The Market for Crypto Zombies: Under-Collateralization in DeFi Lending

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Abstract

This study investigates the systemic risks of over-collateralization using a unique data set of a decentralized lending platform Venus, revealing a significant proportion of borrowers exceeding the required loan-to-value (LTV) range. Employing difference-in-differences, we examine the detrimental effect of an exogenous XVS price crash on borrowers. The results show that the borrowers with a high LTV suffered a greater loss. On the supply side, we introduce the concept of zombie debt, loans near liquidation yet unresolved, revealing distinct short- and long-term risks. The price shock's impact on zombie debt varies: short-term instances decrease in number while aggregate value rises, hinting at liquidity reduction. Conversely, medium- and long-term cases experience reduced numbers and magnitudes, mitigating supplier losses. Given the higher LTV observed among short-term zombie loans, it is deduced that the price volatility ameliorates the prevalence of zombies characterized by lower LTVs. This research provides a fresh analysis of the credit risk associated with varying degrees of leverage in the context of decentralized lending.

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1 Introduction

Collateral acts as a means to reduce the credit risk exposure of lenders. Unlike conventional financial markets, which conduct a credit check on the borrower[1], borrowers in decentralized markets [2] are required to borrow in an over-collateralized position to reduce credit risk. The paper documents the systematic risk of over-collateralization in decentralized lending.

The paper analyzes one of the largest decentralized lending markets, Venus. We collect transaction data for the top 16 tokens[3] in this market and analyze more than 130 million transactions from 186,897 accounts from September 2020 to October 2021. There are 12 million borrowing transactions among 36,189 borrowers.

We examine the risk from the loan demand and supply side respectively. First, for the borrowers, we find that not all of them satisfy the over-collateralization requirement. More than half of our samples have a loan-to-value ratio (LTV) greater than the liquidation ratio, 0.6. Since a high LTV leads to great credit risk in conventional lending, the paper plans to test whether this is the same in decentralized lending. We start by examining the effect of an exogenous and significant change in the price of XVS on the debt situation using diff-in-diff. We then focus on categorizing borrowers based on how much they've borrowed compared to their own assets. From the empirical results, we find that the XVS price change indeed affects borrowers' wealth in the lending system. But there's more to it than just negative effects; we notice that the higher the LTV, the stronger the negative impact.

On the supply side, we first define zombie debt, which is a loan that has reached the liquidation

[1] This is known as the "Know-Your-Customer" (KYC) procedure.

[2] Driven by the development of blockchain, the decentralized finance (DeFi) market is thriving. One major application of DeFi is decentralized lending. Users can borrow any of the supported cryptocurrencies, stablecoins, or digital assets from a DeFi market. The collaterals, which are cryptocurrencies, will be locked on the protocol.

[3] Including 15 vTokens and XVS. XVS is the Venus governor token. The vToken is the platform token used to deposit, exchange, and set as collateral in Venus. All cryptocurrencies (e.g. Bitcoin) are required to be exchanged into vTokens first (i.e., vBTC) based on an exchange rate. Then users could make transactions in Venus. Once they want to withdraw their assets from Venus, they could exchange their Vtokens for the corresponding token. XVS is the only token that could be directly used in Venus.

threshold but remains unresolved. We categorize it into short-term instances lasting at least three days due to user engagement gaps and long-term situations arising from a minimal price disparity between collateral and borrowed tokens, potentially resulting in losses for the lending platform. The short- and long-term zombie debts have different risks. While a short-term one results in temporary liquidity reduction within Venus, a long-term one creates the risk of eventually necessitating the platform and depositors to absorb the loss from the value disparity between the loan and the collateral.

We find mixed effects of the price shock on zombie debt of varied durations. The number and value of the medium- and long-term zombie debt in the market decreased after the shock, mitigating the permanent loss of the suppliers. Conversely, short-term zombie debts also exhibited a reduction in numbers; however, the aggregate value of these debts was amplified by the price shock, inferring an increase in large value short-term zombies. This elevation in value points towards a potential reduction in market liquidity. Given the higher LTV observed among short-term zombie loans, it is deduced that the price volatility effectively ameliorates the prevalence of zombie loans characterized by comparatively lower LTVs.

Meanwhile, the DID analysis shows that the observed price shock induces a notable escalation in the prevalence of zombie debts within accounts using XVS as collaterals. This effect is discernible across both short-term and long-term categories of zombie debt. This suggests a potential amplification of the platform's losses and adverse implications for lenders in scenarios where the collateral backing the zombie debt undergoes subsequent depreciation, exacerbating the existing financial strain.

The fast development of decentralized lending presents a distinctive setting for examining the credit risk associated with varying degrees of leverage. The distinctive attribute of blockchain settlement is that it facilitates the availability of many exogenous shocks, such as flash loans, effectively sidestepping credit risks and thereby providing unconstrained research materials. Besides, the inherent transparency of the blockchain affords the capacity to monitor transaction rules and data at a granular level and accurately gauge their influence.

The paper contributes to the burgeoning literature on decentralized market risks, building upon existing scholarship. Specifically, Li and Mayer, 2022 sheds light on vulnerabilities in stablecoin systems, Aramonte et al., 2021 examines high leverage practices in decentralized derivatives exchanges, and Qin et al., 2021 emphasizes robust risk management in DeFi credit markets. Additionally, Cong et al., 2022 investigates the impact of gas fees and transaction costs on transaction failures. Our work closely aligns with Parlour et al., 2022, delving into the negative feedback loop caused by significant liquidation waves in decentralized lending, while also introducing a novel dimension by identifying and quantifying two distinct forms of systematic risk.

Our article extends the investigation into the correlation between credit risk and the employment of collateral in loan operations (e.g., Orgler, 1970, Hester, 1979). Notably, Berger and Udell, 1990 observes the use of collateral in lending to high-risk borrowers as a security measure. Additionally, Jim, 2004 demonstrates an increased likelihood of default for collateralized loans within conventional financial institutions. Jiménez and Saurina, 2004 and Jimenez et al., 2006 studies the determinants of the collateral. Our paper introduces fresh empirical evidence pertaining to the potential risks and benefits of secured loans in DeFi.

Our research enhances the current understanding of the phenomenon of zombie debt. Prior scholarship has extensively examined various forms of financial zombies that can diminish market liquidity, including zombie banks (e.g., Bruche and Llobet, 2014, Gabor and Ban, 2016), zombie firms (e.g., Rashid et al., 2022), and zombie corporate loans (e.g. Caballero et al., 2008, Hu and Varas, 2021, Jordà et al., 2022). This study contributes to this literature by introducing a distinct perspective: defining and analyzing zombie debt in the decentralized market context with granularity in terms of duration. The paper investigates the diverse impacts of a price crash on these categories of zombie debt, thereby extending the analytical scope of this research strand.

1.1 Background

The study's primary focus lies in one of the largest decentralized lending platforms, Venus, situated on the Binance Smart Chain (BSC)[4] Venus offers a dynamic array of functionalities, enabling users to supply collateral, accrue interest on said collateral, leverage their collateral for borrowing, and instantly generate stablecoins. The platform's core mission involves bridging the gap between conventional financial lending systems and decentralized protocols anchored on blockchains.

A distinctive feature of Venus lies in its ability to facilitate the minting of vTokens, derivative tokens that represent various cryptocurrencies. By pledging their cryptocurrency holdings, users can create vTokens (e.g., vBTC) that mirror these underlying assets (e.g., BTC). These vTokens, in turn, serve as collateral within the platform, forming the bedrock for borrowing activities. This innovative approach not only offers users the advantage of leveraging their assets for loans but also paves the way for the instant issuance of stablecoins, thus enhancing liquidity in the ecosystem. Users can set their preferred borrow-to-collateral value ratio, spanning the range from 0 to 0.6. This level of customization ensures that users can tailor their borrowing activities to align with their risk appetite, financial goals, and prevailing market conditions.

Central to Venus's ethos is the governance token, XVS, which underpins its democratic decision-making process and community-driven development. This token, distributed via a fair launch, empowers users to influence platform policies, fostering a sense of ownership and participation. The platform's borrowing and supplying rates are contingent on the dynamic equilibrium between

[4]BSC is a blockchain platform developed by Binance, one of the largest global cryptocurrency exchanges. Operating on a structure akin to Ethereum, BSC boasts a virtual machine facilitating smart contract execution. Notably, the key distinction between BSC and Ethereum is BSC's utilization of Proof of Stake (PoS) as opposed to Proof of Work (PoW), permitting rapid three-second block confirmations compared to Ethereum's potentially protracted 14 seconds.

demand and supply, as expounded in greater detail in Appendix A.

1.2 Liquidation and Zombie Debt

We now introduce the liquidation process. Liquidation is triggered by insufficient collateral value, manifesting when the ratio of borrowed token value to collateral value surpasses the maximum threshold mandated by the platform and the borrower fails to repay or augment collateral promptly. This maximum threshold, referred to as the liquidation threshold, is set at 0.6 in Venus platform. The responsibility for liquidating the loan falls upon either the borrower or another participant in the market. Two primary triggers for liquidation are the depreciation of collateral token prices and the appreciation of borrowed token prices.

We define zombie debt as follows: when a loan attains the liquidation threshold but no party initiates the liquidation process within a certain period of time, the loan transforms into zombie debt. This category of debt is subdivided into short-term and long-term classifications. Specifically, short-term zombie debt encompasses instances where the debt remains in a zombie state for a span of three days or more. Delays in liquidation might arise due to a lack of user engagement and activity on the platform. While short-term zombie debt results in a temporary liquidity reduction within Venus, long-term zombie debt materializes when the price disparity between collateral and borrowed tokens (collateral value minus borrowed value) dwindles to a minimal level and is projected to persist for an extended duration. In such cases, rational investors abstain from initiating liquidation efforts. Consequently, the debt assumes a long-term zombie state, eventually necessitating the platform and depositors to absorb the associated losses.

1.3 Price Shock

A significant price upheaval occurred on May 18th, 2021, within the Venus Protocol, resulting in a substantial liquidation of approximately $200 million. This event was precipitated by the manipulation of the governance token (XVS), which led to the accumulation of bad debt totaling $100 million.

During the aforementioned day, the value of XVS surged from $80 to $145 within a span of three hours. This rapid price increase encouraged the borrowing of significant loan amounts, leveraging XVS as collateral. Consequently, individuals opted to sell their XVS holdings to capitalize on the prevailing profits. However, within the subsequent four hours, the XVS price experienced a pronounced decline, ultimately regressing to its initial value of $80. This downturn triggered a series of liquidations shown in Figure 1, which ultimately resulted in the accumulation of the substantial $100 million bad debt that continues to burden the Venus Protocol. The XVS price change is illustrated in Figure 5.

On May 19th, Joselito Lizarondo, the founder of Venus, issued a comprehensive report detailing the incident. Lizarondo assured the community that all funds remained secure and that the protocol had not fallen victim to any attacks. He attributed the sudden price surge to the influence of significant market orders and the anticipation surrounding the imminent launch of the new VRT (Venus Reward Token). This token was set to introduce a fresh dynamic into the ecosystem. Around this time, the Venus Protocol executed a substantial token burn, potentially heralding shifts in market dynamics and exerting an influence on the valuation of XVS tokens.

2 Leverage Risk

DeFi lending is marked by a distinctive characteristic—borrowers are required to over-collateralize their loan positions. This over-collateralization is codified through the collateral ratio, a fundamental metric that delineates the maximum borrowing capacity for a specific cryptocurrency. This ratio, always less than 1, is defined by the formula:

$$Collateral\ Ratio\ (CR) = \frac{Total\ Borrowing\ Value}{Total\ Collateral\ Value}$$

The liquidation threshold is a pivotal concept in this context, representing the percentage at which a position is deemed undercollateralized and thus eligible for liquidation. For instance, a liquidation threshold of 70% implies that if the value of the collateral drops below 70% of its initial value, the position is considered undercollateralized and is susceptible to liquidation.

However, the practice of over-collateralization does not provide an absolute safeguard against credit risk. Users often employ the cryptocurrency they borrow as additional collateral, thereby unlocking the potential to borrow more tokens. Consider the example of ETH, where a user deposits $100 BTC as collateral, enabling them to borrow up to $60 ETH (with a collateral ratio of 60%). Subsequently, the user may deposit this $60 ETH to secure an additional $36 in BNB, and so forth. This process can lead to a cumulative borrowing value far exceeding the initial limitation imposed by the collateral ratio, creating a complex web of interconnected borrowing and lending activities.

To quantify this risk, we introduce the collateral leverage multiplier (M), a metric that encapsulates the borrowing ratio within the collateral. A higher borrowing proportion translates to a larger multiplier. The formula for M is as follows:

$$Collateral\ Leverage\ Multiplier\ (M) = \frac{Borrowing\ Value}{(Total\ -\ Borrowing\ Value)\ in\ Collateral}$$

In our illustrative example, M calculates to approximately $\frac{250}{100} = 2.5$, signifying that DeFi lending is not without its inherent risks. Users can potentially employ substantial leverage when borrowing, amplifying their exposure to market fluctuations.

Furthermore, during liquidation events, there exists a risk that the user's collateral may be sold at a price below the prevailing market rate, especially in periods of heightened volatility or liquidity constraints. Users with over-leveraged positions are particularly vulnerable to liquidation, which can result in value erosion for the user.

In summary, while over-collateralization serves as a risk mitigation strategy in DeFi lending, it doesn't eliminate risk entirely. Borrowers can exploit leverage, and liquidation events carry their own set of potential pitfalls, particularly for those with over-leveraged positions. Understanding and quantifying these risks are essential aspects of navigating the DeFi lending landscape effectively.

3 Data and Stylized Facts

3.1 Descriptive Statistics of All Accounts

The paper uses the API of Binance Smart Chain (BSC) to query the transactions and all logs of each transaction in each block in Venus. Then we parse the logs into structured data and keep the targeted logs based on token addresses. We study the top 15 vTokens in Venus based on their market values[5]. The tokens are sorted by size. The total value of the tokens we covered is more than 90% of their market value. We take the assets and loans in the top 15 vTokens as the account's total value and borrowed value in Venus. Initially, we collected 13,007,718 pieces of transaction data from 186,897 accounts. We do the following screen processes to clean the raw data: firstly, delete accounts that have never owned or borrowed any tokens; secondly, eliminate accounts with

[5]The selected tokens are vBTC, vETH, vUSDT, vBNB, vBUSD, vXVS, vUSDC, vSXP, vDAI, vDOT, vLINK, vLTC, vBCH, vXRP, XVS, and vFIL.

less than three transaction records; and thirdly, drop accounts that have abnormal leverage ratios, including 0, inf, and NaN. Finally, our data covers 36,189 unique accounts that contain 1,206,687 pieces of transactions from its start date, September 10, 2020, to October 31, 2021.

Panel A of Table 1 reports the market values (in USD) of transactions for each of the 15 largest vTokens, while Panel B shows the borrowed values of each vToken. vBTC has the greatest average total value and borrowed value among all tokens. The other top tokens are vETH, vBNB, vXVS, and the stablecoins. Table 2 shows the number of borrowers and the average borrowed value of each vToken. Stablecoins have the most borrowers, while vBTC has the largest borrowing value. The median borrowed value of the 1,206,687 transactions is $590. The median LTV is 3.

3.2 Bad Debt and Zombie Debt

In spite of the stipulated liquidation requirement falling below the LTV threshold of 0.6, a substantial number of accounts persist with LTV ratios surpassing 0.6, and in certain cases, significantly exceeding this benchmark. An additional cohort of 31,430 borrowers exhibit LTV ratios surpassing the 0.6 threshold at some point in time. This distribution of LTV ratios is visually represented in Figure 2.

Following the Venus protocol, these loans are labeled as bad debts. Most of these non-performing loans could be quickly sold off, and the borrowers linked to these loans have the choice to add more collateral to avoid selling. These approaches help decrease the risks from these non-performing loans. However, a more complex issue arises with a subgroup of non-performing loans informally called zombie loans. These loans are more concerning due to their prolonged difficulty in finding buyers among investors.

The figure presented in Figure 3 illustrates the combined value of zombie debts for different durations: 3 days, 10 days, 30 days, and 60 days. It is noticeable that, barring the incident of the price shock, a consistent pattern is discernible over time. However, during the XVS price crash, the cumulative value of 60-day zombie debts witnessed a striking oscillation, whereas the remaining durations exhibited a relatively modest reduction. Meanwhile, Figure 4 provides insight into the quantitative aspect, displaying a significant reduction in the count of zombie debts following the occurrence of the shock. The trend of different types of zombie debt varies in the same direction across time.

3.3 Price Changes by vToken

In Section 6.3, the graphical representations of token prices throughout our research period are depicted. In addition to the pronounced decline in XVS prices, it becomes conspicuous that a multitude of tokens, including but not limited to BTC, ETH, etc., underwent substantial price plunges on May 18. Such a synchronized movement in token prices potentially indicates a high degree of intercorrelation. Notably, an exogenous market shock of significant magnitude could exert pervasive effects across the majority of tokens.

The XVS price shock triggered different levels of liquidation for each token. This procedure is detailed in Appendix B. A remarkable surge in repayment amounts is observable for liquidated vBTC, vETH, vUSDT, vBUSD, and vUSDC at the price shock event. In contrast, the repayment amounts for other tokens remain relatively stable. This pattern leads us to infer that the massive liquidation of vBTC, vETH, and stablecoin loans collateralized with devalued assets such as XVS was a prevalent response to the market shock. The price decrease was less significant in the BTC and ETH markets compared to the XVS market. It's important to note that the stability of stablecoin values remained mostly unchanged. This highlights a clear difference in how BTC, ETH, and XVS react to price changes. The gradual increase in the price gap between borrowed tokens and collateral has increased the risk of liquidation. This change in price difference naturally makes the risk landscape more risky, making the ecosystem more prone to forced liquidation.

3.4 Supply, Demand, and Interest Rate

The appendix Section C.1 offers a visual representation of the supply dynamics for each token, while Section C.2 presents a comparable overview of demand considerations. The occurrence of a substantial surge in the supply quantities of vXVS coinciding with the price shock is particularly conspicuous. Similarly, vLTC, vSXP, vBCH, and vFIL all experienced notable supply increases during this period.

Turning our attention to interest rate dynamics, we meticulously computed the annual borrowing interest rates for each token, an exposition of which is provided in Appendix Appendix A. Notably, the interest rates governing most vTokens demonstrated a remarkable degree of volatility throughout the course of our research period. Weekly fluctuations, often attaining magnitudes of up to 10%, underscore the pronounced instability characterizing these rates.

Equally intriguing is the observation within the realm of stablecoins. Specifically, the interest rates associated with vUSDT, vUSDC, and vBUSD underwent a substantial reduction following the XVS price shock. This phenomenon suggests a discernible inclination among investors to channel their holdings into stablecoins during episodes typified by heightened market volatility. Conversely, the interest rate pertaining to vXVS exhibited a modest upswing in the aftermath of the price shock.

4 Empirical Analysis

4.1 Methodology

To examine our hypothesis about the systematic risk of over-collateralization on the borrower side, we leverage the exogenous XVS price shock to the lending market. This event creates a proper diff-in-diff analysis as follows:

$$y_{it} = \alpha + \beta_1 Post_t + \beta_2 Treat_i + \beta_3 Post_t \times Treat_i + CV_{it} + \epsilon_{it}$$

i is the account i, and t is the time. The outcome variable y_{it} is the account value of each user. $Shock_t$ is 1 when the time is on May 18, 2021 and afterwards, and 0 otherwise. We include a series of dummy variables to indicate whether the account has the dominant tokens vBNB, vETH, and stablecoins vUSDC, vBUSD, and vUSDT or not as our control variables in the regression.

The treatment group is the group of borrowers who have self-owned XVS or vXVS, that is, the total value of XVS or vXVS is greater than the borrowed value of it. The control group is the other borrowers that do not own vXVS. First, we do the diff-in-diff on the treatment and control groups to see whether the exogenous XVS price shock hurts the accounts' value significantly.

Then we examine the causal effects of borrowers of different LTVs. We divide the dataset into two groups based on the accounts' LTV. The first group has an LTV from 0 to 0.6, and the other has a ratio above 0.6.

On the supply side, we intend to estimate how the price shock impacts the zombie debt. It is obscure to see whether the shock created more zombies or not by checking the value of total zombie debt because it may be mitigated simply due to the price depreciation across the market. Thus, we first run an OLS with an individual fixed effect on the zombie debt dummy to test whether the loan is more likely to become a zombie after the shock. We can infer the change in the number of zombie debts using this result. Then we run the same regression on the total value of different types of zombie debt. At last, to estimate the causal effect on whether the shock will create more zombie debt for those using the attacked token as collateral, we analyze the diff-in-diff model.

4.2 Empirical Results

4.2.1 Demand Side

In order to comprehensively evaluate the implications stemming from the XVS price shock on the entire spectrum of borrowers within the Venus ecosystem, our investigation is initiated through the utilization of a difference-in-differences (diff-in-diff) framework, which effectively integrates both time-specific and individual-specific fixed effects.

In the initial analysis, the first column of Table 3 presents the empirical evidence that the shock introduced into the system yields statistically significant adverse effects on the collective valuation of accounts vested in XVS or vXVS. Subsequently, in columns (2) and (3), we proceed to elucidate the heterogeneous impact on accounts, stratified based on their respective LTVs. These LTV categories are delineated as those lying below the threshold of 0.6 and those exceeding this threshold. It is evident that the seismic perturbation in prices exacts a more conspicuous toll on accounts characterized by LTVs that surpass the 0.6 threshold, in contrast to their counterparts that exhibit greater resilience.

Moreover, these outcomes remain robust even subsequent to the incorporation of control variables, as evident from the findings presented in columns (4) to (6). The observed alignment with established lending practices is noteworthy, as higher LTVs inherently correspond to heightened risk exposure. This is particularly pertinent within the context of the decentralized lending milieu, where substantial depreciation in asset values can amplify risk, consistent with conventional lending wisdom.

4.2.2 Supply Side

To examine how the price crash impacts the credit risk for the lenders, we analyze how the price shock affects the number of zombie debts and the total zombie value. We classify the zombie debt into 3-day, 10-day, 30-day, and 60-day zombie debts based on the time period from default to liquidation. For example, 30-day zombie debt means that the loan defaults for consecutive 30 days. We define 3-day as short-term, 10-day as medium-term, and 30- and 60-day as long-term zombie debt. Table 4 displays OLS results indicating that the price shock substantially reduces the number of zombie debts across all durations. The effect is progressively more pronounced from 3-day to 60-day terms. These findings persist even after controlling for other variables. In Table 5, OLS results for total zombie value echo the pattern observed in zombie numbers. The price shock significantly mitigates medium- and long-term zombie debts, as reflected by consistent effects for 10-day, 30-day, and 60-day durations.

Certain scenarios emerge wherein a defaulted loan remains unliquidated due to diminishing collateral valuation, sinking below the value of the required repayment, consequently dissuading rational investors from initiating the liquidation process. Paradoxically, in instances of substantial market downturns culminating in a devaluation of the repayment worth, astute investors acquire the profitable debt, thereby mitigating the prevalence of non-performing debt within the market.

However, the result is the opposite for the aggregate value of short-term zombie debt shown in Table 5. Thus, the price shock dampened more large-value short-term bad debt, which did not get liquidated within 3 days and reduced market liquidity by creating more short-term zombie debt. The median LTVs in 3-, 10-, 30-, and 60-day zombie loans are 129, 74, 39, and 29 respectively. Since the total value of the short-term zombies increased and that of the medium- and long-term ones decreased after the shock, we could infer that when the price volatiles in the direction of narrowing the collateral repayment spread, the zombie loans having lower LTV will be better absorbed. In essence, the principle of over-collateralization exhibits robust resilience in the face of drastic price fluctuations, mitigating the long-term losses of the depositors and the platform.

Based on the DID findings presented in Table 6, a notable trend emerges: the occurrence of a price crash effectively amplified both the frequency and the severity of zombie debt across all observed durations. This outcome posits a significant influence of price crash events on borrowers who employ the affected tokens as collateral. The repercussions extend to depositors and the platform, as they stand to encounter more substantial losses in cases where a substantial portion of outstanding loans relies on the compromised token as backing.

5 Conclusion

Collateralized lending is a key application of decentralized finance. Unlike the traditional lending market, the decentralized lending market requires borrowing extra collateral to mitigate the credit risk. The paper studies the systematic risk and consequences of collateralization in the context of decentralized lending.

In the paper, we collect millions of transactions, including total values, borrowed values, and liquidation information, from tens of thousands of accounts on Venus, one of the largest decentralized lending markets. By identifying the exogenous shock as the price of the XVS token on May 18, 2021, we find the shock significantly decreases the wealth of borrowers holding XVS. The effect is pronounced among accounts that have higher LTV ratios.

Moreover, from the supply side, we find mixed effects of the price shock on zombie debts of varied duration. The number and value of the medium- and long-term zombie debt in the market decreased after the shock, mitigating the permanent loss of the suppliers. Conversely, short-term zombie debts also exhibited a reduction in numbers; however, the aggregate value of these debts was amplified by the price shock. This elevation in value points towards a potential reduction in market liquidity. Given the LTV observed among short-term zombie loans, it is deduced that heightened price volatility constricts collateral valuations and diminishes the temporal dispersion between collateral and repayment, thereby effectively ameliorating the prevalence of zombie loans characterized by comparatively lower LTVs.

In light of these findings, further research could delve deeper into the mechanisms through which collateral, borrower behavior, and market dynamics interact, exploring potential avenues for risk mitigation and improved system resilience. There is a growing imperative to develop robust risk management strategies and regulatory frameworks that can mitigate the potential systemic consequences of credit risk in decentralized lending. Such measures are crucial to ensuring the sustainability and stability of these innovative financial systems in the face of volatile market conditions.

References

Aramonte, S., Huang, W., and Schrimpf, A. (2021). Defi risks and the decentralisation illusion.

Berger, A. N. and Udell, G. F. (1990). Collateral, loan quality and bank risk. *Journal of Monetary Economics*.

Bruche, M. and Llobet, G. (2014). Preventing Zombie Lending. *Review of Financial Studies*, 27(3):923–956.

Caballero, R. J., Hoshi, T., and Kashyap, A. K. (2008). Zombie lending and depressed restructuring in japan. *American economic review*.

Cong, L. W., Tang, K., Wang, Y., and Zhao, X. (2022). Inclusion and Democratization Through Web3 and DeFi? Initial Evidence from the Ethereum Ecosystem.

Gabor, D. and Ban, C. (2016). Banking on Bonds: The New Links Between States and Markets. *JCMS: Journal of Common Market Studies*.

Hester, D. D. (1979). Review of Customer Relationships and Terms of Loans: Evidence from a Pilot Survey: Note. *Journal of Money, Credit and Banking*.

Hu, Y. and Varas, F. (2021). A Theory of Zombie Lending. *The Journal of Finance*, 76(4):1813–1867.

Jim, G. (2004). Collateral, type of lender and relationship banking as determinants of credit risk q.

Jimenez, G., Salas, V., and Saurina, J. (2006). Determinants of collateral. *Journal of financial economics*.

Jiménez, G. and Saurina, J. (2004). Collateral, type of lender and relationship banking as determinants of credit risk. *Journal of banking & Finance*.

Jordà, , Kornejew, M., Schularick, M., and Taylor, A. M. (2022). Zombies at Large? Corporate Debt Overhang and the Macroeconomy. *The Review of Financial Studies*.

Li, Y. and Mayer, S. (2022). Money Creation in Decentralized Finance: A Dynamic Model of Stablecoin and Crypto Shadow Banking.

Orgler, Y. E. (1970). A Credit Scoring Model for Commercial Loans. *Journal of Money, Credit and Banking*.

Parlour, C. A., Rajan, U., and Walden, J. (2022). Payment System Externalities. *The Journal of Finance*.

Qin, K., Zhou, L., Gamito, P., Jovanovic, P., and Gervais, A. (2021). An empirical study of DeFi liquidations: incentives, risks, and instabilities. In *Proceedings of the 21st ACM Internet Measurement Conference*, IMC '21, New York, NY, USA. Association for Computing Machinery.

Rashid, S., Iqbal Khan, K., Nasir, A., and Rashid, T. (2022). Unveiling living dead: characteristics and consequences of zombie firms. *Cogent Business & Management*.

6 Figures

6.1 Liquidation and LTV

Figure 1: Liquidation Value

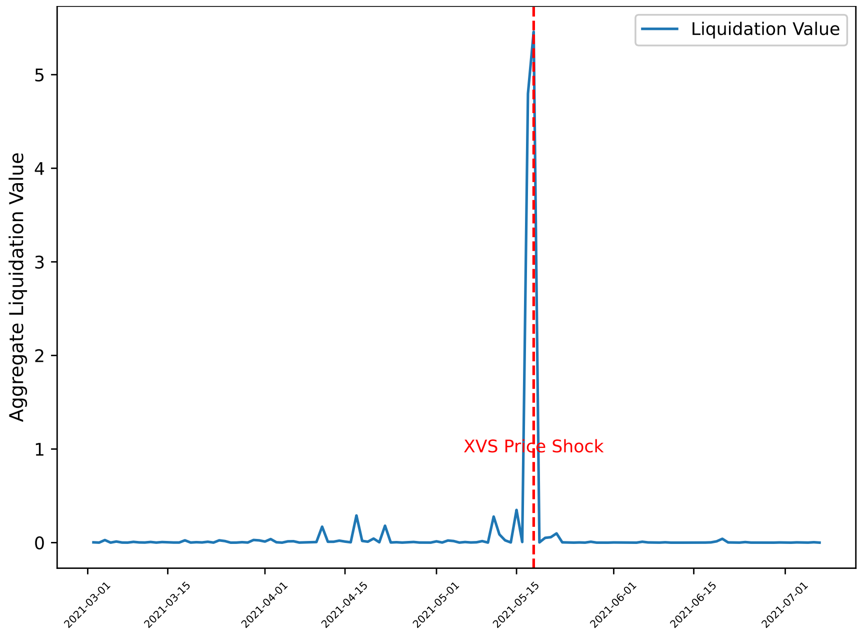
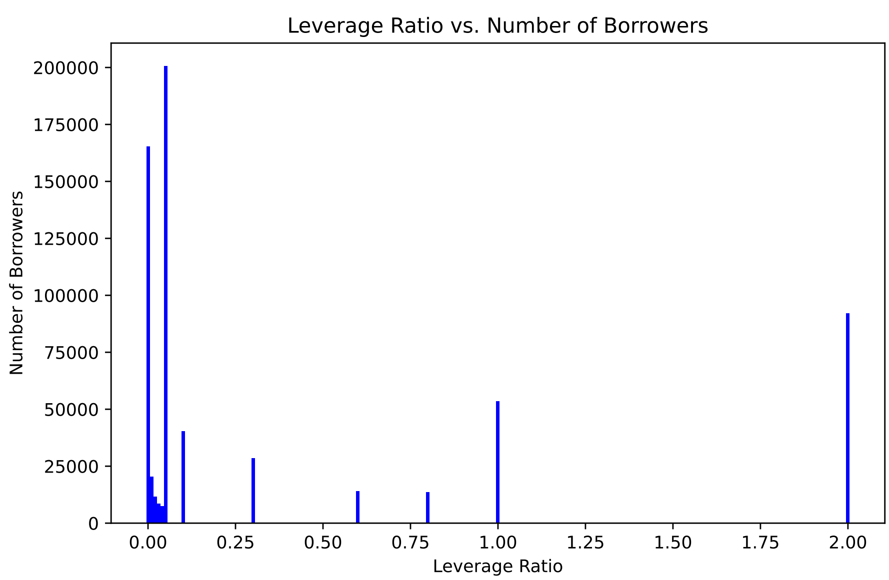


Figure 2: Distribution of Borrower LTV



6.2 Zombie Debt

Figure 3: Zombie Debt Total Value

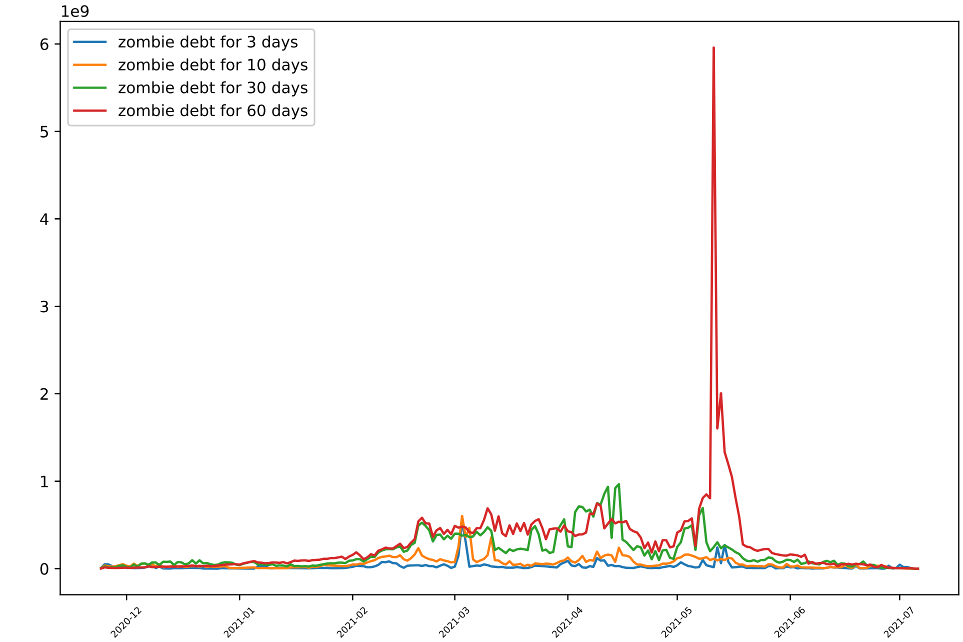
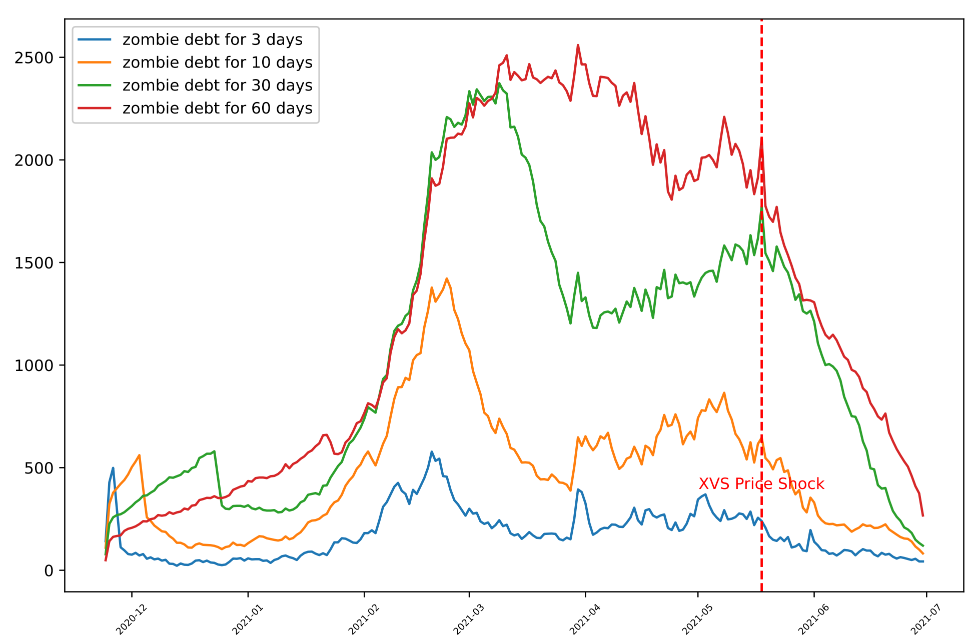


Figure 4: Number of Zombie Debt by Duration



6.3 Token Price

Figure 5: XVS Hourly Price

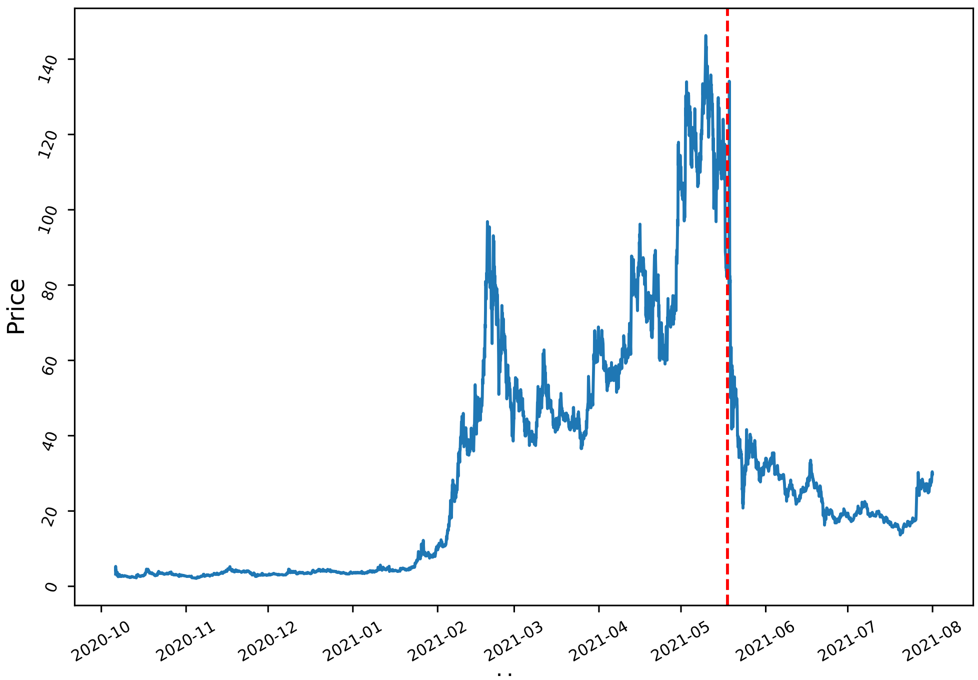


Figure 6: BTC, ETH, BNB, and XRP Price

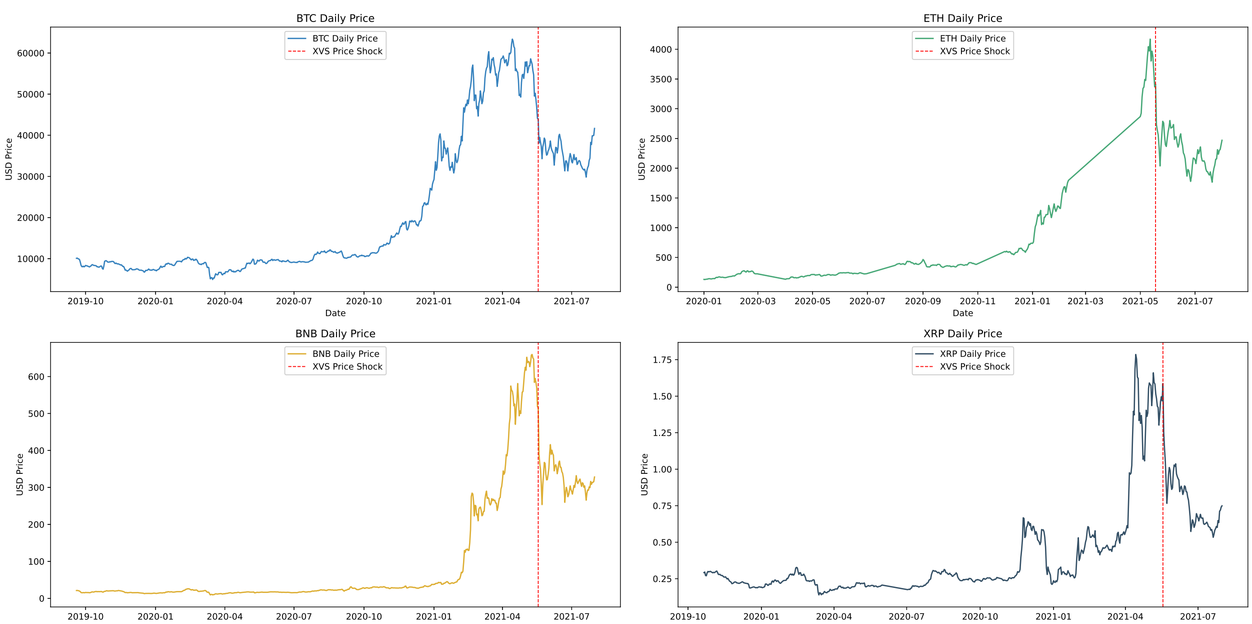


Figure 7: DOGE, DOT, DAI, and LTC Price

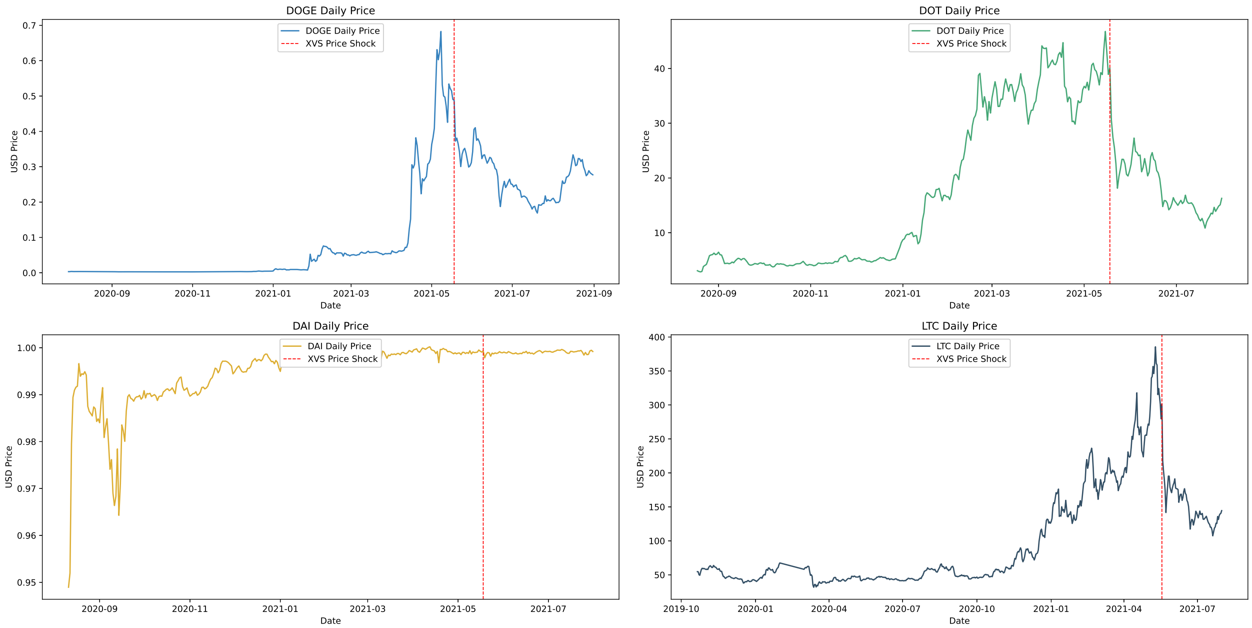
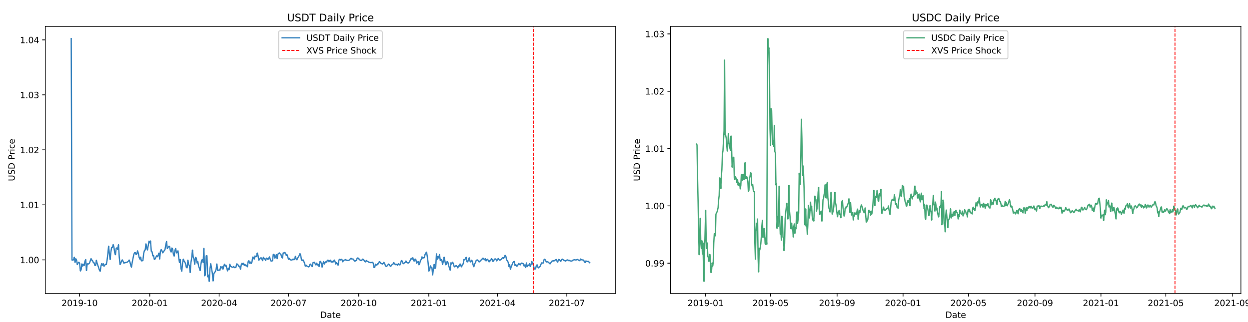


Figure 8: USDT and USDC Price



7 Tables

Table 1: Descriptive Statistics of All vTokens

Panel A: Total value (in USD)					
	Mean	Std	Min	Median	Max
XVS	618,640.56	57,051,536	0	36	24,535,404,146
vBTC	410,486.14	30,800,491	0	0	8,152,003,465
vETH	3,727.26	351,863	0	0	70,580,210
vBNB	2,401.88	143,630	0	0	44,053,715
vLTC	769.40	44,257	0	0	6,403,266
vUSDT	300.55	16,457	0	0	5,676,572
vBCH	299.30	63,741	0	0	26,553,559
vBUSD	294.74	16,260	0	0	3,574,998
vUSDC	279.35	15,141	0	0	2,579,377
vXVS	167.30	10,770	0	0	3,476,289
vDOT	124.21	9,241	0	0	3,544,957
vLINK	98.31	6,961	0	0	1,278,682
vSXP	85.87	3,759	0	0	833,270
vDAI	81.74	3,828	0	0	694,410
vFIL	18.58	1,722	0	0	448,152
vXRP	16.62	786	0	0	201,832
Panel B: Borrowed value (in USD)					
	Mean	Std	Min	Median	Max
vBTC	56,281.05	2,556,560	0	0	1,317,053,508
vBNB	27,670.83	2,173,829	0	0	1,553,529,318
vETH	22,766.31	2,215,371	0	0	831,226,289
vXVS	16,751.06	577,526	0	0	190,162,530
vSXP	7,551.74	353,570	0	0	71,595,198
vUSDT	6,932.06	1,132,007	0	0	756,436,027
vBUSD	5,901.52	778,203	0	0	601,309,408
vUSDC	3,964.18	233,246	0	0	69,148,722
vDOT	3,468.20	132,250	0	0	34,580,389
vXRP	2,962.17	253,707	0	0	91,082,765
vBCH	2,323.49	213,380	0	0	61,572,998
vLINK	2,044.78	101,498	0	0	24,324,788
vLTC	1,724.23	102,314	0	0	25,227,108
vFIL	1,111.88	85,781	0	0	17,897,338
vDAI	255.94	25,979	0	0	13,811,374
XVS	0.00	0	0	0	0

This table shows the descriptive statistics of the 16 different vTokens in Venus from September 10, 2020, to October 31, 2021. Panel A reports the statistics about the total values of each token, while Panel B shows the borrowed values of each token. The 15 studied tokens were selected according to their market values. We only keep accounts that have traded or borrowed tokens and have had more than three transactions. We also drop accounts that have abnormal leverage ratios (inf, NaN, and 0). Our sample data contains 1,206,687 pieces of transactions from 36,189 different accounts.

Table 2: Distribution of Loans by vToken

vToken	Num. Borrowers	Total Borrowed Value
vBUSD	12,179	355,664,209.71
vUSDT	8,727	362,669,645.51
vBNB	6,614	2898317043.88
vUSDC	6,596	337,084,723.76
vDAI	2,585	98,638,659.03
vSXP	1,947	103615134.50
vBTC	1,497	495,328,293,614.35
vETH	1,161	4,497,636,419.87
vDOT	1,221	149881539.43
vXRP	662	20,057,006.67
vLTC	588	928,423,055.38
vLINK	513	118,623,927.59
vBCH	574	361161283.77
vFIL	463	22,416,559.39
vXVS	364	201,874,435.21

The table shows the descriptive statistics of the borrowed tokens in Venus during the research period. The most prevalent borrowed token is vBUSD, followed by another stablecoin, vUSDT, which has the highest number of total borrowers. Tokens like vBTC and vETH are also mainstreaming in the market since they have the highest total borrowed value. Note that the borrowing value of vBTC is much higher than that of any other vTokens.

Table 3: DID Results by LTV

	(1)	(2)	(3)	(4)	(5)	(6)
	Global	LTV $\leq$ 0.6	LTV $\geq$ 0.6	Global	LTV $\leq$ 0.6	LTV $\geq$ 0.6
DID	-0.3632***	0.1820	-0.2674***	-0.2480**	0.4411	-0.2056**
	(0.0936)	(0.5796)	(0.0979)	(0.1005)	(0.5183)	(0.1001)
vETH dummy				0.3600***	0.6801***	0.2575***
				(0.0477)	(0.1216)	(0.0505)
vUSDT dummy				0.3942***	0.4803***	0.3767***
				(0.0475)	(0.1127)	(0.0511)
vUSDC dummy				0.4661***	0.4915***	0.4677***
				(0.0553)	(0.1509)	(0.0579)
vBUSD dummy				0.0815**	0.0341	0.0983**
				(0.0411)	(0.0981)	(0.0432)
vBTC dummy				0.3752***	0.3910***	0.3760***
				(0.0563)	(0.1392)	(0.0600)
Constant	4.9684***	4.0375***	5.5371***	4.6555***	3.7627***	5.1650***
	(0.0312)	(0.2384)	(0.0280)	(0.0407)	(0.2166)	(0.0413)
Time Effect	YES	YES	YES	YES	YES	YES
Entity Effect	YES	YES	YES	YES	YES	YES
Observations	1,201,077	507,519	669,233	1,201,077	507,519	669,233
Adj. R2	0.792	0.854	0.724	0.795	0.856	0.728

This table shows the results of DID group regressions with respect to the values of LTV (loan-to-value ratio). The dependent variable is the logarithmic total value of all vTokens held by different accounts. The treatment group is the group of borrowers who have self-owned XVS or vXVS; that is to say, the total value of XVS or vXVS is greater than the borrowed value of it. The control group is the other borrowers that do not own XVS or vXVS. The exogenous shock event happened on May 18, 2021. Control variables include a series of dummy variables indicating whether the account has the dominant tokens vBTC, vETH, and stablecoins vUSDC, VBUSD, and vUSDT. Columns (1) and (4) show the results based on all sample accounts. Columns (2) and (5) are based on accounts with LTV lower than 0.6, while columns (3) and (6) are based on accounts with LTV larger than 0.6. Robust standard errors clustered at the account and date levels are shown in parentheses.

Table 4: OLS Results of the Impact on Zombie Debt Amount

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	3-Day	10-Day	30-Day	60-Day	3-Day	10-Day	30-Day	60-Day
Shock	-0.0335***	-0.0949***	-0.1873***	-0.2130***	-0.0310***	-0.0898***	-0.1762***	-0.1992***
	(0.0005)	(0.0013)	(0.0028)	(0.0036)	(0.0005)	(0.0014)	(0.0028)	(0.0035)
vETH dummy					-0.0242***	-0.0516***	-0.1128***	-0.1426***
					(0.0015)	(0.0037)	(0.0069)	(0.0091)
vUSDT dummy					-0.0085***	-0.0248***	-0.0318***	-0.0240***
					(0.0019)	(0.0041)	(0.0071)	(0.0074)
vUSDC dummy					-0.0279***	-0.0523***	-0.0748***	-0.0494***
					(0.0021)	(0.0046)	(0.0077)	(0.0086)
vBUSD dummy					0.0045***	-0.0067*	0.0039	0.0218***
					(0.0017)	(0.0037)	(0.0062)	(0.0066)
vBTC dummy					-0.0451***	-0.0756***	-0.0347***	0.0193**
					(0.0021)	(0.0050)	(0.0089)	(0.0098)
Constant	0.0426***	0.1222***	0.2620***	0.3203***	0.0589***	0.1564***	0.2911***	0.3292***
	(0.0002)	(0.0005)	(0.0011)	(0.0014)	(0.0007)	(0.0015)	(0.0028)	(0.0033)
Entity Effect	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077
Adj. R2	0.178	0.251	0.382	0.575	0.183	0.257	0.388	0.579

This table shows the impact of the XVS price shock on the amount of zombie debt. Zombie debt is defined as a loan that has reached the liquidation threshold but has remained unresolved for some time. We use 3-, 10-, 30-, and 60-day periods to define the zombie debt. The dependent variable is the dummy variable indicating whether the account holds zombie debts. The independent variable is the dummy variable indicating whether the transaction happened before (0) or after (1) the XVS price shock on May 18, 2021. Control variables include a series of dummy variables indicating whether the account has the dominant tokens vBTC, vETH, and stablecoins vUSDC, VBUSD, and vUSDT. Robust standard errors clustered at the account level are shown in parentheses.

Table 5: OLS Results of the Impact on Zombie Debt Values

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	3-Day	10-Day	30-Day	60-Day	3-Day	10-Day	30-Day	60-Day
Shock	0.1429*	-0.2219***	-0.3767***	-0.5158***	0.0515	-0.3177***	-0.4624***	-0.6150***
	(0.0801)	(0.0534)	(0.0278)	(0.0266)	(0.0834)	(0.0519)	(0.0267)	(0.0253)
vETH dummy					0.7174***	0.7759***	0.5856***	0.5318***
					(0.0724)	(0.0446)	(0.0321)	(0.0361)
vUSDT dummy					0.2391***	0.2201***	0.2241***	0.2827***
					(0.0290)	(0.0209)	(0.0220)	(0.0278)
vUSDC dummy					0.3336***	0.3014***	0.2821***	0.3263***
					(0.0484)	(0.0305)	(0.0268)	(0.0330)
vBUSD dummy					0.2019***	0.2025***	0.2593***	0.2420***
					(0.0246)	(0.0184)	(0.0184)	(0.0239)
vBTC dummy					1.1768***	1.0316***	1.0682***	1.1177***
					(0.0764)	(0.0419)	(0.0416)	(0.0478)
Constant	8.3036***	8.3111***	8.3851***	8.5190***	7.7662***	7.7916***	7.8082***	7.8725***
	(0.0084)	(0.0061)	(0.0046)	(0.0044)	(0.0253)	(0.0151)	(0.0159)	(0.0190)
Entity Effect	YES	YES	YES	YES	YES	YES	YES	YES
Observations	29,212	100,446	228,138	286,989	29,212	100,446	228,138	286,989
Adj. R2	0.941	0.947	0.942	0.930	0.947	0.952	0.949	0.938

This table shows the impact of the XVS price shock on the values of zombie debts. Zombie debt is defined as a loan that has reached the liquidation threshold but has remained unresolved for some time. We use 3-, 10-, 30-, and 60-day periods to define the zombie debt. The dependent variable is the value of zombie debts from transaction accounts. The independent variable is the dummy variable indicating whether the transaction happens before (0) or after (1) the XVS price shock on May 18, 2021. Control variables include a series of dummy variables indicating whether the account has the dominant tokens vBTC, vETH, and stablecoins vUSDC, VBUSD, and vUSDT. Robust standard errors clustered at the account level are shown in parentheses.

Table 6: DID Results of Zombie Debts

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	3-Day	10-Day	30-Day	60-Day	3-Day	10-Day	30-Day	60-Day
DID	0.1116	0.1577***	0.1314***	0.0933***	0.1073***	0.1499***	0.1223***	0.0828***
	(0.0000)	(0.0108)	(0.0150)	(0.0168)	(0.0080)	(0.0109)	(0.0149)	(0.0164)
vETH dummy					-0.0195***	-0.0315***	-0.0470***	-0.0771***
					(0.0020)	(0.0041)	(0.0077)	(0.0105)
vUSDT dummy					-0.0081***	-0.0189***	-0.0219***	-0.0186***
					(0.0021)	(0.0042)	(0.0064)	(0.0070)
vUSDC dummy					-0.0176***	-0.0274***	-0.0271***	-0.0076
					(0.0024)	(0.0047)	(0.0071)	(0.0080)
vBUSD dummy					0.0067***	-0.0012	0.0111**	0.0268***
					(0.0021)	(0.0035)	(0.0053)	(0.0061)
vBTC dummy					-0.0302***	-0.0359***	0.0059	0.0356***
					(0.0025)	(0.0047)	(0.0079)	(0.0094)
Constant	-0.0073	0.0335***	0.1470***	0.2082***	0.0055*	0.0551***	0.1576***	0.2083***
	(0.0000)	(0.0036)	(0.0050)	(0.0056)	(0.0028)	(0.0040)	(0.0054)	(0.0063)
Time Effect	YES	YES	YES	YES	YES	YES	YES	YES
Entity Effect	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077	1,201,077
Adj. R2	0.228	0.338	0.490	0.629	0.230	0.339	0.491	0.630

This table shows the results of DID regressions about the values of the zombie debts according to the XVS price shock on May 18, 2021. Zombie debt is defined as a loan that has reached the liquidation threshold but has remained unresolved for some time. We use 3-, 10-, 30-, and 60-day periods to define the zombie debt. The treatment group is the group of borrowers who have self-owned vXVS or XVS, that is, the total value of vXVS or XVS is greater than the borrowed value of it. The control group is the other borrowers that do not own vXVS or XVS. Control variables include a series of dummy variables indicating whether the account has the dominant tokens vBTC, vETH, and stablecoins vUSDC, VBUSD, and vUSDT. Robust standard errors clustered at the account and date levels are shown in parentheses.

Appendices

A Interest Rate and Exchange Rate

In this section, we explain how interest rates and exchange rates work in Venus. The borrowing interest rate and supplying interest rate are determined by the utilization rate of the vToken:

$$\begin{cases} R_{borrow,U} = aU + b \\ R_{supply,U} = R_{borrow,U} \times U \times (1 - reserve\ factor) \end{cases}$$

where $U = \frac{borrow}{supply}$ is the utilization rate, $a > 0$, $b \geq 0$, and $reserve\_factor \in [0, 1)$. a, b, and $reserve\_factor$ are set by the platform.

The exchange rate between a token and its vToken depends on market supply and demand. $exchange\ rate = \frac{TotalAsset + TotalBorrow - TotalReserves}{TotalSupply}$. TotalAsset on the Venus platform is defined as the aggregate value of specific tokens that are locked in Venus, comprising both deposited and collateralized tokens. TotalBorrow is the summation of the borrowed tokens on the platform, while TotalReserves represents the collective amount of that particular token that is held in reserve. It represents the price of a particular asset on the platform. It is used to calculate the value of the underlying asset when a user mints vTokens or redeems them back to the original asset. Higher demand for a particular asset on Venus can result in a higher exchange rate and interest rate, while a higher supply of an asset available for lending can result in lower rates. Thus, the platform could dynamically adjust liquidity and avoid bank runs.

B Liquidation By Token

Figure 9: vXVS, vBTC, vETH, vBNB, vXRP, and vADA Liquidation Repayment

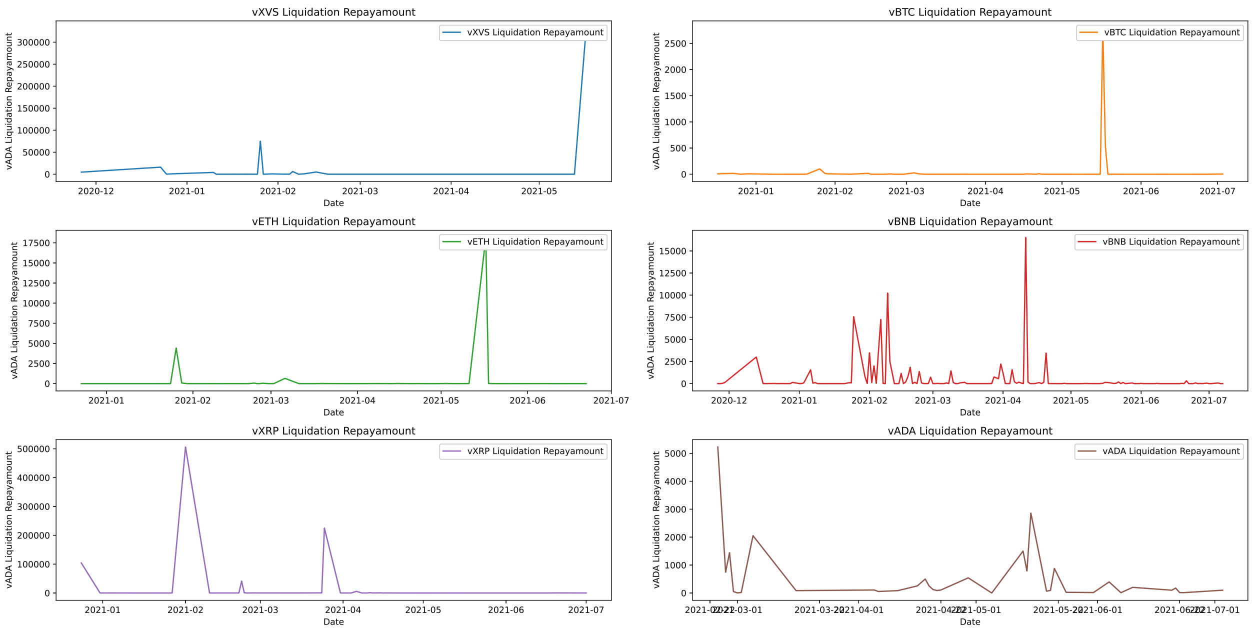


Figure 10: vDOGE, vDOT, vDAI, vLTC, vLINK and vSXP Liquidation Repayment

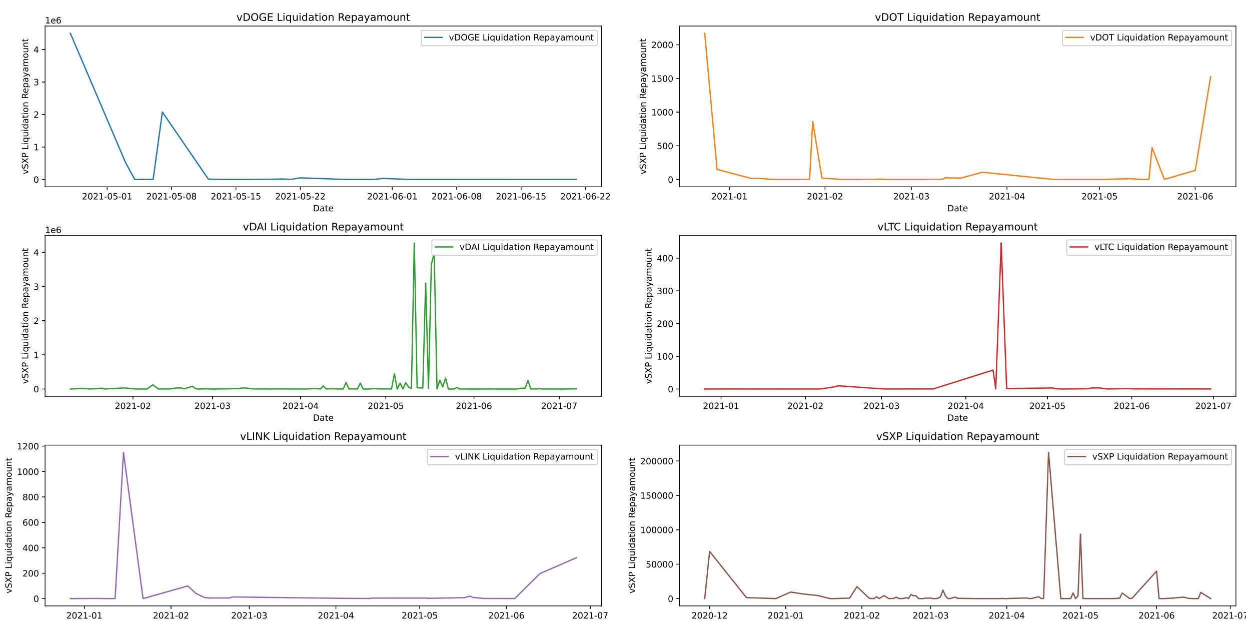
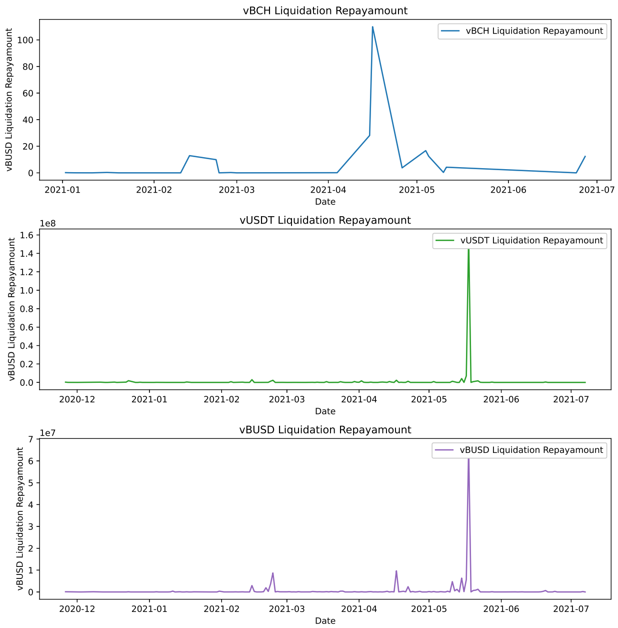


Figure 11: vBCH, vFIL, vUSDT, vUSDC, and vBUSD Liquidation Repayment



C Supply, Demand, and Interest Rate

C.1 Supply

The following section illustrates the supply of vTokens we studied during the research period. We could see that there is a great increase in the supply amount of vXVS at the price shock, and so do the amounts of vLTC, vSXP, vBCH, and vFIL.

Figure 12: Supply Amount of vXVS, vBTC, vETH, and vBNB

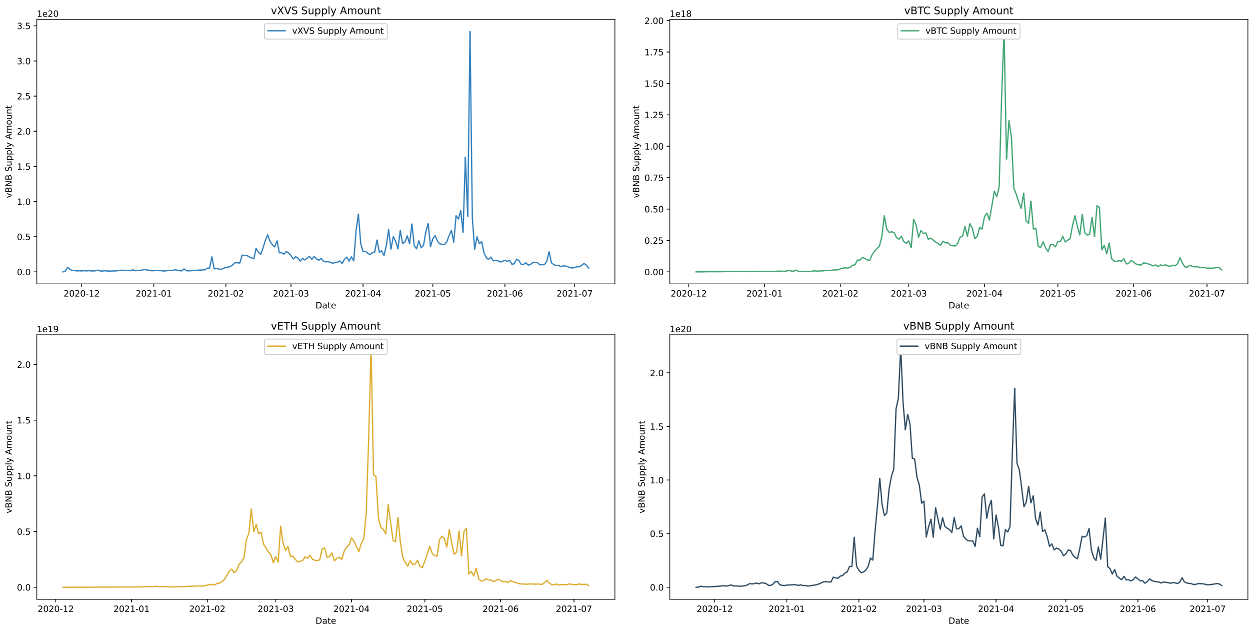


Figure 13: Supply Amount of vDAI, vLTC, vLINK, and vSXP

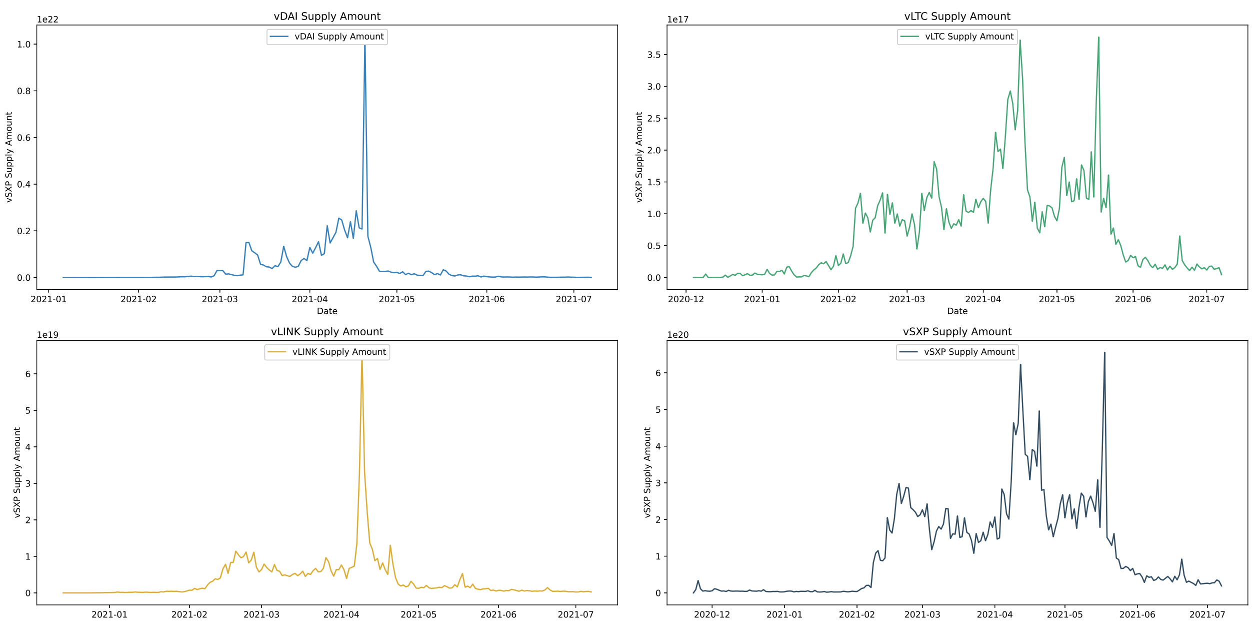


Figure 14: Supply Amount of vXRP, vADA, vDOGE, and vDOT

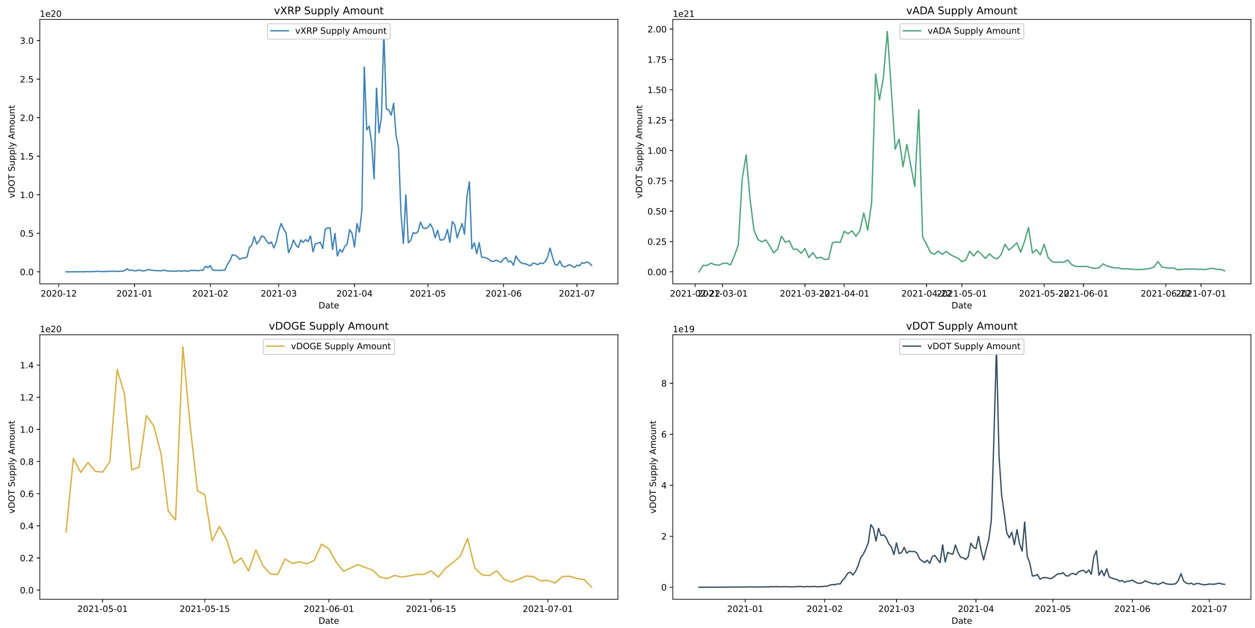
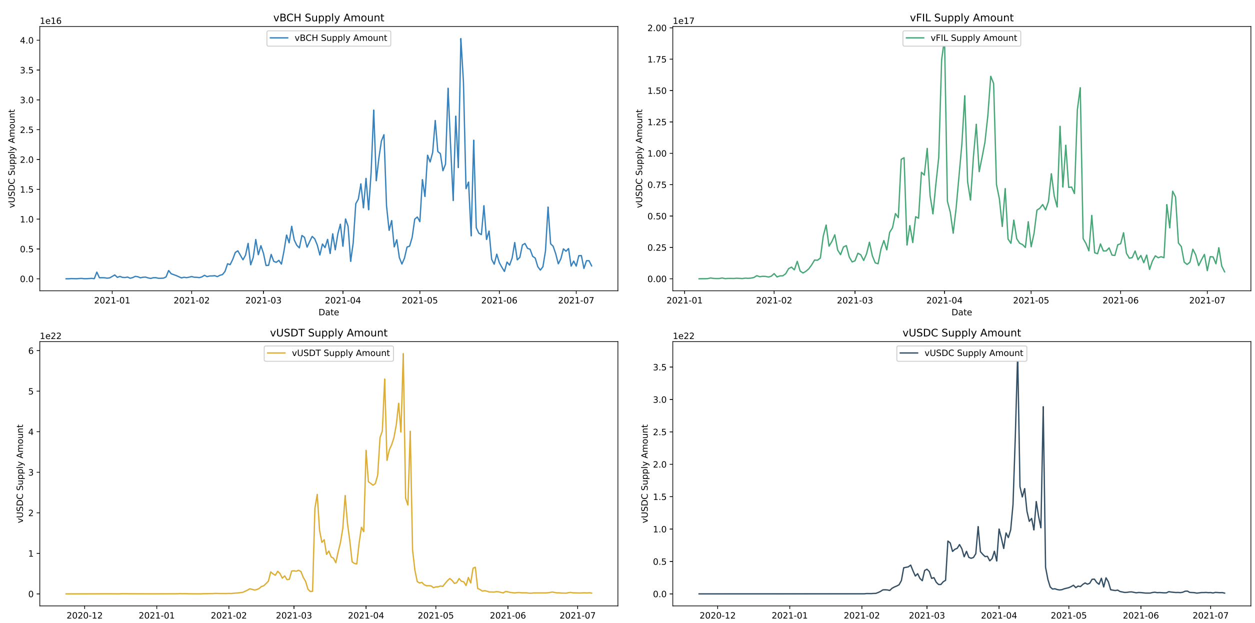


Figure 15: Supply Amount of vBCH, vFIL, vUSDT, vUSDC



C.2 Demand

The following section illustrates the demand, which is the borrowed amount of vTokens. We could see that there was a great increase in the borrowed amount in mid-April 2021 for most of the vTokens, while during the price shock in May, the supply was mainly stable for all vTokens except for vBCH and vFIL. There is a small increase in demand due to the price shock for most of the vTokens.

Figure 16: Borrow Amount of vXVS, vBTC, vETH vBNB, vXRP, and vADA

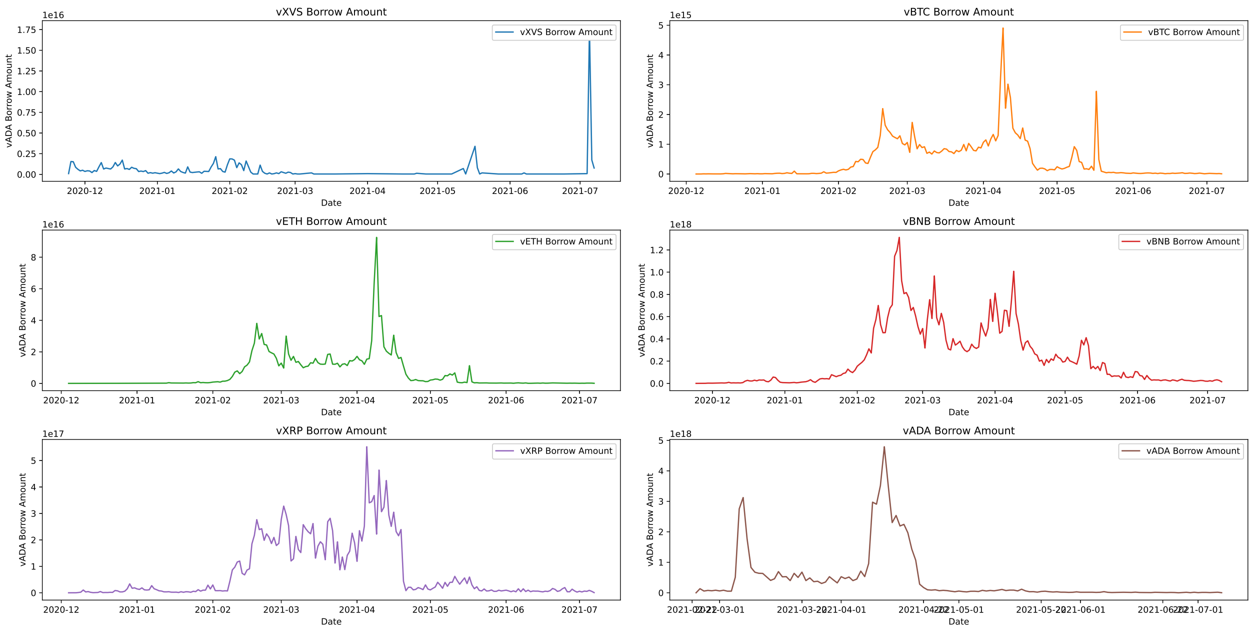


Figure 17: Borrow Amount of vDOGE, vDOT, vDAI, vLTC, vLINK, and vSXP

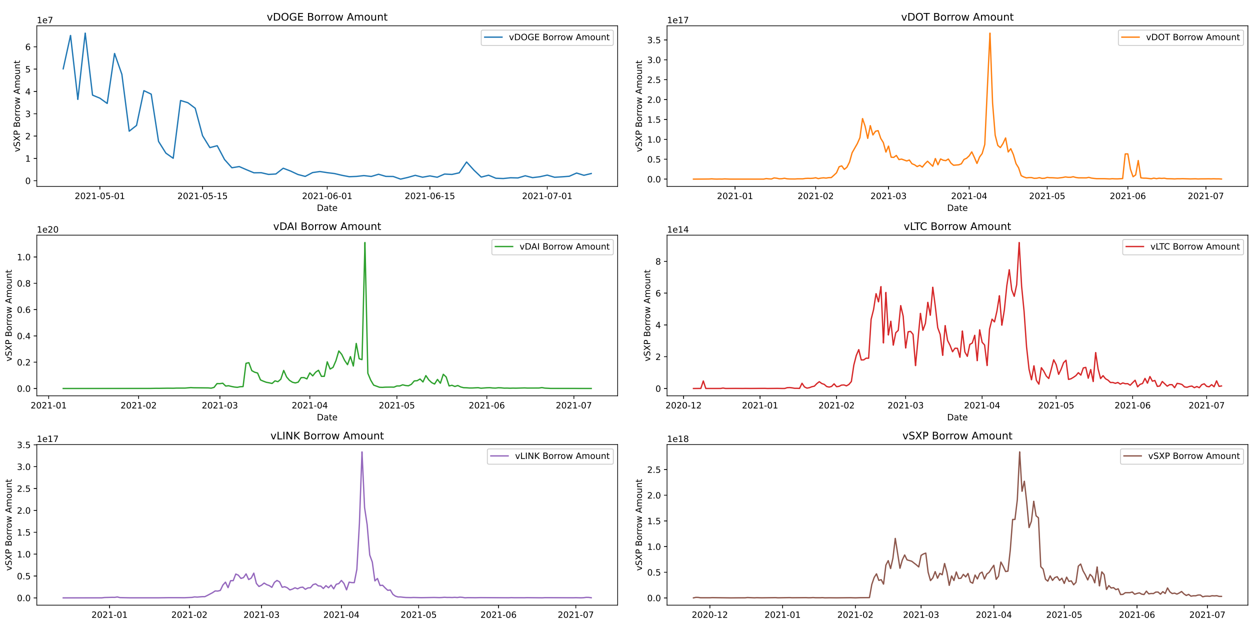
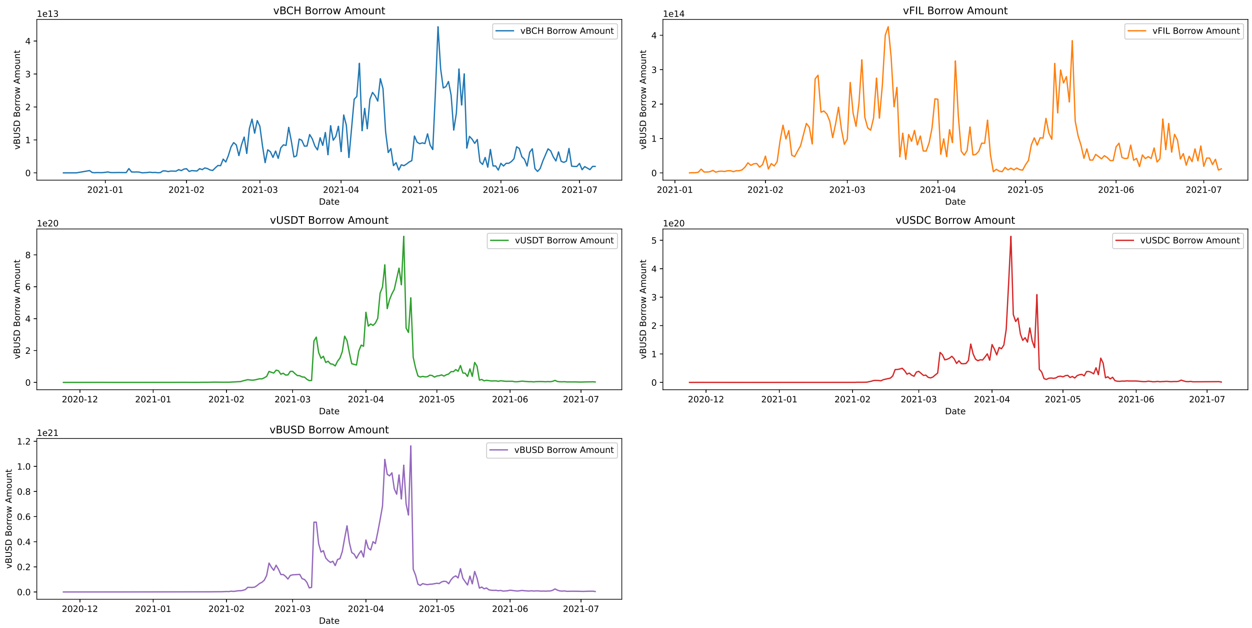


Figure 18: Borrow Amount of vBCH, vFIL, vUSDT, vUSDC, and vBUSD



C.3 Interest Rate

This section shows the annual interest rates of vTokens. The rates were highly volatile for most of the vTokens during our research period. The range of fluctuation could be up to 10% in one week. The stablecoins vUSDT, vUSDC, and vBUSD all witnessed a great interest rate decrease around the XVS price shock, inferring that more investors chose to deposit stablecoins during the highly volatile period. The interest rate of vXVS had a small jump at the price shock.

Figure 19: Annual Interest Rate of vXVS, vBTC, vETH, vBNB and vADA

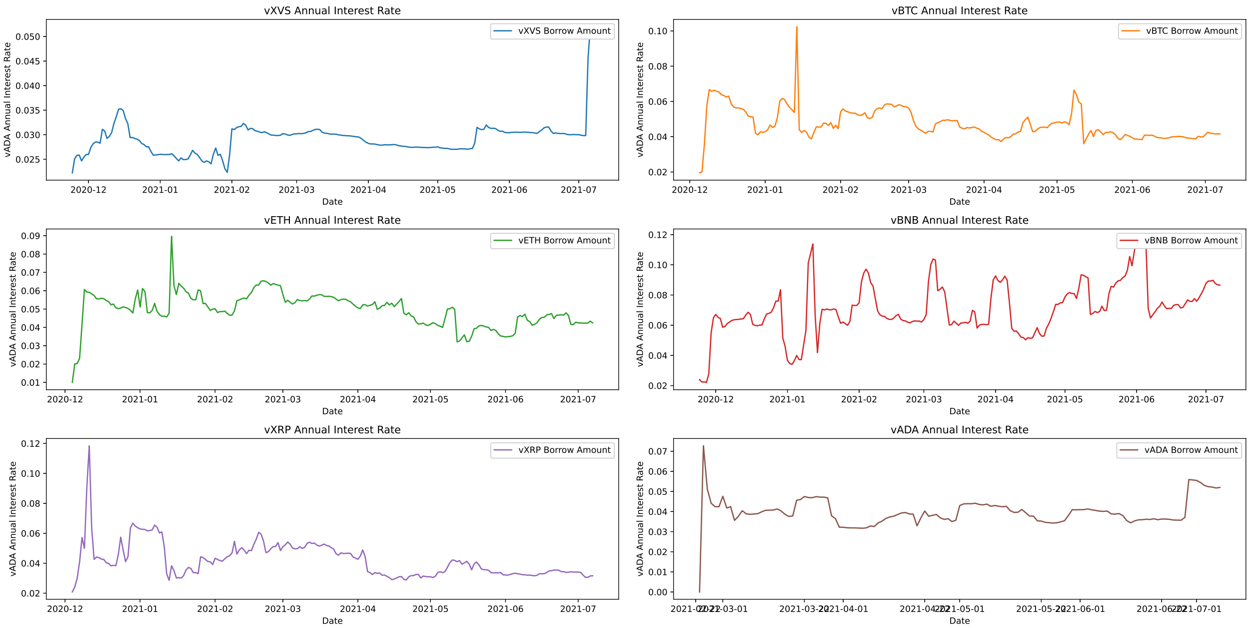


Figure 20: Annual Interest Rate of vDOGE, vDOT, vDAI, vLTC, vLINK, and vSXP

Figure 21: Annual Interest Rate of vBCH, vFIL, vUSDT, vUSDC, and vBUSD