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Risk-Free Uncollateralized Lending in Decentralized Markets: An Introduction to Flash Loans

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Abstract

A flash loan is a special type of uncollateralized loan with zero default risk that is native to blockchain ecosystems. Since its inception in 2018, the technology has seen significant adoption across decentralized finance markets, having facilitated over US$2 trillion in lending activity in 2024 on Ethereum-Virtual-Machine-compatible (EVM-compatible) blockchains. Despite their high levels of adoption, flash loans are not well understood by academics and central bank researchers. I provide a detailed description of flash loans, document their usage across major EVM-compatible blockchains, present key findings from the data, and provide the necessary background and context to motivate further research on the topic. Key results show that flash loans expand access to liquidity and are used by highly sophisticated actors for many practical applications.

Topics: Digital currencies and fintech; Financial markets
JEL codes: G0, G1, G2

Résumé

Un prêt éclair est un type particulier de prêt non garanti sans aucun risque de défaut propre aux écosystèmes de chaînes de blocs. Depuis son invention en 2018, la technologie derrière ces prêts a été largement adoptée sur les marchés de finance décentralisée, facilitant des activités de prêt se chiffrant à plus de 2 000 milliards de dollars américains en 2024 sur des chaînes de blocs compatibles avec la machine virtuelle Ethereum (EVM). Malgré leur taux d'adoption élevé, les prêts éclair ne sont pas bien compris par les universitaires et le personnel de recherche des banques centrales. Je fournis une description détaillée de ces prêts, dresse un bilan de leur utilisation dans les principales chaînes de blocs compatibles avec l'EVM, présente des constats clés obtenus à partir de données et fournis le contexte historique et actuel nécessaire pour motiver la conduite d'autres recherches sur le sujet. Les principaux résultats de mon étude montrent que les prêts éclair élargissent l'accès à la liquidité et sont utilisés par des acteurs très avertis pour de nombreuses applications pratiques.

Sujets : Monnaies numériques et technologies financières; Marchés financiers
Codes JEL : G0, G1, G2

1 Introduction

The rise of decentralized finance (DeFi) has unleashed a wave of groundbreaking financial tools, and flash loans stand out as one of the most revolutionary. A flash loan is a special type of uncollateralized loan with zero maturity, zero default risk and, in some cases, zero limit to the size of the loan. Since their initial use in early 2020, flash loans have seen notable adoption in the DeFi ecosystem. For example, in 2024 they facilitated over US$2 trillion in lending activity across 10 million unique flash loan events.

Because of their novelty and lack of a parallel in the existing financial system, flash loans are just beginning to be studied by academics and central bank researchers. I introduce the technology and provide the necessary foundation and context to motivate further work on the topic. To do this, I offer a detailed overview of the technology, provide a comprehensive novel dataset on flash loan usage and adoption across blockchains compatible with the Ethereum Virtual Machine (EVM), and identify key trends and observations in the data. Important contributions of this work are the comprehensive dataset, use case identification and classification, analysis of the users and providers, and identification of key trends in the data.

How precisely a flash loan works is described in Section 2, but for now consider the following high-level definition. In blockchain systems, a transaction refers to a set of sequential operations that instruct the blockchain network on how to update its state. These transactions have a special property where either every operation in the set successfully executes, or none of them do. Flash loans take advantage of this special property by bundling both the issuance and repayment of the loan within a single blockchain transaction, and the overall success of the transaction (including the initial issuance) is conditioned on the successful repayment. The repayment condition guarantees that a lender's liquidity is not exposed to risk, regardless of the size of the loan.

The unique, instantaneous design of flash loans motivates several questions. How often are flash loans used, and how big are they? What are flash loans used for? Who is using flash loans, and why would a lender choose to offer flash loan functionality? I address each of these questions throughout subsequent sections of the paper. Additionally, I provide several explanations as to why it is important to understand flash loan technology and why this is a relevant tool from a policy perspective.

This paper is divided as follows. Section 2 provides a detailed description of flash loan technology, an introduction to fundamental blockchain concepts, an overview of the different flash loan designs and a discussion about the trade-offs of each. Section 3 explores the existing literature on flash loans from both the economic and computer science fields, followed by Section 4, which outlines the data collection methodology and my analytical approach. Section 5 contains a combination of stylized facts, key results and analysis driven by the blockchain data. In particular, this section presents findings on flash loan usage as a whole, the various known use cases, the users and providers, and overall trends in the data. Finally, Section 6 presents several points of discussion regarding future research on the topic, and Section 7 concludes.

2 Flash loan basics

Flash loan technology is possible thanks to specific technical aspects of blockchain systems. Flash loans are useful because of their applications in the broader DeFi ecosystem. In this section, I present fundamental blockchain and DeFi concepts that are necessary to understand flash loans. I then define flash loans and compare each of the popular designs. Section 2.1 provides an overview of blockchain architecture, atomic blockchain transactions and smart contracts. If the reader has a thorough understanding of the technical details of each of these systems, they can proceed to Section 2.2 with no loss of understanding.

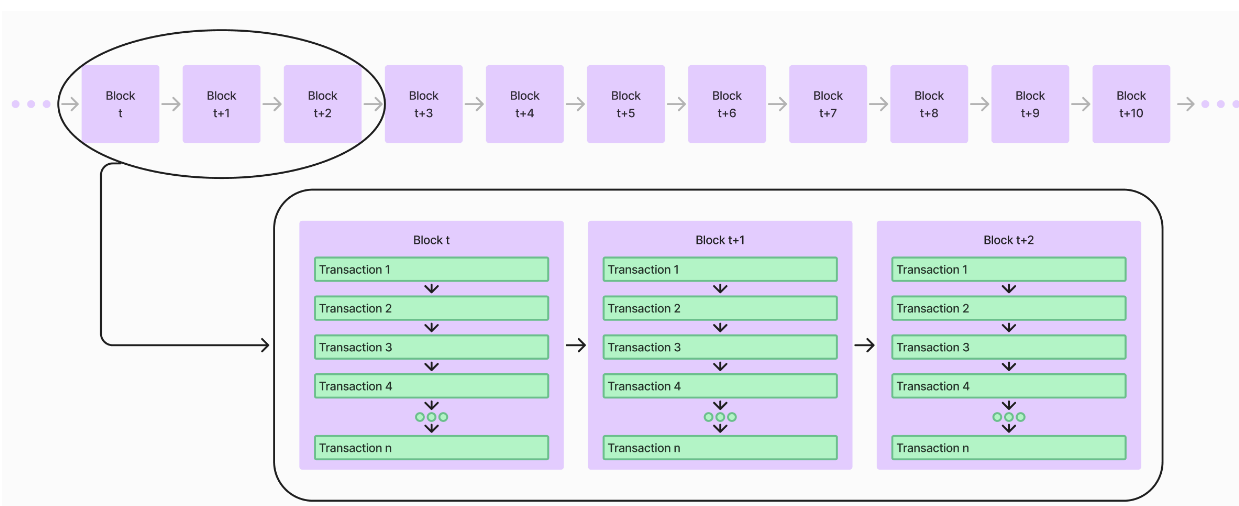
2.1 Fundamental concepts

2.1.1 Blockchain

The Ethereum Foundation defines a blockchain as ”a database of [sequential] transactions that is updated and shared across many computers in a network” (Ethereum 2025a). Blockchain transactions are described in detail in the following subsection, but for now, think of them as a sequence of instructions that update the state of the blockchain. Transactions are grouped into blocks, which are sequentially added to the end of the blockchain (**Figure 1**).[1] At a high level, blockchains operate as follows:

When a user wishes to change the state of the blockchain, they submit a transaction to the network.[2] Each additional block contains a reference to the previous one and updates the state of the blockchain in accordance with the transactions it contains.

Figure 1: Blockchain and transactions



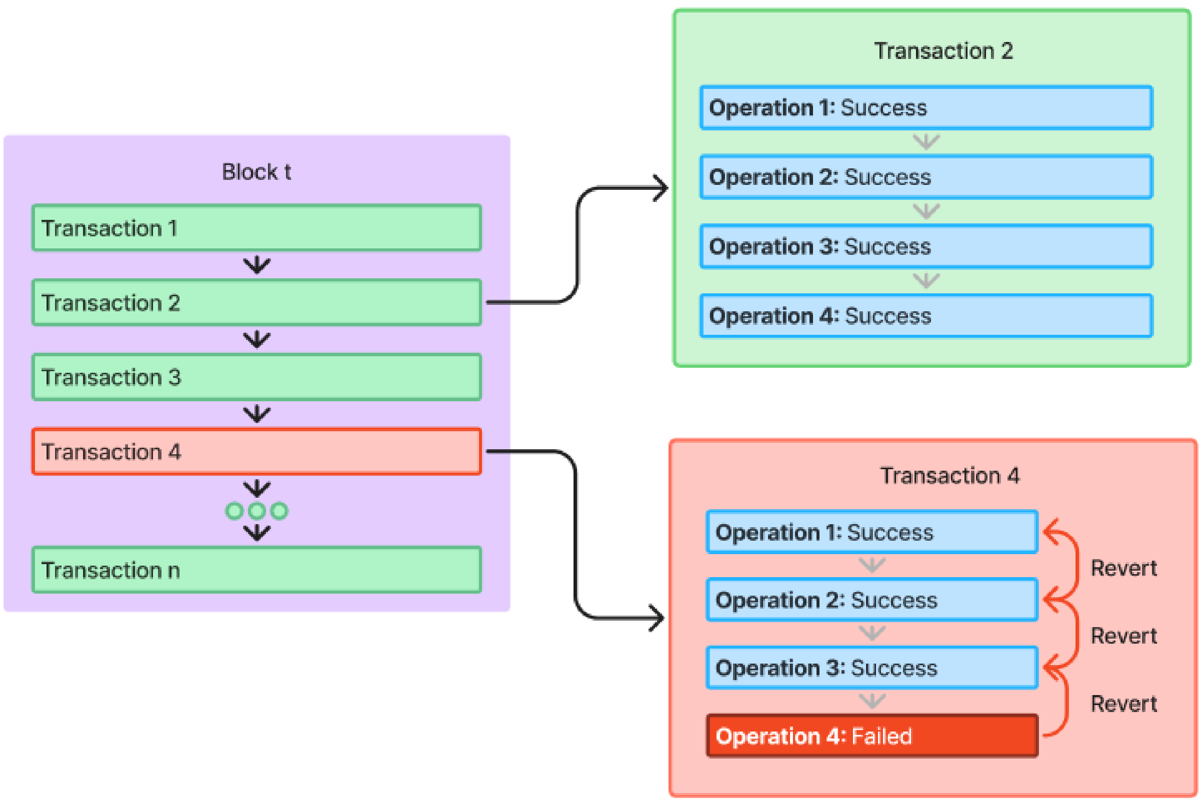
1. Some high-throughput blockchains implement sharding or parallelization, both of which can process unrelated transactions simultaneously. But blockchains of this nature are outside of the scope of this work.
2. A change to the state of the blockchain could mean a wide variety of actions, a simple example being the transfer of ownership recorded on the blockchain.

2.1.2 Transactions and atomicity

In Ethereum and compatible EVM blockchains, a transaction refers to a series of cryptographically signed instructions sent from an externally owned account (EOA) that results in a change in the state of the blockchain (**Figure 2**). The sequence of operations can vary in complexity. One of the simplest examples is an EOA sending some balance of Ether, the native currency of Ethereum, to another EOA. More complex transactions are described in subsequent sections.

An important characteristic of blockchain transactions is that they are atomic. Atomicity is a concept from database systems: a series of indivisible and irreducible database operations is atomic when either all actions occur, or none of them do (Nadcab Labs 2025). Likewise, when a user submits a transaction to the blockchain, either all actions triggered by the transaction occur, or none of them do. As shown in Section 3, this key concept enables flash loans and guarantees their risk-free nature to the lender.

Figure 2: Atomic transactions



When the sequence of operations triggered by the transaction does not fully execute, the full transaction reverts. In this case, the user still pays the gas fee.[3] And the transaction is still included in the block as a failed transaction, but it does not impact the state of the blockchain. This is illustrated in Figure 2.

3. Gas is the fee paid by the user to the network for processing the transaction. When a transaction fails, the gas is still paid, but no other state changes included in the transaction are enacted.

2.1.3 Smart contracts

A smart contract is an immutable piece of code stored at a blockchain address that executes when certain conditions are met (Ethereum 2025d). Both users (EOAs) and other smart contracts can interact with a smart contract by providing data or calling functions on the smart contract code, to achieve some preprogrammed functionality. Smart contracts come in a wide variety of designs for customized purposes.

Smart contracts in Ethereum and other EVM-compatible blockchains can be characterized by atomic execution, predictable outcomes and data availability on the public record. Common examples of use cases for smart contracts include the creation and sending of stablecoins, creation and distribution of unique digital assets, decentralized exchange (Dex), decentralized gaming and more (Ethereum 2024). As will become clear in the following section, smart contracts are a fundamental component of the blockchain architecture that allows for flash loan technology.

2.2 Flash loans

A flash loan is a special type of uncollateralized loan that is both issued and repaid within a single atomic transaction. Flash loans are generally denominated in ERC-20 tokens, which are a type of digital asset that adheres to the Ethereum Request for Comment 20 standard (**Appendix A-2**) but could in theory be a digital representation of anything on the blockchain. Transaction atomicity ensures that if the loan is not repaid within the transaction, the full transaction reverts and has no impact on the state of the blockchain.[4] By conditioning the success of the transaction on the subsequent return of the liquidity, lenders can rest assured that they face no default risk since, if a lender defaults, the full transaction including the initial issuance will be void.

Flash loans are facilitated through functions in smart contract code. This code controls both the initial transfer of ownership of the flash-loaned liquidity and conditions the overall success of the transaction on the successful closing of the position. Users are able to initiate flash loans by sending a transaction to the blockchain that triggers the function.

The instantaneous maturity of flash loans restricts the set of potential uses for the liquidity beyond that of a more traditional loan, since the position must be resolved within a single transaction. That said, there are several use applications in which flash loans make for a superior alternative to standard sources of liquidity. This is discussed in detail in Section 4.2.

2.3 History of flash loans

The idea of a flash loan was conceived in 2018 by the developers of Marble, a bank based on open-source smart contracts operating on the Ethereum blockchain (Wolff 2018). In his article on the website *Medium*, Wolff describes this innovation—initially coined ”flash lending”—as follows:

4. The exception is the gas payment from the transaction initiator to the block producer.

> ”Flash lending lets anyone borrow Ether and ERC-20 tokens to take advantage of arbitrage opportunities on Ethereum. A smart contract can execute any arbitrary code after borrowing as long as the funds are returned to the bank within the scope of the same transaction. While simple in design, this allows developers to easily profit from the prices of Ethereum assets without using their own capital.”

Although Marble was the first to conceive of on-chain uncollateralized lending guaranteed by transaction atomicity, it was not the first to successfully implement the tool. In early 2020, the first iteration (V1) of the Aave protocol wrote its smart contract with flash loan functionality to the Ethereum blockchain. The smart contract was published on January 8, and the first flash loan event took place on January 17. The first flash loan consisted of US$33.10 worth of Dai for what appears to have been an arbitrage transaction.[5]

Aave V1’s time as the sole flash loan provider was short-lived because new entrants quickly created their own competitive offering. Within months of the Aave V1 launch, dYdX began offering zero-fee flash loans, and Uniswap V2 began offering a new type of flash loan known as a flash swap. In December 2020, Aave V2 began offering flash loans that can in some special cases be rolled over into a standard collateralized loan. In early 2021, flash loan services began to roll out onto other EVM-compatible blockchains, and more protocols with access to deep liquidity began offering flash loan functionality. In September 2021, Maker began offering a new type of flash loan known as a flash mint, where the liquidity is both minted and burned within a single atomic blockchain transaction.[6]

Currently, flash loans are available on most major blockchains compatible with DeFi. Many protocols now offer the functionality, though they vary in fees charged, token availability, liquidity depth and other features. As mentioned, some differences exist with respect to flash loan design. The different designs are known as basic flash loans, flash swaps and flash mints.

2.4 Flash loan design

Although each of the three designs have some unique aspects, they all follow the same general structure. Upon request, the flash loan provider allocates liquidity to a borrower; the borrower can then use the liquidity and returns it within the same atomic transaction. Similarly, all three designs are a function on a smart contract that has control over liquidity in one or more tokens, and users must use a facilitator contract to interact with the flash loan function. Variation in design stems from differences in how liquidity is sourced and repaid as well as in other nuances to the operational logic.

2.4.1 Basic flash loan

A basic flash loan is the simplest form of flash loan. Basic flash loans are both issued and repaid in the same denomination. That is, the type of token that is borrowed is the same type of token that gets returned.

5. Dai is a popular decentralized stablecoin.

6. Minting and burning are events similar to issuance and destruction of a currency. They occur when liquidity of a digital asset is created or destroyed, respectively.

To fund the lending activity, basic flash loans rely on a liquidity pool, a smart contract that holds liquidity in certain tokens. In order to operate, the liquidity pool must hold some positive amount of one or more token. Basic flash loans follow the following general pattern:

1. The initiator calls a custom function on a facilitator contract to handle the flash loan operations.
2. The facilitator contract calls the flash loan function on the provider contract, specifying the type of token, amount and receiving address.
3. The provider contract sends the requested liquidity to the specified address.
4. The facilitator contract uses the liquidity to execute some predetermined set of operations.
5. The facilitator contract returns the full amount of the loan to the liquidity pool, sometimes with an additional protocol fee.

In the event any step in the process fails, the transaction reverts, and the state of the blockchain remains unchanged (with the exception of the gas paid for the transaction). Note the following observations about basic flash loans:

- Only one type of token can be borrowed, and the same type of token must be returned.
- The flash loan amount is constrained by the volume of tokens available in the liquidity pool.
- Depositors require an incentive to provide liquidity to the liquidity pool, typically through protocol fees.

2.4.2 Flash swap

Flash swaps follow the same general structure as a basic flash loan, but with more flexibility with respect to the denominations of the tokens involved. Flash swap liquidity pools contain two or more distinct tokens, and the borrower can choose to borrow and return different arbitrary amounts of each token, as long as the overall value of the pool does not decrease at the end of the transaction. That is, a borrower can initiate a flash swap in one token and return another token.

Flash swaps are generally offered by protocols that already have the infrastructure to facilitate token swaps, namely Dex protocols. Rather than conditioning on the return of the same asset, flash swap protocols are based on the condition that the end state of the liquidity pool has a value greater than or equal to the beginning state. The change in the state of the liquidity pool is equivalent to the change had a user initiated a simple swap. A flash swap executes as follows:

1. The borrower initiates a flash swap by calling a custom function on a facilitator smart contract, containing the operational logic.
2. The facilitator contract calls the flash swap function on the provider contract, specifying the quantity, denomination and receiver address.

3. The provider contract sends the requested liquidity to the specified address.
4. The facilitator contract executes a predetermined set of operations using the liquidity.
5. The facilitator contract returns some combination of the liquidity pool tokens, where the sum of the tokens must adhere to the pool conditions, typically with a protocol fee.

Flash swaps offer improved flexibility for the borrower and are a better fit for some use cases. Notice the following:

- An arbitrary combination of the two tokens can be borrowed, and a different combination of the same two tokens can be returned.
- The amount of each token that can be borrowed is constrained by the volume of that token in the liquidity pool.
- Depositors require incentives to lock tokens into liquidity pools, thus requiring protocol fees.
- Dex pools typically offer services for a wider range of tokens than dedicated lending pools do, implying a wider range of available tokens.

2.4.3 Flash mint

Both flash loan designs discussed so far require liquidity pools to fund the lending activity, which constrains the maximum amount of liquidity that can be borrowed. Flash mints do not face this same constraint. A flash mint is a special type of flash loan where the provider has mint and burn capabilities for a specific token. Rather than relying on a liquidity pool with a fixed amount of tokens, flash mint providers mint new liquidity specifically for the duration of the loan, and burn the minted liquidity at the end of the loan. This gives flash mint providers the ability to lend virtually unlimited liquidity without impacting the token supply.

The number of protocols offering flash mint services are small, with MakerDAO being the most popular. MakerDAO is the issuer of Dai, a stablecoin pegged to the US dollar, and flash mints allow users to borrow an arbitrary amount of Dai through the flash mint mechanism (MakerDAO 2024). The upper limit on the amount of Dai that can be borrowed is arbitrary and is set by MakerDAO governance. Flash mint providers can choose not to impose a limit, in which case it is an architectural limit that is currently $2^256 - 1$ tokens (Zeppelin Group Ltd. 2020).

A flash mint operates as follows:

1. The initiator calls a custom function on a facilitator contract, which handles the operational logic.
2. The facilitator contract calls the flash mint function on the provider contract specifying the amount and receiver address.
3. The provider transfers the requested amount to the specified address.
4. The facilitator contract uses the liquidity in a predetermined set of operations.

5. The facilitator contract returns the full amount of borrowed liquidity to the provider contract.
6. The provider contract burns the full amount of the minted liquidity.

Note the following observations:

- Flash mint providers must have mint and burn capabilities for a token. This limits the number of potential flash mint providers and the number of tokens with flash mint capabilities.
- There is no hard constraint on the amount that can be borrowed.
- There is no need to incentivize depositors to fund a liquidity pool.
- Flash mints are relatively more computationally expensive, meaning users face higher gas fees.

2.4.4 Design comparison and trade-offs

Each of the three flash loans have their own trade-offs, and each may be suitable for different purposes. The trade-offs are summarized below in **Table 1**. Section 5 introduces the known use cases of flash loans. In that section, it becomes evident that certain flash loan designs are better suited to certain operations.

Table 1: Comparison of flash loan designs

	Basic flash loan	Flash swap	Flash mint
Fees	Medium	High	Low
Token selection	Medium	High	Low
Rollover	Yes	None	None
Liquidity depth	Medium	Low	Unlimited
Gas consumption	Medium to low	Medium to low	High

3 Literature review

There is a growing body of academic and policy work on new innovations in DeFi, on topics such as automated market makers (AMM) used in Dex (Ho, Cazan and Schrumm 2024; Malinova and Park 2024). Flash loans are one of the key innovations of DeFi that have not seen much interest from policy-makers and academics, possibly due to the technology and their applications being not well understood. As far as I know, there has not been extensive documentation of their usage, and limited academic work in the economic literature documenting the applications of flash loans.

To my knowledge, all of the existing economic literature concerning flash loans focus only on Ethereum and a relatively small sample of flash loan providers. Lehar and Parlour (2022) analyze the role flash loans play in collateral liquidations, from the perspective of systemic fragility. Lehar and Parlour (2024) investigate how flash loans are used for front-running transactions pending in the public mempool.[7] Wang et al. (2021) present a brief overview of the developments in flash loans up until the time of writing.

4 Methodological approach

I approach the analytical components of this work as a descriptive empirical analysis, due to the lack of research and comprehensive and transparent existing data on the subject. Using this approach, I present a wide assortment of analysis to motivate and contextualize further work, without testing a formal hypothesis.

4.1 Data collection

I restrict the scope of this work to 11 of the most popular EVM-compatible blockchains. These blockchains are Arbitrum, Avalanche, Base, Blast, BNB, Ethereum, Fantom, Gnosis, Linea, Optimism and Polygon. They represent over 70% of the DeFi market by total value locked as of August 2024 (DeFiLlama n.d.). Focusing on these 11 chains makes the data collection process manageable, while still representing a significant portion of the DeFi landscape.

For each blockchain, I collect observations for each flash loan event, including the design, provider, facilitator contract address, initiator address and destination address as well as loan details including volume, value and fees paid. To identify flash loan providers operating on each blockchain, I use a combination of approaches and verify using a combination of developer documentation and smart contract code. Once a protocol is positively identified as a flash loan provider, I identify the event name (or function name where no event log is emitted) to identify all instances of flash loan events from a particular provider. Each of the desired data fields is subsequently extracted from the raw blockchain data for each event.

To determine the overall value of loans in US dollars, I use Dune's curated pricing data.[8] Many crypto asset markets are thin and subject to excessive volatility. To mitigate noise in the pricing data, I smooth the

7. A mempool is a pool of pending transactions waiting to be processed and written to the blockchain.
8. Dune provides a table of over 2000 unique token prices in US dollars at minute intervals. See Dune (n.d.).

price table by taking the average daily price and merging this with each flash loan's event date and token denomination.

In addition to identifying flash loan transactions, it is helpful for my analysis to classify the use case of each event. To do this, I use a combination of mapping and heuristic approaches to group events according to their use. In most instances, use cases are determined as a function of the other types of smart contracts they interacted with within a single flash loan transaction. Additional details regarding the individual use cases are outlined in **Appendix B**.

5 Results and analysis

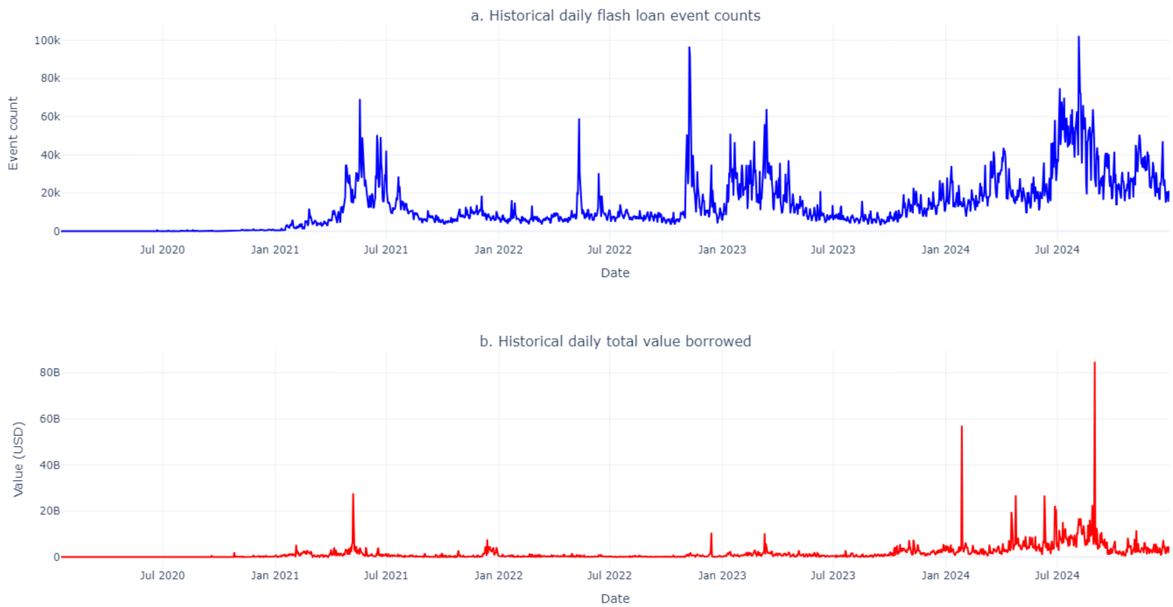
In this section I present key findings on the overall usage, use cases, users, providers and trends in the ecosystem. Each section contains necessary background information, results from the novel flash loan dataset and data-driven insights.

5.1 Overview of usage in the Ethereum ecosystem

Across the 11 EVM-compatible blockchains studied, I identify nearly 24 million unique flash loan events, facilitating over US$3 trillion in lending activity as of January 2025. Over the sample, from 2020 to the time of writing, there has been a steady increase in the number of blockchains actively offering flash loan services, the number of protocols where flash loans are actively being used and the number of tokens actively involved in flash loan operations. **Chart 1**, panel a illustrates the historical number of daily flash loan events throughout the sample. Flash loan adoption has increased throughout the sample and has been somewhat cyclical in nature. The peaks in average daily usage in 2021 and 2024 can possibly be attributed to the bull markets for cryptocurrencies over the same periods. The cause of the persistent increase in usage in 2023 is less clear, but is plausibly due in part to the adoption of the technology on blockchains with a high throughput, such as Optimism and Arbitrum.

Looking at the historical daily total value of flash loans in **Chart 1**, panel b, we see that the overall value is concentrated with the crypto bull markets in 2021 and 2024. This is largely to be expected given that, on average, cryptoassets rose in value, and there were significant increases in usage over these periods.

Chart 1: Historical daily flash loans



Sources: Dune and Bank of Canada calculations
Last observation: December 31, 2024

Table 2 provides a breakdown of flash loan activity across blockchains since the beginning of the sample, yielding significant differences between environments. Ethereum was the first blockchain to offer flash loan services but, relative to Polygon, Arbitrum, BNB, Optimism and Base, there is very little activity on Ethereum. That said, Ethereum has the highest value borrowed by more than an order of magnitude, with an average value borrowed of over US$3 million. The next closest blockchain is Optimism, with an average value borrowed of just over US$40 thousand. This stark contrast in values borrowed through flash loans in each environment is partly due to the majority of value being concentrated on Ethereum, but it does suggest that the types of activities flash loans are used for may also differ between ecosystems. This becomes more clear in Section 5.2, where I identify the different use cases across ecosystems.

Table 2: Summary statistics by blockchain

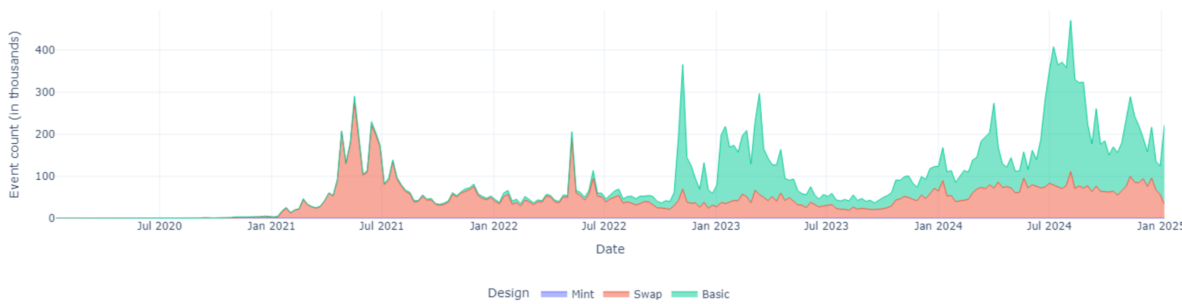
Blockchain	Event count	Total value (USD)	Mean value (USD)
Polygon	10,133,756	9,836,787,711.40	970.70
Arbitrum	3,890,310	67,725,330,080.79	17,408.72
BNB	3,263,948	51,808,845,201.95	15,873.06
Optimism	3,242,077	132,452,803,306.76	40,854.31
Base	1,609,449	7,539,433,822.85	4,684.48
Ethereum	892,837	2,736,345,948,813.36	3,064,776.60
Other	785,937	3,325,315,156.26	4,231.02

Sources: Dune and Bank of Canada calculations

Chart 2 depicts the weekly number of flash loan events broken down into the three distinct designs identified in Section 2. Interestingly, although basic flash loans were the first type of flash loan to be offered, they made up a very small portion of the overall flash loan activity in the period from January 2021 to approximately January 2023. During that period, flash swaps were by far the most common form of flash loan. This can potentially be explained by users' familiarity at that time with popular Dexes, such as Uniswap V2, Sushiswap and Quickswap (on Polygon), while lending protocols were a relatively new concept. Additionally, flash swap providers serviced a significantly wider range of tokens than the other designs did over this period and thus may have had a wider range of practical use cases.

In more recent periods of high levels of flash loan activity, basic flash loans increased in adoption relative to flash swaps. This could be a consequence of dedicated lending protocols becoming increasingly adopted in the ecosystem, a rise in the demand for deep liquidity or the relative decrease in cost of basic flash loans compared with flash swaps. Notice that throughout the sample, flash mints were very infrequently used, making up only approximately 4,000 of the 24 million distinct events. This is in part due to the limited number of flash mint providers and consequently the number of available tokens, but also due to the overall costs of using flash mints, given their increased computational complexity.

Chart 2: Weekly event counts by design over time



Sources: Dune and Bank of Canada Calculations
Last observation: January 6, 2025

5.2 Use cases

One of the most interesting questions about flash loans concerns their use cases. Indeed, the instantaneous nature of flash loans does limit their potential applications beyond that of a standard multi-period loan, to those that can be completed within a single atomic transaction. As I highlight in this section, however, there are specific applications in which flash loans provide a more compelling source of liquidity than alternative options. I identify five distinct use cases. Three of these are considered positive, and two are negative.

To help think about the decision to use flash loans, consider the borrower's profit maximization problem characterized by Equation 1. In this simple setup, a user chooses to fund their operations using a combination of capital, K, and flash loans, F. The user finds a profitable opportunity with probability, ρ, and this opportunity requires liquidity, A, to exploit. Both methods of funding are costly. Self-funding requires holding capital idle, which incurs an opportunity cost equal to the market interest rate, R. If the user chooses to fund their activity using flash loans, they face increased costs through flash loan fees, R^f, and increased gas fees, θ^f. Solving the borrower's problem tells us that flash loans are used when θ^f, R^f and ρ are low and R is high. For completeness, see the full comparative statics in **Appendix C**.

$$\max_{A,K,F>0} \rho[\pi(A) - F(R^f + \theta^f)] - KR \tag{1}$$
$$\text{s.t. } F + K \geq A$$

For each of the use cases, I present an overview of how the operation works, the role flash loans play in the operation and why flash loans make a compelling alternative to other sources of liquidity. I then present findings from the data and discuss flash loans that do not neatly fit into any of the identified use cases.

5.2.1 Arbitrage

Arbitrage is defined by Sharpe and Alexander (1990) as "the simultaneous purchase and sale of the same, or essentially similar, security in two different markets for advantageously different prices," as cited by Shleifer and Vishny (1997). Triangular arbitrage opportunities are common in DeFi markets, and given that arbitrage transactions are executed across an atomic blockchain transaction, they fit the standard definition perfectly. Flash loans are often used as a liquidity source by arbitrageurs for their arbitrage operations.

The design of DeFi exchange markets leads to frequent exchange rate discrepancies between the same token pairs. The permissionless design of many Dex protocols allows any user to create a pool used to swap tokens, in some cases with custom parameters. The result is a vast number of Dex pools, many of which overlap in the token pairs they facilitate trade between.[9] When a user makes a sufficiently large swap on any individual Dex pool, there is a price impact.[10] This throws the affected pool's exchange rate out of equilibrium with other Dex pools servicing the same token pair. This presents an opportunity for arbitrageurs.

Arbitrageurs play an important role by exploiting advantageously different exchange rates across Dex pools, bringing exchange rates back into equilibrium. **Figure 3** illustrates a simple example of a triangular arbitrage transaction, where the arbitrageur has a sufficient amount of liquidity of token A to fund their arbitrage transaction. The arbitrageur identifies an arbitrage opportunity between three different Dex pools facilitating exchange between tokens A and B, tokens B and C, and tokens C and A, respectively. The exchange rates in each pool are out of equilibrium such that by sequentially swapping A for B, B for C, and C back to A, the arbitrageur ends up with more of token A than they originally started with.

To facilitate arbitrage activity, an arbitrageur must have access to sufficient liquidity to deploy when a profitable opportunity arises. Typically, this liquidity is in the form of self-funding, which is costly. Since the arbitrageur must hold liquidity idle as they wait for opportunities, they face an opportunity cost, where they forego interest or revenue they could have generated had they locked their liquidity into a staking, or Dex protocol. In the case where an arbitrageur finds their activity using a multi-period loan, they face an additional interest rate cost.

Additional problems arise when an arbitrageur engages in arbitrage across a wide range of token pairs. If an arbitrageur wishes to engage in arbitrage between token pairs that they do not hold liquidity in, they must either acquire sufficient liquidity in each of the tokens they wish to engage with, or perform an additional swap from the denomination of their liquidity to the requisite token. Each additional swap incurs additional costs through protocol fees and gas fees.[11]

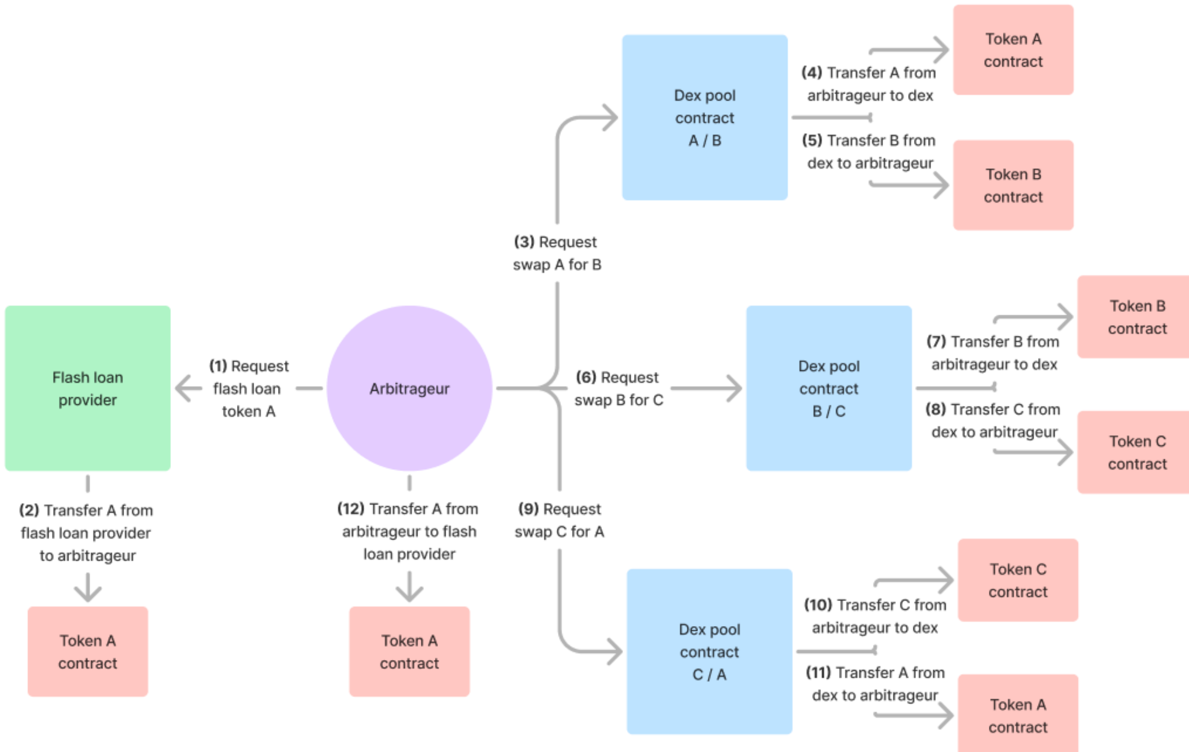
Flash loans provide a compelling alternative to traditional liquidity sources. Notice in Figure 3 that the arbitrageur uses a flash loan as the source of liquidity to fund the arbitrage trade. At the beginning of the transaction, the arbitrageur borrows liquidity in token A from the flash loan provider. After securing liquidity in token A, the arbitrageur makes the same sequence of operations as the previous example, resulting in a

9. To put the number of Dex pools into perspective, I identify over 430,000 unique Dex pool addresses across the 11 blockchains within the scope of this study. In the case of popular token pairs, many exchange pools exist that service the same token pair, both within and between Dexes.

10. The minimum swap size needed for a price impact varies among Dex pools and is typically a function of the liquidity depth and token balance in the pool.

11. Protocol fees typically range between 0.05% and 1% for popular exchanges.

Figure 3: Simple flash loan triangular arbitrage



final quantity of token A greater than the initial amount borrowed. The arbitrageur then returns the borrowed tokens to the flash loan provider, resolving their debt. The arbitrageur keeps the difference between the loan repayment and the final token A balance as profit from the transaction.

By sourcing liquidity using flash loans, arbitrageurs are able to borrow the exact required liquidity for the duration of their arbitrage operation. Flash loan fees tend to be small, and therefore are a compelling alternative source of liquidity for arbitrage activity. That said, using a flash loan is not without costs. In blockchain systems such as Ethereum, users pay gas to dedicated participants to process transactions. The amount of gas paid is proportional to the computational complexity of the transaction. Using a flash loan increases this complexity, making flash loans relatively more expensive. Additionally, some protocols charge a flash loan fee proportional to the value borrowed.

Arbitrageurs face a trade-off between flash loans and alternative sources. Flash loans can be a superior choice when:

- protocol fees are sufficiently low
- the increase in gas cost is sufficiently low
- market interest rates, and therefore the opportunity cost of alternative liquidity sources, are high
- the arbitrageur engages in activity across a wide range of tokens

• the arbitrageur faces capital constraints

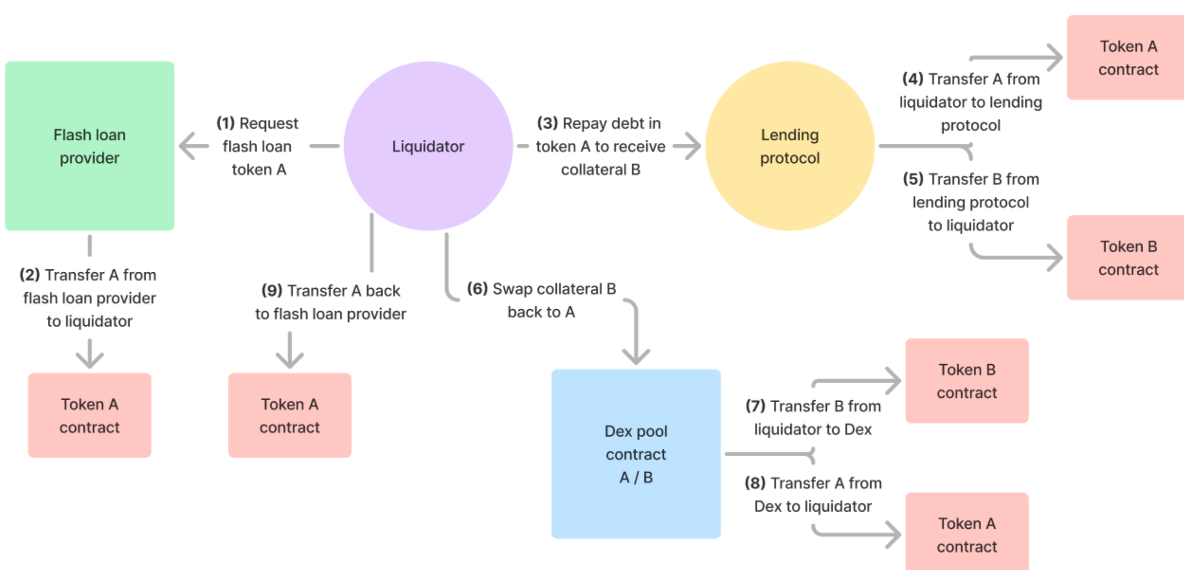
On the contrary, flash loans may not be beneficial if they are expensive (in both protocol and gas fees), if the opportunity cost of self-funding is low, or if the arbitrageur does not face capital constraints.

5.2.2 Liquidations

The second use case I identify is liquidations. DeFi lending markets are notoriously capital-inefficient, largely relying on an over-collateralized model where the loan-to-value ratio is less than 1. Due to the high volatility of cryptocurrency markets, the value of collateral occasionally falls below a specific threshold. In this situation, certain lending protocols incentivize the prompt liquidation of the position by offering liquidators a discount on the collateral in return for repayment of the debt asset.

Similar to arbitrage, liquidations require liquidity upfront. **Figure 4** illustrates the operational logic of a flash loan liquidation transaction. The liquidator first borrows liquidity in the debt asset, token A, from the flash loan provider. Once liquidity in token A is secured, the liquidator transfers token A to the lending protocol to repay the outstanding debt, and the lending protocol transfers the underlying collateral, token B, at a discounted price back to the liquidator. The liquidator swaps the liquidity in token B back to token A at a Dex, resulting in a larger quantity of token A than they originally had. The liquidator repays their outstanding balance of token A to the flash loan provider and keeps the difference as their reward for liquidating the risky position.

Figure 4: Simple flash loan liquidation



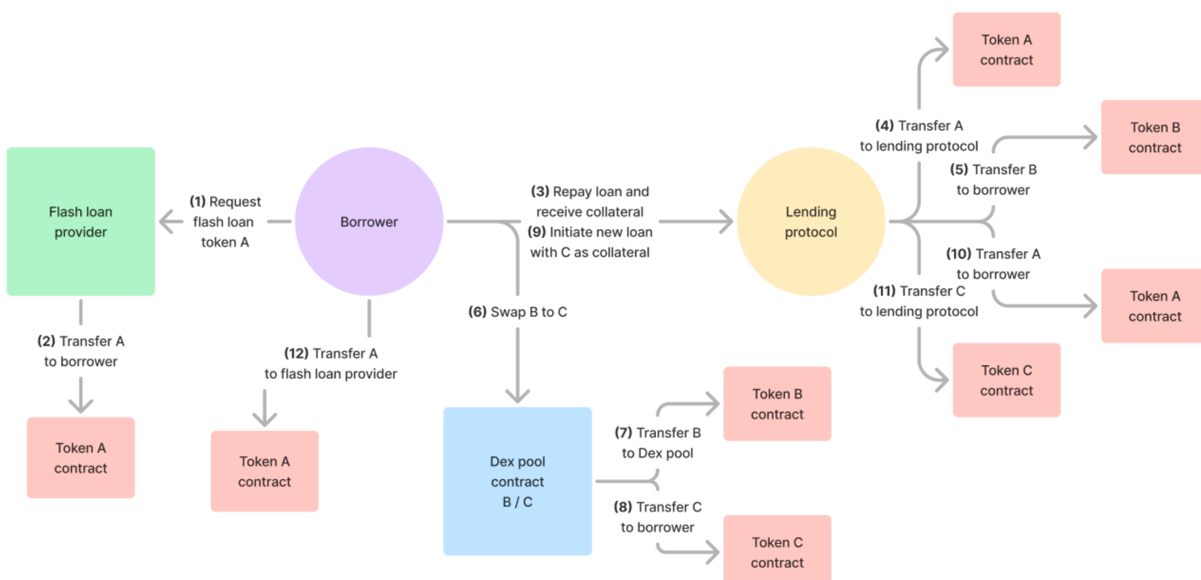
As in the case of arbitrage, the choice to use a flash loan for liquidation presents a trade-off.

5.2.3 Liquidity management

In addition to arbitrage and liquidations, flash loans are used to improve the capital efficiency of liquidity management operations. Flash loans have in particular been used to facilitate debt swaps and collateral swaps as well as repay-with-collateral operations. Each of these operations are possible without using flash loans, but flash loans can improve the capital efficiency of the operation. In this subsection, I describe how the three operations work and outline the benefit of using a flash loan over alternative methods.

Collateral and debt swaps are particularly relevant in DeFi lending markets due to the high collateral requirements to borrow. A collateral swap is a liquidity management operation where a user closes one position and opens a new one with a different collateral token, all in a single atomic blockchain transaction. **Figure 5** illustrates the operational logic of a flash loan collateral swap. Consider a borrower who has used token B as collateral to borrow token A. Suppose that borrower wants to swap their collateral denomination from token B to token C. In the illustrated example, they initiate a flash loan in token A, which they use to repay their collateralized position in token A, receiving the collateral in token B. The borrower then swaps their liquidity in token B back to token C and initiates a new collateralized loan in token A, using token C as collateral. They use their new liquidity in token A to repay their flash loan. The end result is the same debt position denominated in token A as before, with a new collateral in token C rather than token B.

Figure 5: Simple flash loan collateral swap



There are several reasons why a borrower may want to change the denomination of their collateral asset. For example, they may anticipate their collateral in token B to decrease in value relative to token C in the near future. In this case, the borrower might want to decrease their exposure to token B and increase exposure to token C, all while maintaining the liquidity in token A. In an environment without flash loans, this operation would require the borrower to have the liquidity available to close their initial position before they could reopen a position with the updated collateral. This can be particularly problematic if the borrowed token A has been used for other DeFi activities and is not available at the time.

Debt swaps are a similar example where flash loans can improve the capital efficiency of the operation. In a debt swap, a user can take a flash loan to close an existing debt position denominated in token A, then use the token B collateral they receive to open a new position denominated in token C. Similar to the collateral swap example, this could be driven by expectations about the relative return between token A and token C.

In addition to swapping either the underlying or debt asset, users may choose to use a flash loan to repay a portion of their debt, the common case being to repay with collateral. For example, a user may choose to borrow the debt asset using a flash loan, repay a portion of their debt and receive the associated collateral, then use the collateral to swap and repay the flash loan. In this case, users are able to restructure their debt without liquidating the debt asset. This can be particularly useful in the case of debt restructuring or deleveraging in volatile markets.

5.2.4 Wash trading

Unfortunately, not all use cases of flash loans are positive. As highlighted by Wang et al. (2021), flash loans play a role in enabling wash trading in DeFi markets. Wash trading is a form of market manipulation in which a user simultaneously buys and sells a financial instrument without changing their overall position. This type of manipulation can mislead potential investors by artificially increasing the transaction volumes of a token pair.

Wash trading has been banned in traditional markets in many jurisdictions. However, due to its permissionless design and lack of regulation in decentralized markets, wash trading has been increasing. Flash loans enable wash trading by providing users with access to liquidity to engage in artificial trading behaviour. In a flash-loan-enabled wash trade, a user borrows an arbitrary amount of token A, swaps token A to token B, swaps token B back to token A, and returns the borrowed amount of token A to the flash loan provider. A wash trader can swap to and from a token multiple times within a single atomic transaction, artificially increasing the volume traded between a given token pair.

Wash trading with flash loans is not without costs. Most Dex pools take a fee for each swap, so the wash trader receives a smaller amount of their debt token after each round of swaps. This cost increases as a function of the volume swapped and the number of swaps. Although flash loans do enable wash traders to artificially increase the volume traded, the high costs present a disincentive.

5.2.5 Exploits

Now, for the most obvious downside of flash loans: exploits, hacks and attacks. Many instances of attacks on the DeFi infrastructure—which are well documented by the crypto community—result in economic loss for platforms, users and service providers. DeFiLlama and ImmuneBytes (2024) provide aggregations of data documenting many of these exploits, including a classification of the exploit type, values lost and links to the original articles documenting how the exploits occurred.

A non-negligible portion of the documented attacks involves the use of flash loans. Given their novelty and recent increase in popularity, many smart contracts have vulnerabilities that can be exploited by the large liquidity volumes users can borrow through flash loans. Common types of attack according to DeFiLlama include price oracle attacks, donate function logic exploits, governance attacks and reentrancy attacks (DeFiLlama n.d.). In each case, smart contract infrastructure contains vulnerabilities that are only exposed when a user deploys significant amounts of liquidity to the protocol.

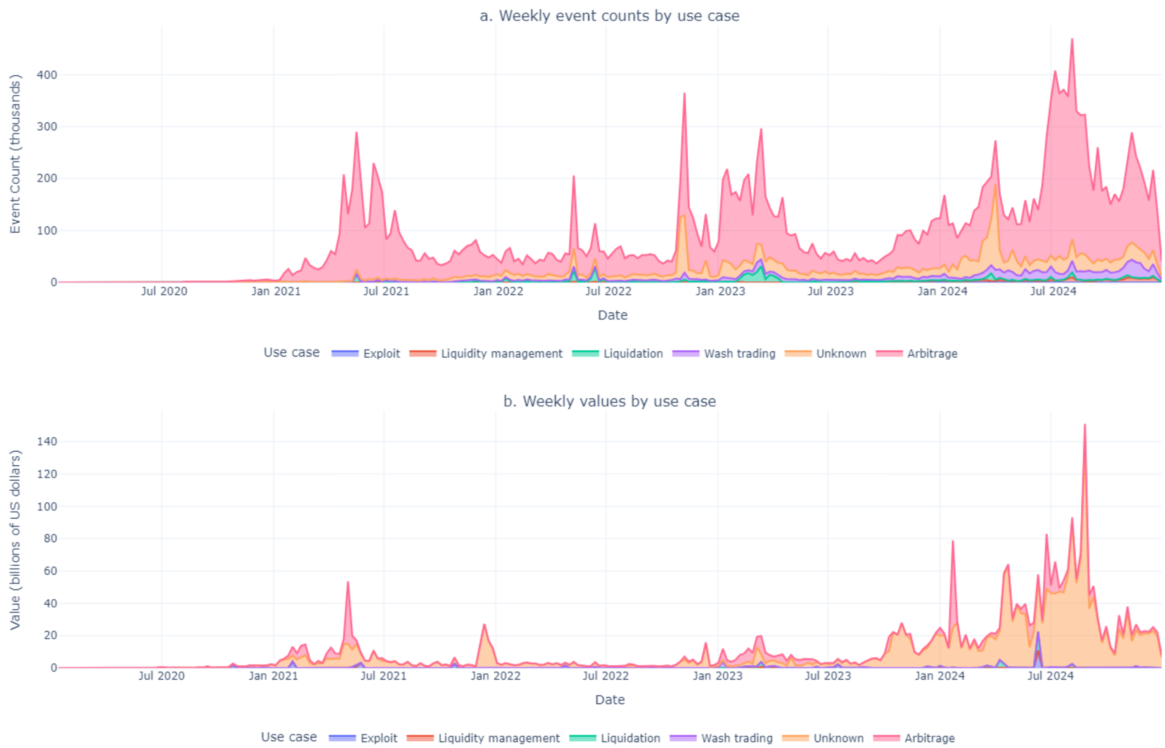
The most common type of exploit related to flash loans is a price oracle attack. Knowing how exactly this type of attack works requires a detailed understanding of several DeFi concepts. For an explanation of Dex protocols, see **Appendix A.1**.

Price oracle attacks work by using large amounts of liquidity to skew the relative price of token pairs, and then using this skewed price to borrow a disproportionate amount of another token. In DeFi, it is often useful to rely on exogenous data as a variable in smart contract code, for example pricing information. DeFi oracles are often used as a trusted source for pricing data, providing information that has direct implications for smart contract execution (Deng et al. 2024). When Dex prices are used as an input for price oracles, the output prices are prone to manipulation. Price oracle attacks with flash loans exploit the ability to temporarily manipulate sources of pricing information by deploying large volumes of liquidity to Dex pools, using the price impact to borrow a disproportionally large loan denominated in another token, and then defaulting on the loan.

5.2.6 Data

Using a combination of heuristic approaches (**Appendix B**), I classify a significant portion of the flash loan event data into one of the outlined use cases. **Chart 3**, panel a and **Chart 3**, panel b depict the weekly number of flash loan events and weekly total values of flash loans, respectively, broken down by use case.

Chart 3: Weekly flash loans by use case



Sources: Dune and Bank of Canada calculations
Last observation: December 31, 2024

Across the sample, arbitrage is consistently a top use case, with over 75% of flash loan events classified as such. Arbitrage also tends to be the primary driver of overall activity growth. This is particularly evident in the case of the 2021 and 2024 crypto bull markets. Liquidations tend to have large spikes around disruptive events such as the crash following the 2021 bull market. Flash loan event counts for wash trading, liquidity management and unknown use cases increased steadily throughout the sample.

Intuitively, there are significant differences in the value of flash loans across the different use cases. This is evident both in Chart 3 and in **Table 3**, below. This table provides a breakdown of the event counts as well as the total, mean and median flash loan values, by use case. Flash loans for arbitrage and wash trading are relatively small, with median values near US$100 or less, while exploits are on average in the millions.

5.2.7 The unknown

Of the nearly 24 million flash loan events contained in the sample, more than 13% cannot be easily classified into one of the known use cases. It is possible that a portion of the flash loans used for unknown purposes are indeed one of the known use cases, but do not fit the pattern or mapping used in the classification process. That said, the average value of flash loans labeled as unknown is significantly higher than those found in arbitrage, liquidation, liquidity management or wash trading, and are closer to the average

Table 3: Summary statistics for flash loan use cases

Transaction Class	Event Count	Total Value (USD)	Mean Value (USD)	Median Value (USD)
Arbitrage	19638232	519,700,163,120.85	26,463.69	35.70
Unknown	4436785	5,709,293,311,318.1	1,286,808.65	413.51
Wash Trading	1395751	6,510,740,077.90	4,664.69	123.49
Liquidation	450389	50,234,213,376.95	111,535.17	623.46
Liquidity Management	391270	9,978,116,572.91	25,501.87	2,321.12
Exploit	539	30,598,722,616.03	56,769,429.71	9,585,684.50

Sources: Dune and Bank of Canada calculations

value of exploit flash loans. For this reason, I suspect that many of the unlabeled flash loans might actually be exploits. Flash loan events are categorized as exploits if there is a news article on DeFiLlama or ImmuneBytes documenting the attack. It is likely that many exploits fly under the radar and do not get widely reported on, and are thus not labeled as exploits in my dataset.

5.3 Users

In this subsection, I outline the technical barriers to using flash loans in order to draw characterizations about the types of entities who use them. Additionally, I present my findings from the blockchain data and describe the optimization problem these entities face in their decision to use flash loans as a liquidity source.

5.3.1 User characterization

Flash loans are a complex tool native to an even more complex DeFi ecosystem. The significant technical barriers faced by flash loan users allow us to characterize the types of entities that use them. To illustrate, consider the simple example of flash loan arbitrage presented in Section 5.2.1, where a user exploits a triangular arbitrage opportunity between three Dex pools. Refer back to Figure 3 for an illustration of flash loan arbitrage.

Before an arbitrageur can submit their initial transaction to the network, two prerequisites must be in place. First, the arbitrageur must have access to a facilitator smart contract to handle the operational logic. In the example above, this is the arbitrage contract. These facilitator contracts are often custom smart contracts written by the user to facilitate a specific activity. Second, the arbitrageur must be able to effectively scan the DeFi network for arbitrage opportunities in real time. To do this, they need advanced knowledge of DeFi markets, blockchain data sources and computer programming skills.

The complexity described above refers specifically to flash loan arbitrage. Other flash loan operations have similarly complex knowledge and skill requirements. Exploits, for example, require users to have a nuanced technical understanding of smart contract vulnerabilities, in addition to the fundamental skills required to use the technology. With these established complexities involved in using flash loans, we are able to characterize the types of entities that use flash loans.

Flash loan users are generally knowledgeable about DeFi markets and infrastructure, understand smart contract design, and are skilled at computer programming. Several activities related to flash loans are both time-sensitive and competitive in nature, suggesting that users successful in these types of activities are highly sophisticated. Malicious actors who use flash loans for smart contract exploits are highly knowledgeable about the nuanced technical aspects of blockchain infrastructure and smart contract vulnerabilities. Overall, it is reasonable to conclude that flash loan users are generally highly sophisticated actors.

5.3.2 User data

Estimating the number of users of flash loans, or other blockchain technologies more generally, is not a straightforward task. The challenge lies in the open-access and permissionless design of blockchains, where users are free to create and use multiple EOA addresses. Since a single user can be represented in the data by multiple unique addresses, EOA activity should be interpreted as an upper bound on the number of users. Alternatively, we could use the address of the smart contract that made the flash loan function call. This approach, however, has its own issues since a single user can use multiple smart contracts, and a smart contract can be used by multiple users.

The flash loan dataset contains, for each distinct flash loan event, the address of the EOA that initiated the transaction and the facilitator contract that called the flash loan function.[12] These two metrics can be used together to derive a rough estimation of the number of flash loan users. **Chart 4** provides time-series data on the number of EOA addresses that initiated a flash loan transaction and the number of facilitator contract addresses that successfully initiated a flash loan function call, across the full sample of flash loan events. Panel a contains the monthly number of unique addresses of each type, and panel b contains the cumulative amount.

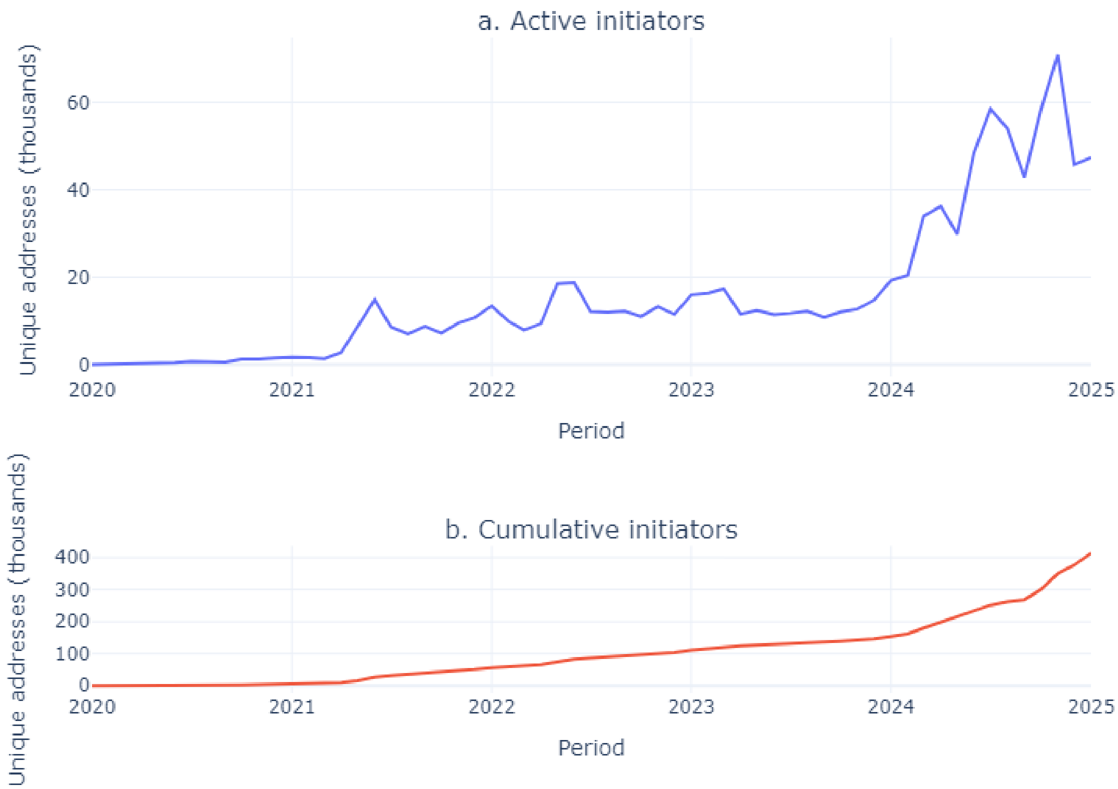
Chart 4 shows a significant uptick in active initiators in the last quarter of the sample. This is likely the result of multiple changes to the ecosystem, most notably the rise of dominant layer-2 EVM blockchains and the recent introduction of new blockchains.[13] Take the Base blockchain, for example. Base launched to the public in late 2023 and has since gained significant traction, exhibiting some of the highest transactions per second and user operations per second (L2Beat n.d.). Both of these metrics suggest that layer-2 blockchains such as Base are onboarding large volumes of users to the ecosystem, explaining the uptick in active EOAs. Similarly, the uptick in facilitator contracts is potentially driven largely by activity on Base.

One interesting result from the user data shows that a small fraction of users operate across multiple blockchain ecosystems. EVM blockchains are consistent in their derivation of blockchain addresses as a function of public keys passed through the Kekkak-256 hashing algorithm. Thus, when a user generates an address from their public key on Ethereum, Polygon or Base, they have the same blockchain address.

12. I define an **initiator** as the address of the EOA that initiated the transaction, and the **facilitator** as the address of the smart contract that called the flash loan function.

13. Layer-2 blockchains are scaling solutions of the Ethereum (layer-1) blockchain. These systems work by processing transactions on a distinct layer-2 blockchain and registering the transactions to the Ethereum blockchain periodically.

Chart 4: Flash loan initiators over time



Sources: Dune and Bank of Canada calculations
Last observation: January 1, 2025

This allows us to trace EOA addresses across multiple blockchain ecosystems. **Table 4** below illustrates the number of EOA addresses across the sample that operate on a different number of blockchains. While the majority of EOA addresses only actively use flash loans on a single blockchain, there is at least some evidence of users operating across multiple ecosystems. This is relevant to the upcoming discussion of flash loan activity drivers in Section 5.5.

Flash loan activity, particularly in the case of flash loan arbitrage, tends to be increasingly competitive over time. **Chart 5** shows the 365-day rolling average Herfindahl-Hirschman index (HHI) for flash loan arbitrage market share by event count, calculated at the level of transaction initiator. Competition among flash loan arbitrageurs on the established blockchains Ethereum and Polygon is high, with a rolling HHI below 1,000 since January 2022. Notice that, in the period following the introduction of flash loans on each blockchain, there tends to be an increase in HHI. This suggests that for a short period following the initial introduction of flash loans, activity is dominated by a few users before becoming mainstream.

Interestingly, for Arbitrum and BNB, the trend reverses toward the end of the sample. I suspect that the increase in concentration of flash loan arbitrage activity among a few dominant users could be driven by a structural change favoring specific arbitrage strategies, for example, maximal extractible value (MEV) (see subsection 5.5.1). Additional work is needed to conclude what is driving concentration and whether or not

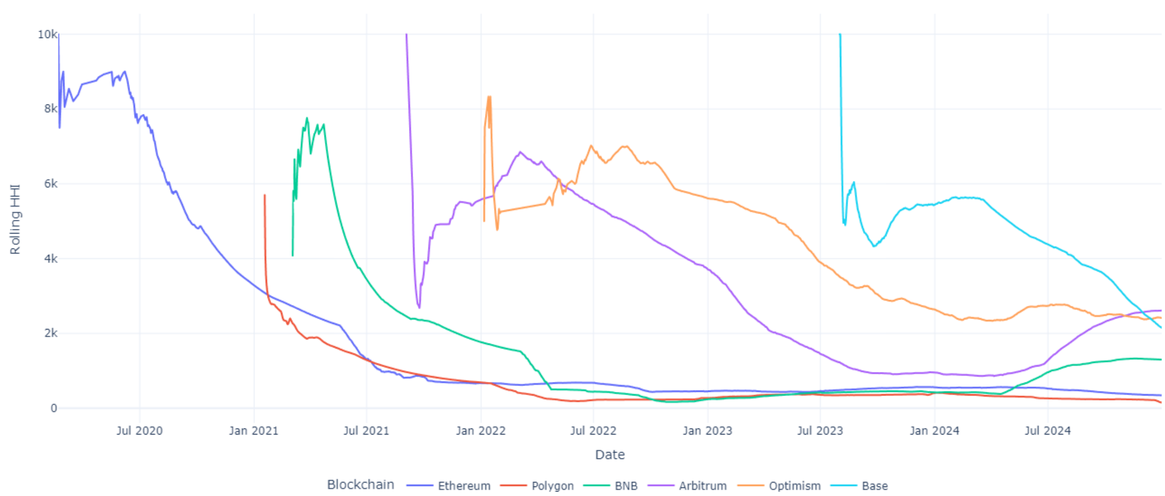
Table 4: Multi-blockchain users

Number of blockchains used	Number of initiators
1	337,365
2	20,492
3	4,189
4	887
5	254
6	80
7	44
8	5
9	5
10	5

Sources: Dune and Bank of Canada calculations

it is persistent.

Chart 5: 365-day rolling Herfindahl-Hirschman index by blockchain over time



Sources: Dune and Bank of Canada calculations
Last observation: December 31, 2024

5.3.3 The decision to use flash loans

Flash loans provide a compelling alternative source of liquidity for certain atomic use cases. That said, this is not always the case, and users weigh the costs against the benefits to determine if flash loans are the appropriate tool for their scenario. When deciding whether or not to use a flash loan, rational users choose the option that maximizes their profit from the transaction. To illustrate this profit maximization, I again point to the example of a simple triangular arbitrage.

To understand the profit-maximizing choice faced by users, we must first understand the costs of using a flash loan. Flash loan providers in many cases charge a fee proportional to the value of the loan, typically ranging between 0% and 0.3%. Additionally, including a flash loan in a transaction increases the computational complexity of the transaction, which has a marginal impact on the fees the user must pay to the network to process the transaction. This marginal increase in gas fees can be significant, as highlighted by flash loan transactions on Ethereum, where between 60% and 90% of the gas consumed tends to be directly related to the flash loan logic. These costs are weighed against the cost reductions (or profit increase) of using a flash loan.

Arbitrageurs who opt not to use flash loans also face costs, although these costs are not as direct as those associated with using flash loans. One of the key benefits of flash loans is the access they provide to deep liquidity. In instances where there are large price discrepancies between Dex pools, it can take a greater amount of liquidity to fully exploit the opportunity than the arbitrageur has access to. In this case, the arbitrageur can increase their profit by borrowing a flash loan large enough to fully resolve the price discrepancy, resulting in a larger profit to the arbitrageur. If the increase in the profit from realizing the full arbitrage opportunity outweighs the marginal increase in total costs, the arbitrageur would likely choose to use a flash loan.

As the borrower's problem highlights, the arbitrageur faces an opportunity cost of holding idle capital for the purposes of funding arbitrage activity. If an arbitrageur chooses to self-fund, they forego interest earnings from locking liquidity into a productive activity. If arbitrageurs consistently engage in arbitrage activity that requires tens of thousands of dollars' worth of liquidity to fully execute, this opportunity cost can be significant. If an arbitrageur specializes in activities requiring deep liquidity to resolve, it may be beneficial to choose flash loans if the expected aggregate cost of borrowing is less than the expected return of staking or depositing the liquidity.

5.4 Providers

The data show that the number of flash loan providers has steadily increased over time. In this subsection, I dive deeper into the ecology of flash loan providers, break down the incentives to offer flash loans, examine the two-sided nature of flash swap and basic flash loan providers and present key findings from the data.

5.4.1 Ecology of flash loan providers

Flash loan providers are protocols with access to deep liquidity that offer flash loan functionality. Generally, these providers operate in other primary business operations, such as Dex, collateralized lending or collateralized debt position operations. They provide flash loans as a value-added service. The reason we do not see dedicated flash loan providers where flash loans are the sole business objective becomes clear throughout this section.

With the exception of flash mint providers, flash loan providers require access to deep liquidity. This liquidity is generally solicited from the market by offering a rate of return, or a share of the protocol's profitability. Flash loans are inherently not a high-revenue activity. Because of this, a dedicated flash loan provider would not be able to offer sufficient returns on liquidity to incentivize liquidity providers. What we see in the data is that all of the major flash loan providers primarily operate in a high-revenue sector and distribute the fees from their primary business back to liquidity providers.

The reason flash loan operations cannot drive sufficient revenue is because, with the exception of the cost of soliciting liquidity, the marginal cost of providing a flash loan is zero.[14] Flash loan providers face an upfront development cost to create the smart contract infrastructure to facilitate flash loans, but there is no operational cost past this stage. Gas fees are paid by the user, and there is no opportunity cost to providing flash loans since the liquidity position does not change.

Once a protocol has sufficient liquidity and the requisite infrastructure, they compete among flash loan providers to attract business. Providers compete on computational efficiency, protocol fees, liquidity depth and token selection. They are likely to consider offering flash loans if they plan to charge a fee and thus increase their overall revenue, or if they believe that offering flash loans will have a positive impact on their other revenue-generating business.

Flash mints are a unique case, where the provider does not need to solicit liquidity from the market. Rather, a flash mint provider issues new tokens specifically for the duration of the loan. There are only a couple of flash mint providers, and they are not used often. In both cases, fees are set to zero. The incentives for a flash mint provider to offer flash loans are likely associated with an anticipated increase in token adoption across the DeFi ecosystem.

5.4.2 Provider data

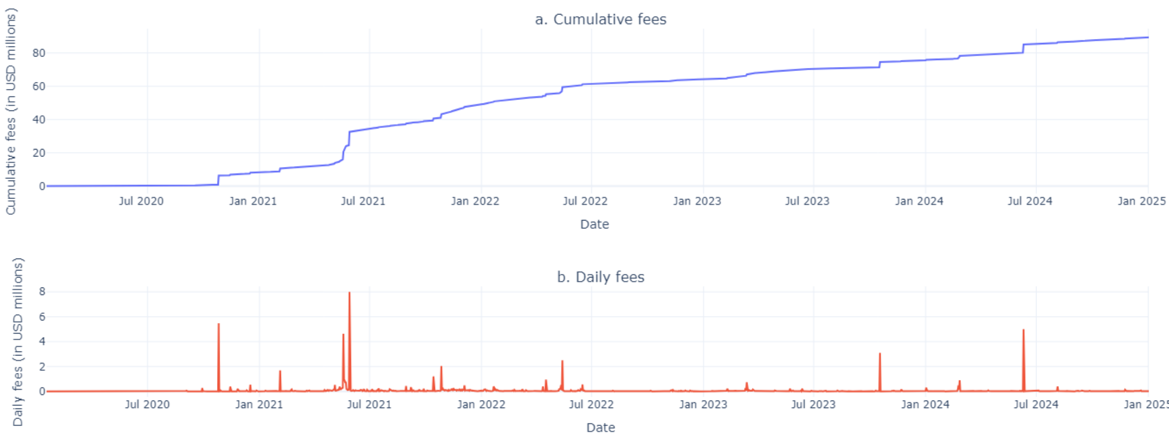
The first observation from the data is that flash loan services can provide protocols with a meaningful extra income stream. In **Chart 6**, panel a and panel b show, respectively, the cumulative and daily fees generated by flash loan providers throughout the sample. Over the lifetime of the technology, providers have generated over US$90 million in revenue. This works out to an approximate average fee of 0.003% of loan value. This is small relative to the total value of lending activity facilitated using flash loans. However, considering that the marginal cost of offering flash loan functionality is zero, this revenue should be considered as a bonus.

One interesting pattern from Chart 6 is that much of the fee revenue is generated from large, one-time flash loans. In some cases, these big revenue events can be attributed to exploits, and others to flash loans with unknown use cases. If we remove the exploits from the sample, the total revenue generated drops to approximately US$60 million. Removing unknown use case transactions further reduces the cumulative fees generated to just over US$40 million.

Two of the key parameters by which flash loan providers compete are on the cost side of the equation. These costs can be broken down into protocol fees and gas fees. Across the sample, 18 of the 93 unique providers collected zero fees throughout. Overall, the average protocol fees paid were very small, with both median and mean fees paid close to zero. The total cost of a flash loan can to a great extent be attributed to the gas fees of the protocol. One potential explanation as to why providers may choose to offer flash

14. Since flash loan providers do not in any case solicit liquidity with the sole purpose of providing flash loans, but rather for a primary liquidity-intensive purpose, it is reasonable to assume that the costs of soliciting liquidity are not a consequence of offering flash loan services.

Chart 6: Protocol revenue from flash loans



Sources: Dune and Bank of Canada calculations
Last observation: January 1, 2025

loans even though the fees are low could be that flash loan services increase adoption of their platform. Additional work is needed to understand if flash loan services indeed do increase platform adoption.

Across the sample, the mean and median cost of gas for a flash loan transaction are US$0.02 and US$0.03, respectively. Providers vary significantly in their gas efficiency, as illustrated in **Box 1**, below. **Chart 1-A** shows the proportion of gas consumed within the aggregate flash loan transactions over a weekly period, broken down into gas consumed by operations directly involving the flash loan contract and those not involving the flash loan contract for Aave V1.[15] **Chart 1-B** shows the same information for Sushiswap V2.

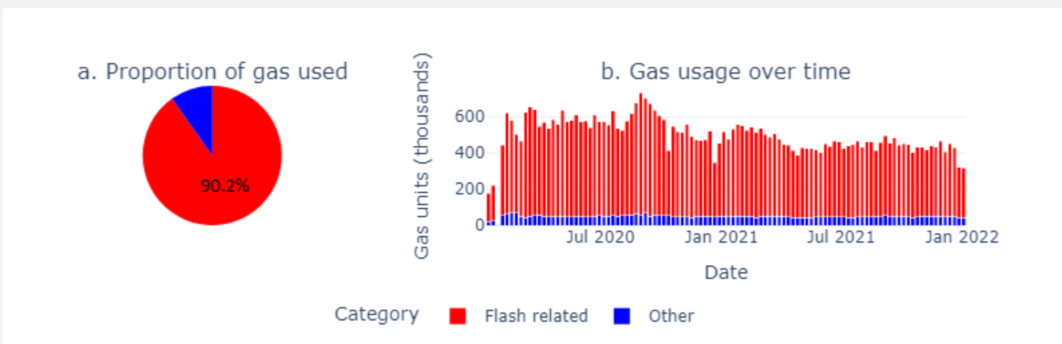
15. Ethereum transaction data include the amount of gas consumed at each operation within a transaction. The amount of gas involved in the flash loan logic is estimated as the sum of the gas consumed in sub-operations, where the flash loan contract is receiving an instruction or sending an instruction to another contract.

Box 1: Relative gas consumption between protocols

Not all flash loan providers are equal when it comes to relative gas consumption for a flash loan transaction.[16] The blockchain data provide the units of gas consumed at each step in a transaction. I classify operations as ”flash related” if they directly involve the flash loan contract address as either the ”sender” or ”receiver.”[17] Aggregating the flash-related and non-flash-related gas consumption over a period gives us an idea of what proportion of the overall gas consumption is due to the flash loan operations. If a protocol has high proportions of gas labeled as flash-related, it is likely that the protocol's flash loans are more computationally complex, and therefore more expensive.

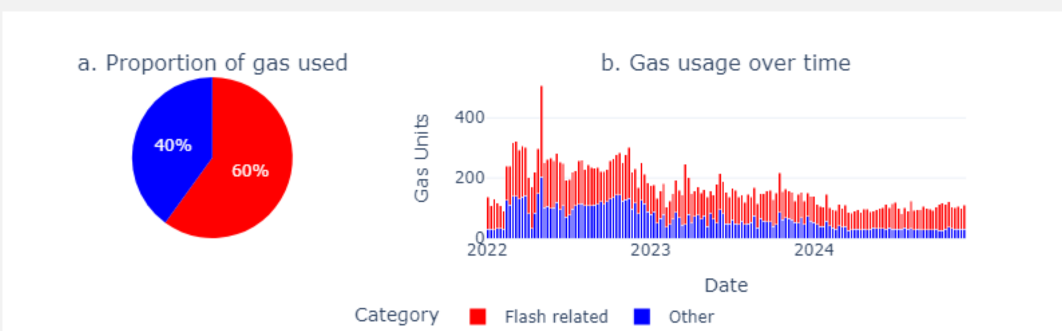
Chart 1-A and **Chart 1-B** show a breakdown of the gas consumed in Aave V1 and Sushiswap V2 flash loans, respectively, over time. Overall, it appears that Aave V1 has more computationally complex flash loans and is therefore more costly to use.

Chart 1-A: Aave V1 relative gas consumption



Sources: Dune and Bank of Canada calculations
Last observation: January 3, 2022

Chart 1-B: Sushiswap V2 relative gas consumption



Sources: Dune and Bank of Canada calculations
Last observation: Dec 31, 2024

16 . Gas is a unit measuring to the computational complexity of a transaction. This is distinct from a gas fee, which is a monetary fee used to pay for gas units. The gas fee is calculated as units of gas times the gas fee. Here we look at the number of units of gas consumed, to understand the relative gas consumption of different protocols irrespective of gas price.
17 . Ethereum trace data includes a ”sender” and ”receiver” field for each operation in the transaction execution, indicating which smart contracts are involved in each operation. The ”sender” is the address calling a function, and the ”receiver” is the address containing the function being called.

5.5 Trends

Both the data and discussions surrounding flash loans and related topics reveal several key trends in the flash loan sector.

5.5.1 Role in maximal extractable value (MEV)

MEV refers to the “maximum value that can be extracted from the block production process in excess of the standard block reward and gas by including, excluding, and changing the order of transactions in a block” (Ethereum Foundation 2025c). MEV is one of the most contentious topics in blockchains today, and flash loans play an important role in enabling certain MEV operations.

Because of different block production processes between blockchains, the particular MEV operations used vary between ecosystems. That said, certain types of MEV operations enabled by flash loans are possible across several popular systems, such as Ethereum and other EVM-compatible blockchains. To understand the role of flash loans in MEV, consider flash loan arbitrage and liquidation activity outlined in subsection 5.2 and the following example.

The Ethereum proof-of-stake consensus mechanism relies on dedicated network participants to build and validate new blocks. A pool of validators is selected every epoch (32 slots), and for each slot a validator is selected through a pseudo-random process to propose a block for that slot (Ethereum Foundation 2025c). A common example of MEV takes place through this block proposal process, where a sophisticated validator chooses to, for example, scan the pool of pending transactions for those resulting in a large price impact on a Dex pool and include their own arbitrage transaction immediately after. Using a flash loan expands available liquidity and thus increases the number of profitable MEV opportunities.

An alternative example could be a block proposer who scans the network for incoming profitable liquidations, where sophisticated liquidators have identified an opportunity and submitted a transaction to the network. If the liquidator does not take additional precautions to keep the opportunity from being publicly broadcast to the network, an opportunistic block producer may see the pending transaction, determine that it would be profitable to replace the liquidation transaction with their own using a flash loan for liquidity, and capture the liquidation profit for themselves. This could similarly be done for known exploits.

The ethics of this MEV are not clear. Regardless, it is important to acknowledge that flash loans do increase the accessibility of this type of activity for opportunistic block producers.

5.5.2 Flash loan activity drivers

In this subsection, I qualitatively discuss certain exogenous variables associated with a change in the frequency of flash loan activity. There are several potential explanations for fluctuations in flash loan activity, particularly when flash loans are used for arbitrage or liquidation operations.

DeFi arbitrage opportunities arise when swaps take place on an exchange of sufficient size to have a price impact, resulting in exchange rate disequilibrium between the affected pool and other pools servicing the same token pairs. These exchange rate discrepancies occur at a greater frequency when there are high levels of token speculation and trading activity in decentralized markets. It is thus likely that flash loans happen more often in periods with high volumes of trading activity on Dexes. This mechanism is corroborated by the flash loan data, which show that the number of flash loans in a period increased in the number of Dex swaps in the same period.

On the other hand, when flash loan arbitrage opportunities are sufficiently costly, the frequency of profitable flash loan arbitrage opportunities decrease, and there is a corresponding decrease in the volume of flash loan activity. When blockchain networks are congested, gas prices increase. Given that flash loans are computationally expensive, increased gas prices make flash loan arbitrage transactions less profitable, and thus flash loan activity decreases. This mechanism is similarly shown in the data, where flash loan activity decreased in the average price of gas over the same period.

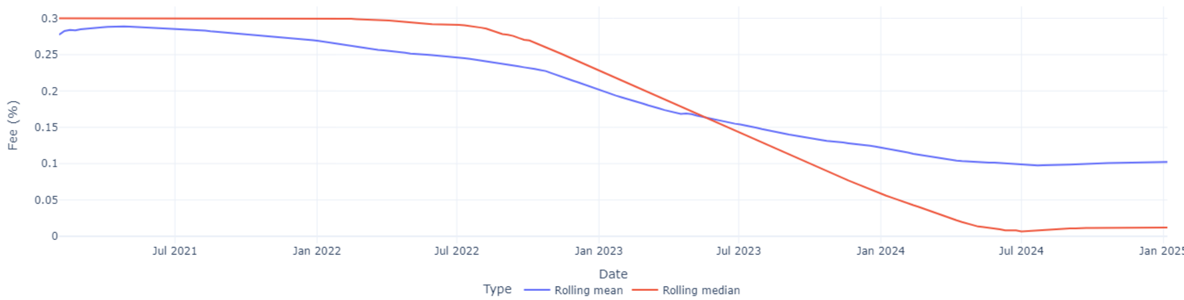
Flash loan liquidation activity experiences both a similar effect to those listed above and an additional driver. When prices of popular collateral cryptoassets—for example, Ether and its related liquid staking tokens, Bitcoin, and others—are volatile, loans become eligible for liquidation at greater frequency, and flash loan liquidation activity increases.

5.5.3 Race to zero fees

The dataset shows that over time the average fee charged by the protocol as a percentage of the loan value has consistently decreased.[18] This is illustrated by **Chart 7**. This finding is consistent with the view that there is an ongoing race to zero fees, which has reasonable theoretical support.

18. An exception occurs at the beginning of the sample, where there is a limited number of providers and fees are set to zero.

Chart 7: Average daily protocol fees over time



Sources: Dune and Bank of Canada calculations
Last observation: Jan 6, 2025

Flash loan providers face zero marginal cost to offer flash loans. There is a fixed cost associated with initially developing the smart contract infrastructure to facilitate flash loans. However, since the liquidity position does not decrease from flash loans at a transaction level, there is neither a marginal cost paid by the provider—because the user bears the gas cost—nor an opportunity cost—because the liquidity position does not change at the transaction level. Given sufficient levels of competition among flash loan providers, the protocol fee approaches zero. Particularly when protocols generate revenue from alternative business operations (trading, collateralized lending, etc.), there are no downsides to offering flash loan services with the pooled liquidity.

5.5.4 Ecosystem resilience

Flash loans do enable malicious actors to exploit smart contract logic by providing virtually unlimited liquidity for specific operations, as outlined in subsection 5.2.5. Some smart contracts, particularly in the period following the introduction of flash loans, contained vulnerabilities that malicious actors could exploit using such loans. This has historically led to a significant loss of funds, as protocols containing the vulnerabilities suffered attacks.

The theft of funds is clearly a negative consequence of flash loans. But it is important to acknowledge that, once a vulnerability is recognized, the ecosystem does eventually adapt. The data show there are typically one or more attacks following a new design. However, after a few major attacks, the broader ecosystem adapts, and value moves to more secure contracts. This pattern suggests that, over time, network participants do become resilient to vulnerabilities related to flash loans and that, although there is some short-term risk, the overall resulting system is also more resilient.

6 Discussion

The previous sections establish the unique nature of flash loans, their suitability for certain use cases and their growing demand in the DeFi ecosystem. I take this section to provide additional context regarding flash loans and why understanding them is relevant from both research and policy perspectives.

6.1 Ecosystem benefits

The provision of flash loans has several potential benefits across the DeFi ecosystem:

- **Increased investment capital**—Flash loans allow users to borrow liquidity specifically for an atomic use case, such as arbitrage or liquidation, which relaxes the requirement to hold idle capital. If flash loans see widespread, low-cost adoption, this can lead to an increase in the overall liquidity available for investment. Capital availability could thus improve for investment across the ecosystem.
- **Efficient pricing**—Flash loans have the potential to increase competition in arbitrage markets by removing barriers to entry and capital constraints for arbitrageurs. These improvements could lead to increased price efficiency in DeFi markets.

6.2 Infrastructure design and tokenization

Currently, flash loans are only available on blockchains, but the underlying technology enabling flash loans is not unique to these systems. Atomic transactions are a concept borrowed from database systems, referring to an irreducible sequence of database operations where either every operation in the sequence successfully executes, or none of it does. As financial market infrastructure continues to digitize, it is feasible that flash loan functionality may be possible. This is exemplified by the ongoing discussions around tokenization.

Tokenization is becoming an increasingly relevant topic for central banks around the world, largely motivated by the emergence of popular decentralized ledgers such as Ethereum and Solana. The Bank for International Settlements and the Committee on Payments and Market Infrastructures highlight that tokenization can change existing financial market structures by providing platform-based intermediation across the end-to-end life cycle of financial assets (Bank for International Settlements and Committee on Payments and Market Infrastructures 2024). Depending on the technical specifications of a system for tokenized assets and money, flash loans may be possible and applicable to a similar range of operations as seen in DeFi markets.

Take, for example, a future system where tokenized money, tokenized securities and multiple security exchanges exist on one ledger, and tokenized securities are cross-listed on multiple exchanges. Flash loans could present a source of low-cost liquidity of tokenized money. If the price of asset x is lower on exchange A than asset X on exchange B, then a user could borrow money to purchase X at the lower price and sell on the more expensive exchange, bringing the market into equilibrium.

6.3 Financial stability implications

Flash loans have the potential to increase systemic risks to the existing financial system. The particular risk mechanism depends on how the technology is integrated and can generally be broken down into direct and contagion risks.

Direct risks:

- **Flash loan adoption**—Given the requisite technological infrastructure and interoperability within the existing financial system, if flash loans or tools with similar functionality become mainstream, unknown systemic vulnerabilities may arise.
- **Blockchain integration**—If financial institutions begin to interact directly with the decentralized financial system through smart contract development, they may face associated risks. Vulnerabilities based on both flash loans and non-flash loans would pose a risk to financial institutions that develop on-chain services.

Contagion risks:

- **Blockchain asset integration**—Blockchain-based assets are becoming increasingly integrated with the traditional financial sector, potentially exposing the existing financial system to contagion risks of flash-loan-based exploits in the DeFi ecosystem. In 2024, the United States passed milestone legislation approving the issuance of Bitcoin and Ether spot exchange-traded funds, which have since gained notable attraction among traditional investors. Large exploits and volatility related to flash loan activity may, particularly in the case of Ether, see a pass-through to asset prices, which could have financial stability implications for the broader ecosystem. Additionally, the value of DeFi assets is in many cases a function of a business objective, which may face risks due to flash loan technology.

7 Conclusion

Flash loans are an interesting technological innovation that build on blockchain architecture. This paper provides an overview of flash loan technology, documents its use in DeFi ecosystems and offers preliminary analysis to motivate further work. My novel dataset provides a comprehensive and transparent overview of flash loan usage across the Ethereum-compatible DeFi ecosystem. Descriptive empirical analysis on the dataset quantifies the known use cases, users and providers, and it identifies key trends. My data and results contribute significantly to the existing literature on flash loans and provide a starting point for academics and policy-makers to understand the technology.

As financial market infrastructure modernizes and blockchain technology integrates with the existing financial infrastructure, it will be important to understand the risks and benefits of this technology from a policy perspective. Further technical research is needed to understand whether or not flash loan functionality is feasible on existing financial market infrastructure systems. Similarly, further work on the economics of flash loans is required to better understand the trade-offs of adopting the technology into existing systems.

Appendix A: Blockchain concepts

A.1 Protocols

Smart contracts serve as the building blocks for modern DeFi protocols. A protocol refers to a collection of smart contracts that operate under the same umbrella to achieve some desired functionality. Many of the largest DeFi protocols are designed to mimic or improve upon financial service offerings seen in the traditional financial system. In this section, I define three key types of protocols necessary for understanding flash loans.

A.1.1 Lending

Lending protocols are a collection of smart contracts designed to facilitate lending and borrowing activity on a blockchain. This activity takes place via a liquidity pool, where lenders (liquidity providers) lock their assets in exchange for a specified rate of interest. Borrowers (liquidity users) can then borrow assets from the liquidity pool in exchange for a fee. Flash loans are one example of the lending activity that takes place in the DeFi ecosystem, but lending protocols also offer longer-duration loans as well.

Lending in a decentralized and anonymous ecosystem presents a challenge because there is no legal system to keep account and mitigate liability in the event of a default. There are multiple different approaches to mitigating this issue, but the most common is by requiring over-collateralization to take a loan. This is the approach taken by Aave, one of the most popular lending protocols with over US$20 billion locked into liquidity pools across eight blockchain networks.

A.1.2 Decentralized exchange

Decentralized exchange (Dex) protocols are designed to facilitate the exchange of on-chain assets. Dex protocols typically have a complex smart contract structure, where different smart contracts have different roles in the Dex system. For this analysis, it is important to understand two functionalities typical of Dex protocols: the pool factory contract and the liquidity pool contract. As the name implies, pool factory contracts are responsible for creating liquidity pools. Liquidity pools are the contracts responsible for facilitating exchange between a number of cryptoassets (tokens).

Dex liquidity pools allow users to exchange one token for another at a price (exchange rate) determined by the liquidity pool as a function of the tokens in the pool. The exchange rate mechanism used by many popular DEX protocols is an automated market maker (AMM), and the body of literature about this mechanism is growing. AMMs automatically adjust the exchange rate to account for changes in the token balances in the pool, by increasing the exchange rate of token A to token B when token A decreases relative to token B.

One last important point about the Dex protocol structure is that liquidity pools can be created for any fungible asset on the blockchain, as long as the pool is able to attract sufficient liquidity to operate. The decision-making structure about which tokens to service varies by Dex, but in some cases users are free to interact with the pool factory contract to create a liquidity pool for the exchange of niche tokens.

A.1.3 Oracle

A fundamental issue in DeFi is the disconnect between the blockchain and the real world. Oracle protocols are designed to address this issue, where a trusted third party takes real-world information (such as stock prices, election results, etc.) and publishes it on-chain where the DeFi ecosystem can access it. Smart contracts can then use it as an input in their infrastructure.

While oracles were originally used to bridge off-chain information onto the blockchain, they have evolved to be trusted sources of on-chain asset exchange rates. As an example of how this works, the oracle looks at a liquidity pool used to facilitate the exchange of two distinct cryptoassets. The oracle contract would monitor the exchange rate offered by the liquidity pool, and other contracts would point to the oracle contract to get an exchange rate between the two assets.

A.2 Tokens

In the context of Ethereum and EVM-compatible blockchains, a token is defined as a representation of anything virtual on the blockchain (Ethereum 2025b). This definition encompasses a wide range of possibilities, but for this work, a token is a digital representation of value contained in a smart contract. It is somewhat like a smart-contract-based ledger system.

To ensure interoperability of tokens on the network, the Ethereum community implements technical standards through formal proposals known as Ethereum Requests for Comment (ERCs). Flash-loan-compatible tokens generally fall under the ERC-20 standard for fungible tokens. Ethereum (2025b) explains that this standard ensures the ability to:

- ”transfer tokens from one account to another
- get the current token balance of an account
- get the total supply of the token available on the network
- approve whether an amount of tokens from an account can be spent by a third-party account”

One common category of ERC-20 tokens that is particularly relevant for discussing flash loans is stablecoins. Stablecoins are designed to maintain a peg to a fiat currency (typically to the US dollar) through a variety of methods, including fiat collateralization, cryptocurrency stabilization and algorithmic supply adjustment.

Appendix B: Flash loan events

To build a dataset of flash loan events, I first needed to identify flash loan providers on each blockchain network. The identification process was two-fold. First I identified popular flash loan providers, based on market research. News articles, web pages and blog posts pointed to several popular providers. Second, I used string matching on decoded function and event names to find any protocol that included the word flash.

Once I had a list of potential flash loan providers, I used individual protocol white papers, developer documentation, smart contract code and block explorers to verify whether or not each provider's events were truly flash loans.

B.1 Event classification

Each flash loan event in the dataset receives a classification label: arbitrage, liquidation, liquidity management, exploit, wash trading or unknown. The classification takes place at the transaction level and is a function of the contract interactions taking place in that transaction. In cases where a single transaction contains multiple flash loan events, each flash loan event in the transaction receives the same label.

B.1.1 Arbitrage and wash trading

Flash loan events are positively classified as arbitrage based on the following heuristic: If all event logs not related to flash loans in a transaction containing a flash loan are emitted only by contracts known to be involved in the swapping of tokens, and the transaction involves at least two swaps, the transaction is an arbitrage transaction. Contracts known to be involved in swapping activity are Dex pool contracts, Dex aggregator contracts and ERC-20 token contracts. Any transaction containing a log event emitted from a contract not known to be involved in token swaps cannot be classified as arbitrage.

Transactions are labeled as wash trading using a heuristic approach similar to that for arbitrage: If all event logs not related to flash loans in a transaction containing a flash loan are emitted only by contracts known to be involved in the swapping of tokens, and the transaction only interacts with a single Dex pool contract, then the transaction is considered to be a wash trade. This approach is based on the assumption that wash traders do not engage in wash trading across multiple pools in a single transaction.

Note that neither of the above approaches guarantee a perfect classification into either category; rather, it is a likely estimate. In an ideal world, we would be able to use trace data and the calculation of arbitrage profits to ensure proper categorization. However, for simplicity it is reasonable to use a heuristic approach.

B.1.2 Liquidations and liquidity management

Transactions containing flash loan events are positively classified as liquidation or liquidity management based on the transaction containing an event log known to be used for either purpose. Certain Aave smart contracts emit log events for select liquidity management operations: debt swap, collateral swap, and repay with collateral. To identify liquidation functions, I use string matching on decoded function names for any that include *"%liquida%."* If a transaction interacts with a smart contract identified as liquidation or liquidity management, the transaction is labeled accordingly.

The outlined approach should capture only those transactions that are indeed liquidation or liquidity management, due to the inclusion of the respective event. It is possible that some transactions with liquidation or liquidity management functionality do not emit a publicly decodable event and cannot be classified.

B.1.3 Exploits

To classify a flash loan event as an exploit, I matched the transaction to news articles of known flash-loan-related exploits. DeFiLlama and ImmumeBytes provide an aggregation of DeFi exploits. I used both of these sources to identify flash loan exploits. A combination of analytic reports, news articles, blog posts, tweets and block explorers allowed me to identify the specific transaction hashes the exploits take place on. These were then matched to flash loan events on the transaction hash and labeled as an exploit.

B.1.4 Unknown

Any transaction that cannot be classified as one of the known use cases is labeled as unknown. This likely includes some transactions that fit the functionality of the above use cases, but does not fit the heuristic. It is also likely that some flash loan events labeled as unknown are indeed a new use case that I am not aware of. Further analysis of the unknown transactions may yield additional use cases.

Appendix C: Simple problem of a borrower

A borrower will choose to use flash loans when it maximizes their profit. The borrower's profit maximization problem is as follows:

$$\max_{A,K,F>0} \rho[\pi(A) - F(R^f + \theta^f)] - KR$$
$$\text{s.t. } F + K \geq A$$

$$\implies \max_{K,F} \rho[\pi(K+F) - F(R^f + \theta^f)] - KR$$

F.O.C.

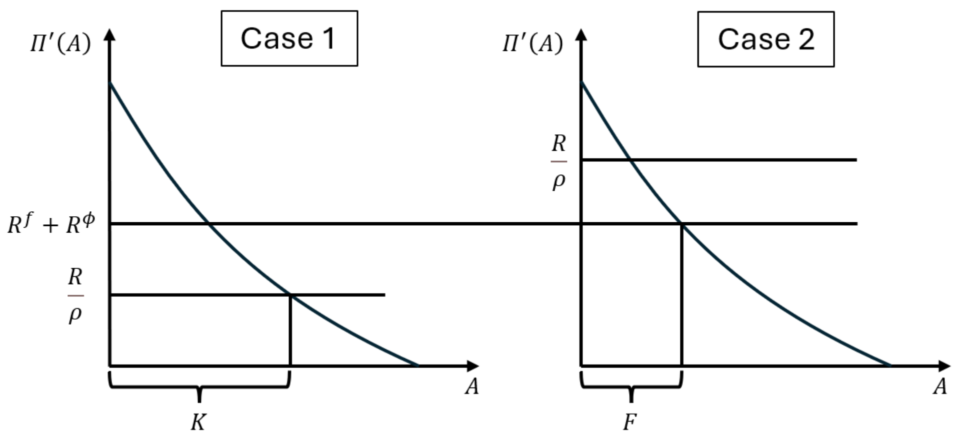
$$K : \pi'(K+F) \leq \frac{R}{\rho} \qquad , = ifK > 0$$
$$F : \pi'(K+F) \leq R^f + \theta^f \qquad , = ifF > 0$$

$$\text{Case 1: } \rho > \frac{R}{R^f + \theta^f} \implies F = 0, A = K$$
$$\pi'(K) = \frac{R}{\rho}$$
$$\text{Case 2: } \rho < \frac{R}{R^f + \theta f} \implies K = 0, A = F$$
$$\pi'(F) = R^f + R^\theta,$$

where ρ is the probability of finding an opportunity, A is the value required to exploit the opportunity, F is the flash loan value, K is capital, R^f is the flash loan fee, θ^f is the flash loan gas fee, and R is the interest on capital.

Flash loans are used when θ^f, R^f and ρ are low, and R is high. See **Chart C-1**.

Chart C-1: Borrower's problem



Note: $\Pi'(A)$ is the users profit

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