corrupted country. Indeed, the reputation of ethics for Facebook and Google is significantly and negatively correlated with CPI (Pearson's $\rho = -0.8103, p < 0.001$). Moreover, as shown in Fig. S4B, the perceived stability of PFP is significantly and negatively associated with CPI. This can be because the corruption in a country is highly correlated with its economic performance (Pearson's $\rho = 0.9016, p < 0.001$ between CPI and GDP per capita). Meanwhile, Fig. S4C shows that the correlation between the perceived stability of LS and CPI is weaker.

**Economic Development.** We also investigated whether the perceived stability of a currency is correlated with the level of economic development. This is especially relevant for the currency PFP, which can be affected by the economic performance of the nation. Fig. S5B shows that the perceived stability of PFP is significantly and negatively associated with the GDP per capita. This suggests that the poorer the country, the more stable its people will feel PFP. This result may be due to the higher expectations on the global company's profitability than that of domestic companies in a less developed country. This is supported by the fact that the expected financial condition of Google and Facebook is significantly and negatively correlated with GDP per capita (Pearson's $\rho = -0.7417, p < 0.001$). In addition, Fig. S5A shows that the perceived stability of MH is significantly and negatively associated with the GDP per capita. As noted earlier, this can be because a country's economic performance is highly correlated with its corruption level (Pearson's $\rho = 0.9016, p < 0.001$ between GDP per capita and CPI). Lastly, Fig. S5C shows that the correlation between the perceived stability of LS and GDP per capita is weaker.

**Freedom.** We present the relationship between the perceived stability of currencies and how much individual freedom is guaranteed in a country. Figs. S6∼S8 show that the perceived stability of currencies MH, PFP, and LS is strongly associated with all four indices of country level freedom that we considered: World Index of Moral Freedom, Press Freedom Index, Freedom in the World, and Human Freedom Index. The result implies that people from countries with low individual freedom feel that the currencies are more stable than those from countries with high individual freedom.

**Culture.** Fig. S9 presents the correlation between the perceived stability of currencies and two cultural dimensions: power distance and individualism. Recall that power distance and individualism reflect the acceptance of centralization. The figure suggests that people from a country with a higher acceptance of power inequality or with lower individualism believe that the price stability is higher for each currency. Moreover, Figs. S9E and F show a weaker correlation between the perceived stability of LS and the cultural dimensions compared to that for MH and PFP. This may be because MH and PFP feature centralization[8].

**Unbanked Rate.** We also analyzed the relationship between the unbanked rate and perceived stability of currencies, considering that one of the main purposes of stablecoins is to help the unbanked population. Thus, the higher the unbanked rate is, the more stable the citizens generally felt that the currencies are (Fig. S10).

### 3.3 Currency Choice

Similar to the analysis for the perceived stability of currencies, we investigated whether each of the following country characteristics is correlated with currency choices.

[8] We do not argue that PFP is a centralized stablecoin; in fact, the PFP type of currency is usually referred to as a *decentralized stablecoin* (applying blockchain technology) in the real world. Here, we just consider that the dependence on the operating entity is similar to the characteristic of centralization in a broad sense.

**Risk Aversion.** Fig. S11 shows that the currency choices were more strongly correlated with risk aversion under the gain condition than those under the loss condition. In addition, countries with a high risk aversion had a higher probability of choosing PFP over MH, LS over MH, and LS over PFP.

**Reputation of Companies.** Figs. S12A, C, and E show that currency choices are significantly correlated with reputation on firm ethics. Specifically, countries in which the reputation of ethics for the issuing company is high have a higher probability of choosing MH over PFP, MH over LS, and PFP over LS. Meanwhile, Figs. S12B, D, and F indicate that currency choices are not significantly correlated with the expected financial conditions of the issuing company.

**Corruption.** Fig. S13 presents the relationship between currency choices and corruption measured using the corruption perception index (CPI). Figs. S13A and B show that the choice of PFP over MH and the choice of LS over MH did not have a significant correlation with CPI. Meanwhile, Fig. S13C shows that people from corrupted countries generally answered that PFP is more stable than LS.

**Economic Development.** Fig. S14 presents the relationship between currency choices and economic development indexed by the GDP per capita. Figs. S14A and B show that the choices of PFP over MH and LS over MH were not significantly related to economic development. Meanwhile, Fig. S14C suggests that people from less-developed countries tend to think that PFP is more stable than LS.

**Freedom.** A strong correlation was also observed between currency choices and how much individual freedom is guaranteed in a country. Figs. S15, S16, and S17 show that countries with higher individual freedom had a higher probability of choosing PFP over MH, LS over MH, and LS over PFP. Further, the choice between LS and MH or between LS and PFP was more strongly associated with freedom indices than the choice between MH and PFP.

**Culture.** Fig. S18 shows that the currency choices were significantly associated with power distance and individualism. Specifically, a country with a lower acceptance of power inequality or higher individualism had a higher probability of choosing PFP over MH, LS over MH, and LS over PFP. In fact, with reference to Figs. S18A and B, we observe that the correlation was weaker for the choice of PFP over MH than that for the other choices. This may be because both MH and PFP are characterized similarly to centralization, unlike LS.[8] Note that their price stability completely depends on the operating entity, unlike LS; MH's stability is guaranteed unless moral hazard of the operating entity occurs, and PFP's stability is guaranteed unless the entity has a poor financial performance.

**Unbanked Rate.** We also analyzed the relationship between currency choices and the unbanked rate. Fig. S19 shows that there was no significant correlation, barring the choice of LS over PFP.

### 3.4 Differences in Currency Choices by the Issuing Company

In this section, we compare the currency choices considering the following six companies as the issuer: Amazon, Facebook, Google, JPMorgan Chase, Netflix, and Walmart. Fig. S20A presents a distribution of the US respondents who thought each currency is the most stable considering that the currencies are operated by each company. The figure shows that LS was commonly perceived as the most stable one in the US, regardless of the issuing companies. Note that, in the figure, we considered only responses from the US participants for the comparison because JPMorgan, Netflix, and Walmart were only included in the survey administered to participants from the US. Further, we globally compared the currency choices for Amazon, Facebook, and Google. Fig. S20B presents a distribution of the global respondents who believed each currency is the most stable given that currencies are operated by each company[9]. The figure shows that most people believed LS is the most stable for all three companies. This is similar to the case for US described above. In summary, we found that the currency choices did not vary significantly across the six companies considered.

[9] Note that 12 out of total 34 countries in our survey were considered to compare the results of Amazon, Facebook, and Google because questions regarding Amazon were asked only in 12 countries.

# 4 Figures

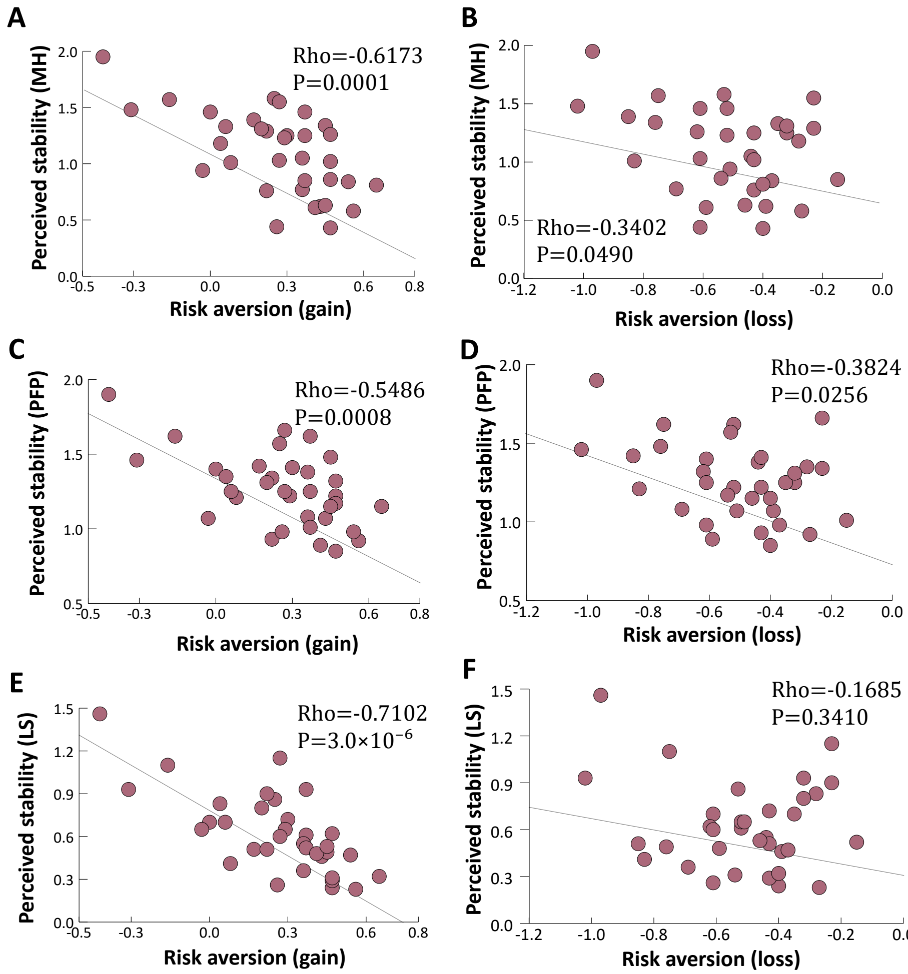


**Fig. S2. Association between the perceived stability of currencies and risk aversion.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A&B**) Association between the perceived stability of MH and risk aversion in gains and losses (n=34). (**C&D**) Association between the perceived stability of PFP and risk aversion in gains and losses (n=34). (**E&F**) Association between the perceived stability of LS and risk aversion in gains and losses (n=34).

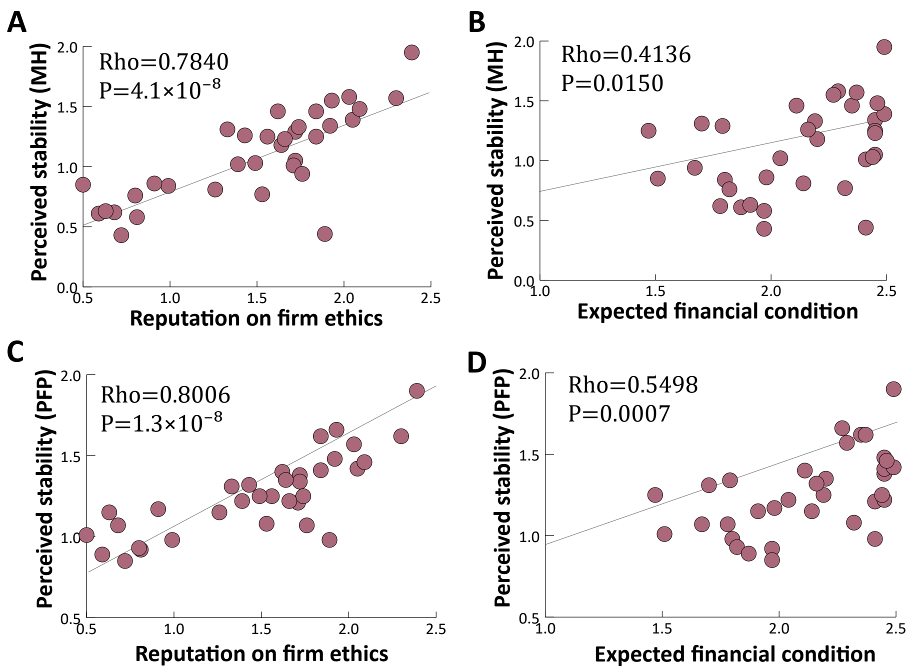


**Fig. S3. Association between the perceived stability of currencies and reputation of an operating company.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of MH and reputation on firm ethics (n=34). (**B**) Association between the perceived stability of MH and expected financial conditions (n=34). (**C**) Association between the perceived stability of PFP and reputation on firm ethics (n=34). (**D**) Association between the perceived stability of PFP and expected financial conditions (n=34).

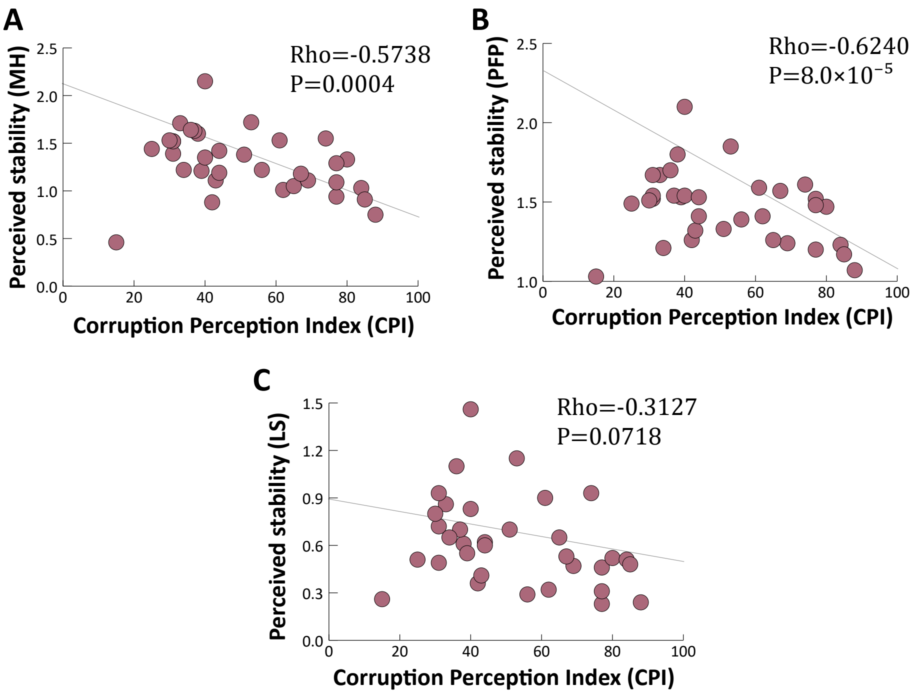


**Fig. S4. Association between the perceived stability of currencies and corruption of a country.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of MH and the corruption perception index (CPI) (n=34). (**B**) Association between the perceived stability of PFP and CPI (n=34). (**C**) Association between the perceived stability of LS and CPI (n=34). A higher CPI represents less corruption of a country.

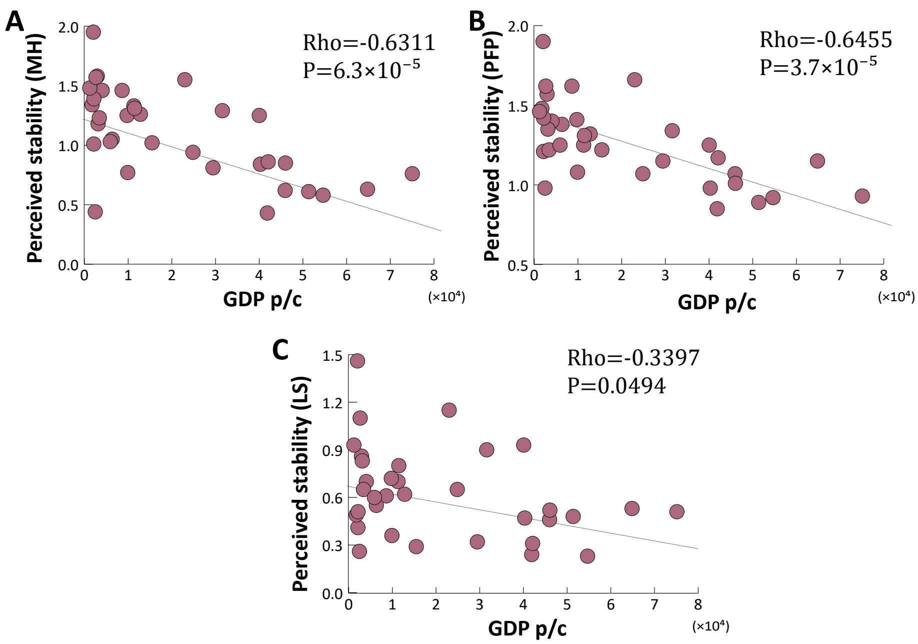


**Fig. S5. Association between the perceived stability of currencies and economic development of a country.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of MH and GDP per capita (n=34). (**B**) Association between the perceived stability of PFP and GDP per capita (n=34). (**C**) Association between the perceived stability of LS and GDP per capita (n=34).

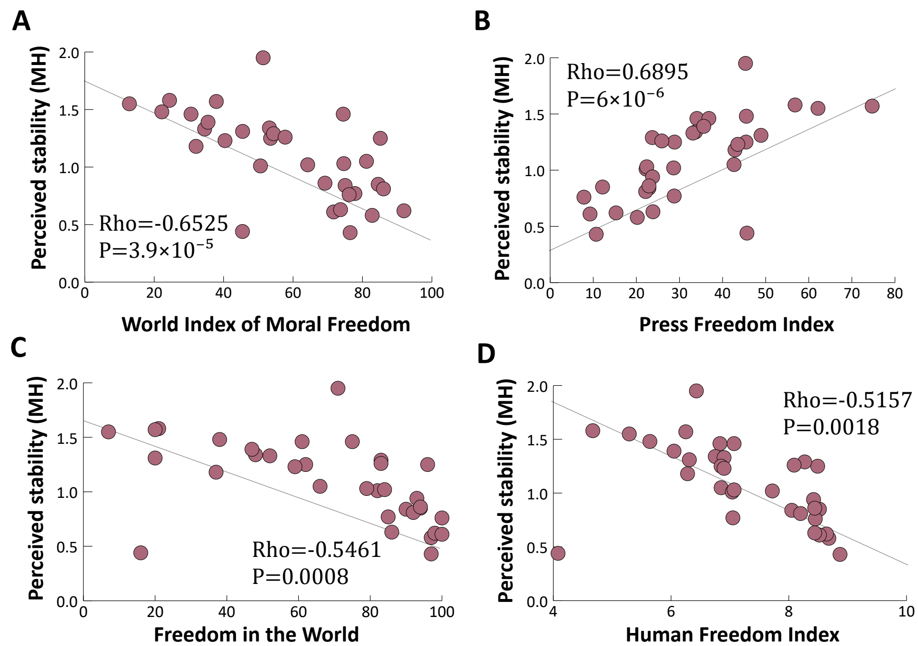


**Fig. S6. Association between the perceived stability of MH and individual freedom.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of MH and World Index of Moral Freedom (n=33). A higher value of World Index of Moral Freedom represents that the moral freedom of individuals is more guaranteed in their country. (**B**) Association between the perceived stability of MH and Press Freedom Index (n=34). A higher value of Press Freedom Index represents that the press freedom of individuals is less guaranteed in their country. (**C**) Association between the perceived stability of MH and Freedom in the World (n=34). A higher value of Freedom in the World indicates higher civil and political rights. (**D**) Association between the perceived stability of MH and Human Freedom Index (n=34). A higher value of Human Freedom Index represents that the human freedom of individuals is more guaranteed in their country.

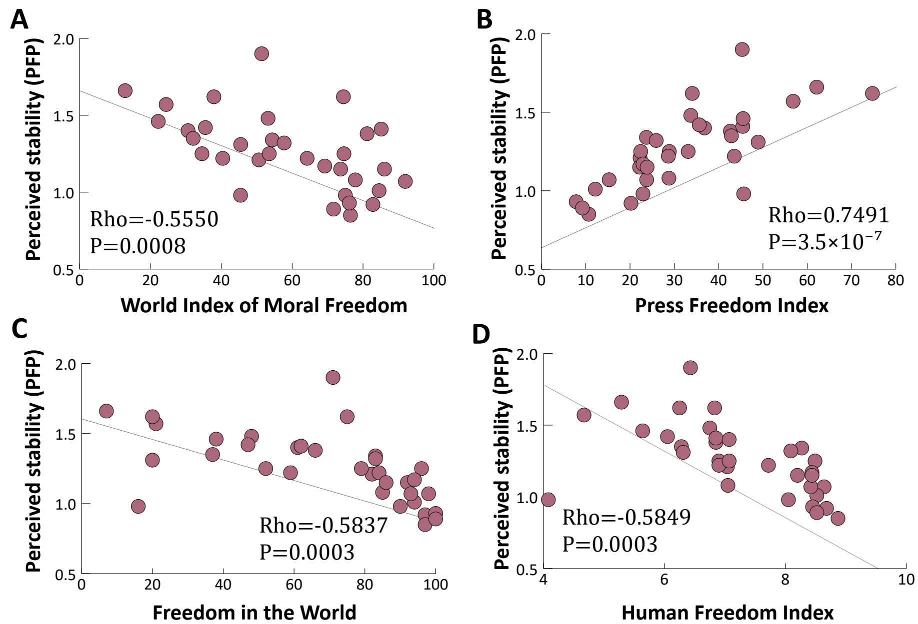


**Fig. S7. Association between the perceived stability of PFP and individual freedom.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of PFP and World Index of Moral Freedom (n=33). A higher value of World Index of Moral Freedom represents that the moral freedom of individuals is more guaranteed in their country. (**B**) Association between the perceived stability of PFP and Press Freedom Index (n=34). A higher value of Press Freedom Index represents that the press freedom of individuals is less guaranteed in their country. (**C**) Association between the perceived stability of PFP and Freedom in the World (n=34). A higher value of Freedom in the World indicates higher civil and political rights. (**D**) Association between the perceived stability of PFP and Human Freedom Index (n=34). A higher value of Human Freedom Index represents that the human freedom of individuals is more guaranteed in their country.

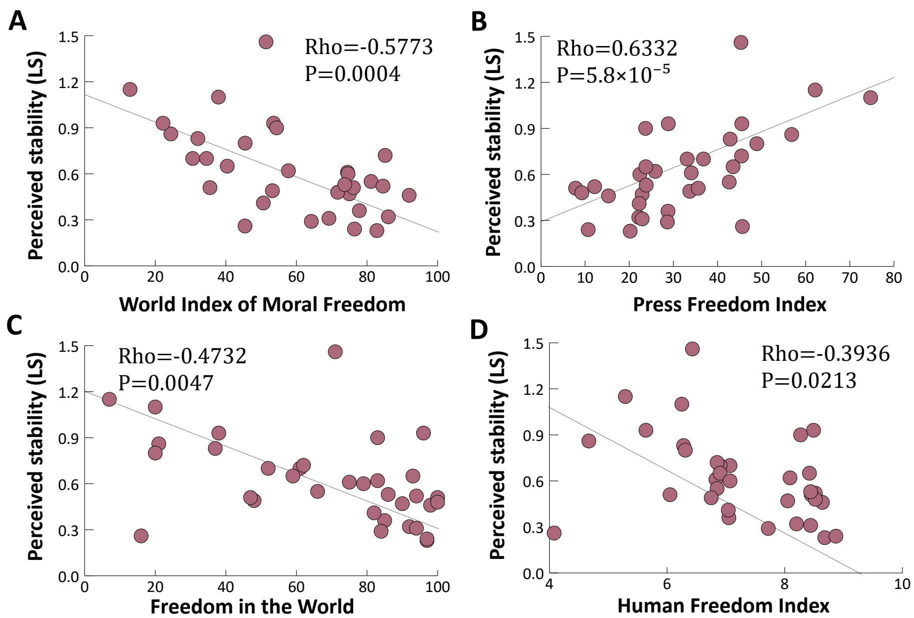


**Fig. S8. Association between the perceived stability of LS and individual freedom.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of LS and World Index of Moral Freedom (n=33). A higher value of World Index of Moral Freedom represents that the moral freedom of individuals is more guaranteed in their country. (**B**) Association between the perceived stability of LS and Press Freedom Index (n=34). A higher value of Press Freedom Index represents that the press freedom of individuals is less guaranteed in their country. (**C**) Association between the perceived stability of LS and Freedom in the World (n=34). A higher value of Freedom in the World indicates higher civil and political rights. (**D**) Association between the perceived stability of LS and Human Freedom Index (n=34). A higher value of Human Freedom Index represents that the human freedom of individuals is more guaranteed in their country.

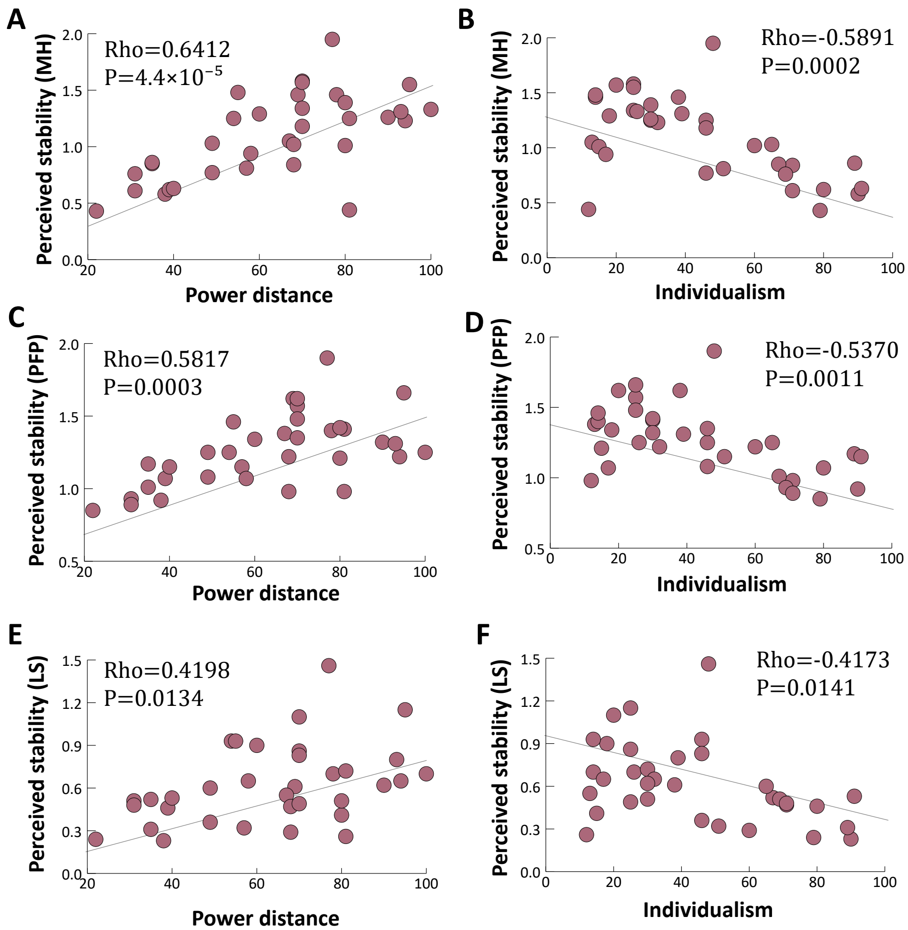


**Fig. S9. Association between the perceived stability of currencies and cultural dimensions.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of MH and power distance (n=34). A high value of power distance indicates a high degree of acceptance for inequity and power differences. (**B**) Association between the perceived stability of MH and individualism (n=34). A high value of $x$-axis indicates strong individualism. (**C**) Association between the perceived stability of PFP and power distance (n=34). (**D**) Association between the perceived stability of PFP and individualism (n=34). (**E**) Association between the perceived stability of LS and power distance (n=34). (**F**) Association between the perceived stability of LS and individualism (n=34).

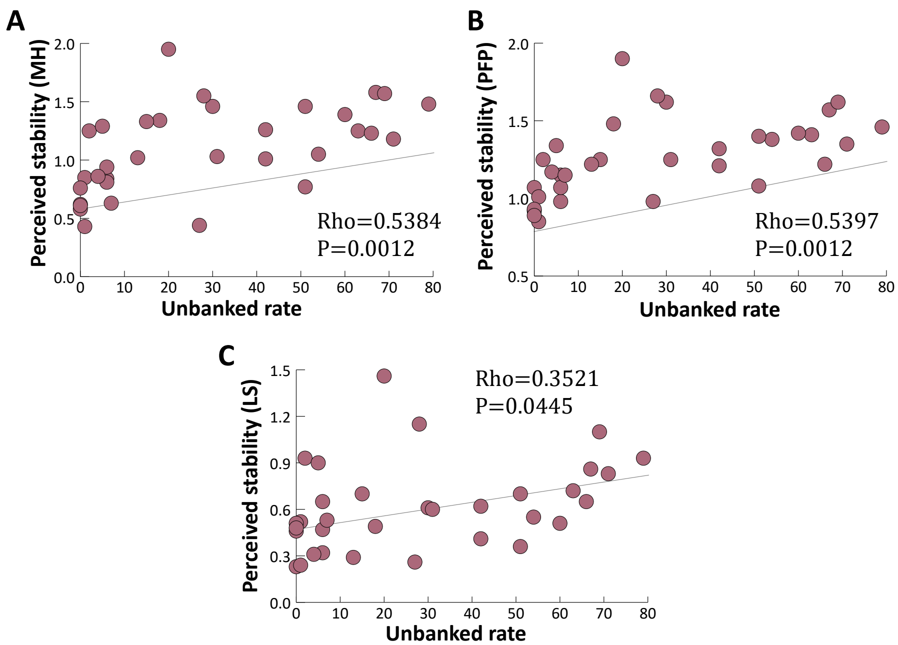


**Fig. S10. Association between the perceived stability of currencies and unbanked rate.** Each panel shows Pearson's Rho and p-value for the linear correlation. (**A**) Association between the perceived stability of MH and unbanked rate (n=34). (**B**) Association between the perceived stability of PFP and unbanked rate (n=34). (**C**) Association between the perceived stability of LS and unbanked rate (n=34).

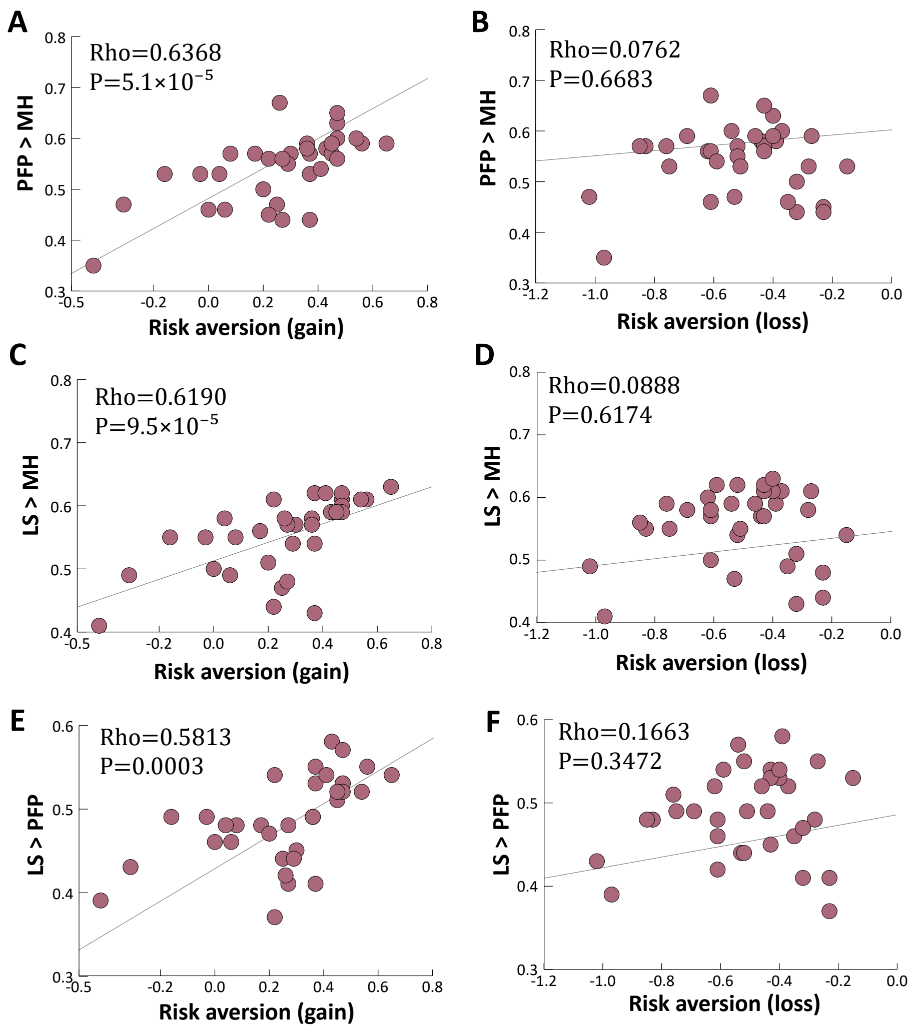


**Fig. S11. Association between currency choices and risk aversion.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A&B**) Association between a ratio of respondents choosing PFP over MH and risk aversion in gains and losses (n=34). (**C& D**) Association between a ratio of respondents choosing LS over MH and risk aversion in gains and losses (n=34). (**E&F**) Association between a ratio of respondents choosing LS over PFP and risk aversion in gains and losses (n=34).

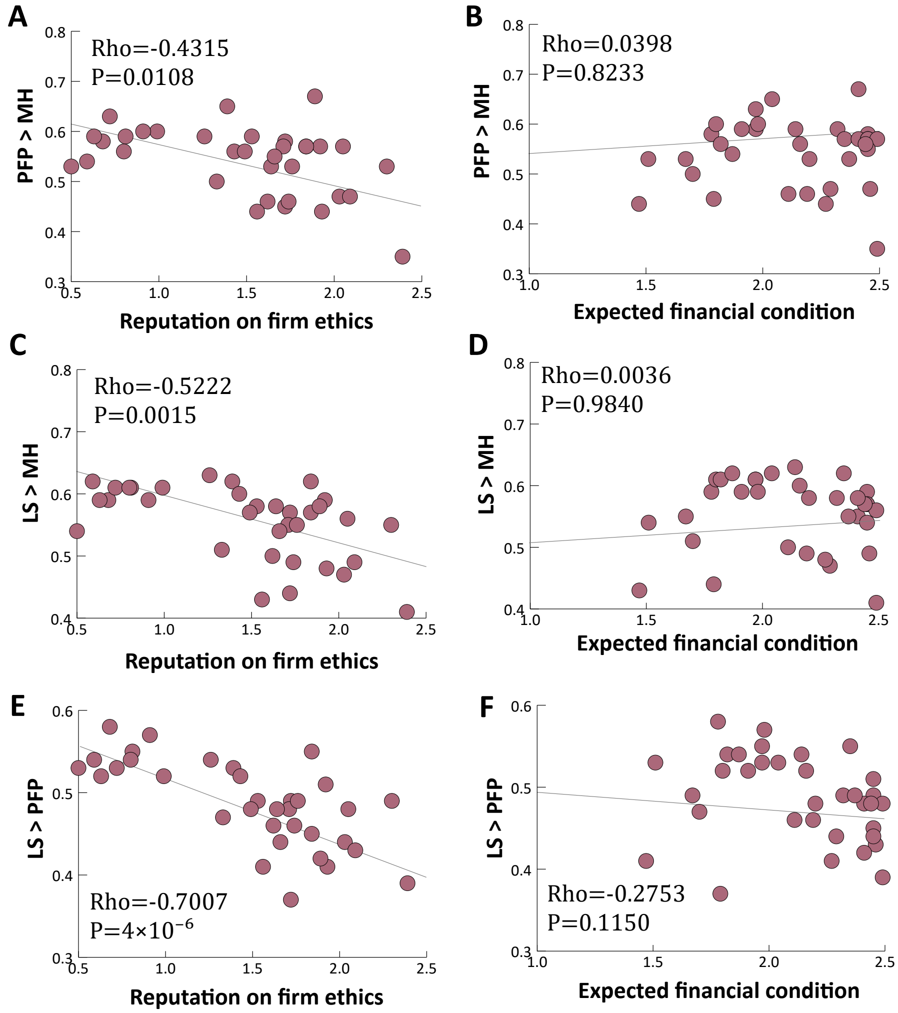


**Fig. S12. Association between currency choices and reputation on the operating company.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing PFP over MH and reputation on firm ethics (n=34). (**B**) Association between a ratio of respondents choosing PFP over MH and expected financial conditions (n=34). (**C**) Association between a ratio of respondents choosing LS over MH and reputation on firm ethics (n=34). (**D**) Association between a ratio of respondents choosing LS over MH and expected financial conditions (n=34). (**E**) Association between a ratio of respondents choosing LS over PFP and reputation on firm ethics (n=34). (**F**) Association between a ratio of respondents choosing LS over PFP and expected financial conditions (n=34).

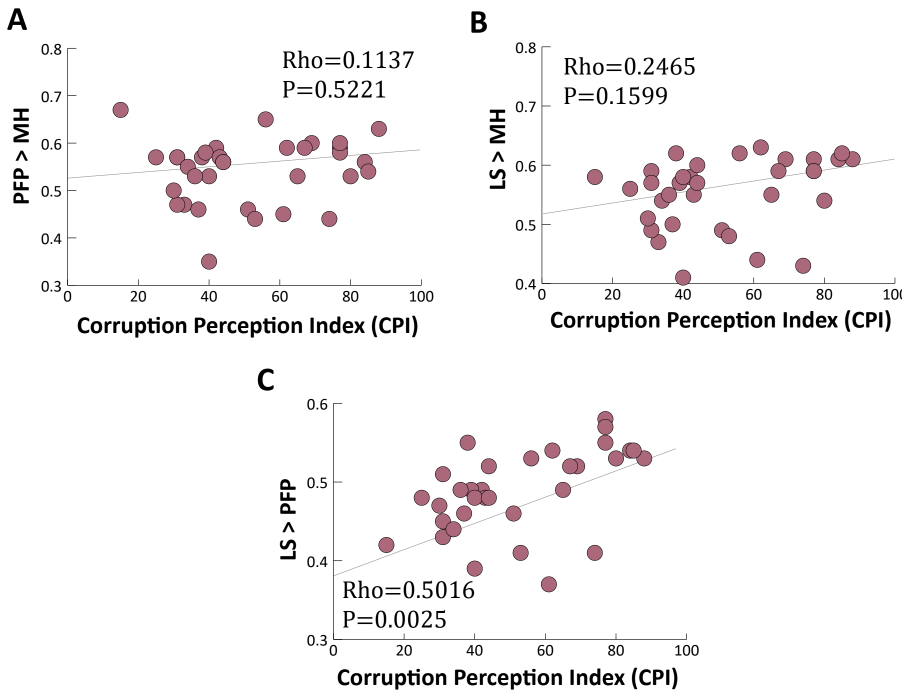


**Fig. S13. Association between currency choices and corruption of a country.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing PFP over MH and the corruption perception index (CPI) (n=34). (**B**) Association between a ratio of respondents choosing LS over MH and CPI (n=34). (**C**) Association between a ratio of respondents choosing LS over PFP and CPI (n=34). A higher CPI represents less corruption of a country.

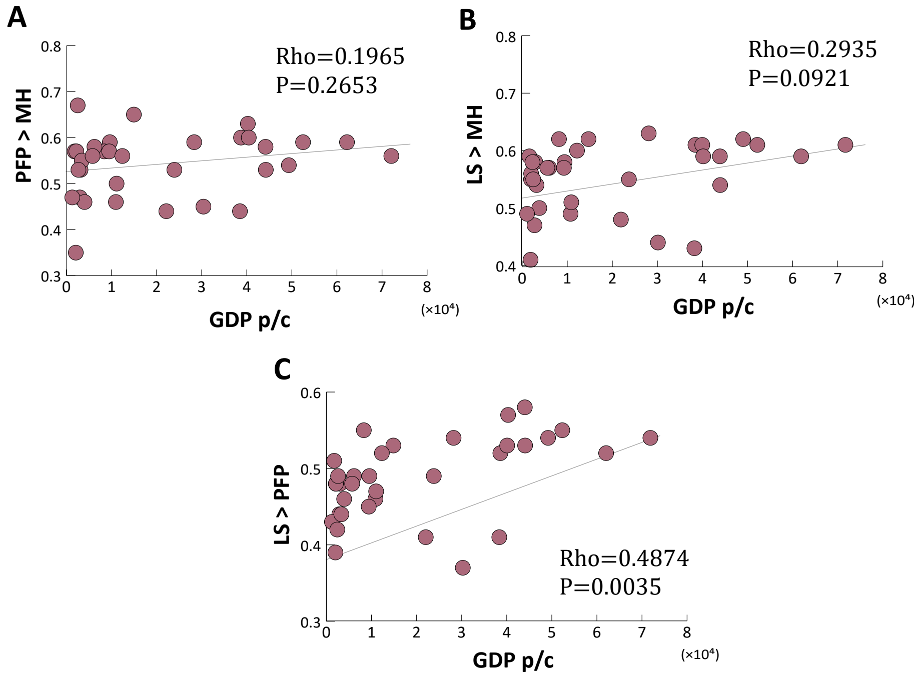


**Fig. S14. Association between currency choices and economic development of a country.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing PFP over MH and GDP per capita (n=34). (**B**) Association between a ratio of respondents choosing LS over MH and GDP per capita (n=34). (**C**) Association between a ratio of respondents choosing LS over PFP and GDP per capita (n=34).

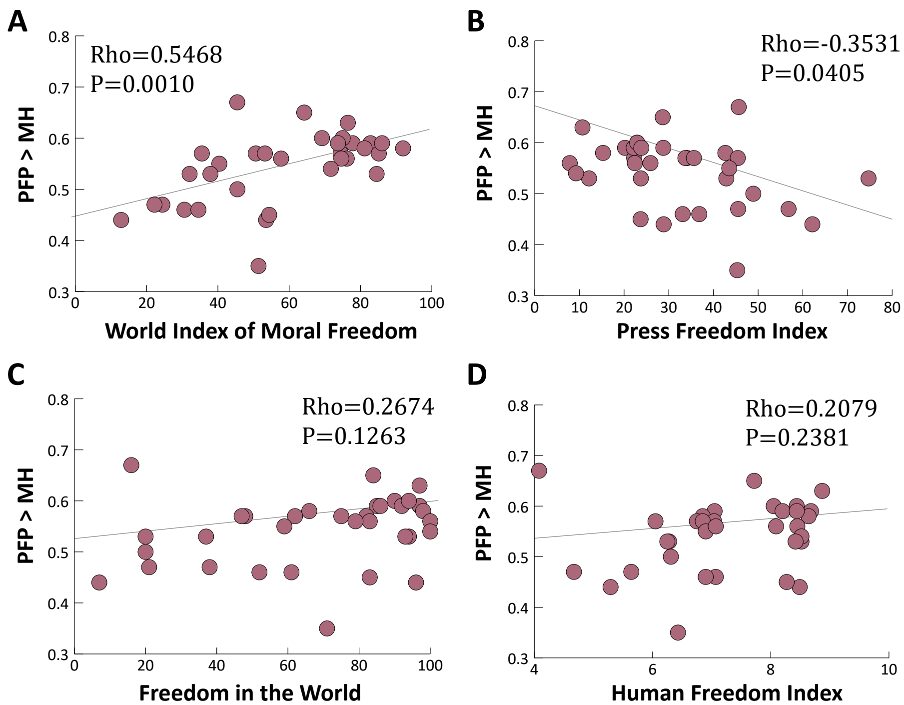


**Fig. S15. Association between the choice of PFP over MH and individual freedom.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing PFP over MH and World Index of Moral Freedom (n=33). A higher value of World Index of Moral Freedom represents that the moral freedom of individuals is more guaranteed in their country. (**B**) Association between a ratio of respondents choosing PFP over MH and Press Freedom Index (n=34). A higher value of Press Freedom Index represents that the press freedom of individuals is less guaranteed in their country. (**C**) Association between a ratio of respondents choosing PFP over MH and Freedom in the World (n=34). A higher value of Freedom in the World indicates higher civil and political rights. (**D**) Association between a ratio of respondents choosing PFP over MH and Human Freedom Index (n=34). A higher value of Human Freedom Index represents that the human freedom of individuals is more guaranteed in their country.

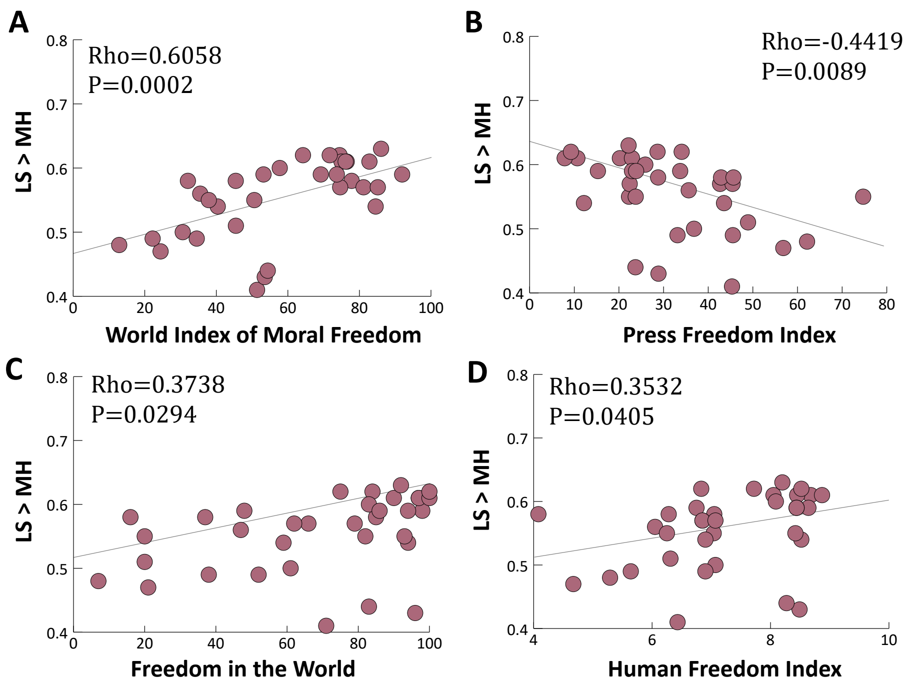


**Fig. S16. Association between the choice of LS over MH and individual freedom.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing LS over MH and World Index of Moral Freedom (n=33). A higher value of World Index of Moral Freedom represents that the moral freedom of individuals is more guaranteed in their country. (**B**) Association between a ratio of respondents choosing LS over MH and Press Freedom Index (n=34). A higher value of Press Freedom Index represents that the press freedom of individuals is less guaranteed in their country. (**C**) Association between a ratio of respondents choosing LS over MH and Freedom in the World (n=34). A higher value of Freedom in the World indicates higher civil and political rights. (**D**) Association between a ratio of respondents choosing LS over MH and Human Freedom Index (n=34). A higher value of Human Freedom Index represents that the human freedom of individuals is more guaranteed in their country.

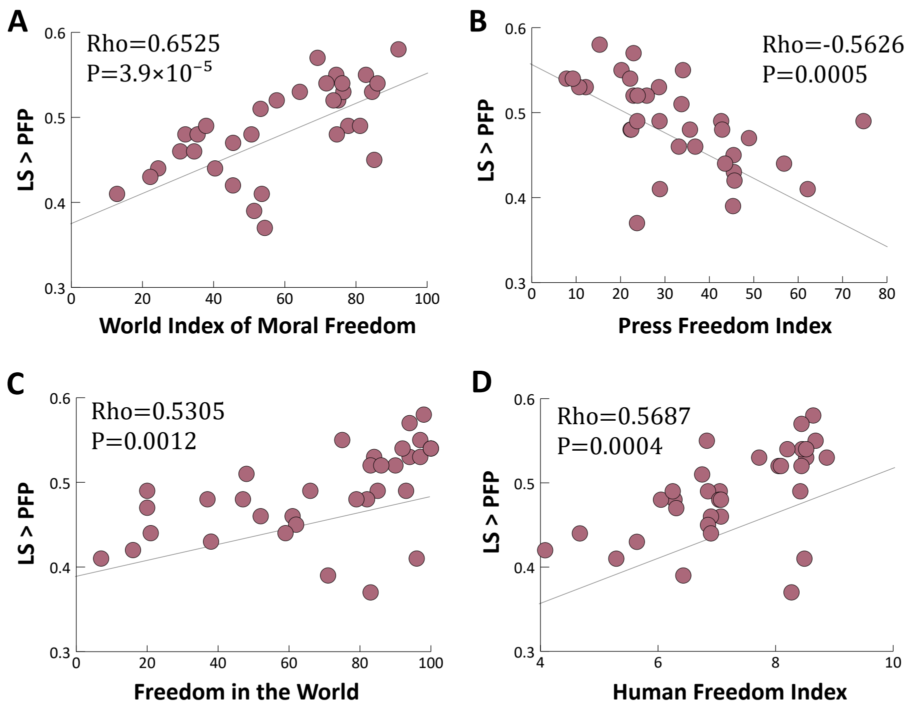


**Fig. S17. Association between the choice of LS over PFP and individual freedom.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing LS over PFP and World Index of Moral Freedom (n=33). A higher value of World Index of Moral Freedom represents that the moral freedom of individuals is more guaranteed in their country. (**B**) Association between a ratio of respondents choosing LS over PFP and Press Freedom Index (n=34). A higher value of Press Freedom Index represents that the press freedom of individuals is less guaranteed in their country. (**C**) Association between a ratio of respondents choosing LS over PFP and Freedom in the World (n=34). A higher value of Freedom in the World indicates higher civil and political rights. (**D**) Association between a ratio of respondents choosing LS over PFP and Human Freedom Index (n=34). A higher value of Human Freedom Index represents that the human freedom of individuals is more guaranteed in their country.

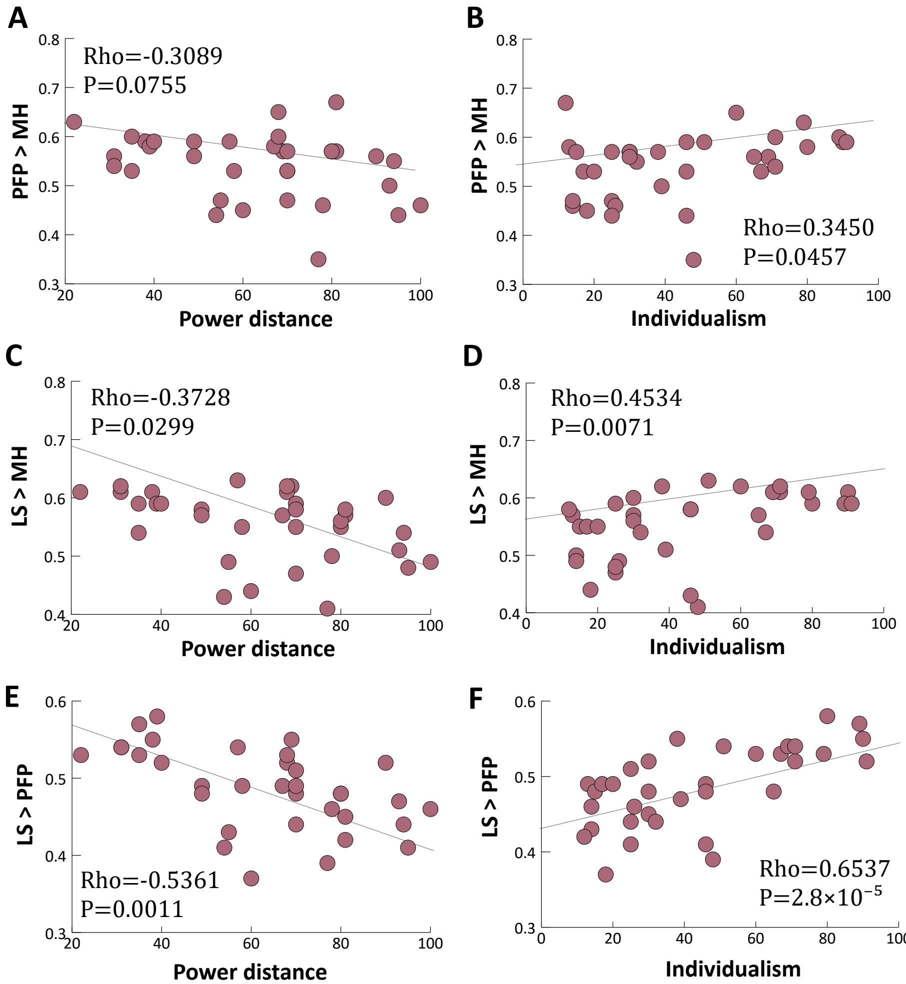


**Fig. S18. Association between currency choices and cultural dimensions.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing PFP over MH and power distance (n=34). A high value of power distance indicates a high degree of acceptance for inequity and power differences. (**B**) Association between a ratio of respondents choosing PFP over MH and individualism (n=34). A high value of $x$-axis indicates strong individualism. (**C**) Association between a ratio of respondents choosing LS over MH and power distance (n=34). (**D**) Association between a ratio of respondents choosing LS over MH and individualism (n=34). (**E**) Association between a ratio of respondents choosing LS over PFP and power distance (n=34). (**F**) Association between a ratio of respondents choosing LS over PFP and individualism (n=34).

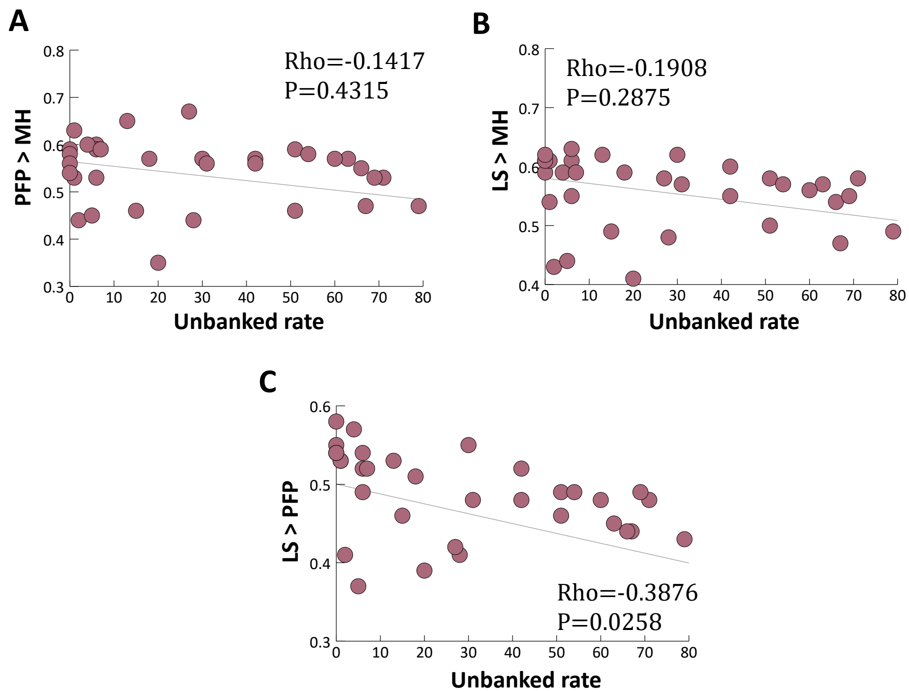


**Fig. S19. Association between currency choices and unbanked rate.** Each panel shows Pearson's Rho and p-value for the linear correlation. Notation of x>y indicates a proportion of respondents choosing x over y in a country. (**A**) Association between a ratio of respondents choosing PFP over MH and unbanked rate (n=34). (**B**) Association between a ratio of respondents choosing LS over MH and unbanked rate (n=34). (**C**) Association between a ratio of respondents choosing LS over PFP and unbanked rate (n=34).

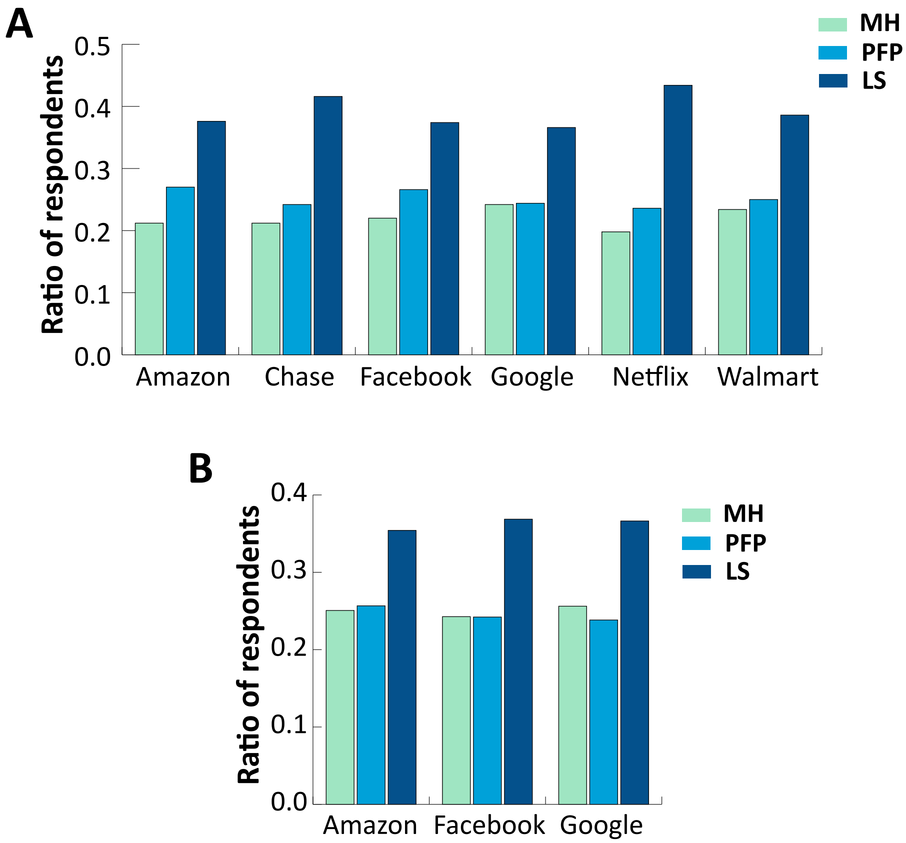


**Fig. S20. Distribution of the respondents who thought each currency is the most stable given that the currencies are operated by each company.** (**A**) Distribution of the U.S. respondents. For each company, we collected 500 answers. (**B**) Distribution of the respondents from 12 countries. For each company, we collected 6,000 answers.

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