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Market Manipulation in NFT Markets^{*}

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Abstract

Non-Fungible Tokens (NFTs) are a new form of digital asset used for fundraising purposes, similar to equity crowdfunding, but within an unregulated environment. The NFT market has been described as an unregulated and prone to misconduct, but there is a lack of detailed analysis on such behaviors. This paper examines the use of manipulative trading, specifically unrevealed insider trading and wash trading, within the NFT market using publicly available transaction data on the Ethereum blockchain. The results show that insiders buying behavior strongly predicts higher future price returns. Even if the circulated USD amount in wash trades is more than 422 million, wash trades fails to impact meaningful market outcomes. I find that some investors engage in wash trading to earn rewards from NFT marketplaces or promote emerging marketplaces in competition with the dominant platform.

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1 Introduction

NFTs, or non-fungible tokens, are digital assets that utilize blockchain technology for fundraising. During 2021 and early 2022, the NFT market gained significant attention alongside the cryptocurrency bubble. News articles¹ reported single cartoon pictures selling for over \$23 million. However, many people, including academics, focus on the potential investment returns or the size of the irrational market bubble, rather than the underlying purpose of NFT projects. Essentially, NFTs can be viewed as a form of securitized crowdfunding in an unregulated environment.

Similar to crowdfunding, NFT creators raise funds for their projects by selling their NFT collections to initial investors in the primary market. To understand this better, imagine an apartment company (NFT creator) raising funds for an apartment-to-be-built (NFT collection) by pre-selling all the studios (a predetermined fixed number of NFT items). The main difference between crowdfunding and NFTs is that, in equity crowdfunding, shares of firms are traded, while NFT creators sell virtual items to NFT investors as a fundraising method. NFT items are often represented as virtual profile pictures (see Figure 2), but they actually function as membership tickets that may include voting rights in a secret community or unique characters in a game-in-development or metaverse (Oh, Rosen, and Zhang, 2022).

One of the critics NFT and the cryptocurrency community face is the unregulated or less regulated market environment. Since the creators of NFTs are anonymous in most cases, it is not uncommon for projects to be abandoned if they are not successful on the primary market. Some creators intentionally raised funds by selling NFTs and then disappeared². In fact, even for successful NFT projects that have received considerable investor attention, it is difficult to verify whether there is insider trading based on asymmetric information as there is no obligation to report. In addition, the NFT community voluntarily has reported several cases of wash trading³. Wash trade in NFT markets is used as price and

¹See articles from Forbes or Nasdaq. Both gives examples of expensive NFTs traded around 2022.

²NFT community calls this as a rug pull. Some examples are Frosties and Evolved Apes. The founders of Frosties were arrested in California but it is a rare case.

³See an article from Chainalysis, Decrypt, or @hildobby_ for example.

volume manipulation method to generate fake trading volume and index price to allure investors by repeating buying and selling behavior. However, there is still a lack of compelling evidence on how widespread these misconduct behaviors are in this new market and their consequence.

In this paper, I study whether there exists unrevealed insider trading and wash trading in the NFT market. Insiders are defined as investors who have received free items from creators in the primary market, and I focus on their purchase activity rather than their selling activity to eliminate frequent trading noise as much as possible. Wash trades are defined as three types of transactions: (1) identity trade, where the seller and buyer are the same wallet, (2) 1-1 trade, where a seller purchases the same item again within 7 days after selling, or (3) matched order, where three wallets are involved in trading and all trades occur within 7 days. In NFT market, insiders are 4.9% of total wallets participated in primary market, and wash trades are 0.3% out of 3.7 million secondary market transaction.

I investigate the impact of these misconduct behaviors on market outcomes for 558 successful NFT projects that successfully minted (i.e., sold) all items in the primary market from March 2021 to January 2023. There are two potential ways that unrevealed insider trading and wash trading can affect the market. First, unrevealed insiders may use their information on the NFT collection earlier than other investors since they can directly communicate with NFT creators. However, they may not be able to use their information effectively since they already hold an illiquid membership ticket. Second, NFT wash traders may create investor attention by driving up trading volume and price, but this may not be effective since the NFT community voluntarily alerts wash trades in the NFT space. Lastly, Banerjee, Davis, and Gondhi (2018) predicts that more information access can be harmful when speculative motives dominate in the market. The speculative motivation was the main driver of the NFT bubble in the sample period, and the blockchain technology guarantees information access. Therefore it is an empirical problem that I can test the theory through data.

The results show that insider buying activity is a strong predictor of future daily price index returns. A one standard deviation increase in insider buying activity leads to around a four percentage point increase in future daily median price returns. Wash trading de-

creases future price returns, but the effect is economically insignificant. Moreover, insider purchases and wash trades do not meaningfully decrease future changes in trading volume. This suggests that unrevealed insiders take advantage of information asymmetry in NFT markets, but wash trading, which is often used as a manipulation method, is actually ineffective in manipulating market outcomes. Moreover, the USD amount circulated in wash trades is over 422 million in the sample. The purpose of wash trading may not be market manipulation.

Therefore, I analyzed the possible purpose of wash trades, and one answer could be the cryptocurrency reward from NFT marketplaces (i.e., NFT exchanges). Several marketplaces charge a platform fee close to 0 percent and reward traders proportionally to the transaction value of traded items. Further analysis indicates that rewarding platforms are highly associated with the occurrence of wash sales, while insiders are not associated with wash sales. This suggests that some investors perform wash trades to generate artificial financial rewards or attract market attention to startup marketplaces to compete with the dominant marketplace, OpenSea.

The equity crowdfunding market is relatively well-known to investors and entrepreneurs even before the emergence of NFTs. With the help of the internet, early-stage companies and startups can raise relatively small funds from a large number of investors who are either interested in investing or in purchasing the company's products (Chemmanur and Fulghieri, 2014). Many researchers have discussed this new venture capital market so far (See e.g. Lukkarinen, Teich, Wallenius, and Wallenius (2016); Hornuf and Schwienbacher (2018); Gong, Krishnan, and Liang (2022)). However, the transaction amount in the worldwide crowdfunding market at 2022 is 1.08 billion USD, while the transaction amount is 2.4 billion USD in the NFT market⁴. This is a significant difference that has been largely overlooked, even after the crypto market downturn in 2022.

One might wonder why financial economists should care about a speculative market that may no longer exist in 5 years. However, this paper makes three contributions to the literature. First, it discusses how to detect unreported insider and manipulative trading in recent crypto assets using blockchain technology. The unique market structure of NFTs

⁴See Statistica for crowdfunding and for NFT.

provides an opportunity to study manipulative behaviors. Secondly, the findings are crucial for regulators and policymakers interested in ensuring fair and efficient markets. The study suggests that efforts should be made to increase transparency in the NFT market, particularly with regard to unreported insider trading practices. Additionally, the study highlights the importance of regulating cryptocurrency reward systems in NFT marketplaces to prevent artificial price and volume manipulation through wash trading. Lastly, this paper demonstrates the direct application of blockchain in data governance and transparency in financial markets. Overall, this paper provides valuable insights into the functioning of the NFT market and sheds light on the extent and impact of misconduct behaviors in this emerging asset class.

I provide some technical background on the NFT space and how to measure insider and wash trades in section 2. Sample selection procedure and summary statistics are shown in section 3. In section 4, I examine the impact of insider and wash trading activities on market outcomes using predictive regression analysis. Additionally, I propose another purpose of wash trades and discuss the aftermath effect on wash-traded items in section 5. Finally, I present my conclusions in section 6.

Related Literature

This paper discusses various topics related to market misconduct, including unreported insider trading and manipulative trading. Several studies have examined the spread of unrevealed insider information through family connections (Anderson, Reeb, and Zhao, 2012; Sun and Yin, 2017). Other social ties, such as friends and geographic proximity, have also been explored as means of spreading inside information. Ahern (2017), for example, showed how these ties can be used to spread insider information. In the context of revenue-sharing crowdfunding, Pourghannad, Kong, and Debo (2020) found that early investors who have a social tie with the entrepreneur may be informed about the project. However, Cohen, Malloy, and Pomorski (2012) argued that not all insider trading involves the use of nonpublic information. They decomposed insider trading into routine trade and opportunistic trade based on past trading history and found that only opportunistic trades are predictors of future returns. My paper contributes to the literature by suggesting that face-to-face or

limited online community connections could potentially serve as an insider mechanism in the context of cryptoassets.

Manipulative trading has also been the subject of research. Aggarwal and Wu (2006) showed that from 1990 to 2001, SEC litigation releases revealed that market manipulation occurred in small and illiquid OTC markets, with insiders and brokers potentially being the manipulators. Kyle and Viswanathan (2008) identified various forms of illegal price manipulation, such as corners and squeezes, pump-and-dump, and not making required disclosures. Massoud, Ullah, and Scholnick (2016) discussed the price and liquidity effects of hiring undisclosed promoters for publicly traded firms, and Li, Shin, and Wang (2022) analyzed pump-and-dump schemes in the cryptocurrency market, finding that they produce abnormal short-term increments in price, volume, and volatility.

The concept of manipulation is closely linked to high frequency and fake trading (spoofing), where there is no change in ownership. Aitken, Cumming, and Zhan (2015) explored the relationship between high frequency trading and market manipulation in stock markets. Wash trading, which is another form of fake trading, has been a focal point of many studies. Although investors and scholars commonly refer to it as wash trading, the U.S. Internal Revenue Services (IRS) has formally defined it as non-tax deductible trades due to the absence of change in ownership (see e.g. Grinblatt and Keloharju (2004) for tax-related research). Wash trading can be misleading to investors as daily trading volume is often used as a prominent market attention measure. Previous research on wash trading has primarily focused on exchanges or brokers. Cao, Li, Coleman, Belatreche, and McGinnity (2016) utilized directed graph theory and dynamic programming to detect wash trading. In the context of the crypto space, Gandal, Hamrick, Moore, and Oberman (2018) and Aloosh and Li (2019) directly investigated manipulative behavior through bot trading, using leaked secret information from a Bitcoin exchange. Additionally, Cong, Li, Tang, and Yang (2022) indirectly estimated wash trading using Benford’s law on regulated and unregulated crypto exchanges.

Detecting wash trades in the NFT space may be easier compared to traditional markets such as stocks or cryptocurrencies, as unique NFT items are traded directly between buyers and sellers. It requires a specific wash trade counterpart wallet or conspirator, which

is not the case for stock or cryptocurrency wash trading. Additionally, the public blockchain enables tracking of manipulations. Furthermore, NFT creators and insiders may have an incentive to participate in wash trading as it generates fake abnormal liquidity and an unusually high price to attract investors as in Aggarwal and Wu (2006) or Massoud, Ullah, and Scholnick (2016). Wachter, Jensen, Regner, and Ross (2022) analyzed 52 NFT collections using graph theory and found that wash trades accounted for around 2% of total sale transactions. However, further research is needed to better understand the extent and impact of wash trading in the NFT market. My paper explores the economic analysis of wash trading and demonstrates the potential of blockchain technology for enhancing data governance and transparency.

This paper adds to the existing literature on NFT markets and equity crowdfunding, specifically addressing market structure and the potential for manipulation. For a discussion of NFT markets from finance perspective, Kräussl and Tugnetti (2022) provided an overview of NFT markets and summarizes the pricing methods of other papers. Oh, Rosen, and Zhang (2022) compared the returns of experienced and inexperienced investors, Bao, Ma, and Wen (2022) examined herding behaviors and found inexperienced investors' entering can be a trigger of herding, Borri, Liu, and Tsyvinski (2022) and Kong and Lin (2022) attempted to construct market indices and conduct related analysis. Wilkoff and Yildiz (2023) examined the effect of media coverage on NFT market liquidity, and Falk, Tsoukalas, and Zhang (2022) discuss how NFT royalties to creators are determined. In the equity crowdfunding space, Meoli and Vismara (2021) investigate information manipulation, Cumming, Hornuf, Karami, and Schweizer (2021) analyzed the determinants of crowdfunding fraud using social media data, and Babich, Marinesi, and Tsoukalas (2021) demonstrated that crowdfunding can benefit entrepreneurs and investors but may also be theoretically harmful.

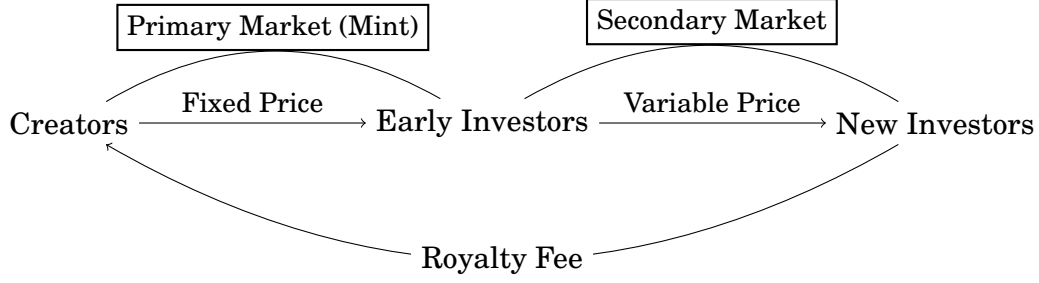


Figure 1. Overview of NFT Markets

Notes. The figure above shows the simplified NFT market. Creators sell NFT items at fixed price to initial investors and then initial investors trade items in secondary market. Creators receive royalty fee on every realized trades.

2 NFT Markets and Measures

2.1 Backgrounds

Before describing the data and summary statistics, it is necessary to clearly explain the terminologies and background with Figure 1. An *NFT collection* is a set of NFTs on the same theme and launched by an NFT creator team. An *NFT* is an individual item in an NFT collection. Alternatively, an NFT is a single picture, while an NFT collection is a set or brand of pictures. For example, the right picture of Figure 2 is an NFT, and the left picture is an NFT collection. The *primary market* is a market where NFT creators sell NFTs directly to early investors at fixed prices⁵. It is also called *minting* or *mint*. NFT creators advertise their minting process through Twitter and other online communication channels such as Discord and Reddit. These early investors can sell their minted items to other investors, and some investors buy and sell items from others on the *secondary market*. As well as raising funds on the primary market, creators are paid a percentage *royalty fee* on every secondary market sale. As a result creators keep updating their development process and promoting sales to potential investors and NFT holders after the primary market sales. Note that successfully minting all NFTs is imperative in the subsequent secondary market

⁵Some NFT collections have different set of fixed prices depending on the amount of mints. When an investor buys more items, the cheaper the mint price for each NFT. However, there is a limit on the maximum amount one can mint set by creators.

sales as new entrants can buy NFTs at a fixed price from creators anytime if there is an unsold item.

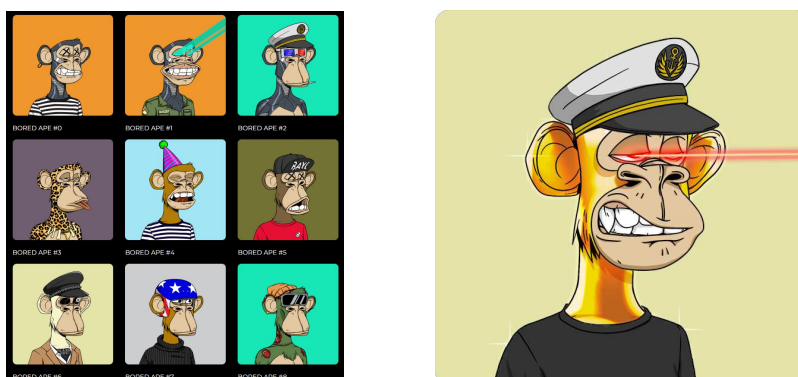


Figure 2. Example of NFT collection and NFT item

Notes. The left picture shows an NFT collection which is a set of pictures on the same theme under the same brand name called the *Bored Ape Yacht Club*. The right figure is an item (#3749) of *Bored Ape Yacht Club* that is sold at record price, 740 ETH (2.9 million USD) at September 6th, 2021.

The focus of this paper is on NFT collections based on the Ethereum (ETH) blockchain system, one of the most popular cryptocurrencies. Note that buyers and sellers do not need to trade in ETH cryptocurrency. Transaction information is recorded in the ETH blockchain system, allowing participants to pay with other cryptocurrencies such as USDC, USDT, or ApeCoin. Although it is not discussed in this paper, traders that use the Ethereum system must pay the *ETH transaction fee* or *gas fee* to blockchain miners for transaction verification in every NFT trade including mints. This fee depends on the complexity of the Ethereum network. In late 2021, when the cost of transactions on ETH became high due to increased demand for trading ETH itself or crypto-based NFTs, some NFT creators launched their collections on other blockchain systems, such as Polygon. Nevertheless, the vast majority of NFTs are still based on the Ethereum ecosystem, so I restrict the sample to Ethereum-based NFT collections. Furthermore, the fixed supply⁶ of NFT items plays a crucial role in defining the scarcity and limited access of the NFT market, making it possible to apply economic principles that are applicable to other traditional asset classes such as equity,

⁶Some famous NFTs like CryptoKitties do not have supply limit as their cyber-cats repeatedly generate their kittens, which may lead to infinite number of items.

housing, or the arts as in the setting of Oh, Rosen, and Zhang (2022).

2.2 Insiders in NFT markets

Insider trading in a public firm refers to the stock trading behavior of managers who hold more than a certain amount of shares. Insiders of public companies are required to report their trading records to the U.S. SEC. Unlike the stock market, there is no regulation requiring insiders in the NFT market to report their trading records. Furthermore, the personal identity of each wallet is not revealed unless the owner of the wallet chooses to disclose it. Therefore, insiders can only be inferred from transaction records. Without legal consequences for insider trading, those with information advantages are more likely to exploit their information advantage for trading purposes.

One prominent feature of the NFT market is the simultaneous online conversation system using Twitter and Discord. In Discord, each NFT project has two types of chat rooms. The first chat room is open to everyone, including aspiring investors who do not yet hold an NFT, while the second is exclusively for current NFT holders. Through the automated verification system, NFT owners can establish their ownership, and all they need to do is show their verified ownership to Discord managers, who are NFT creators and their communication teams. Thus, access to member-only chat rooms is restricted to NFT owners, as creators and their communication teams use these rooms to engage with members of their community.

In this paper, insiders are defined as wallets who receive free items (*Free Minters*) as they may have access to internal information. Anderson, Reeb, and Zhao (2012), Sun and Yin (2017), and Ahern (2017) discussed family and face-to-face connection can be a channel for information leakage. Pourghannad, Kong, and Debo (2020) found that early investors in crowdfunding is likely to have a social connection with the project creators and obtain benefits from internal information. Recall that NFTs are used to launch new projects and raise funds from investors. Free Minters are likely to be creators themselves, since creators need to join their NFT social communities, individuals who have social connections with project creators, or recipients of free giveaway events⁷. This giveaway event is mostly for

⁷These free giveaway items are sometimes called as airdrops.

marketing purposes, and creators usually give an item to someone who shares lots of tweets tagging NFT on Twitter.

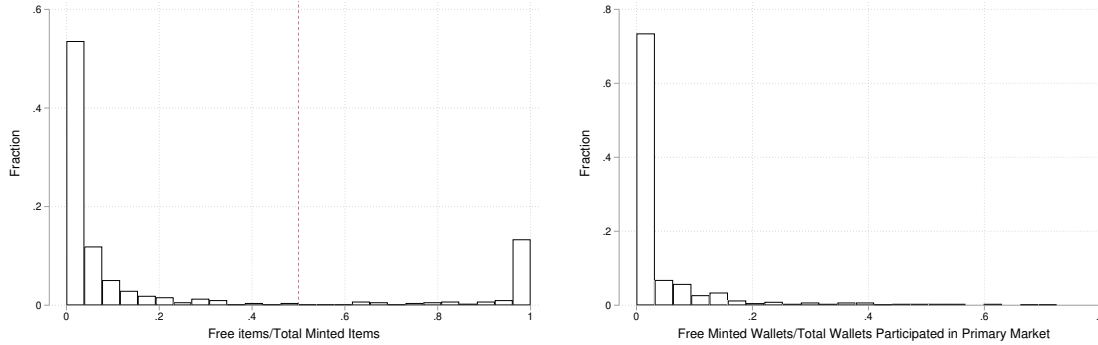


Figure 3. Distribution of Insiders in Primary Market

Notes. These figures report the distribution of potential insiders in collection-wise primary market. The left figure shows the distribution of free items out of total items including collections that are omitted in the sample selection process. In the analysis, NFT collections on the right side of red dotted line are deleted. Potential insiders are defined as wallets that received free items in primary market. The right figure describes the distribution of such insiders out of total wallets involved in primary market.

Figure 3 shows the distribution of insiders in two ways. The left figure is the histogram of items using full sample, and it is not difficult to see most NFT collections does not give most items freely. It's an ad hoc but I omitted 131 collections for further analysis that distributed more than 50% of its items without any cost (right side of red dotted line) as they have higher probability of being derivatives for already successful main projects and they are less likely to be fundraising projects. The right figure depicts the distribution of wallets in the final sample. On average, 4.9% of wallets were classified as insiders on the primary market. Other relevant summary statistics are present in Table A.1.

2.3 Wash Traders in NFT Markets

By the U.S. IRS, if one sells securities at a loss and buys substantially identical securities within 30 days before or after the sale, and there is no change in beneficial ownership, it is classified as a wash sale. When there is a related third person or party, it is called a matched order. Loss from wash trades is not tax deductible, but the wash trade itself is permitted.

Table 1. Example of Wash Trades in NFT Markets

Notes. One of manipulative trading records on a single item is presented in this table. This collection is named “The Wonder Quest” with its unique contract address 0x08bEBEB5f042CCbaEb128582DA560cb25a5dB7e9. It is easily noticeable that investor 0x70e09... (marked as red) and 0x40c39... (marked as blue) buy and sell identical item #1320 frequently on February 4th, 2022. Moreover their transaction prices from wash trades (bolded) are enormously higher than previous transaction price.

Item #	Trading Time	Seller	Buyer	Price (ETH)	Notes
1320	2021-07-26 20:12:29	0x00	0x31992b19c40f2e472da5d39b167dc6fe952d3777	0.088800	Mint
1320	2021-08-12 03:39:03	0x31992b19c40f2e472da5d39b167dc6fe952d3777	0x3dcba64c3596aa254ad41502d8e15f9b54aa6e61	0.077000	-
1320	2022-02-02 01:10:17	0x3dcba64c3596aa254ad41502d8e15f9b54aa6e61	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0.020000	-
1320	2022-02-02 02:21:49	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0x40c398c0a3def59757683c82659f64678595f2de	0.045318	-
1320	2022-02-04 05:23:42	0x40c398c0a3def59757683c82659f64678595f2de	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	36.812552	Wash
1320	2022-02-04 05:48:57	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0x40c398c0a3def59757683c82659f64678595f2de	34.646000	Wash
1320	2022-02-04 05:57:23	0x40c398c0a3def59757683c82659f64678595f2de	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	33.953000	Wash
1320	2022-02-04 06:09:45	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0x40c398c0a3def59757683c82659f64678595f2de	31.950000	Wash
1320	2022-02-04 06:13:11	0x40c398c0a3def59757683c82659f64678595f2de	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	31.316000	Wash
1320	2022-02-04 06:31:15	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0x40c398c0a3def59757683c82659f64678595f2de	29.479841	Wash
1320	2022-02-04 06:38:10	0x40c398c0a3def59757683c82659f64678595f2de	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	28.890749	Wash
1320	2022-02-04 06:50:57	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0x40c398c0a3def59757683c82659f64678595f2de	27.188134	Wash
1320	2022-02-04 06:54:59	0x40c398c0a3def59757683c82659f64678595f2de	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	26.648171	Wash
1320	2022-02-04 07:01:16	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0x40c398c0a3def59757683c82659f64678595f2de	25.081046	Wash
1320	2022-02-04 07:09:42	0x40c398c0a3def59757683c82659f64678595f2de	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	24.579425	Wash
1320	2022-02-04 07:15:45	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	0x40c398c0a3def59757683c82659f64678595f2de	23.133958	Wash
1320	2022-02-04 17:43:29	0x40c398c0a3def59757683c82659f64678595f2de	0x70e09c770c8bb76ed309db5ad9eab63a89a93788	35.000000	Wash

Focusing on the repetition of buy and sell, a wash trade also refers to manipulative trading or behavior of providing false impression to market participants. Recall that in general, investors interpret significant changes in trading volume or price as the degree of market attention. Two investors can generate fake signals by buying and selling one NFT item at an unusually high price at the same time. This simple two participant wash sale model is shown in Table 1. By only looking at the overall price index and trading volume, a new investor would be trapped by wash traders and pay a significantly higher price.

Scholarly examination of this specific form of manipulative trading has been limited because most academics do not have access to micro-level transaction data. However, with the blockchain system, the NFT market structure is exceptionally useful to analyze wash trades since each item has a distinguishable number, and all wallet addresses are revealed, even without proprietary exchange data. Intuitively, it is less likely to argue that trades are normal if one sells and buys the exact same item again out of similar items in a collection. Wachter et al. (2022) suggested a graph theory-based algorithm that directly detects wash sales in the NFT market. On the NFT industry or community side, a method used by Dune

Analytics⁸ has been used so far.

Table 2. Logic of Wash Trades Detection

Type	Wash Type (1)	Wash Type (2)	Wash Type (3)
Name	Identity Trade	1-1 Trade	Matched Order
Transactions	A Sell → A Buy	A Sell → B Buy	A Sell → B Buy
		B Sell → A Buy	B Sell → C Buy
			C Sell → A Buy
Time Span	-	Within 7 days	Within 7 days
Observations	346	8808	1183

In this paper, a wash trade is defined similar to Wachter et al. (2022) and Dune but time span is incorporated as in IRS definition. A wallet first buys an item at normal price as a preparation step. As shown at Table 2, trades are classified as wash sales if (1) an item is sold and purchased by exact same identity at the same time, (2) an item is purchased again by previous seller within 7 days, or (3) as a matched order, 3 wallets are involved in trading and all trades occurred within 7 days. Although IRS impose 30 days to define wash trades, it is too long period in NFT and cryptocurrency markets as we can check in Table 1. The result is consistent with shorter periods such as 3 or 5 days (8564 and 8705 observations each). Even with this simple definition, it is possible to find total 10166 (0.3%) suspicious wash trades out of 3.6 million secondary market trade volume, and 44% of 558 collections had at least one suspicious wash trade even though wash trade volume in each collection is just 0.3% on average. Detailed summary statistics are shown at Table A.2.

Another remarkable characteristic of wash trades to check is timing. The above plot of Figure 4 shows the histogram of elapsed days from the first mint sales to wash trades in each collection. More than 20% of wash trades occurred within 60 days after mints but more mature collections also had wash trades. Combining with around half of collection have at least one wash trades, wash trades may be market-wide phenomena.

⁸See this online community posting for his algorithm.

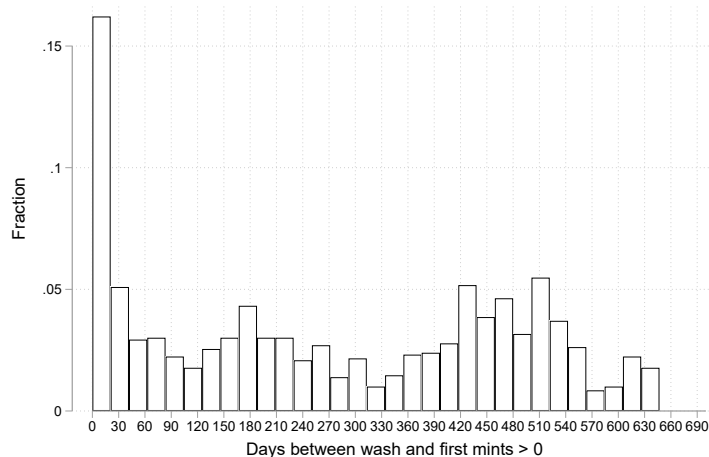


Figure 4. Timing of Wash Trade in Secondary Market

Notes. This figure reports the distribution of wash trade ratio out of secondary market trade in collection-wise. Collections that do not have wash trades are omitted in the figure.

3 Data

The list of NFT collections was hand-collected in October 2021 from the "Top Collectibles NFT rankings" on the largest NFT trading platform, OpenSea. The NFT list extends the sample in Oh, Rosen, and Zhang (2022) with some new successfully launched projects after October 2021 and before December 2021. After only selecting collections that successfully minted all items, the final sample consists of 558 ERC-721 NFT collections traded in the Ethereum blockchain system. Transaction data is primarily obtained from Dune, a commercial data company, but is also cross-checked at Etherscan, one of the biggest free websites. Non-direct trades that include DeFi platforms like Uniswap and Sushiswap are omitted, but direct ERC-1155 trades are allowed⁹. The number of mint transactions is 3.6 million, and the number of secondary transactions is 3.6 million as well. To eliminate extremely high-priced outliers and unusual near 0 ETH transactions, only secondary market trades of at least 0.01 ETH are considered in the sample, and all return variables that will be discussed in Table 3 are further winsorized at the 1/99 percentile level. The sample covers the period

⁹ERC-1155 allows for batch transfers, i.e., multiple trades in a single smart contract. In ERC-721, one NFT item is traded under one smart contract, thus ERC-1155 reduces a significant amount of transaction cost.

from February 17th, 2021 to February 14th, 2023, which allows for the incorporation of the crypto winter in 2022.

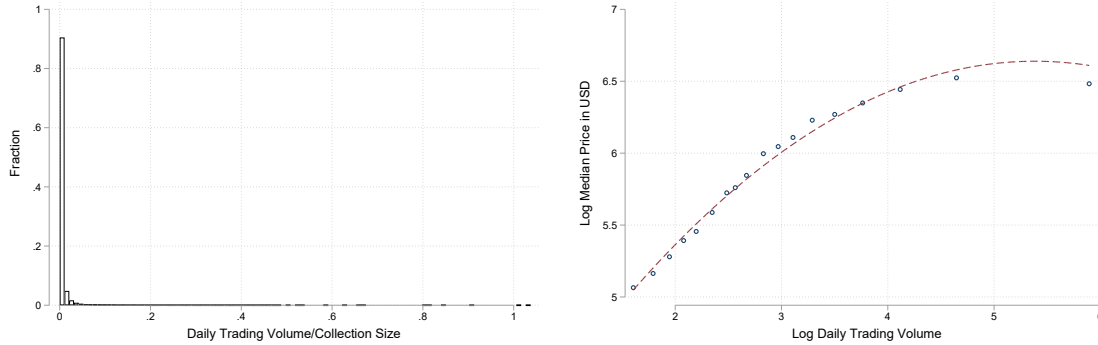


Figure 5. Trading volume and Median Price of NFT

Notes. The figure left shows the daily secondary market trading volume divided by each collection supply in collection-wise. The right plot shows the square-root relation between logged daily median price and logged daily secondary market trading volume.

Figure 5 displays the illiquidity of NFT markets in plots. The left figure shows the daily secondary market trading volume divided by each collection’s minted items. It is evident that transactions are rare compared to the number of issued items. The right plot shows the positive square-root relation between daily median price and daily trading volume which is similar to the traditional price-volume relationship observed in finance. As a result, investors pay attention to a collection’s trading volume since the market is illiquid on average. This suggests attention from investors and the arrival of new information will drive the price much higher than usual (Wilkoff and Yildiz, 2023). Therefore, it is logical to expect that information advantages, such as insider trading and false investor attention from wash trading, may contribute to a collection’s investment return and longevity.

The variables used in the analysis are aggregated at the collection-day level, as shown in Table 3. The dependent variables are the rate of median price and trading volume change, with and without wash trades. The daily median price is used as the price index since most NFT items are homogeneous, and the most common items in the collection are traded around a similar price (Oh, Rosen, and Zhang, 2022). Wash trades can distort the representative market price and trading volume of NFTs, so it is better to consider values that

Table 3. Variable Definitions

Notes. This table shows the definition of variables in this paper. Only at least 0.01 ETH secondary market trades are considered in the sample and variables with † is further winsorized at 1/99 percentile level. Daily transaction volume less than 5 is also omitted from the data. Note that dependent variables are leads.

Variables	Description
<i>Dependent Variables</i>	
†Price Return	Rate of median price change from day t to $t + 1$
†Price Return nowash	Rate of median price change from day t to $t + 1$, omitting all wash sales
†Volume Change	Rate of trading volume change from day t to $t + 1$
†Volume Change nowash	Rate of trading volume change from day t to $t + 1$, omitting all wash sales
<i>Independent Variables</i>	
Insider Buy Activity	Free minters’ buying volume at day t scaled by the number of total minted items
Wash Activity	Wash sales volume at day t scaled by the number of total minted items
<i>Control Variables</i>	
Log(1+Days after mints)	Log(1 + number of days past after first mint)
†Past Day Returns	Rate of median price change from day $t - 2$ to $t - 1$
†Past Week Returns	Rate of median price change from day $t - 7$ to $t - 2$
Log Market Value of Collection	Log(Median Price \times Trading Volume at day t)
Dummy category Art	1 if the purpose of an NFT collection is related to pure art (used as baseline)
Dummy category Gaming	1 if the purpose of an NFT collection is related to games
Dummy category Metaverse	1 if the purpose of an NFT collection is related to Metaverse
Dummy category Social	1 if the purpose of an NFT collection is related to social group
Dummy has twitter url	1 if an NFT collection has its own twitter account
Dummy has website url	1 if an NFT collection has its own website
Dummy has roadmap	1 if an NFT collection has roadmap for its project
Dummy artist name	1 if creators revealed their name (including nickname)

include wash sales, as these are what most non-experienced traders would face. While investors typically focus on the floor price, which is the minimum available list price at that time, median price is the best possible measure for the price index due to data constraints.

The independent variables are insider buy volume and wash trade volume at day t , both scaled by the total minted amount in each collection. Insiders’ sell volume is not included, as it is challenging to distinguish routine trades from information-based trades of free minters. Instead, buying additional illiquid items when already holding items is more likely to represent an informational advantage and positive prospect of the collection’s success as chat group members. The return variables are winsorized at 1/99 percentile level. Summary statistics of the variables are presented in Table 4. Note that the number of observations of dependent variables is not equal. This indicates there are cases where all transactions in a whole day involve wash trades. Secondary market trading volume, daily

median price in USD, are daily median price in USD omitting wash sales are not winsorized in the table.

Table 4. Summary Statistics

Notes. This table shows the summary statistics of variables defined at Table 3. Only at least 0.01 ETH secondary market trades are considered in the sample and variables with † are further winsorized at 1/99 percentile level. Daily transaction volume less than 5 is also omitted from the data. Secondary market trading volume, daily median price in USD, and daily median price in USD omitting wash sales are not winsorized.

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) p50	(6) max
†Price Return nowash	58,213	0.0330	0.261	-0.544	0.000473	1.275
†Price Return	58,206	0.0328	0.260	-0.544	0.000538	1.262
†Volume Change	58,220	0.245	1.097	-0.833	-0.0357	6.500
†Volume Change nowash	58,214	0.245	1.097	-0.833	-0.0357	6.500
InsiderBuy Activity	75,399	0.000105	0.000940	0	0	0.0775
Wash Activity	75,399	2.44e-05	0.00118	0	0	0.125
Wash Dummy	75,399	0.0172	0.130	0	0	1
Days between wash and first mint sales	75,399	175.0	143.2	0	138	711
†Past Day Returns	50,393	0.0271	0.248	-0.544	-0.00146	1.275
†Past Week Returns	46,591	0.0562	0.429	-0.620	-0.0264	2.232
Market Value of Collection	75,386	2.256e+07	1.748e+08	11,298	2.297e+06	5.675e+09
Dummy category Gaming	75,399	0.0706	0.256	0	0	1
Dummy category Art	75,399	0.0170	0.129	0	0	1
Dummy category Metaverse	75,399	0.0605	0.238	0	0	1
Dummy category Social	75,399	0.852	0.355	0	1	1
Dummy Has Twitter	75,399	0.989	0.105	0	1	1
Dummy Has Website	75,399	0.987	0.113	0	1	1
Dummy Has Roapmap	75,399	0.606	0.489	0	1	1
Dummy Artist Name	75,399	0.569	0.495	0	1	1
Secondary Market Trading Volume (Raw)	75,399	47.16	177.2	5	13	7,995
Daily median price in USD (Raw)	75,386	2,405	17,552	9.699	282.9	567,495
Daily median price in USD omitting wash sales (Raw)	75,378	2,359	16,949	9.699	282.7	540,458

4 The Impact of Manipulative Trades

In this section, I examine the impact of manipulative trades on the rate of price index return and trading volume change through predictive regressions. The regression structure is similar to Cohen, Malloy, and Pomorski (2012). I focus on analyzing the collection-day level, as simple values such as index price and trading volume are easily accessible but still vital market signals for investors. The dependent variables are the rate of index price change or trading volume change, and the main independent variables are insider buy or wash activ-

ity scaled by the amount of mints. As discussed in the previous section, it is inappropriate to include *InsiderSell* in the model due to the market structure. For a collection c and day t , the baseline regression model is as below:

$$DV_{c,t+1} = \beta_1 InsiderBuyActivity_{c,t} + \beta_2 WashActivity_{c,t} + \gamma X_{c,t} + FE_c + u_{c,t+1} \quad (1)$$

where $DV_{c,t+1}$ is the median price return or volume change variable from day t to $t+1$ as defined in Table 3. The main independent variables are insider buy and wash volume of collection c at day t divided by the total minted amount of collection c . $X_{c,t}$ is a control variable matrix at day t , and FE_c is date fixed effects.

For the choice of control variables, I assume that investors focus on the past day return from day $t-2$ to $t-1$ and past week return from day $t-7$ to $t-2$ as momentum factor. Market value of collection which is median price times total minted volume is considered, and as a general classification of NFTs that are either arts, gaming, metaverse, or social is included. Dummy variable whether a collection is arts is used as a baseline. Lastly, quality-related information such as the existence of a collection Twitter account, collection website, roadmap, presence of artist for a collection is also considered. Regression tables with all control variables are in the appendix.

Note that the daily index price and trading volume can be measured in two ways. The first is the entire or nominal value, including manipulative trades, which is what most investors see at trading platforms. The other is the true or real value, which excludes wash trades since wash trades distort the price and trading volume. I present both estimated results in Table 5 that uses nominal information and Table 6 that only considers real information.

The estimated result without omitting wash trades is shown at Table 5. Columns (1) and (2) show regression results with only insider buying term. Column (1) explains returns on day $t+1$ without date fixed effects while Column (2) regress with date fixed effects. Both have positive coefficients and p-values close to 0. One standard deviation increase in *InsidersBuy Activity* or $\frac{InsiderBuyVolume}{TotalMinted}$ lead to 4.6, or 4.2 percentage points increase in future daily index returns, controlling for other factors. Columns (3) and (4) of

Table 5. Performance of Manipulative Trades: With Wash Trades

Notes. In this table, I report the results from estimates of specification (1) in which I regress future median price returns on a daily activity of insider and wash trade activity scaled by NFT collection-size for collection c as of day t . The dependent variable is $Return_{c,t+1}$ which is the rate of median price change in USD from day t to day $t + 1$. Control variables are a day before price return, weekly price return, collection age, market value of collection, and other collection characteristics. Standard errors are clustered by collection. t -statistics are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

VARIABLES	(1) Price	(2) Price	(3) Price	(4) Price	(5) Price	(6) Price
InsiderBuy Activity	24.60*** (5.604)	22.65*** (5.274)			24.61*** (5.605)	22.66*** (5.275)
Wash Activity			-1.412*** (-3.594)	-1.250*** (-3.674)	-1.424*** (-3.530)	-1.259*** (-3.642)
Log(1+Days after mints)	0.00483*** (3.771)	0.0223*** (8.077)	0.00344*** (2.716)	0.0202*** (7.369)	0.00486*** (3.792)	0.0223*** (8.082)
Past Day Returns	-0.0169** (-2.175)	-0.0222*** (-2.864)	-0.0161** (-2.071)	-0.0216*** (-2.792)	-0.0169** (-2.175)	-0.0222*** (-2.863)
Past Week Returns	-0.00193 (-0.643)	-0.00609* (-1.934)	-0.00145 (-0.484)	-0.00591* (-1.877)	-0.00195 (-0.651)	-0.00610* (-1.938)
Log Market Value of Collection	-0.0167*** (-6.075)	-0.0170*** (-6.678)	-0.0169*** (-6.091)	-0.0171*** (-6.658)	-0.0167*** (-6.074)	-0.0170*** (-6.674)
Observations	39,838	39,814	39,838	39,814	39,838	39,814
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.0154	0.0158	0.0134	0.0140	0.0154	0.0158
Adj R-squared	0.0154	0.0602	0.0134	0.0585	0.0154	0.0602

Table 5 present results on wash trades. The coefficient of Wash activity is negative and near 0 p-value, meaning that wash trades decrease the future nominal return. One standard deviation increase in *Wash Activity* induces 0.6 percentage point decrease in daily price return. Thus actual economic significance is negligible even if it is daily price return. These results are consistent in Columns (5) and (6) with two variables (*Insiders Buy*, *Wash Activity*) combined. As in Columns (2) and (4), insiders buy do meaningfully increase future returns but wash trades is economically insignificant. The economic impact is similar to that of (2).

Next I examine the impact of misconduct behavior on real market value that is without wash sales in index price calculation. The structure is exactly same as Table 5 and the estimated result is presented at Table 6. Surprisingly, the standardized coefficients are very similar to nominal outcomes, and again, *Wash Activity* slightly decreases the real price re-

turns, but its impact on economic significance is small. One standard deviation increase in *InsiderBuy Activity* leads to a 4.6 or 4.2 percentage point increase in future daily index returns, and one standard deviation increase in *Wash Activity* leads to a 0.6 or 0.5 percentage point decrease in future daily index returns.

Table 6. Performance of Manipulative Trades: Without Wash Trades

Notes. In this table, I report the results from estimates of specification (1) in which I regress future median price returns on a daily activity of insider and wash trade activity scaled by NFT collection-size for collection c as of day t . The dependent variable is $Return_{c,t+1}$ which is the rate of median price change in USD from day t to day $t + 1$ omitting all trades that are classified as wash trades. Control variables are a day before price return, weekly price return, collection age, market value of collection, and other collection characteristics. Standard errors are clustered by collection. t -statistics are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

VARIABLES	(1) Price	(2) Price	(3) Price	(4) Price	(5) Price	(6) Price
InsiderBuy Activity	24.59*** (5.610)	22.62*** (5.274)			24.59*** (5.611)	22.62*** (5.274)
Wash Activity			-1.336*** (-3.808)	-1.169*** (-3.884)	-1.348*** (-3.749)	-1.178*** (-3.860)
Log(1+Days after mints)	0.00478*** (3.744)	0.0221*** (8.023)	0.00339*** (2.684)	0.0200*** (7.315)	0.00481*** (3.764)	0.0221*** (8.028)
Past Day Returns	-0.0168** (-2.175)	-0.0222*** (-2.868)	-0.0160** (-2.071)	-0.0216*** (-2.795)	-0.0168** (-2.175)	-0.0222*** (-2.867)
Past Week Returns	-0.00222 (-0.736)	-0.00644** (-2.033)	-0.00174 (-0.578)	-0.00626** (-1.976)	-0.00224 (-0.743)	-0.00645** (-2.037)
Log Market Value of Collection	-0.0166*** (-6.073)	-0.0169*** (-6.676)	-0.0168*** (-6.089)	-0.0170*** (-6.657)	-0.0166*** (-6.072)	-0.0169*** (-6.672)
Observations	39,838	39,814	39,838	39,814	39,838	39,814
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.0153	0.0157	0.0133	0.0139	0.0153	0.0157
Adj R-squared	0.0153	0.0602	0.0133	0.0585	0.0153	0.0602

However, these results are somewhat confusing, given that wash trades are typically conducted at high ETH prices and can distort the market price as in Table 1. It is unclear whether most investors realize the unusual market outcome while wash trading, even though they can check through free websites that provide detailed records. It is possible that wash trades have temporary effects on market outcomes that do not persist beyond a single day.

To investigate this possibility, I test a modified version of equation 1 in Table 7, in which I regress the rate of median price change in USD from day $t - 1$ to day t (i.e., same-day return) on daily activity of Free Minters scaled and wash trade activity scaled by NFT collection-size for collection c as of date t , omitting all wash trades. The control variables are the same as in the previous estimations.

Table 7. Performance of Manipulative Trades: Same Day Without Wash Trades

Notes. In this table, I report the results from estimates of specification (1) in which I regress future median price returns on a daily activity of insider and wash trade activity scaled by NFT collection-size for collection c as of day t . The dependent variable is $Return_{c,t}$ which is the rate of median price change in USD from day $t - 1$ to day t omitting all trades that are classified as wash trades. Control variables are a day before price return, weekly price return, collection age, market value of collection, and other collection characteristics. Standard errors are clustered by collection. t -statistics are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

VARIABLES	(1) Price	(2) Price	(3) Price	(4) Price	(5) Price	(6) Price
InsiderBuy Activity	35.48*** (5.527)	32.18*** (5.084)			35.48*** (5.527)	32.18*** (5.083)
Wash Activity			-0.521 (-0.577)	-0.217 (-0.239)	-0.538 (-0.607)	-0.229 (-0.254)
Log(1+Days after mints)	-0.00361** (-2.457)	0.00476* (1.656)	-0.00563*** (-4.005)	0.00180 (0.625)	-0.00360** (-2.448)	0.00476* (1.657)
Past Day Returns	-0.221*** (-18.86)	-0.246*** (-22.13)	-0.220*** (-18.61)	-0.245*** (-21.94)	-0.221*** (-18.86)	-0.246*** (-22.13)
Past Week Returns	-0.0247*** (-6.291)	-0.0362*** (-9.029)	-0.0240*** (-6.113)	-0.0360*** (-8.950)	-0.0247*** (-6.292)	-0.0362*** (-9.029)
Log Market Value of Collection	0.00469*** (3.437)	0.00513*** (2.988)	0.00437*** (3.336)	0.00499*** (2.985)	0.00469*** (3.437)	0.00513*** (2.988)
Observations	42,946	42,922	42,946	42,922	42,946	42,922
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.0538	0.0649	0.0500	0.0616	0.0538	0.0648
Adj R-squared	0.0538	0.104	0.0500	0.101	0.0538	0.104

The estimated results in Table 7 continue to support the argument that wash trades have little effect on market outcomes. The coefficient of *Wash Activity* remains statistically insignificant, while *InsiderBuy Activity* remains statistically significant and economically meaningful (6.5 and 5.7 percentage points, respectively). This suggests that wash trades do not affect the trading volume of NFTs, as otherwise, we would expect to see an effect on same-day returns.

Does it capture trivial mechanism? The demand for an illiquid item increases the price, which is nothing special. If insider buy and wash trades does not meaningfully change the trading volume, then it is not a simple price-demand relation. The other dimension of market outcome I haven't tested is trading volume. It can be examined using similar manner as in previous estimation with same control variables.

Table 8. Impact of Manipulative Trades on Trading Volume: Without Wash Trades

Notes. In this table, I report the results from estimates of specification (1) in which I regress the rate of change in daily trading volume on a daily activity of insider and wash trade activity scaled by NFT collection-size for collection c as of day t . The dependent variable is $Volume\ Change_{c,t+1}$ which is the rate of daily trading volume change from day t to day $t + 1$ omitting all trades that are classified as wash trades. Control variables are a day before price return, weekly price return, collection age, market value of collection, and other collection characteristics. Standard errors are clustered by collection. t -statistics are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

VARIABLES	(1) Volume	(2) Volume	(3) Volume	(4) Volume	(5) Volume	(6) Volume
InsiderBuy Activity	-127.1*** (-9.290)	-126.1*** (-9.200)			-127.1*** (-9.284)	-126.1*** (-9.196)
Wash Activity			-8.368*** (-3.414)	-9.069*** (-3.770)	-8.305*** (-3.497)	-9.022*** (-3.822)
Log(1+Days after mints)	0.0364*** (7.912)	0.0595*** (6.388)	0.0440*** (9.818)	0.0712*** (7.844)	0.0366*** (7.940)	0.0596*** (6.398)
Past Day Returns	-0.112*** (-4.495)	-0.131*** (-4.812)	-0.116*** (-4.672)	-0.134*** (-4.931)	-0.112*** (-4.494)	-0.131*** (-4.809)
Past Week Returns	-0.0284*** (-2.822)	-0.0357*** (-3.378)	-0.0311*** (-3.144)	-0.0368*** (-3.537)	-0.0285*** (-2.837)	-0.0358*** (-3.388)
Log Market Value of Collection	-0.0300*** (-7.697)	-0.0318*** (-7.482)	-0.0288*** (-7.772)	-0.0313*** (-7.638)	-0.0301*** (-7.696)	-0.0319*** (-7.474)
Observations	39,838	39,814	39,838	39,814	39,838	39,814
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.00597	0.00585	0.00354	0.00344	0.00601	0.00590
Adj R-squared	0.00597	0.0255	0.00354	0.0232	0.00601	0.0256

The result at Table 8 shows that the impact of manipulative behavior on the rate of change in future daily trading volume without wash sales. Columns (1) and (2) show one standard deviation change in insider buying ratio decreases 5 percentage points future volume change. Columns (3) and (4) displays one standard deviation change in wash trades leads to 1 percentage points decrease in future trading volume. Note that the average daily

trading volume is 47, so 5 percentage points decrease in trading volume is less than two transactions on average. These values indicate a relatively marginal change in trading volume that are not economically significant in illiquid market, and this result is consistent in Columns (5) – (6) either.

In summary, the results suggest that insider buying strongly predicts higher future price index returns, while wash trades do not have a significant impact on the returns. Therefore, investors are not lured into NFT collections by wash traders, but insiders still have an advantage due to their internal information.

5 The Purpose of Wash Trade

In fact, the total traded amount of money flagged as wash sales in the sample is 422 million USD. It is noteworthy that wash traders circulate enormous amounts of money but fail to allure investors. This empirical result is opposite to theoretical predictions of Banerjee, Davis, and Gondhi (2018) that “improving information access about asset fundamentals can be counterproductive when speculative motives dominate”. Do NFT investors really check freely available transaction history data, find wash trade information, check Discord and Twitter account, and avoid buying such items during the NFT boom? Moreover, Aggarwal and Wu (2006) and Massoud, Ullah, and Scholnick (2016) discusses the possibility of insiders being part of manipulative trades.

Perhaps the purpose of wash trades is not related to market manipulation. For example, there have been discussions about cryptocurrency rewards in NFT marketplaces, such as the case of LooksRare, which reportedly generated 8 billion USD in NFT wash trading¹⁰. Thus it is important to check the distribution of wash trades in terms of exchanges. Table 9 presents a two-way frequency table of wash trades and NFT marketplaces, showing that OpenSea is the largest and leading NFT marketplace. Additionally, many marketplaces have policies in which market fees are rewarded as marketplace coin or near 0 percent fee compared to the leading marketplace. Thus, it is plausible to speculate that the purpose of wash trades in NFT marketplaces may be to generate a profit through artificially inflated

¹⁰See an article about LooksRare.

cryptocurrency rewards, or to gain attention to marketplaces as followers.

Table 9. Wash Trades and NFT Marketplaces

Notes. In this table, I present the descriptive statistics related to NFT marketplaces and their potential wash trades. The numbers represent the observations out of secondary market trades in the 558 collection sample, and the figures in parentheses indicate the percentage of trades in that particular marketplace. The marketplace fee policy data is as of March 5th, 2023.

NFT Marketplaces	Not Wash Trade	Wash Trade	Total	Related Policy
Blur	39124 (96.40)	1460 (3.60)	40584 (100.00)	0% fee Receive token when traders pay full royalty to creators
Element	625 (83.56)	123 (16.44)	748 (100.00)	0.5% fee
Foundation	2 (100.00)	0 (0.00)	2 (100.00)	5% fee
LooksRare	10542 (98.36)	176 (1.64)	10718 (100.00)	2% fee. Token stakers earn 75~100% of the trading fees
OpenSea	3590664 (99.96)	1573 (0.04)	3592237 (100.00)	2.5% platform fee (temporarily 0% after the sample period)
Sudoswap	8589 (97.67)	205 (2.33)	8794 (100.00)	0.5% fee
X2Y2	24436 (78.66)	6628 (21.34)	31064 (100.00)	0.5% fee. Fees are rewarded to X2Y2 stakers
Zora	18 (94.74)	1 (5.26)	19 (100.00)	0% fee
Total	3674000 (99.72)	10166 (0.28)	3684166 (100.00)	

Instead of collecting token rewards at each wash traders' wallets, I regress the probability of wash trade on various marketplace using transaction-level secondary market data. In addition, by checking whether buyers and sellers are insiders shows that insiders' possible participation in wash trades. The binary dependent variable is *WashTradeDummy* that is 1 if a trade is wash trade defined in subsection 2.3, or 0 otherwise. Main independent variable is a combination of 8 NFT marketplaces in Table 9, and a combination of two dummy variables: *InsiderBuyDummy* and *InsiderSellDummy* which have a value 1 if buyer or seller is a free minter respectively. Control variables are logged holding period in a fractional day, log transaction price, collection volume, and collection characteristics.

The estimated result of linear probability model is shown at Table 10. Column (1) shows controlling for holding period and NFT price, insiders do not increase the probability of an occurrence of wash sale. In other words, insiders do not participate in wash trades. Column (2) shows the impact of marketplace in the probability of wash trades. When a trade

Table 10. Determinants of Wash Trades

Notes. In this table, I present the estimates of linear probability model related to wash trades and their potential factors using secondary market transaction level data. The dependent variable is *Wash Sales Dummy* that is 1 if a trade is denoted as a wash trade. Dependent variables are marketplace dummy, and interaction of insider buy and seller dummy. Control variables are log holding period and log NFT transaction price. Standard errors are clustered by collection. *t*-statistics are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

VARIABLES	(1) Wash Sales Dummy	(2) Wash Sales Dummy	(3) Wash Sales Dummy
Marketplace = OpenSea		(baseline)	(baseline)
Marketplace = Blur		0.0360*** (3.896)	0.0360*** (3.895)
Marketplace = Element		0.181 (1.526)	0.181 (1.526)
Marketplace = Foundation		0.00700 (1.513)	0.00701 (1.515)
Marketplace = LooksRare		0.0238** (2.026)	0.0238** (2.026)
Marketplace = Sudoswap		0.0326*** (4.827)	0.0326*** (4.822)
Marketplace = X2Y2		0.364*** (3.191)	0.364*** (3.192)
Marketplace = Zora		0.0573* (1.663)	0.0573* (1.664)
InsiderBuyer=0×InsiderSeller=0	(baseline)		(baseline)
InsiderBuyer=0×InsiderSeller=1	0.000838 (1.020)		0.000992 (1.379)
InsiderBuyer=1×InsiderSeller=0	-0.00109 (-0.840)		-0.000303 (-0.380)
InsiderBuyer=1×InsiderSeller=1	7.65e-05 (0.0955)		0.00131* (1.896)
Log(1+Holding Period)	-0.00462*** (-2.840)	-0.00301*** (-4.409)	-0.00301*** (-4.410)
Log(NFT Price)	0.00202** (2.440)	0.00143* (1.751)	0.00143* (1.747)
Log(Mint Volume)	-0.00320 (-0.723)	-0.00206 (-0.798)	-0.00206 (-0.797)
Observations	3,303,324	3,303,324	3,303,324
Collection Controls	YES	YES	YES
Date FE	YES	YES	YES
Within Adj R-squared	0.0213	0.245	0.245
Adj R-squared	0.115	0.317	0.317

is in X2Y2 platform, the probability that a trade is wash is 36 percentage points higher compared to that in OpenSea, controlling for holding period, price, and collection volume. Sudoswap and Blur is 3 percentage points higher, LooksRare is 2 percentage higher than OpenSea. These results are consistent in Column (3). In conclusion, wash trades in NFT market is not to allure investors, but to generate artificial financial reward to wash traders,

or make market attention and attract NFT investors to start-up marketplaces.

Lastly, whether investors still trade a wash traded item after wash trade is eventually finished can be investigated. If so, is there any difference in returns compared to non-wash traded NFTs? Investors may avoid and penalize buying such an item like plague. This can be discussed whether the realized return is substantially different when the previous trade of an item is flagged as a wash trade. As in Oh, Rosen, and Zhang (2022), the realized return for a collection c , item i , purchased at τ , sold at t is defined as $RealizedReturn_{c,i,\tau,t} = \frac{Price_{c,i,t}}{Price_{c,i,\tau}} - 1$, without considering gas, royalty, and marketplace fee. Further it is winsorized at 1/99 percentile level.

Table 11. Realized Returns After Wash Trades

Notes. In this table, I present the estimates that I regress realized return on the past wash trade history. The independent variable is 1 if a previous trade for the same collection c , item i is wash trade, current trade is not wash trade, and previous buyer is recorded as seller at current trade. Control variables are collection characteristics, log holding period, log collection volume, and other quality characteristics. Standard errors are clustered by collection. t -statistics are in parentheses. * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

VARIABLES	(1) Realized Return	(2) Realized Return	(3) Realized Return
Dummy Previous Is Wash	-0.293** (-2.094)	0.218 (1.078)	0.231 (1.096)
Log(1+Holding Period)		0.267*** (3.031)	0.268*** (2.987)
Log(Mint Volume)		0.174 (1.001)	0.173 (0.993)
Observations	3,303,324	3,303,324	3,293,225
Collection Controls	NO	YES	YES
Date FE	YES	YES	YES
Within Adj R-squared	1.10e-06	0.00837	0.00830
Adj R-squared	0.0445	0.0525	0.0521

Simple regression estimation using realized return is shown at Table 11. The independent variable is *Dummy previous is wash*, which is 1 if a previous trade for the same collection c , item i is wash trade, current trade is not wash trade, and previous buyer is recorded as seller at current trade. Control variables are collection characteristic variables and holding period. Column (1) describes that wash traded NFTs has 29.3 percentage points lower realized returns than non-wash traded NFTs without control variables. The result at

Column (2) indicates that there is no difference in returns depending on the history that previous trade is wash trade, controlling for holding period, collection volume, and other collection characteristics. This is consistent in Column (3) where all transactions marked as wash trades are eliminated for precise subsample analysis.

6 Conclusion

NFT is a new form of crowdfunding via blockchain technology. The regulation free environment but with data transparency allows us to conduct interesting analysis on the market misconduct that are limited in traditional finance research. It is available to detect possible unrevealed insider and manipulative trading in NFT markets using publicly available blockchain data. Insiders are investors who obtained free items in the primary market directly from creators, and wash trades are classified using 3 types of transactions similar to the definition of the United States Internal Revenue Service. Insiders are 4.9% of total wallets participated in primary market, and wash trades are 0.3% out of 3.7 million secondary market transaction.

I examine the effect of misconduct behaviors on market outcomes for NFT projects that successfully minted all items over March 2021 to January 2023. The results indicates that insiders' buying activity is a strong predictors for future daily price index returns. However, wash trading is economically insignificant. Moreover, insiders purchase and wash trades does not meaningfully decrease future trading volume change. This suggests that unreported insiders take an advantage of information asymmetry in NFT markets but wash trade is actually ineffective to manipulate market outcomes. Lastly, I checked the purpose of wash trades. The empirical analysis shows that some investors perform wash trade to artificially gain platform reward, or make market attention to start-up marketplaces to catch up a dominant marketplace.

For further research, alternative measure can be considered. Investors care more about the floor price which is minimum available listed price in each NFT collection. Instead of median price that can be affected a lot by wash trading, new outcomes can be considered as an alternative independent variable. Another point to consider is the network

of wash traders. These wash traders' identity and connection can be analyzed further.

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Appendix

A Supplementary Materials

Table A.1. Summary Statistics: Insiders

Notes. This table shows summary statistics of insiders and wallets.

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Total Trading Volume	558	6,602	7,263	13	44,372
Collection Volume (# of Minted Items)	558	6,535	3,780	1,000	25,000
Insider Buying Volume	558	105.4	343.5	0	5,777
Insider Buy/Collection Volume	558	0.0323	0.0762	0	0.701
Wallets in Primary Market	558	1,528	1,113	61	7,724
Potential Insider Wallets (Free Minted)	558	61.61	164.8	0	1,964
Insider Wallets/Total Wallets in Primary Market	558	0.0464	0.105	0	0.725

Table A.2. Summary Statistics: Wash Trades

Notes. This table shows summary statistics of wash trades defined in subsection 2.3.

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Average # of Type 1 Wash Sales	558	0.620	3.617	0	67
Average # of Type 2 Wash Sales	558	15.78	166.3	0	3,375
Average # of Type 3 Wash Sales	558	2.120	15.86	0	297
Average # of Wash Sales	558	18.22	168.9	0	3,385
Collection Volume (Total # of Minted Items)	558	6,535	3,780	1,000	25,000
Average Type 1 Wash Sales Volume/Collection Volume	558	6.94e-05	0.000373	0	0.00670
Average Type 2 Wash Sales Volume/Collection Volume	558	0.00305	0.0484	0	1.125
Average Type 3 Wash Sales Volume/Collection Volumes	558	0.000238	0.00164	0	0.0297
Average Wash Sales Volume/Collection Volume	558	0.00332	0.0486	0	1.128
Has Type 1 Wash Sales	558	0.115	0.319	0	1
Has Type 2 Wash Sales	558	0.398	0.490	0	1
Has Type 3 Wash Sales	558	0.142	0.349	0	1
Has Wash Sales	558	0.432	0.496	0	1

Table A.3. Performance of Manipulative Trades: With Wash Trades

VARIABLES	(1) Price	(2) Price	(3) Price	(4) Price	(5) Price	(6) Price
InsiderBuy Activity	24.60*** (5.604)	22.65*** (5.274)			24.61*** (5.605)	22.66*** (5.275)
Wash Activity			-1.412*** (-3.594)	-1.250*** (-3.674)	-1.424*** (-3.530)	-1.259*** (-3.642)
Log(1+Days after mints)	0.00483*** (3.771)	0.0223*** (8.077)	0.00344*** (2.716)	0.0202*** (7.369)	0.00486*** (3.792)	0.0223*** (8.082)
Past Day Returns	-0.0169** (-2.175)	-0.0222*** (-2.864)	-0.0161** (-2.071)	-0.0216*** (-2.792)	-0.0169** (-2.175)	-0.0222*** (-2.863)
Past Week Returns	-0.00193 (-0.643)	-0.00609* (-1.934)	-0.00145 (-0.484)	-0.00591* (-1.877)	-0.00195 (-0.651)	-0.00610* (-1.938)
Log Market Value of Collection	-0.0167*** (-6.075)	-0.0170*** (-6.678)	-0.0169*** (-6.091)	-0.0171*** (-6.658)	-0.0167*** (-6.074)	-0.0170*** (-6.674)
Dummy category Gaming	0.00864 (0.740)	0.00379 (0.366)	0.00905 (0.786)	0.00441 (0.432)	0.00862 (0.738)	0.00380 (0.367)
Dummy category Metaverse	0.000728 (0.0595)	-0.00497 (-0.459)	0.00463 (0.368)	-0.00139 (-0.125)	0.000698 (0.0570)	-0.00496 (-0.459)
Dummy category Social	-0.00592 (-0.604)	-0.00813 (-0.906)	-0.00504 (-0.527)	-0.00730 (-0.832)	-0.00591 (-0.604)	-0.00809 (-0.904)
Dummy Has Twitter	-0.00470 (-0.328)	-0.0235 (-1.461)	-0.0103 (-0.871)	-0.0280** (-2.093)	-0.00468 (-0.327)	-0.0235 (-1.459)
Dummy Has Website	0.000525 (0.0391)	0.00764 (0.496)	0.00482 (0.399)	0.0116 (0.841)	0.000565 (0.0421)	0.00768 (0.498)
Dummy Has Roadmap	-0.00703* (-1.939)	-0.00757** (-2.185)	-0.00731** (-2.018)	-0.00770** (-2.229)	-0.00706* (-1.948)	-0.00760** (-2.193)
Dummy Artist Name	0.00543* (1.850)	0.00259 (0.898)	0.00582** (1.966)	0.00298 (1.026)	0.00538* (1.835)	0.00255 (0.884)
Observations	39,838	39,814	39,838	39,814	39,838	39,814
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.0154	0.0158	0.0134	0.0140	0.0154	0.0158
Adj R-squared	0.0154	0.0602	0.0134	0.0585	0.0154	0.0602

Table A.4. Performance of Manipulative Trades: Without Wash Trades

VARIABLES	(1) Price	(2) Price	(3) Price	(4) Price	(5) Price	(6) Price
InsiderBuy Activity	24.59*** (5.610)	22.62*** (5.274)			24.59*** (5.611)	22.62*** (5.274)
Wash Activity			-1.336*** (-3.808)	-1.169*** (-3.884)	-1.348*** (-3.749)	-1.178*** (-3.860)
Log(1+Days after mints)	0.00478*** (3.744)	0.0221*** (8.023)	0.00339*** (2.684)	0.0200*** (7.315)	0.00481*** (3.764)	0.0221*** (8.028)
Past Day Returns	-0.0168** (-2.175)	-0.0222*** (-2.868)	-0.0160** (-2.071)	-0.0216*** (-2.795)	-0.0168** (-2.175)	-0.0222*** (-2.867)
Past Week Returns	-0.00222 (-0.736)	-0.00644** (-2.033)	-0.00174 (-0.578)	-0.00626** (-1.976)	-0.00224 (-0.743)	-0.00645** (-2.037)
Log Market Value of Collection	-0.0166*** (-6.073)	-0.0169*** (-6.676)	-0.0168*** (-6.089)	-0.0170*** (-6.657)	-0.0166*** (-6.072)	-0.0169*** (-6.672)
Dummy category Gaming	0.0103 (0.894)	0.00543 (0.527)	0.0107 (0.940)	0.00605 (0.593)	0.0103 (0.893)	0.00544 (0.529)
Dummy category Metaverse	0.00235 (0.195)	-0.00339 (-0.315)	0.00625 (0.502)	0.000183 (0.0166)	0.00232 (0.192)	-0.00338 (-0.314)
Dummy category Social	-0.00422 (-0.439)	-0.00646 (-0.723)	-0.00334 (-0.354)	-0.00564 (-0.641)	-0.00422 (-0.439)	-0.00643 (-0.721)
Dummy Has Twitter	-0.00408 (-0.286)	-0.0226 (-1.415)	-0.00968 (-0.820)	-0.0271** (-2.038)	-0.00406 (-0.284)	-0.0226 (-1.413)
Dummy Has Website	0.000481 (0.0359)	0.00754 (0.491)	0.00477 (0.395)	0.0115 (0.836)	0.000518 (0.0386)	0.00757 (0.493)
Dummy Has Roadmap	-0.00689* (-1.909)	-0.00742** (-2.151)	-0.00716** (-1.987)	-0.00754** (-2.194)	-0.00692* (-1.917)	-0.00744** (-2.158)
Dummy Artist Name	0.00546* (1.871)	0.00264 (0.919)	0.00585** (1.987)	0.00303 (1.048)	0.00542* (1.857)	0.00260 (0.905)
Observations	39,838	39,814	39,838	39,814	39,838	39,814
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.0153	0.0157	0.0133	0.0139	0.0153	0.0157
Adj R-squared	0.0153	0.0602	0.0133	0.0585	0.0153	0.0602

Table A.5. Performance of Manipulative Trades: Same Day Without Wash Trades

VARIABLES	(1) Price	(2) Price	(3) Price	(4) Price	(5) Price	(6) Price
InsiderBuy Activity	35.48*** (5.527)	32.18*** (5.084)			35.48*** (5.527)	32.18*** (5.083)
Wash Activity			-0.521 (-0.577)	-0.217 (-0.239)	-0.538 (-0.607)	-0.229 (-0.254)
Log(1+Days after mints)	-0.00361** (-2.457)	0.00476* (1.656)	-0.00563*** (-4.005)	0.00180 (0.625)	-0.00360** (-2.448)	0.00476* (1.657)
Past Day Returns	-0.221*** (-18.86)	-0.246*** (-22.13)	-0.220*** (-18.61)	-0.245*** (-21.94)	-0.221*** (-18.86)	-0.246*** (-22.13)
Past Week Returns	-0.0247*** (-6.291)	-0.0362*** (-9.029)	-0.0240*** (-6.113)	-0.0360*** (-8.950)	-0.0247*** (-6.292)	-0.0362*** (-9.029)
Log Market Value of Collection	0.00469*** (3.437)	0.00513*** (2.988)	0.00437*** (3.336)	0.00499*** (2.985)	0.00469*** (3.437)	0.00513*** (2.988)
Dummy category Gaming	-0.0178* (-1.710)	-0.0179* (-1.814)	-0.0169 (-1.641)	-0.0169* (-1.700)	-0.0178* (-1.713)	-0.0180* (-1.815)
Dummy category Metaverse	-0.0310** (-2.537)	-0.0361*** (-3.039)	-0.0252** (-2.216)	-0.0309*** (-2.798)	-0.0310** (-2.540)	-0.0361*** (-3.041)
Dummy category Social	-0.0286*** (-3.240)	-0.0294*** (-3.372)	-0.0272*** (-3.136)	-0.0281*** (-3.248)	-0.0286*** (-3.244)	-0.0294*** (-3.375)
Dummy Has Twitter	0.0179 (1.166)	0.00523 (0.428)	0.0108 (0.613)	-0.000238 (-0.0156)	0.0179 (1.167)	0.00524 (0.429)
Dummy Has Website	-0.00842 (-0.507)	0.00136 (0.111)	-0.00337 (-0.193)	0.00593 (0.437)	-0.00841 (-0.506)	0.00137 (0.111)
Dummy Has Roadmap	-0.00213 (-0.661)	-0.000710 (-0.209)	-0.00243 (-0.755)	-0.000809 (-0.237)	-0.00214 (-0.665)	-0.000716 (-0.211)
Dummy Artist Name	-0.00210 (-0.662)	-0.00398 (-1.255)	-0.00154 (-0.491)	-0.00342 (-1.085)	-0.00212 (-0.667)	-0.00399 (-1.257)
Observations	42,946	42,922	42,946	42,922	42,946	42,922
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.0538	0.0649	0.0500	0.0616	0.0538	0.0648
Adj R-squared	0.0538	0.104	0.0500	0.101	0.0538	0.104

Table A.6. Impact of Manipulative Trades on Trading Volume: Without Wash Trades

VARIABLES	(1) Volume	(2) Volume	(3) Volume	(4) Volume	(5) Volume	(6) Volume
InsiderBuy Activity	-127.1*** (-9.290)	-126.1*** (-9.200)			-127.1*** (-9.284)	-126.1*** (-9.196)
Wash Activity			-8.368*** (-3.414)	-9.069*** (-3.770)	-8.305*** (-3.497)	-9.022*** (-3.822)
Log(1+Days after mints)	0.0364*** (7.912)	0.0595*** (6.388)	0.0440*** (9.818)	0.0712*** (7.844)	0.0366*** (7.940)	0.0596*** (6.398)
Past Day Returns	-0.112*** (-4.495)	-0.131*** (-4.812)	-0.116*** (-4.672)	-0.134*** (-4.931)	-0.112*** (-4.494)	-0.131*** (-4.809)
Past Week Returns	-0.0284*** (-2.822)	-0.0357*** (-3.378)	-0.0311*** (-3.144)	-0.0368*** (-3.537)	-0.0285*** (-2.837)	-0.0358*** (-3.388)
Log Market Value of Collection	-0.0300*** (-7.697)	-0.0318*** (-7.482)	-0.0288*** (-7.772)	-0.0313*** (-7.638)	-0.0301*** (-7.696)	-0.0319*** (-7.474)
Dummy category Gaming	0.0377 (0.709)	0.0365 (0.707)	0.0354 (0.653)	0.0332 (0.631)	0.0376 (0.707)	0.0366 (0.711)
Dummy category Metaverse	0.0398 (0.711)	0.0421 (0.745)	0.0193 (0.350)	0.0223 (0.400)	0.0396 (0.708)	0.0422 (0.748)
Dummy category Social	-0.00878 (-0.178)	-0.00266 (-0.0560)	-0.0133 (-0.265)	-0.00686 (-0.142)	-0.00876 (-0.178)	-0.00243 (-0.0511)
Dummy Has Twitter	-0.0548 (-0.771)	-0.0782 (-1.022)	-0.0256 (-0.301)	-0.0528 (-0.571)	-0.0546 (-0.769)	-0.0780 (-1.019)
Dummy Has Website	0.100 (1.404)	0.0920 (1.223)	0.0783 (0.993)	0.0703 (0.830)	0.100 (1.406)	0.0922 (1.226)
Dummy Has Roadmap	-0.0253** (-2.388)	-0.0268** (-2.421)	-0.0243** (-2.363)	-0.0265** (-2.450)	-0.0255** (-2.403)	-0.0270** (-2.439)
Dummy Artist Name	0.0145 (1.393)	0.0130 (1.147)	0.0120 (1.200)	0.0103 (0.942)	0.0142 (1.367)	0.0127 (1.120)
Observations	39,838	39,814	39,838	39,814	39,838	39,814
Collection Controls	YES	YES	YES	YES	YES	YES
Date FE	NO	YES	NO	YES	NO	YES
Within Adj R-squared	0.00597	0.00585	0.00354	0.00344	0.00601	0.00590
Adj R-squared	0.00597	0.0255	0.00354	0.0232	0.00601	0.0256

Table A.7. Determinants of Wash Trades

VARIABLES	(1) Wash Sales Dummy	(2) Wash Sales Dummy	(3) Wash Sales Dummy
Marketplace = OpenSea		(baseline)	(baseline)
Marketplace = Blur		0.0360*** (3.896)	0.0360*** (3.895)
Marketplace = Element		0.181 (1.526)	0.181 (1.526)
Marketplace = Foundation		0.00700 (1.513)	0.00701 (1.515)
Marketplace = LooksRare		0.0238** (2.026)	0.0238** (2.026)
Marketplace = Sudoswap		0.0326*** (4.827)	0.0326*** (4.822)
Marketplace = X2Y2		0.364*** (3.191)	0.364*** (3.192)
Marketplace = Zora		0.0573* (1.663)	0.0573* (1.664)
InsiderBuyer=0×InsiderSeller=0	(baseline)		(baseline)
InsiderBuyer=0×InsiderSeller=1	0.000838 (1.020)		0.000992 (1.379)
InsiderBuyer=1×InsiderSeller=0	-0.00109 (-0.840)		-0.000303 (-0.380)
InsiderBuyer=1×InsiderSeller=1	7.65e-05 (0.0955)		0.00131* (1.896)
Log(1+Holding Period)	-0.00462*** (-2.840)	-0.00301*** (-4.409)	-0.00301*** (-4.410)
Log(NFT Price)	0.00202** (2.440)	0.00143* (1.751)	0.00143* (1.747)
Log(Mint Volume)	-0.00320 (-0.723)	-0.00206 (-0.798)	-0.00206 (-0.797)
Dummy category Gaming	-0.00938 (-0.764)	-0.00820 (-0.664)	-0.00820 (-0.664)
Dummy category Metaverse	-0.00869 (-0.681)	-0.00834 (-0.659)	-0.00835 (-0.659)
Dummy category Social	-0.00775 (-0.625)	-0.00698 (-0.566)	-0.00698 (-0.566)
Dummy Has Twitter	0.00686** (2.016)	0.00582* (1.686)	0.00584* (1.703)
Dummy Has Website	0.000590 (0.216)	-0.000557 (-0.188)	-0.000570 (-0.192)
Dummy Has Roadmap	9.87e-05 (0.0581)	0.000424 (0.399)	0.000422 (0.397)
Dummy Artist Name	-0.00173 (-1.010)	-0.00119 (-1.130)	-0.00119 (-1.128)
Observations	3,303,324	3,303,324	3,303,324
Collection Controls	YES	YES	YES
Date FE	YES	YES	YES
Within Adj R-squared	0.0213	0.245	0.245
Adj R-squared	0.115	0.317	0.317

Table A.8. Realized Returns After Wash Trades

VARIABLES	(1) Realized Return	(2) Realized Return	(3) Realized Return
Dummy Previous Is Wash	-0.293** (-2.094)	0.218 (1.078)	0.231 (1.096)
Log(1+Holding Period)		0.267*** (3.031)	0.268*** (2.987)
Log(Mint Volume)		0.174 (1.001)	0.173 (0.993)
Dummy category Gaming		0.877 (1.515)	0.880 (1.507)
Dummy category Metaverse		0.178 (0.292)	0.179 (0.292)
Dummy category Social		0.567 (1.164)	0.569 (1.154)
Dummy Has Twitter		-0.132 (-0.186)	-0.135 (-0.189)
Dummy Has Website		0.946** (2.279)	0.949** (2.278)
Dummy Has Roadmap		-0.552* (-1.831)	-0.553* (-1.832)
Dummy Artist Name		0.139 (0.564)	0.139 (0.563)
Observations	3,303,324	3,303,324	3,293,225
Collection Controls	NO	YES	YES
Date FE	YES	YES	YES
Within Adj R-squared	1.10e-06	0.00837	0.00830
Adj R-squared	0.0445	0.0525	0.0521