

Strategic arbitrage in segmented markets<sup>☆</sup>Svetlana Bryzgalova<sup>a</sup>, Anna Pavlova<sup>a,b,\*</sup>, Taisiya Sikorskaya<sup>c</sup><sup>a</sup> London Business School, Regents Park, London, NW1 4SA, United Kingdom<sup>b</sup> CEPR, United Kingdom<sup>c</sup> University of Chicago, Booth School of Business, 5807 S Woodlawn Ave, Chicago, 60637, IL, USA

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## ABSTRACT

We propose a model in which arbitrageurs act strategically in markets with entry costs. In a repeated game, arbitrageurs choose to specialize in some markets, which leads to the highest combined profits. We present evidence consistent with our theory from the options market, in which suboptimally unexercised options create arbitrage opportunities for intermediaries. We use transaction-level data to identify the corresponding arbitrage trades. Consistent with the model, only 57% of these opportunities attract entry by arbitrageurs. Of those that do, 49% attract only one arbitrageur. Finally, we detail how market participants circumvent a regulation devised to curtail this arbitrage strategy.

## 1. Introduction

The dominant paradigm in the literature studying limits to arbitrage and arbitrage in general is the competitive arbitrageur paradigm, whereby arbitrageurs are atomistic. Yet in practice, we often observe just a handful of large arbitrageurs operating in some markets, because of high fixed costs of entry or owing to economies of scale. These arbitrageurs may act strategically. Moreover, in many applications, arbitrageurs interact repeatedly, which gives rise to repeated game considerations. An environment incorporating these features may offer

a better description of arbitrageur interaction in markets that are more opaque and concentrated.

In this paper, we contribute to the limits-to-arbitrage literature by introducing repeated game considerations. Our intermediaries (acting as arbitrageurs) face fixed costs of entry in all markets except for their “natural” ones, where their per-period fixed costs are low (zero). In a one-shot Nash equilibrium, arbitrageurs typically enter all the markets. Instead, in a repeated game, (i) they enter their natural markets and refrain from entering natural markets of their opponents; (ii) only one arbitrageur exploits each remaining market. This is a “tacit collusion”

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equilibrium, which results in higher (per-period) arbitrageur profits, compared to those in one-shot games.

As a laboratory for the study of arbitrageur interactions, we use the so-called dividend play, a strategy available to the intermediaries in the U.S. options market that produces (virtually) riskless arbitrage profits. These profits derive from call options left suboptimally unexercised before the underlying goes ex-dividend. Exploiting transaction-level data, we are able to accurately identify arbitrageur dividend play trades in each option contract.

We document that only 57% of arbitrage opportunities – pertinent call option contracts – attract entry of arbitrageurs. We argue that this does not imply that the remaining arbitrage profits are left on the table: Our theory predicts that these profits accrue to the incumbent intermediary – a natural arbitrageur in that market, already positioned to exploit the opportunity without incurring further costs. In line with our model, other intermediaries do not enter that market. Furthermore, consistent with our model's predictions, we show that about 50% of the opportunities attracting entry are exploited by *only one* arbitrageur.

Neither costs nor other arbitrageur constraints seem to explain the lack of entry in our sample. Strikingly, it persists even among the most profitable contracts. These findings are puzzling in light of most limits-to-arbitrage theories because these theories typically imply a pecking order in the arbitrageur entry decisions based on, for example, profitability. Yet, a model of repeated game equilibria with entry costs and natural markets provides a simple alternative framework consistent with our empirical findings.

Here is how the model works. There are three markets with one arbitrage opportunity of fixed value each. There are two risk-neutral intermediaries who exploit these opportunities and face fixed per-period costs of entry in each market. The first (second) market is the natural market for the first (second) intermediary. We call a market “natural” for an arbitrageur if she has (exogenously given) zero or lower per-period fixed costs of entry in it. Examples of natural markets include securities in which an intermediary is already a market maker or a major dealer and thus has a natural advantage in monitoring and accessing potential arbitrage opportunities. An order imbalance from market-making activities could further position an intermediary to exploit a specific arbitrage opportunity without actively entering it. Economies of scale could also create natural markets. In all other markets, intermediaries in our model face higher per-period fixed costs of entry. Intermediaries act strategically, choosing which markets to enter and, conditional on entry, the amount of resources to commit to each market. The share of arbitrage opportunities that is captured by them in each market is proportional to their market share. The game is symmetric in payoffs and we focus on symmetric equilibria.

We first consider a one-shot game. The only Nash equilibrium in that game is one in which the intermediaries enter all markets and equally split the arbitrage opportunities in them. This split, however, does not maximize the joint welfare of the intermediaries. In a welfare-maximizing allocation, arbitrageurs specialize in a subset of markets and thus reduce the total (per-period) fixed cost paid, while still harvesting the same arbitrage gains. A cooperative equilibrium of this type is not a Nash equilibrium of a one-shot game but it becomes a subgame perfect equilibrium of an infinitely-repeated game, supported by trigger strategies (Green and Porter, 1984). This equilibrium is known in the literature as a tacit collusion equilibrium. The term “tacit” conveys that the equilibrium does not require any explicit agreements between intermediaries. In a tacit collusion equilibrium in our model, intermediaries do not enter each others' natural markets and alternate their entry in the third market. This results in the minimum per-period fixed costs. The testable predictions of the model is that in the data, we should observe (i) no market entry into intermediaries' natural markets and (ii) entry of a limited number of arbitrageurs – only one in our model – in markets that are neither intermediaries' natural markets.

The U.S. options market offers a unique laboratory to test our theory. We are able to identify an arbitrage opportunity for which we

observe arbitrageur entry and the amount of resources they commit to exploiting it. The literature on limits to arbitrage has mostly focused on the effects of arbitrage on prices, normally because quantities are not observed in non-proprietary data. Our setting is an exception. In fact, the effects on prices are not relevant to our application. The arbitrage opportunity, as in our model, is best thought of as a windfall gain, which accrues to arbitrageurs in proportion to their market shares. The opportunity results from a failure of investors to exercise in-the-money call options before the underlying goes ex-dividend when it is optimal to do so.<sup>1</sup> In the U.S., options writers who receive an exercise notice and must deliver the underlying are randomly assigned. The writers who are not assigned receive a windfall capital gain. To divert this gain, arbitrageurs engage in “dividend play”, which involves writing a large number of call option contracts, thus maximizing the probability that the gain from suboptimal exercise is assigned to them rather than to the original option writer. Arbitrageurs simultaneously establish an offsetting large long position in a similar contract to hedge the large short position required for the strategy. Dividend play trades are usually prearranged by pairs of arbitrageurs who serve as counterparties to each others' long and short positions. So price impact is not a concern in our application; the windfall gain is fixed and it is effectively divided pro-rata between arbitrageurs who participate in the dividend play strategy, as in our model.

The dividend play strategy is normally executed on a physical exchange floor. This is because some exchanges facilitate this trade by capping the fees for this strategy for floor participants,<sup>2</sup> and because the floor offers pairs of arbitrageurs an opportunity to execute (large) bilateral trades on agreed terms, without exposing them to other market makers' quotes. Our empirical strategy for classifying dividend play trades relies on the flags for floor trades in the transaction-level Options Price Reporting Authority (OPRA) data. With most of the options trading being electronic, exchange floors are more akin to a library than to a bustling trading floor of the past. So, like in our model, there is usually a small number of participants in the dividend play arbitrage, who interact repeatedly with each other on pre-scheduled (last cum-dividend) dates.

The daily trading volume on the last cum-dividend dates in in-the-money call options targeted by the dividend strategy significantly exceeds the trading volume on the remaining dates, often by a factor of 100. So profit-driven arbitrageurs do exploit the strategy. There are, however, four striking patterns that emerge from our examination of their transactions. First, arbitrageurs enter only 57% of profitable arbitrage opportunities (option contracts) and harvest only 44% of total potential profits.<sup>3</sup> Second, if arbitrageurs do decide to participate in dividend play in a given contract, they harvest most of the available profits in that contract. Third, 37% of contracts in the top profitability

<sup>1</sup> It has been previously documented that not all American options are exercised rationally (e.g., Poteshman and Serbin, 2003). Battalio et al. (2020), Cosma et al. (2020), Jensen and Pedersen (2016), Barraclough and Whaley (2012) and Rantapuska and Knüpfer (2008) focus on early exercise decisions and show in more recent data that a fraction of investors still fail to exercise their options optimally. We also acknowledge that sometimes call options may be purchased as part of a strategy that involves holding multiple option contracts. In those circumstances, or whenever transaction costs outweigh profits from early exercise, exercising an option may not be optimal.

<sup>2</sup> For example, PHLX imposes daily fee caps for floor market makers and other floor traders engaging in dividend play. See, e.g., <https://listingcenter.nasdaq.com/rulebook/phlx/rules/phlx-options-7>, accessed July 26, 2023, for the dividend strategy fee caps imposed by the PHLX options exchange. More than two-thirds of dividend play transactions in our sample are executed on PHLX. Dividend play is not the only strategy that benefits from fee caps. For example, PHLX offers similar fee caps for five other arbitrage strategies.

<sup>3</sup> Table 4 quantifies forgone profits of arbitrageurs in the top 40 most popular underlying stocks and exchange-traded funds (ETFs) for the dividend play strategy in our sample.

tercile do not attract entry by arbitrageurs. Furthermore, even among the contracts on the same underlying, arbitrageurs enter only a subset of contracts yet forgo some of the most profitable ones. The first and third patterns are quite puzzling in light of the standard explanations based on limits to arbitrage. Arbitrageurs' daily fee on dividend play trades is capped by most exchanges on which dividend play trades take place, so additional fees are not a plausible explanation for leaving money on the table. Trading costs are quite low because dividend play transactions are executed close to the midpoint of the bid–ask spread. Capital constraints are also unlikely to explain the findings because market participant exposure is normally computed at a ticker level, and so the large long and short positions in contracts on the same ticker, required for the dividend play trade, are netted to zero.

Fourth, we find that the number of arbitrageurs engaging simultaneously in dividend play in a given contract is strikingly small: In 49% of the contracts in which we detect arbitrageur entry, we estimate that the entire profit is captured by a single arbitrageur.<sup>4</sup> Across all contracts, the number of arbitrageurs simultaneously participating in dividend play in a given contract exceeds 4 in only 8% of the cases and exceeds 10 in less than 1%. If we remove one exchange (PHLX) from the sample, over 95% of contracts that attract entry have only one arbitrageur participating in it. This is surprising because there are no obvious restrictions on the entry of other arbitrageurs who already engage in dividend play in other contracts. Partly owing to their sheer size and distinct execution patterns, dividend play trades are easy to detect in transaction-level data (e.g., OPRA). Arbitrageurs are, therefore, aware of the history of other arbitrageurs' dividend play activity in a given contract before they decide to engage in dividend play in it.

The implications of our model are consistent with all of the above patterns. We interpret the contracts in which we observe no entry as natural markets of some options market intermediaries, namely market makers. If a market maker holds in its inventory a short position in a contract that an option buyer fails to exercise, it does not incur any fixed costs and simply pockets the windfall gain on this contract unless other arbitrageurs enter and compete away this gain. This fits exactly our definition of a natural market for an intermediary. In our empirical tests, we use two proxies for natural markets of market makers: contracts with retail buy imbalances (implying that market makers hold short positions in these contracts in their inventory) and contracts with market maker sell imbalances. The former proxy is further motivated by the fact that retail investors are more likely to fail to exercise options optimally. Our empirical tests reveal that arbitrageurs are less likely to actively enter the natural markets of other intermediaries, forgoing profitable arbitrage opportunities. In contrast, in written contracts that neither intermediary has in their inventory, we should expect the entry of only one arbitrageur, and our empirical results indeed reveal that in a large fraction of contracts, we observe the entry of a single arbitrageur. These results hold even if we restrict our sample of contracts to the top most profitable tercile.

There are other potential explanations of the patterns we document. It is possible that the reluctance of some firms to engage in the dividend play arbitrage could be explained by the operational risk of the trade.<sup>5</sup> There is also residual overnight risk related to the dividend play execution. However, we show that the risk-related measures have little relation to contract selection. It is also possible that there is a stigma associated with the dividend play strategy since it is frowned upon by the U.S. Securities and Exchange Commission (SEC). However, it is unclear why arbitrageurs that enter some contracts and incur reputational

costs do not engage in other, often more profitable, contracts on the same underlying.

Finally, we discuss the difficulties of devising effective regulation in the derivatives market. Concerned about the impact of dividend play trades on the orderly functioning of the market, in 2014 the SEC approved a new clearing rule designed to make the strategy impractical.<sup>6</sup> As our analysis reveals, however, it took little time for arbitrageurs to find a way to circumvent the barriers created by the SEC rule by altering the implementation of the strategy. We propose a rule change that may curtail the strategy.

Our paper is related to the limits-to-arbitrage literature, such as Gromb and Vayanos (2002) and Shleifer and Vishny (1997). In most of this literature, arbitrageurs are competitive, while ours are strategic.<sup>7</sup> Strategic trading has been emphasized in the influential strand of market microstructure literature starting from Kyle (1985).<sup>8</sup> Our focus is not on price impact but on multi-market arbitrageur interactions and specialization in a repeated-game setting. Arbitrage opportunities are fully exploited in our case, and limits to arbitrage should be understood as (endogenous) limits on the number of arbitrageurs in a given market. Siriwardane et al. (2024), and Boyarchenko et al. (2020) document that arbitrageurs specialize in a subset of arbitrage opportunities. Eisfeldt et al. (2023b) study complex asset markets where expertise creates arbitrageur specialization. Our models are similar in terms of selective entry, but our mechanism relies on strategic interactions, while in their model, arbitrageurs are competitive.

The closest paper considering a repeated game in financial markets is a tacit collusion model of Dutta and Madhavan (1997). As in the classical industrial organization literature, the authors consider pricing strategies that give rise to prices above competitive levels. Their model explains the puzzling tendency of NASDAQ market makers in equities to avoid odd-eighth quotes, uncovered in an influential paper by Christie and Schultz (1994). There is, of course, a vast literature in industrial organization on tacit collusion (see Ivaldi et al., 2007 and references therein, and especially, Bernheim and Whinston, 1990 for multimarket interaction), but it normally studies the behavior of price-setting firms. Our mechanism is novel in that the welfare gain to the players from tacit collusion is generated by reduced fixed costs from selective market entry as opposed to higher prices. The application to arbitrage in financial markets is also novel.

Our empirical application, dividend play, has been considered in Hao et al. (2009) and Pool et al. (2008), who were the first to describe this strategy.<sup>9</sup> Unlike us, they do not compute the number of arbitrageurs in a given contract and do not document the widespread selective entry of arbitrageurs in profitable contracts, which is our primary focus. More broadly, financial markets with entry costs and economies of scale, intermediated by a limited number of players in largely opaque environments, for example, over-the-counter markets, may present other applications of our model.

<sup>6</sup> See <https://www.sec.gov/rules/sro/occ/2014/34-73438.pdf>. According to the rule, the same contract's exposure must now be netted before the Options Clearing Corporation (OCC) assigns the exercise. This makes buying and selling of the same contract unsuitable for the purposes of dividend play.

<sup>7</sup> Fardeau (2021), Zigrand (2004) and Basak and Croitoru (2000) and also consider strategic arbitrageurs. Their focus is different from ours and they do not consider repeated games.

<sup>8</sup> In this strand of literature, Goldstein and Guembel (2008) discuss market manipulation. Hörner et al. (2018) study price setting by strategic dealers who possess private information and interact repeatedly. More recently, Dou et al. (2023) discuss a possible emergence of tacit collusion equilibria in algorithmic trading.

<sup>9</sup> In Section 5, we demonstrate how the strategy described in these papers has evolved in response to the 2014 SEC rule aimed at curtailing it.

<sup>4</sup> More precisely, we observe entry of one pair of arbitrageurs. One of them establishes a large short position in a profitable contract and harvests the windfall gain, and the other serves as the counterparty to this trade. Since only one party receives the gain, we count each pair as one arbitrageur.

<sup>5</sup> For example, a human error in the dividend play strategy inflicted a \$10 million loss on Bank of America Merrill Lynch. See <https://www.reuters.com/article/us-usa-options-apple-idUSKBN0IQ2FA20141106>.

## 2. Model

In this section, we develop a game-theoretic model of arbitrage in segmented markets with a small number of arbitrageurs, who repeatedly interact with each other. In the empirical part of the paper, we focus on a specific application, which is likely to satisfy the model's assumptions – dividend play – and show that the patterns of arbitrage we observe in the data are consistent with our model's predictions. The model, however, is applicable more broadly to environments which feature strategic arbitrage with repeated arbitrageur interactions. We elaborate on this in Section 6.

### 2.1. Economic environment

Time is discrete and the horizon is infinite. There are three markets,  $M_1$ ,  $M_2$ , and  $M_3$ , each with one arbitrage opportunity. For simplicity, the per-period value of the arbitrage opportunities in the first two markets is the same, and we denote it by  $A$ . The per-period value of the arbitrage opportunity in the third market is  $A^*$ .

There are two special intermediaries, 1 and 2, who are the natural arbitrageurs in markets  $M_1$  and  $M_2$ , respectively. That is, Intermediary 1 has a zero cost of harvesting the arbitrage opportunity in market  $M_1$  and Intermediary 2 in market  $M_2$ . Neither of the two intermediaries is a natural arbitrageur in market  $M_3$ . Both intermediaries are risk-neutral. In what follows, we use the terms “arbitrageur” and “intermediary” interchangeably.

Each intermediary has 1 unit of resources that she allocates across the three markets. Intermediary 1's per-period costs of exploiting the arbitrage opportunities in markets  $M_1$ ,  $M_2$ , and  $M_3$  are 0,  $f$ , and  $f^*$ , respectively, and those of Intermediary 2 are  $f$ , 0, and  $f^*$ . The fixed cost is incurred only if an intermediary enters a market, i.e., commits non-zero resources to the market. If an intermediary does not enter a market, its payoff in that market is 0.

Intermediary 1's per-period payoff is

$$\pi_1(k_1^1, k_1^2, k_1^3) \equiv A \frac{k_1^1}{k_1^1 + k_1^2} + A \frac{k_1^2}{k_1^2 + k_1^3} + A^* \frac{k_1^3}{k_1^3 + k_1^3} - f 1_{k_1^2 > 0} - f^* 1_{k_1^3 > 0}, \quad (1)$$

where resources allocated to each of the three markets ( $k_1^1, k_1^2, k_1^3$ ) are choice variables and  $k_1^1 + k_1^2 + k_1^3 \leq 1$ . Analogously, Intermediary 2's per-period payoff is

$$\pi_2(k_2^1, k_2^2, k_2^3) \equiv A \frac{k_2^1}{k_2^1 + k_2^2} + A \frac{k_2^2}{k_2^2 + k_2^3} + A^* \frac{k_2^3}{k_2^3 + k_2^3} - f 1_{k_2^1 > 0} - f^* 1_{k_2^3 > 0}, \quad (2)$$

where  $k_2^1 + k_2^2 + k_2^3 \leq 1$ . The intermediaries, therefore, harvest the arbitrage opportunities in proportion to their market share of resources invested in a given market. In the special case of  $k_2^1 = 0$ , Intermediary 1 harvests the entire arbitrage opportunity in market  $M_1$ , even if she commits no resources to that market. Likewise, if Intermediary 1 refrains from entry in market  $M_2$ , the entire arbitrage profit  $A$  accrues to Intermediary 2, regardless of the amount of resources in that market. If none of the intermediaries enter market  $M_3$ , the arbitrage opportunity in that market remains unexploited.

Our main focus is on repeated games. The time discount factor is  $\delta$ . The risk-neutral intermediaries act strategically and choose their best response per-period resource allocations ( $k_{it}^1, k_{it}^2, k_{it}^3$ ) to maximize

$$\sum_{t=0}^{\infty} \delta^t \pi_i(k_{it}^1, k_{it}^2, k_{it}^3),$$

taking the resource allocation of the other intermediary as given. We will also consider Pareto efficient allocations, which maximize social welfare, i.e.,

$$\mu_1 \sum_{t=0}^{\infty} \delta^t \pi_1(k_{1t}^1, k_{1t}^2, k_{1t}^3) + \mu_2 \sum_{t=0}^{\infty} \delta^t \pi_2(k_{2t}^1, k_{2t}^2, k_{2t}^3), \quad (3)$$

subject to the resource constraints  $k_{it}^1 + k_{it}^2 + k_{it}^3 \leq 1$ ,  $i \in \{1, 2\}$ , where  $\mu_1$  and  $\mu_2$  are the Pareto weights. Social welfare here is understood in the game-theoretic sense: it takes into account the welfare of the two players (the intermediaries) but not any other agents in the economy. With a restriction on the time discount factor  $\delta$ , Pareto efficient equilibria can be supported as non-cooperative (subgame perfect) equilibria of a repeated game, as we demonstrate below.

The concept of arbitrageurs' natural markets is new to this paper. We think of natural markets as the ones where an arbitrageur incurs lower costs than the competition. This can happen if an arbitrageur is an intermediary that is close to the order flow in the market (e.g., a market maker or a large high-frequency trading firm) or has a structure of its balance sheet that gives it a natural advantage in exploiting a particular arbitrage opportunity. One example is the options market arbitrage from the trading floor that we use as a laboratory in the next section.<sup>10</sup> In other markets, natural hedges may create a similar environment. For example, Bolton and Oehmke (2013) and Atkeson et al. (2015) argue that in credit default swaps (CDS) markets, large banks that hedge their exposure by buying/selling CDS contracts are naturally placed to act as CDS dealers and possibly arbitrageurs, as they are best able to generate enough fee income from trading CDS to cover the fixed cost of entry. They can also use their balance sheets to net large long and short positions, saving on required collateral. Similarly, if intermediaries have structured products on their balance sheets, they may be “naturally” exposed to dividend risk (Mixon and Onur, 2017), which makes dividend derivatives their natural markets.

Fixed costs of market access are an important ingredient of our model. Recent limits-to-arbitrage literature (Siriwardane et al., 2024) stresses that in practice, arbitrage is segmented, whereby arbitrageurs specialize in one market or a small handful of markets. Such segmentation would naturally happen in the presence of fixed costs of arbitrage. We model fixed costs in the natural markets to be zero for simplicity, but what is key to our implications is that fixed costs in a given market are lower for natural arbitrageurs in that market.

It is important to consider a repeated game for the emergence of tacit collusion equilibria as subgame perfect equilibria in our model. Repeated interaction of arbitrageurs commonly occurs in practice. If arbitrage is indeed segmented, it is practical for the same arbitrageurs to specialize in a given market over time instead of switching to a different market every period.

Finally, the model focuses on the markets with a fixed number of arbitrageurs who act strategically. An important macroeconomic trend of the past few decades is the rise in industry concentration. (See Grullon et al., 2019; Autor et al., 2020; De Loecker et al., 2020.) Financial intermediation and market making are no exception.<sup>11</sup> We believe that it is important to step away from the competitive arbitrageur paradigm and consider strategic interactions, at least in some more opaque and in more concentrated markets.

### 2.2. Pareto efficient and Nash equilibria of a stage game

We first consider a one-shot game and derive its Nash equilibrium. Intermediary 1's best response to Intermediary 2's actions is the

<sup>10</sup> A market maker, most notably a Designated Market Maker, may hold an inventory of option contracts because of their market-making activities. This makes them a natural arbitrageur in those contracts.

<sup>11</sup> There are numerous financial markets in which intermediaries have been shown to have market power, such as agency MBS (An and Song, 2023), Canadian government bonds (Allen and Wittwer, 2023), foreign exchange derivatives (Wallen, 2022), triparty repo (Huber, 2023), UK government and corporate bonds (Pinter and Uslu, 2022), and even the market for catastrophe risk (Froot, 2001). Those are the markets that can potentially be natural markets for some intermediaries.



solution to the following optimization problem, taking  $(k_1^1, k_2^2, k_3^3)$  as given:

$$\max_{k_1^1, k_1^2, k_1^3} A \frac{k_1^1}{k_1^1 + k_2^1} + A \frac{k_1^2}{k_1^2 + k_2^2} + A^* \frac{k_1^3}{k_1^3 + k_2^3} - f \mathbf{1}_{k_1^1 > 0} - f^* \mathbf{1}_{k_1^3 > 0}, \quad (4)$$

$$\text{s.t. } k_1^1 + k_1^2 + k_1^3 \leq 1. \quad (5)$$

Analogously, Intermediary's 2 best response is the solution to

$$\max_{k_2^1, k_2^2, k_2^3} A \frac{k_2^1}{k_1^1 + k_2^1} + A \frac{k_2^2}{k_1^2 + k_2^2} + A^* \frac{k_2^3}{k_1^3 + k_2^3} - f \mathbf{1}_{k_2^1 > 0} - f^* \mathbf{1}_{k_2^3 > 0}, \quad (6)$$

$$\text{s.t. } k_2^1 + k_2^2 + k_2^3 \leq 1, \quad (7)$$

where she takes the resource allocation of Intermediary 1,  $(k_1^1, k_1^2, k_1^3)$ , as given. The best responses are presented in Lemmas 1 and 2 in Appendix. The intersection of the best responses is a Nash equilibrium of the one-shot game. We are particularly interested in the interior equilibria, in which the intermediaries enter all markets.

**Proposition 1 (Nash Equilibrium).** Suppose that a Nash equilibrium in which  $k_i^j > 0$ ,  $i \in \{1, 2\}$ ,  $j \in \{1, 2, 3\}$ , exists. Then it is given by a solution to the following system of equations:

$$k_1^1 = \left[ \Lambda_1 \left( \frac{A}{k_2^1} \right)^{1/2} - 1 \right] k_2^1, \quad k_1^2 = \left[ \Lambda_1 \left( \frac{A}{k_2^2} \right)^{1/2} - 1 \right] k_2^2, \quad (8)$$

$$k_1^3 = \left[ \Lambda_1 \left( \frac{A^*}{k_2^3} \right)^{1/2} - 1 \right] k_2^3,$$

$$k_2^1 = \left[ \Lambda_2 \left( \frac{A}{k_1^1} \right)^{1/2} - 1 \right] k_1^1, \quad k_2^2 = \left[ \Lambda_2 \left( \frac{A}{k_1^2} \right)^{1/2} - 1 \right] k_1^2, \quad (9)$$

$$k_2^3 = \left[ \Lambda_2 \left( \frac{A^*}{k_1^3} \right)^{1/2} - 1 \right] k_1^3,$$

$$\Lambda_1 = 2 \left[ (A k_1^1)^{1/2} + (A k_2^2)^{1/2} + (A^* k_2^3)^{1/2} \right]^{-1}, \quad (10)$$

$$\Lambda_2 = 2 \left[ (A k_1^1)^{1/2} + (A k_1^2)^{1/2} + (A^* k_1^3)^{1/2} \right]^{-1}. \quad (11)$$

In this paper, we focus on symmetric Nash equilibria. Substituting  $k_1^1 = k_2^1$ ,  $k_1^2 = k_2^2$ , and  $k_1^3 = k_2^3$  in (8)–(11), we arrive at the following corollary to Proposition 1.

**Corollary 1 (Symmetric Nash Equilibrium).** In a symmetric Nash equilibrium,

(i) the resource allocations to markets  $M_1$  and  $M_2$  are

$$k_1^1 = k_2^1 = k_1^2 = k_2^2 = \frac{A}{2A + A^*}$$

and to market  $M_3$  are

$$k_1^3 = k_2^3 = \frac{A^*}{2A + A^*}.$$

Furthermore,  $k_1^1 < k_1^3$  iff  $A < A^*$ .

(ii) each intermediary's payoff is  $A + A^*/2 - f - f^*$ . The symmetric Nash equilibrium exists if  $A/2 \geq f$  and  $A^*/2 \geq f^*$ .

In what follows, we maintain the assumption that entry costs are not prohibitively high, i.e.,  $A/2 \geq f$  and  $A^*/2 \geq f^*$ , and hence the symmetric Nash equilibrium reported in Corollary 1 exists. Since in this equilibrium, the market shares of the two intermediaries in each market are the same, each arbitrage opportunity is split equally between the two of them. Moreover, the larger the arbitrage opportunity, the more resources an arbitrageur is willing to commit to exploiting it. This implication is intuitive. In equilibrium, however, the market shares in all three markets end up being the same because the best response to

the opponent who commits more resources to a market is to commit more resources herself.

In the symmetric Nash equilibrium, arbitrageurs enter all three markets, paying the maximum per-period fixed cost jointly. This allocation is clearly not Pareto efficient. For example, an allocation whereby both arbitrageurs enter their natural markets but not the natural markets of their opponents (while still equally splitting the third market), yields exactly the same gain from harvesting the arbitrage opportunities as in Corollary 1, but at a lower individual fixed cost. To generalize this reasoning, we explore the set of payoffs that maximize social welfare in a stage game.

Fig. 1 depicts the Pareto frontier and the symmetric Nash equilibrium of this game. The solid line represents the Pareto frontier, which is the boundary of the feasible set of payoffs. To understand its shape, let us start from its rightmost point, denoted by a triangle ( $\Delta$ ), corresponding to the highest possible payoff to Intermediary 1 and zero to Intermediary 2. The highest payoff achievable by Intermediary 1 occurs when she enters all three markets, and Intermediary 2 enters none. As Intermediary 2 enters its natural market,  $M_2$  (and no other market), the share of the arbitrage opportunity in market  $M_2$ ,  $A$ , captured by Intermediary 1 decreases, while the value captured by Intermediary 2 increases proportionately to its market share of that market. The slanted segment on the Pareto frontier originating from its rightmost point ( $\Delta$ ) corresponds to this case. When Intermediary 1 exits market  $M_2$  (while remaining in markets  $M_1$  and  $M_3$ ), the Pareto frontier jumps up by the value of the fixed cost  $f$ , because of the fixed cost savings when market 2 is left to the natural arbitrageur in that market, Intermediary 2. This allocation is denoted by a square ( $\square$ ). The slanted segment right after the jump corresponds to the case in which Intermediary 1 is operating in markets  $M_1$  and  $M_3$  and Intermediary 2 in markets  $M_2$  and  $M_3$ . To maximize the total surplus, it is inefficient for both intermediaries to be present in the market  $M_3$  simultaneously, both paying a fixed cost of operating in that market. Pareto efficient equilibria that lie on the segment that contains the symmetric Pareto efficient equilibrium, therefore, involve randomization, in which Intermediary 1 enters market  $M_3$  half of the time and Intermediary 2 the remaining half (denoted by a circle,  $\bullet$ ). Since (except for the natural markets) the problem is symmetric, the remaining part of the Pareto frontier is the mirror image of the right part of the frontier.

We are going to focus on the Pareto efficient equilibrium that is symmetric in payoffs, denoted by a circle ( $\bullet$ ) in Fig. 1. The following proposition formally derives and characterizes this equilibrium.

**Proposition 2 (Symmetric Pareto Efficient Equilibrium).** In the Pareto efficient equilibrium that is symmetric in payoffs,

(i) the two intermediaries agree to allocate no resources to markets  $M_1$  and  $M_2$ . That is,  $(k_1^1, k_2^1) = (0, 0)$ , and  $(k_1^2, k_2^2) = (0, 0)$ . Hence, the intermediaries fully harvest the arbitrage opportunities in their natural markets.

In market  $M_3$ , the intermediaries randomize their market entry and agree that only one intermediary enters at a time. Intermediary 1 plays  $k_1^3 \in (0, 1]$  and captures the entire market  $M_3$  with probability  $\frac{1}{2}$  and stays away from the market ( $k_1^3 = 0$ ) with probability  $\frac{1}{2}$ . Intermediary 2 plays the mirror image of this strategy.

(ii) each intermediary's expected payoff is  $A + A^*/2 - f^*/2$ .

The Pareto frontier contains a set of cooperative equilibria in this game. Comparing the intermediaries' payoffs in the symmetric Nash and Pareto efficient equilibria (Corollary 1 and Proposition 2), denoted by a star ( $*$ ) and a circle ( $\bullet$ ) in Fig. 1, we see that the latter is clearly higher. The Pareto efficient equilibrium is a cooperative equilibrium that involves explicit agreements between players. It is not achievable in a one-shot game if the intermediaries are playing non-cooperatively. This is because a deviation from playing the Pareto efficient equilibrium

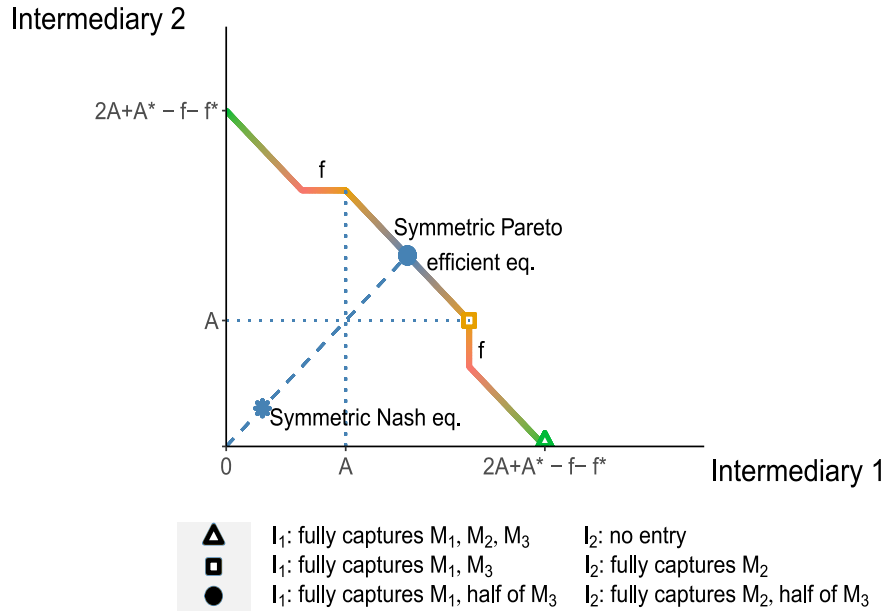


Fig. 1. Pareto frontier. The solid line depicts the Pareto frontier of the stage game. The symmetric Nash equilibrium is denoted by the star symbol (\*), and the symmetric (cooperative) Pareto efficient equilibrium by a circle (●).

is profitable for each intermediary. Indeed, by entering the other intermediary's natural market, the player captures the entire natural market of the opponent, increasing its payoff in the stage game by  $A - f$ . The unique symmetric equilibrium in a non-cooperative game is the Nash equilibrium.

Achieving a Pareto efficient equilibrium in a one-shot game is possible only if the intermediaries make explicit agreements with each other. In an infinitely repeated game, however, a Pareto efficient equilibrium becomes one of the possible equilibria of the stage game, and supporting it does not require any explicit agreements between arbitrageurs.

### 2.3. Tacit collusion in an infinitely repeated game

We now move from the stage game to the infinitely repeated game. Our objective is to support the symmetric Pareto efficient equilibrium of the stage game, analyzed in the previous subsection. In the infinitely repeated game, the set of possible strategies expands considerably, and in particular, it now includes strategies that depend on the other intermediary's actions in previous periods. This significantly enlarges the set of subgame perfect equilibria if the intermediaries are sufficiently patient. Each period's randomization in the third market is also no longer required: the intermediaries can simply implicitly agree to alternate their entry in the market, i.e., one of them enters in odd periods while the other in even. An infinite horizon is required because if the horizon were finite, the intermediaries would have the incentive to deviate from the Pareto efficient equilibrium in the last period, which by backward induction implies that they deviate in all previous periods and, therefore, the Pareto efficient equilibrium is not subgame perfect and the only symmetric non-cooperative equilibrium of this game is the Nash equilibrium of the stage game, played every period.

To support the symmetric Pareto efficient equilibrium as a subgame perfect equilibrium, we focus on the following *trigger strategy*: cooperate and play the Pareto efficient equilibrium if the other player cooperates and punish the opponent for any deviation from it by playing the non-cooperative stage game strategies thereafter. Considering again the symmetric case, in the post-deviation phase, the intermediaries, therefore, play the stage-game Nash equilibrium computed in Corollary 1 in every stage game forever. The following proposition makes these statements more precise.

**Proposition 3 (Symmetric Tacit Collusion Equilibrium).** Consider the following symmetric trigger strategy:

**Cooperative phase:** Cooperate and

- (i) allocate no resources to markets  $M_1$  and  $M_2$ . That is,  $(k_{1t}^1, k_{1t}^2) = (0, 0)$ , and  $(k_{1t}^1, k_{1t}^2) = (0, 0)$ , so that the natural arbitrageurs capture all of the arbitrage opportunities in their natural markets;
- (ii) alternate entry in market  $M_3$ , with Intermediary  $i$  entering the market and harvesting the entire arbitrage opportunity  $A$  in odd periods ( $k_{it}^3 > 0$ ,  $t$  is odd), and Intermediary  $j$ ,  $j \neq i$  in even periods ( $k_{jt}^3 > 0$ ,  $t$  is even).

**Punishment for deviation:** If the opponent deviated from the above cooperative strategy in the previous period, enter all markets ( $M_1, M_2, M_3$ ) and play purely competitively forever, which results in a Nash equilibrium in each stage game thereafter (Proposition 1 and Corollary 1).

If both players play the trigger strategy above and  $\delta \geq \frac{A-f-f^*/2}{A}$ , the symmetric Pareto optimal (or tacit collusion) equilibrium is a subgame perfect equilibrium of the repeated game.

The result of Proposition 3 is consistent with the Folk Theorem of repeated games (see Fudenberg and Maskin, 1986) that for the time discount factor sufficiently close to 1, a cooperative equilibrium of the stage game can be supported via a purely non-cooperative mechanism in a repeated game. An equilibrium of this type is known as a tacit collusion equilibrium in the industrial organization literature. In contrast to the industrial organization literature, where players charge higher prices in the cooperative stage, in our model, cooperation involves staying away from a subset of markets so as to achieve the highest social welfare (3) by paying the minimum combined fixed cost. This is the novelty of our tacit collusion mechanism.

We stress that the trigger strategy played by the intermediaries and the resulting tacit collusion equilibrium does not involve any explicit agreements every period. All that is required to implement the strategy is for the intermediaries to observe that there was market entry by other intermediaries in the previous period. In our application that follows, we observe this information in our commercially available dataset. Finally, the existence of a tacit collusion equilibrium requires that the discount rate between two consecutive rounds of arbitrage trading is small — an assumption that is easily satisfied in our empirical application, in which multiple arbitrage opportunities arrive on a weekly basis.

To better fit our empirical analysis, our model requires a straightforward modification. Instead of there being one market that is natural for neither intermediary,  $M_3$ , we now have two markets,  $M_3$  and  $M_4$ , with an arbitrage opportunity  $A^*$  each. The fixed costs of market entry into markets  $M_3$  and  $M_4$  are the same and are equal to  $f^*$ . In this game, there is a symmetric tacit collusion equilibrium in which (i) neither intermediary enters markets  $M_1$  and  $M_2$ , and therefore the arbitrage opportunity accrues to the natural arbitrageur in that market, and (ii) only one of the intermediaries enters market  $M_3$ , and the other intermediary enters market  $M_4$ . This equilibrium is an equilibrium in an infinitely repeated game, in which reversion to Nash equilibrium upon a deviation acts as a threat. Proposition 4 in the Appendix formalizes this discussion.

We conclude the section by presenting several testable predictions of our model.

**Testable Prediction 1:** The natural markets are fully exploited by the incumbent natural arbitrageur(s), and in the data, we should not observe entry into those markets.

**Testable Prediction 2:** If a market is neither arbitrageur's natural market, we should observe only one arbitrageur entering that market.

**Testable Prediction 3:** If the arbitrageurs are playing one-shot-game Nash equilibrium strategies, they enter all markets. The higher the value of the arbitrage opportunity in a market, the more resources they allocate to that market.

### 3. Dividend play

In this section, we describe a specific arbitrage strategy, dividend play, for which we can accurately identify trades of arbitrageurs and examine the properties of these trades. The environment in which this strategy is executed closely resembles the setup of our model.

#### 3.1. Dataset

Our options data comes from two main sources: OPRA and OptionMetrics. Transaction-level data from OPRA LiveVol is provided by CBOE. The data ranges from November 4, 2019, to June 30, 2023. It contains all transactions in index, ETF, and equity options on 16 U.S. options exchanges. In our analysis, we exclude index options and focus on single-name options on equities and ETFs.

We use daily option price, volume, and open interest data from OptionMetrics, available at a contract level for the period between January 4, 1996, and June 30, 2023. We lag open interest for all the data after November 28, 2000, to have a series of consistent open interest as of the end of day.<sup>12</sup> When implied volatility and Greeks are missing in OptionMetrics, we use linearly interpolated (and extrapolated) values across contracts with different strikes but same expiration (for each underlying and date).<sup>13</sup> We confirmed that the interpolation method choice does not affect our findings.

Our data-cleaning procedure is as follows. Following the literature, we remove canceled trades, trades with nonpositive size or price, and trades with a negative spread (difference between best ask and best bid), and we keep only those trades for which trade price is above the best bid minus spread and below the best ask plus spread. We aggregate trades of the same contract with the same quote time, exchange ID, trade price, and trade condition ID into one line. We do not exclude open or close trades from our analysis, but we confirm that excluding trades before 9:45 a.m. and after 3:50 p.m. does not change our results. To compute trade imbalances, we follow the quote rule,

which classifies trades with prices above (below) the midpoint as “buy” (“sell”) trades.<sup>14</sup>

We also use data from the Nasdaq PHLX Options Trade Outline (PHOTO) End-of-Day files with order classification and trade directions by the originating counterparty (customers, professional customers, market makers, firms, or broker/dealers). The data ranges from November 1, 2019, until June 30, 2023.

For all stock data, we use CRSP. We obtain dividend history, stock prices and returns, outstanding shares, and rolling monthly volatility of daily returns. We rely on the SecId-PERMNO crosswalk provided by WRDS to link CRSP with OptionMetrics.

#### 3.2. Dividend play

Daily trading volume in options on high-dividend underlyings in the U.S. exhibits an intriguing seasonality, illustrated in Fig. 2 for the SPDR S&P 500 ETF (SPY) case. The spikes in trading volume apparent from the figure occur every quarter on the last cum-dividend date, that is, the day before SPY pays a dividend. SPY options are some of the most traded contracts, and yet the average daily traded notional for them is \$2409.5 million on the last cum-dividend dates and \$235.4 million on the remaining dates. This pattern is common among options on high-dividend-paying stocks and ETFs.

On the last cum-dividend dates, arbitrageurs engage in a trade known as the dividend play. This strategy is available only for transactions originating from the exchange floor, or, in other words, only to the market participants who must be physically located on the trading floor. Dividend play could be organized off the exchange floor, but it would not qualify for transaction fee caps. In our data, most abnormal volume on cum-dividend dates goes through floor trades on two exchanges, PHLX and BOX, as discussed below. The distribution of trading volume across all exchanges is reported in Table B.11 in Appendix.

The goal of the dividend play strategy is to take advantage of inattentive or constrained investors who fail to exercise their call options on dividend-paying stocks when it is optimal to do so.<sup>15</sup> It is optimal to exercise a call option if the value of exercising it on the last cum-dividend date and collecting a dividend exceeds the value of the call the next day when the stock goes ex-dividend. Computing option values involves using the Black–Scholes–Merton formula or a more sophisticated option pricing method, which is typically difficult for novice investors. Alternatively, some retail investors may be unaware of the possibility of early exercise. Since a fraction of in-the-money call options remains suboptimally unexercised, the writers of these options would not be asked to deliver the stock and would, therefore, receive a windfall capital gain on their position. It is a zero-sum game.

If all in-the-money call option contracts on a stock have been exercised on or before the last cum-dividend date, all holders of short positions in the same contracts receive a request to deliver the stock. However, if some contracts are left unexercised, the OCC randomly “assigns” short positions that must deliver the stock. The unassigned holders simply hold on to their options and profit from a windfall capital gain. Arbitrageurs can divert this gain to themselves by simultaneously buying and selling many in-the-money call options on the same underlying. They exercise all long positions and deliver on all assigned short positions. Since some fraction of the options remains unassigned (owing to suboptimal exercise by investors), arbitrageurs then capture dividends on their net long stock positions while staying fully hedged.

<sup>12</sup> The lag is due to the change in the reporting format of OptionMetrics. This implies that end-of-day open interest is measured after option exercises.

<sup>13</sup> We enforce theoretical boundaries in these calculations. In particular, we set a call option's delta to zero (one) when its interpolated value is negative (above one).

<sup>14</sup> Our results hold if we use the Lee and Ready (1991) algorithm (that is, applying the tick rule to classify trades at midpoint instead of excluding them). The ticker-level imbalances produced by the two methods have a correlation of over 90%.

<sup>15</sup> There might be other reasons why investors do not exercise, such as the costs of unwinding more complex strategies. Hao et al. (2009) show that dividend play profits outweigh such costs in most cases.

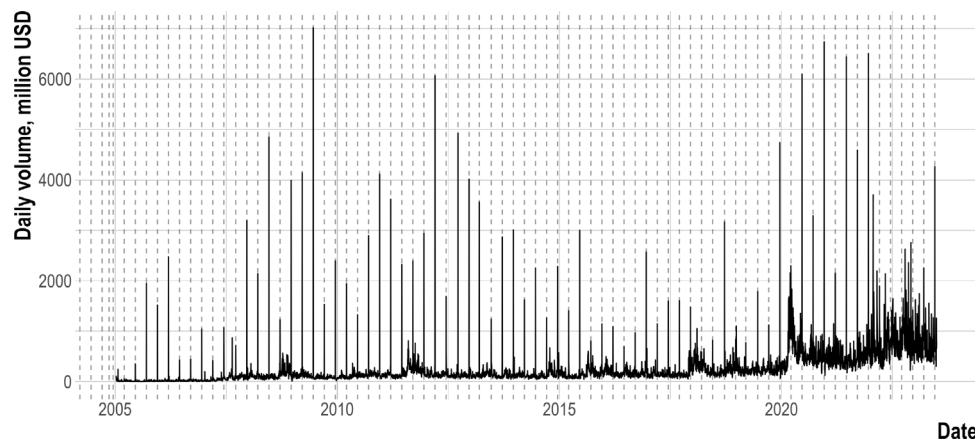


Fig. 2. Abnormal trading volume on last cum-dividend dates for SPDR S&P 500 ETF (SPY). This figure plots daily trading volume for all call option contracts on SPY, in millions of U.S. dollars, as reported in OptionMetrics. The dashed lines indicate the last cum-dividend dates.

Table 1  
Dividend play: An example.

	$OI_{t-1}$	New positions(t)	Available for ex.	No. exercised	Prob. non-assign. orig. option writer	Prob. non-assign. arbitrageur	Gain per share	Expected gain orig. option writer ( $E^*G^*100$ )	Expected gain arbitrageur ( $F^*G^*100$ )
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(E*G*100)	(F*G*100)
<b>Case 1. Optimal exercise</b>									
Customer	1	0	1	1	0		5	0	
<b>Case 2. Suboptimal exercise</b>									
<b>Case 2.1. Without dividend play</b>									
Customer	1	0	1	0	1		5	500	
<b>Case 2.2. With dividend play</b>									
Customer	1	0	1	0	1/101		5	5	
Arbitrageur	0	100	100	100		100/101	5		495
Total	1	100	101	100					

This table illustrates the dividend play strategy. Date  $t$  refers to the last cum-dividend date, and  $OI_t$  stands for the open interest on date  $t$ .

Usually, two arbitrageurs agree on a dividend play trade in advance and serve as a counterparty to each other on their arbitrage positions.

Table 1 illustrates the mechanics of the dividend play strategy using an example. Suppose there is 1 call option contract outstanding, and it is optimal to exercise it.<sup>16</sup> Case 1 corresponds to the case when the option is exercised, the holder of the short position is assigned to deliver the underlying, and there is no profit for the dividend play strategy to harvest. Case 2 describes what happens if the contract is left unexercised. Without arbitrageur involvement, the short position in the contract does not get assigned, and the option writer receives a windfall gain of \$500 for sure.<sup>17</sup> Now consider the entry of an arbitrageur. The arbitrageur attempts to pocket most of the potentially harvestable profit of \$500. To do so, the arbitrageur buys and simultaneously sells 100 contracts and exercises all of their long positions. The probability of assignment increases, but because of the OCC's random assignment, with a probability of 100/101, the arbitrageur holds the short position that does not get assigned and hence yields a gain. For the original option writer, this probability is now only 1/101. Hence, the expected gain of the arbitrageur is \$495 out of the total gain of \$500 and that of the original option writer drops to \$5. Therefore, a dividend play strategy dilutes the share of the gain accruing to the original option writer.

In what follows, we detect dividend play activity at a contract level in the full sample and characterize its importance relative to the overall trading volume on the last cum-dividend dates.

### 3.3. Arbitrageur activity in dividend play strategy

We first present our measure of arbitrageur activity in the dividend play strategy. Through fee caps, exchanges incentivize dividend play strategies to originate from the physical floor. To construct our measure of dividend play activity, we, therefore, exploit OPRA's new detailed trade type flags to isolate option transactions that are executed on the floor. The trade types that cover most of the dividend play transactions are SLFT and MLFT, which are single-leg and multi-leg floor trades, respectively. (See Appendix B.1 for a more detailed description.) Other floor trade types used infrequently in our sample are MLCT, MSFL, SLCN, TLFT, and TLFT. We analyze this measure in detail below and show that it accurately captures dividend play trades in our sample. To our knowledge, this is the most precise measure of arbitrageur activity in the dividend play strategy in the literature, which typically uses trading volume on the last cum-dividend dates in excess of the past average volume.<sup>18</sup>

Table 2 presents descriptive trading activity statistics on the last cum-dividend compared to any other dates for dividend-paying stocks and ETFs. In this paper, we often refer to the last cum-dividend dates on which dividend play trade takes place as *dividend play dates*. We see a considerable difference in floor trading volume and volume of large trades on the last cum-dividend dates relative to other dates. Moreover, on the last cum-dividend dates, we see colossal spikes in volume on two exchanges that cap fees for the dividend play strategy: PHLX and BOX.

<sup>16</sup> Appendix B.2 provides another example, in which multiple contracts are outstanding, some of which are exercised optimally and some are not.

<sup>17</sup> We assume that, as in the data, each option contract is for 100 shares of the underlying.

<sup>18</sup> Strictly speaking, we should define our measure of arbitrageur activity in dividend play as *abnormal* floor volume on the last cum-dividend dates, but our measure is simpler and our results stay virtually the same if we use the abnormal floor volume measure instead.



**Table 2**  
Characteristics of activity on last cum-dividend dates.

	Average ticker dollar volume (\$ million) on		Total market dollar volume share (%) on		Effective trade cost as % of total dollar volume on	
	Cum-dividend date (1)	Any other date (2)	Cum-dividend date (3)	Any other date (4)	Cum-dividend date (5)	Any other date (6)
<b>Panel A. Floor trade</b>						
Yes	65.6	1.8	79.7	10.7	0.51	1.05
No	12.0	3.8	20.3	89.3	0.69	0.92
<b>Panel B. Exchange</b>						
PHLX or BOX	50.5	1.0	82.1	20.3	0.52	1.03
Any other	10.7	3.5	17.9	79.7	0.67	0.91
<b>Panel C. Option type</b>						
Call	54.1	2.1	91.3	48.4	0.52	1.04
Put	5.3	2.4	8.7	51.6	0.78	0.84
<b>Panel D. Moneyness</b>						
In the money	48.0	1.2	78.1	20.1	0.44	0.57
At the money	12.2	3.2	20.4	70.8	0.85	0.87
Out of the money	0.9	0.4	1.5	9.0	1.77	2.33
<b>Panel E. Trade size</b>						
Large	57.9	3.9	92.8	71.3	0.53	0.92
Small	4.2	1.2	7.2	28.7	0.68	0.99

This table compares option trading activity for tickers that enter our dividend play sample at least once (1549 stocks and ETFs) on the last cum-dividend date with any other date. The dividend play sample is described in detail in Appendix B.4. The average volume in columns (1) and (2) is computed at ticker-day level, and the volume share in columns (3) and (4) is for the entire market. In Panel A, we define floor trades as trades with SLFT and MLFT OPRA trade types. In Panel D, we define “in the money” as  $(\text{Midpoint Price} - \text{Strike})/\text{Strike} > 0.1$  for call options and  $(\text{Midpoint Price} - \text{Strike})/\text{Strike} < -0.1$  for put options. “At the money” are contracts for which this value is between  $-0.1$  and  $0.1$ , and “out of the money” are all other contracts. In Panel E, we define trade as ‘small’ if the trade size is at or below 10 contracts. Effective trade costs are measured as daily aggregates of the absolute distances between execution prices and midpoint prices. We scale them by total dollar volume on the day.

Breaking the trades by moneyness, we see that the primary increase in volume comes from trading deep-in-the-money calls (which are more likely to be optimal to exercise). This pattern is a signature of the dividend play strategy. The utter size of the dividend play positions is astonishing.

Table 2 also reveals an economically significant decrease in the trading costs on dividend play dates. Executing large trades in options becomes considerably cheaper. As Table 2 demonstrates, effective trade costs on dividend play dates are almost twice lower, especially if those trades are executed from the floor and on PHLX or BOX. Our calculations reveal that the reduction in trade costs is driven by a dramatic increase in the floor volume executed at the midpoint: 57% of volume at the midpoint on dividend play dates is in floor trades, as compared to 1.6% on other dates. Trades of the size employed in dividend play normally have a significant price impact, but we do not see it for the actual dividend play trades, which supports the hypothesis that these trades are prearranged by pairs of floor arbitrageurs.

In our data, we see bursts of simultaneous buy and sell activity in neighboring-strike call option contracts, executed usually within several seconds, all coming from the floor. See Appendix B.8 for more details on the nature of the bursts.

Before 2014, dividend play typically involved a long and short position in the same contract. A clearing rule change in 2014 made this impractical for arbitrageurs. Market participants have adjusted their trading strategies, and since then they buy and sell contracts with neighboring strikes, which ultimately achieves the same objective. Section 5 below documents such activity in neighboring strikes.

### 3.4. Dividend play profits

We now derive exploitable profits from the dividend play strategy. Some of these profits come from an increase in the open interest, some from investors’ failure to exercise, and some from the value of early exercise of each contract. With an inflow of inexperienced investors in the options market, we expect the first two components to increase. We, therefore, find it useful to decompose the exploitable profit from a contract into three parts: (i) open interest, (ii) fraction unexercised, and (iii) early exercise value.

The exploitable dividend play profit on all the interest for each contract is defined as

$$\pi_t = OI_{t-1} \times f_t \times EEV_t, \quad (12)$$

where  $t - 1$  is the day before the last cum-dividend date,  $OI_{t-1}$  denotes open interest on that date (measured after all trades, exercises, and assignments on that date),  $f_t \equiv OI_t/OI_{t-1}$  is the fraction unexercised, and  $EEV_t$  is the early exercise value, computed below. Note that the fraction unexercised reflects the fraction of open interest in an option contract that remains outstanding after the last cum-dividend date (after all trades, exercises, and assignments on that date). Both  $EEV_t$  and  $f_t$  are estimated quantities. Open interest as of the day before the last cum-dividend day ( $OI_{t-1}$ ) and fraction not exercised ( $f_t$ ) are available from OptionMetrics. In rational and frictionless markets, we expect that  $f_t = 0$  if  $EEV > 0$ .

The early exercise value is model-based, and we rely on the Black–Scholes–Merton option pricing formula to compute it.<sup>19</sup> Denote the expected ex-dividend price of an option by  $c_{ex}$ , its strike by  $K$ , and the current (cum-dividend) underlying stock price by  $S$ . The expected option ex-dividend price represents the expected time value of the option. Early exercise value ( $EEV$ ) is, therefore, the difference between the current stock price, strike, and this expected time value of the option:  $S - K - c_{ex}$ .<sup>20</sup> The details of the computation of  $c_{ex}$  are in Appendix B.3.

In the following analyses, we restrict our sample to call option contracts that are optimal to exercise on cum-dates and refer to it as the *dividend play sample*. Further details related to its construction are provided in Appendix B.4, and Table B.10 in the Appendix presents the descriptive statistics for our dividend play sample.

Using the full dataset from January 1996 to June 2023, available from OptionMetrics, we estimate the total value of potential dividend play profits at \$1.52 billion. While most of our analysis relies on data available since November 2019, thus constituting only 13% of the overall time period, this subsample nevertheless accounts for almost

<sup>19</sup> To ensure our results are robust to the choice of the underlying pricing model, we considered the sample of broad-index ETFs and computed their corresponding option prices with the Merton and Bates models, following Bakshi et al. (1997) and Cosma et al. (2020). Options on these ETFs represent over 10% of contracts in our dividend play sample and 55% of potential dividend play profits. All our results hold in that sample.

<sup>20</sup> Note that this definition is from Pool et al. (2008), and it is equivalent to the definition in Hao et al. (2009). The latter uses dividend instead:  $\text{Dividend} - c_{ex} + S_{ex} - K$ .

**Table 3**

Case study of arbitrageur activity: Two EEM call options on the last cum-dividend date.

	Strike	EEV	OI (t – 1)	Money-ness, %	Spread, %	Fraction unexercised	Cum-date volume	Floor share	Delta	Vega
Contract 1	45,000	0.39	13,770	12.7	1.85	0.10	44,883	0.998	0.991	0.243
Contract 2	46,000	0.39	6477	10.3	3.90	0.07	35	0.000	0.990	0.268

a third of all the potential dividend play profits (see Figure B.6 in the Appendix). The high profitability of dividend play in recent years is largely driven by a sharp increase in options trading and, consequently, open interest. In particular, while in the first quarter of 1996, the total open interest was below 18,000 contracts, in Q2 2023, it was already above 5.5 million contracts.

#### 4. Selective entry by arbitrageurs

In this section, we present empirical evidence regarding the arbitrageur behavior in the dividend play strategy. We begin with a case study in Section 4.1, whereby arbitrageurs fully exploit opportunities in one contract but forgo them in another *very similar* contract on the same underlying. In Section 4.2 we further document the general lack of entry by arbitrageurs in profitable contracts, and in Section 4.3 we explain why existing theories of limits to arbitrage do not seem to explain these patterns. In Section 4.5 we explore the determinants of this puzzling behavior and show that it is consistent with our model. In particular, we interpret the lack of entry of arbitrageurs through the lens of the natural markets and arbitrage profits being captured by the incumbent arbitrageur and provide empirical evidence consistent with this explanation.

##### 4.1. Case study

December 11, 2020, was the last cum-dividend date for EEM (iShares MSCI Emerging Markets), a high-dividend paying ETF, and a number of calls on EEM were in-the-money and optimal to exercise on that day. Table 3 focuses on a pair of such contracts, both expiring on January 15, 2021.

We first compare the trading volume in the contracts on December 11, 2020. Notice that the trading volume in Contract 1 exceeds that in Contract 2 by a factor of 1000. Notice also that Contract 1 has most of the orders from the trading floor on that day, while Contract 2 has zero. We also see characteristic bursts of floor orders in the transaction-level data for Contract 1. This means that arbitrageurs engaging in a dividend play trade exploited Contract 1 but not Contract 2.

Why did the arbitrageurs leave money on the table in Contract 2? The contract had a high EEV and a significant fraction of open interest unexercised. Using Eq. (12) to compute the arbitrageur's forgone profits from not participating in Contract 1, we arrive at  $6477 \times 0.07 \times 0.39 \times 100 \approx \$17,682$ , a significant sum.<sup>21</sup> This is particularly striking, given that the fees for implementing dividend play strategy in all the contracts within a given ticker on a given day are just \$1100 on PHLX.<sup>22</sup> The second contract does not appear riskier either, having almost identical delta and vega to the first.

Trading costs do not explain the market participants' reluctance to trade Contract 2. First, exchanges offer daily fee caps for the dividend play strategy, and so if market makers (or other arbitrageurs) entered Contract 1, they should have also entered Contract 2. Second, contract bid-ask spreads in Table 3 are very similar. In the regression framework that follows, we further control for the option contract's liquidity and show that trading costs do not explain why arbitrageurs forgo profitable opportunities.

<sup>21</sup> Each option contract in our sample is for 100 shares of the underlying stock or ETF.

<sup>22</sup> See <https://listingcenter.nasdaq.com/rulebook/phlx/rules/phlx-options-7>.

It is puzzling that arbitrageurs fully exploited the arbitrage opportunity in Contract 1 but not in Contract 2. In the following section, we show that this is the general pattern in our sample. The unexploited profit in Contract 2 accrued to the writer of this contract, who could be a market maker or perhaps a retail investor. The latter is less likely because retail brokerages take an automated action to close short positions that have dividend risk on behalf of their clients.<sup>23</sup> Appendix B.6 presents an excerpt from Robinhood's Terms and Conditions to provide an example of such automated action. It is, therefore, more likely that the writer of the contract who received the windfall gain was a market maker. The market maker, who is a writer of the contract, of course, has no incentive to engage in a dividend play strategy in this contract because this would mean sacrificing her own profit. But it is puzzling that other market makers or arbitrageurs would not wish to exploit Contract 2 and reap arbitrage profits.

##### 4.2. Lack of entry by arbitrageurs

Table 4 expands our case study and reports forgone profits by ticker for the top 40 underlying stocks and ETFs sorted by the total size of forgone profits in our sample. We aggregate our data to the ticker level and report the number of profitable individual contracts per ticker. Similar to the EEM example above, we assume that arbitrageurs forgo all profits in contracts they do not enter. For the ones they do enter, we associate the floor share with harvested profits and the residual share with the forgone. The total amount of harvested profits in the top 40 tickers in our sample is around \$109 million, whereas the total amount of forgone profit stands at almost \$167 million. The amount of money left on the table is striking for a virtually riskless arbitrage strategy.

In the full sample, the values of harvested and forgone profits are \$161 million and \$204 million, respectively; hence, the total potential arbitrageur profit from the dividend play strategy is a little over \$365 million. To put the total profit from this strategy into perspective, it is useful to compare these numbers to arbitrageurs' profits from other strategies that exploit retail investor mistakes. de Silva et al. (2022) study retail investor trading in options around earnings announcements and find that this trading amounts to a wealth transfer of \$360 million from retail investors to market makers in their sample that is seven times longer than ours, running from 2010 to 2021.

Table 4 does not reveal any particular pattern in harvested and forgone profits: There is a large variation in arbitrageur activity across and within tickers. Next, we examine possible explanations why some contracts attract arbitrageur entry, while some do not.

To examine drivers of arbitrage activity, we start by contrasting potential and harvested profits from the dividend play strategy on the last cum-dividend dates in our sample. Fig. 3 presents potential profits of the dividend play strategy across all contracts, computed using Eq. (12), and profits harvested by floor traders. It emerges from Panel (a) that a large fraction of potential profit, namely 56%, remains unharvested. If we restrict the sample, however, to the contracts with non-zero floor trading volume – that is, contracts in which we detect

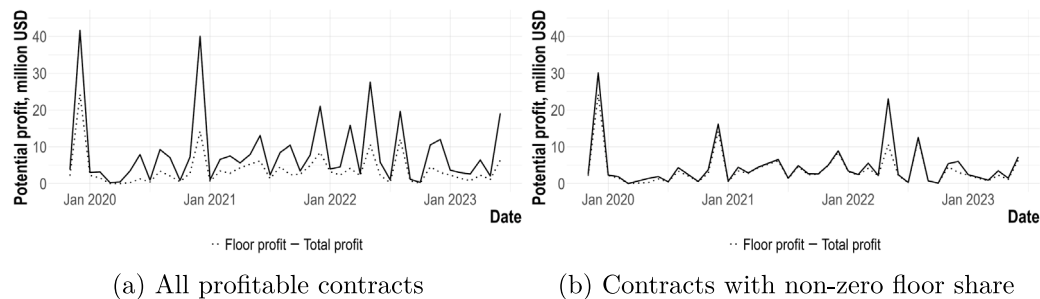
<sup>23</sup> Since each option contract is for delivery of 100 shares of the underlying, for small retail investors, the cash outlay needed for purchases of the underlying stock and delivering it could be quite significant. A brokerage would, therefore, close a short position if there are not enough funds in the account to buy and deliver the underlying.

<sup>24</sup> The average floor share is over 99% in Fully harvested contracts and 67% in Partly harvested contracts.

**Table 4**  
Dividend play profits by ticker.

Ticker	Profit, USD		No. contracts			Traded volume (contracts)
	Harvested (1)	Forgone (2)	Fully harvested (3)	Partly harvested (4)	Forgone (5)	
SPY	3,814,437.0	39,426,292.0	420	111	2474	1,248,234
PBR	24,307,848.0	26,160,422.0	280	64	96	10,459,298
AAPL	3,594,494.0	11,062,548.0	474	212	489	1,667,003
XLE	4,535,588.0	10,071,232.0	565	92	279	2,191,948
IWM	2,063,259.0	9,890,123.0	264	21	503	1,028,606
EWZ	7,592,449.0	8,752,541.0	391	9	119	5,978,316
EEM	12,967,090.0	8,188,594.0	313	14	103	8,405,748
EFA	6,402,670.0	4,886,018.0	387	19	87	5,043,459
FXI	2,167,366.0	4,608,664.0	150	8	66	2,878,501
QQQ	57,656.0	3,678,813.0	31	28	797	40,458
VALE	2,560,822.0	3,480,946.0	152	26	77	2,848,557
XOM	9,277,319.0	3,381,380.0	687	234	321	5,753,019
HYG	495,875.7	3,185,476.0	58	14	192	351,424
XLF	1,453,332.0	2,734,343.0	141	9	136	759,260
STLA	903,257.4	2,141,401.0	32	2	12	444,892
MSFT	1,994,383.0	2,136,713.0	511	79	139	1,974,063
ZIM	1,246,124.0	2,034,154.0	10	184	185	688,872
LQD	10,451.9	1,625,507.0	6	2	75	25,000
ET	2,565,170.0	1,421,305.0	203	58	118	2,250,512
LMT	270,094.5	1,328,768.0	214	56	160	143,963
KO	489,992.4	1,288,311.0	188	56	169	650,724
JPM	2,090,890.0	1,201,065.0	327	106	221	1,833,596
COST	20,985.0	1,104,033.0	34	7	98	4,747
T	5,260,609.0	1,093,420.0	401	79	161	5,564,485
IBM	1,872,265.0	1,077,777.0	480	251	282	970,820
DIA	175,078.0	889,836.5	115	18	360	38,864
SAN	–	888,487.9	0	0	19	–
TLT	80,308.3	844,574.0	18	7	333	7665
QCOM	1,188,971.0	796,391.3	273	97	219	1,025,069
IYR	235,536.9	789,393.1	151	25	106	256,174
AVGO	911,385.9	788,075.1	425	97	198	569,295
XLU	70,308.7	785,100.8	62	15	145	205,115
CSCO	1,041,260.0	774,713.1	261	54	139	2,503,283
XLP	203,193.1	746,480.5	51	9	107	121,385
CVX	1,683,582.0	740,944.6	571	173	274	1,555,946
GOLD	542,518.3	707,007.9	98	7	96	118,310
BHP	270,785.8	695,873.8	97	11	35	146,560
GILD	610,051.6	654,317.3	161	59	134	961,184
MO	2,677,554.0	617,317.8	311	100	168	1,923,990
ABBV	1,431,013.0	571,759.1	350	85	195	2,176,176
<b>Total</b>	<b>109,135,974.4</b>	<b>167,250,118.8</b>	<b>9663</b>	<b>2498</b>	<b>9887</b>	<b>74,814,521</b>

This table reports the top 40 tickers in terms of dividend play profits forgone by floor traders in our sample. Values are aggregated across all contracts within a ticker in 11/2019–06/2023. Total dividend play potential profits are computed as in Eq. (12). To compute Harvested profits, we multiply the total profits by the floor volume share on the last cum-dividend date and attribute the residual to Forgone profits. No. of Fully harvested contracts in column (3) is the number of contracts with floor share above 90%, and in column (5) – with zero floor share.<sup>24</sup> Traded volume in column (6) is the total floor trading volume in all contracts.



**Fig. 3.** Total and floor trader profit from dividend play strategy. This figure illustrates the implied share of potential dividend play profits captured by arbitrageurs on the trading floor. The solid plot depicts the potential profit from the dividend play strategy, and the dashed plot depicts the profit harvested by floor traders (arbitrageurs).

dividend play activity – most of the potential profit resulting from the failure of investors to exercise their options on cum-dividend dates is harvested. In other words, arbitrageurs selectively exploit profitable contracts and capture most of the exploitable gains (specifically, 83%) in the contracts they enter. This is below 100% and is a likely artifact of how we compute their share in profits.

We have now established the following two empirical facts regarding arbitrageur activity on dividend play dates in profitable contracts.

**Fact 1.** *Only 57% of profitable dividend play arbitrage opportunities (contracts) attract arbitrageur entry. They harvest only 44% of total potential profits.*

**Fact 2.** *If an option contract attracts arbitrageur entry, arbitrageurs extract most of dividend play profits in that contract.*

The selective entry of arbitrageurs in profitable dividend play opportunities is puzzling. In what follows, we try to understand the features of the contracts into which market participants are likely to enter.

#### 4.3. Lack of pecking order

A striking fact about the arbitrageurs' entry is the lack of pecking order, in that arbitrageurs do not exploit the most profitable contracts first, followed by the second most profitable, etc. We find that arbitrageurs do not enter 37% of contracts in the top EEV tercile, 38% in the top moneyness tercile, and 37% in the top total potential profit tercile.<sup>25</sup> This helps us establish our next stylized fact.

**Fact 3.** *More profitable arbitrage opportunities do not necessarily attract more arbitrage activity.*

We provide further evidence supporting Fact 3 in Sections 4.5 and 4.6, when we condition on the top profitability tercile and find that our results regarding (the lack of) arbitrageur entry are similar to those in the full sample (see Table 5). Furthermore, Appendix B.12 demonstrates that the lack of arbitrageur entry is similar across a multitude of contract characteristics.

To further highlight the puzzle of arbitrageur's lack of participation, we also pursued an alternative empirical strategy based on propensity score matching. Matching is a natural strategy in our setup because the set of characteristics on which one should match options to keep the expected profitability – the main driver of arbitrageur entry in the limits-to-arbitrage literature – constant is well understood. We match contracts based on open interest, early exercise value, moneyness, and other characteristics that determine profitability. In Appendix B.7, we show that contracts with both zero and positive floor volume exist across the whole propensity score spectrum. This result again suggests that profitability characteristics do not predict entry well.

#### 4.4. How many arbitrageurs engage in dividend play?

Earlier in this section, we documented that arbitrageurs do not enter some profitable contracts, and when they do, they exploit all available profits in a contract. In this subsection, we examine the contracts that do attract arbitrageur entry and provide suggestive evidence for the number of arbitrageurs simultaneously engaging in the dividend play strategy in each contract.

An advantage of our granular, transaction-level data is that we can estimate the number of arbitrageurs exploiting each arbitrage

opportunity, which prior literature has not done. As mentioned previously, dividend play trades in our data appear as a sequence of trades (normally five or more) executed within several seconds from the floor of an options exchange. There are two simultaneously executed legs of this trade by each arbitrageur: One leg is a sequence of buys of one call option contract, and the other is a sequence of sells of a contract with a neighboring strike. Trade sizes within each sequence of trades are typically the same, but they differ across sequences. (See an example in Appendix B.8.) Differences in trade sizes across dividend play trade sequences are likely due to the execution preferences of individual arbitrageurs. We, therefore, use the number of unique trade sizes within each sequence of trades that we classify as dividend play in a given contract as a proxy for the number of arbitrageurs engaging in dividend play in that contract. A pair of arbitrageurs normally execute the dividend play trade, simultaneously establishing long and short positions in the contract. The latter collects (a share of) the windfall gain, and the former facilitates the trade by serving as a counterparty. Our measure identifies the number of such pairs, and we count each pair as one arbitrageur (because only one party receives the gain).

Fig. 4 plots a percentage split of dividend play trades by the number of arbitrageurs exploiting each contract. It is striking that we observe only one arbitrageur in most contracts. Only in a small fraction of contracts is the number of arbitrageurs above three. Since there are no obvious impediments to the free entry of other arbitrageurs who regularly engage in dividend play, it is puzzling that so few arbitrageurs participate in each contract.

The largest gray shaded area in Fig. 4 corresponds to the closure of exchange floors in the U.S. due to the COVID-19 pandemic. Furthermore, the total trading volume on dividend play dates during the closures is the same as on any other day, which provides additional validation of the measure. Even when PHLX floor was closed but ARCA and BOX floors were open, the mean trading volume on dividend play was an order of magnitude lower.

From the data behind Fig. 4, we establish the following stylized fact in our dividend play sample.

**Fact 4.** *Of all arbitrage opportunities (option contracts) that attract arbitrageur entry, 49.1% are exploited by only one arbitrageur.*

Dividend play trades are easy to detect in transaction-level data, which is available to arbitrageurs from standard data feeds (e.g., OPRA or those provided by exchanges). There may be some delays with reporting floor trades, but these delays are hardly significant for our application. Arbitrageurs are, therefore, fully aware of the presence of other arbitrageurs in a given contract before they decide to engage in a dividend play trade in it. According to textbook theories, however, this should not deter them from entering and competing for profits in the same contract.

It is clearly a possibility that our measure of the number of arbitrageurs is inaccurate because the same arbitrageur may break a large dividend play order into trades of unequal size rather than keeping the trade size the same. In our data, we see that some of the characteristic dividend play “bursts” – a sequence of trades in the same contract on the floor broken into smaller trades and executed within a second or two – feature trades of unequal size. We, therefore, use an alternative proxy for trades executed by the same arbitrageur, in which we aggregate all trades in the same contract executed within a second and then assume that aggregated trades of the same size are executed by the same arbitrageur.

Fig. 5 plots the distribution of the number of arbitrageurs engaging in dividend play in the same contract and demonstrates that the number is small. For our baseline proxy for the number of arbitrageurs, across all contracts that attract arbitrageur entry, in only 8% of those contracts, the number of arbitrageurs exceeds 4 (Figure (a)). The number of unique arbitrageurs is even smaller for the alternative proxy (Figure (b)). Curiously, there is a large difference in the concentration of arbitrageurs in the same contract across exchanges. While the distribution

<sup>25</sup> One caveat to our analysis is that arbitrageurs may be using a profitability measure different from ours. We observe some entry (in around 35% of contracts) in cases with EEV between  $-0.5$  and  $0$ . If we include these contracts in our sample, however, our results on selective entry become even stronger.



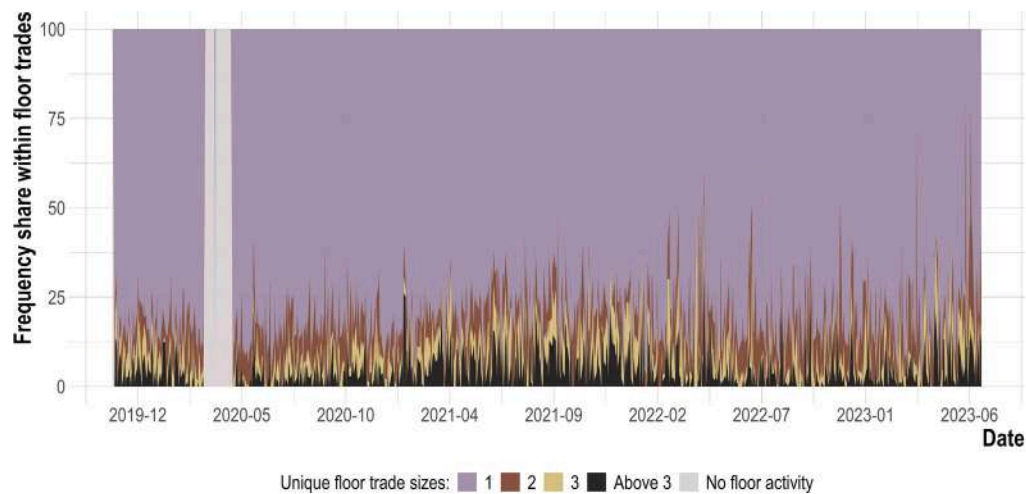


Fig. 4. Number of arbitrageurs in dividend play trades. This figure depicts the percentage split of trades executed on the exchange floor by the number of unique trade sizes, i.e., the number of arbitrageurs. We include only contracts in our dividend play sample. The largest gray-shaded area corresponds to the period of floor closures on all exchanges.

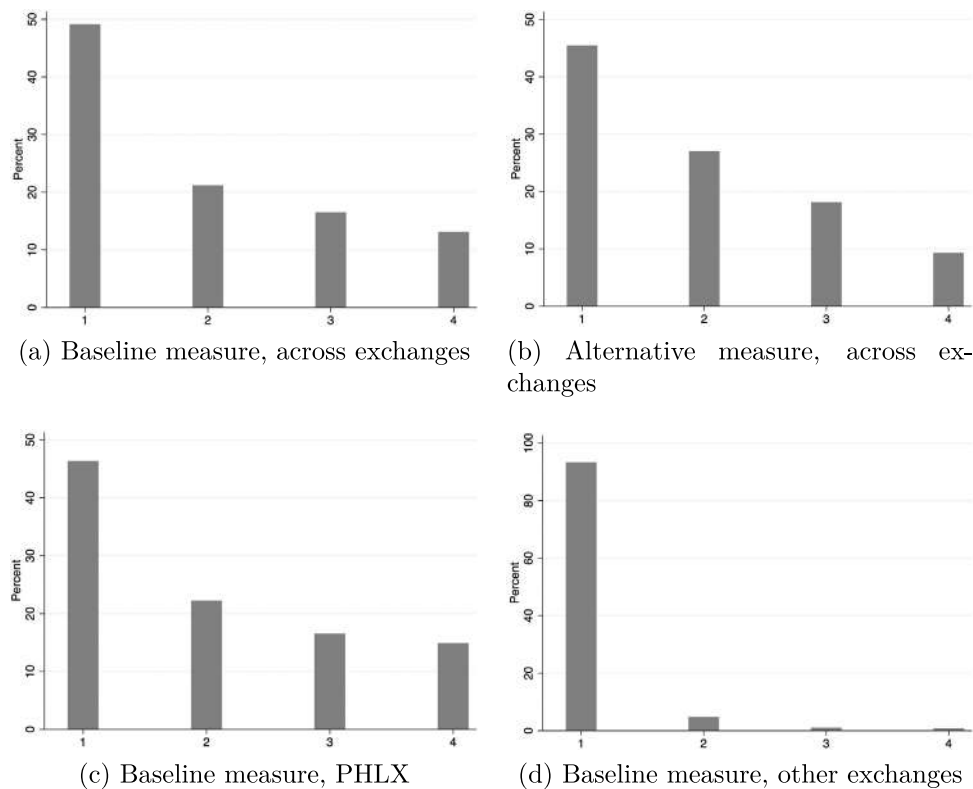


Fig. 5. Distribution of the number of arbitrageurs in dividend play trades. These figures depict the distribution of the number of arbitrageurs in our sample. We include only contracts in our dividend play sample in which there was some floor entry. Figure (a) uses our baseline proxy for the number of arbitrageurs, calculated in the full sample. Figure (b) is for the alternative proxy, calculated in the full sample. Figures (c) and (d) are for our baseline proxy on the PHLX and all other exchanges, correspondingly. Values above 4 are set to 4. See the detailed statistics in Tables 12 and 13 in Appendix.

of arbitrageurs in the same contract is similar to that in the full sample in the largest exchange that facilitates dividend play trades, PHLX, in all other exchanges, over 95% of profitable contracts feature entry of only one arbitrageur.

We finish this discussion by acknowledging the limitation of our baseline proxy for the number of arbitrageurs. It is possible that multiple arbitrageurs use trades of the same size, and hence, our baseline measure would underestimate the number of arbitrageurs. However, the baseline and the alternative proxies deliver similar results, which is reassuring.

#### 4.5. Model-based explanation of selective arbitrageur participation: Tacit collusion

The evidence summarized in Facts 1–4 is consistent with our model. We could interpret the contracts that do not attract any arbitrageur entry as natural markets of some intermediaries. Some of the intermediaries in our application are market makers, who normally have access to the trading floors and are aware of the dividend play strategy. Due to significant economies of scale in market making, this segment

is served by a small number of firms.<sup>26</sup> Prior to the dividend play date, market makers may accumulate an inventory of written options. Because of early exercise mistakes, they are then set to benefit from the windfall gains unless another arbitrageur engages in dividend play in these contracts. This parallels exactly our model's definition of a natural market. We test this interpretation below using two proxies for natural markets of options market makers.<sup>27</sup>

Owing to daily fee caps on dividend play on options exchanges, the entry costs are fixed, as in our model. Our model predicts that we should, therefore, observe no entry in the natural markets of options market makers, and our **Fact 1** is consistent with that. For profitable contracts that are in neither intermediary's inventory, we should observe the entry of only one arbitrageur. Consistent with the model, **Fact 4** indeed documents that, conditional on entry, in the majority of the contracts, we observe entry by only one arbitrageur. The version of the model that is closest to the data is the one discussed at the end of Section 2, in which intermediaries enter only one of the last two markets, leaving the other to the other intermediary. In the data, arbitrageurs operate in pairs, each pocketing a gain in one contract while facilitating the other arbitrageur's gain in another contract.

We note that sometimes we observe entry by two or more arbitrageurs in a given contract. We interpret this not as a reversion to Nash equilibrium (punishment) but as occasional "misfires". Tacit collusion does not require any explicit agreements, so occasional misfires are likely to happen. This is especially true in our application because there are many contracts that may be profitable to exploit on a dividend play date (the median in our sample is 53). Also, unlike in our model, there is some noise in the data. For example, while arbitrageurs are likely to purchase access to a real-time transaction-level datafeed, floor transactions are usually reported late and so an arbitrageur may not realize that another arbitrageur has already entered that contract.

**Fact 3** is also consistent with our model and is inconsistent with standard theories of arbitrage. Unless the arbitrageurs are playing a cooperative strategy, there should be a pecking order in which they enter profitable contracts, with the most profitable being exploited first.

The repeated game assumption of the model hardly requires any defense in our application. Most of the dividend play transactions in our sample occur on the floor of only two exchanges, PHLX and BOX (**Table 2**). Given that most of the options trading is electronic, modern-day exchange floors are populated by a small number of market participants who specialize in floor trading and frequently interact with each other.

We now turn to test the natural markets interpretation of **Fact 1**, i.e., that contracts with no entry belong to the natural markets of market makers present on the exchange floor. A contract in our dividend play sample belongs to the natural market of a market maker if the market maker holds a short position in this contract in its inventory on a dividend play date (and hence is set to receive a windfall gain from early exercise mistakes).

We have been able to construct two proxies for natural markets. The first is a dummy for a (positive) *retail buy imbalance* in a contract. Retail

investors are likely to make early exercise mistakes. In Appendix B.10, we confirm this in our sample and also demonstrate that contracts with a higher retail presence are more profitable. Furthermore, [Bryzgalova et al. \(2023\)](#) argue that (a handful of) market makers that purchase retail order flow of retail brokerages take the opposite side of retail trades. To execute retail buy orders, they write the corresponding options contracts and potentially hold them in their inventory. If so, they receive windfall gains if these contracts are suboptimally left unexercised. A retail buy imbalances dummy would then proxy for a sell imbalance of market makers associated with retail order flow in a given contract.<sup>28</sup> The retail buy imbalances are computed using the methodology in [Bryzgalova et al. \(2023\)](#), and we borrow their acronym SLIM for the transactions their algorithm classifies as retail.<sup>29</sup>

Our second proxy for natural markets of market makers is simply a dummy for a *market maker sell imbalance* in a contract. This is a contract-level variable computed using Nasdaq's PHOTO data, which covers PHLX electronic trades. In contrast to OPRA data, PHOTO classifies trades into those made by market makers and other types of market participants, allowing us to compute their imbalances. PHOTO data also reports trade directions, so we do not need to impute them. We, therefore, simply set the dummy to 1 if the reported sell trade volume of market makers is larger than their buy trade volume in a given contract.

To test whether natural markets are a deterrent to arbitrageur entry, we estimate the following regression in the sample of contracts that should optimally be exercised on cum-date:

$$\begin{aligned} share_{c,t}^{floor} = & \beta_1 \times share_{c,t-1}^{SLIM} + \beta_2 \times D(SLIM \text{ buy imbalance})_{c,t-1} \\ & + D(MM \text{ sell imbalance})_{c,t-1} + \gamma' X_{c,t} + \alpha_{i,t} + \varepsilon_{c,t}, \end{aligned} \quad (13)$$

where the main regressors are  $share_{c,t-1}^{SLIM}$ , the average dollar volume share in SLIM trades as of one day before the last cum-dividend date  $t$ , the dummy for an average buy (volume) imbalance in SLIM trades  $D(Retail \text{ buy imbalance})_{c,t-1}$ , and the dummy for market makers sell (volume) imbalance  $D(MM \text{ sell imbalance})_{c,t-1}$ , computed over the same period.  $X_{c,t}$  includes the following contract-level variables: log OI, EEV, log dollar trading volume, log contract trading volume, relative spread, implied volatility, moneyness, and days to expiration. Our specification also includes the ticker by date fixed effects  $\alpha_{i,t}$ . **Table 5** reports the results of estimating the regression. **Table B.15** in the Appendix presents this analysis for alternative measures of arbitrageur activity and **Table B.16** for more horizons over which the regressors are measured.

**Table 5** reveals that arbitrageur activity, as measured by floor entry, trading share, or volume, is largely unrelated to SLIM Share, the measure of retail investor trading over the preceding day (Panels A–C). This result adds to our argument that it is surprisingly hard to predict arbitrageur entry. From our findings in Appendix B.10, one would

<sup>26</sup> See, e.g., <https://www.barrons.com/articles/market-makers-in-equity-options-are-vanishing-1496459364>. In a recent paper, [Ernst and Spatt \(2022\)](#) list market makers currently operating in the U.S. options market, and their number is small.

<sup>27</sup> In a narrow sense, our model of repeated strategic interaction applies to market makers who can potentially participate in the dividend play strategy. Therefore, an option contract with a sell imbalance of the market maker would be considered a natural market for them only if they are physically present on the floor. One limitation of our data under this definition is that we cannot distinguish order imbalances of markers that have a seat on the floor of a particular exchange and those who do not, introducing a measurement error in our proxies. However, given the high concentration of the market making activity among a relatively few firms, we suspect the measurement error to not be large. Furthermore, its presence is likely to attenuate our findings, not make them stronger.

<sup>28</sup> The anonymous referee and seminar participants suggested a third proxy for natural markets, namely the Designated Market Maker (DMM) in a given ticker. These market makers are likely to hold an inventory of written contracts on that ticker. The issue with options is that contracts on the same ticker are unlikely to be intermediated by the same market maker. This is because intermediaries who process orders normally *can decide* to which of 16 exchanges to route an order for execution. DMMs in a given ticker are not the same across exchanges. So it is entirely possible that one contract on Apple will belong to a natural market for one market maker and another contract to that of a different market maker.

<sup>29</sup> The measure is based on transactions that are likely to be intermediated by wholesalers. Wholesalers, such as Citadel, Susquehanna, and Wolverine, intermediate the overwhelming majority of retail order flow in the U.S., and they often use the so-called price improvement mechanisms to execute the orders. To identify these transactions, we use the OPRA transaction type SLAN, which stands for single-leg non-ISO price improvement auctions. See Appendix B.1 for a description. [Ernst and Spatt \(2022\)](#) and [Hendershott et al. \(2022\)](#) propose the same methodology for identifying wholesaler-intermediated transactions.

**Table 5**  
Arbitrageur activity and natural market proxies.

	Floor trading measure on last cum-date						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<b>Panel A: D(floor share &gt; 0)</b>							
SLIM Share [t – 1]	–0.002 (–0.36)		0.028*** (4.75)	0.017* (1.73)		0.000 (0.07)	0.011 (1.16)
D(SLIM buy imbalance) [t – 1]		–0.058*** (–10.91)	–0.071*** (–11.95)	–0.016* (–1.90)			
D(MM sell imbalance) [t – 1]					–0.141*** (–11.53)	–0.141*** (–11.53)	–0.035*** (–2.83)
Adjusted R-squared	0.396	0.397	0.397	0.409	0.398	0.398	0.409
<b>Panel B: Floor trading share</b>							
SLIM Share [t – 1]	–0.005 (–0.89)		0.025*** (4.58)	0.014 (1.45)		–0.002 (–0.44)	0.008 (0.88)
D(SLIM buy imbalance) [t – 1]		–0.059*** (–11.45)	–0.071*** (–12.52)	–0.015** (–2.02)			
D(MM sell imbalance) [t – 1]					–0.143*** (–12.58)	–0.143*** (–12.57)	–0.042*** (–3.76)
Adjusted R-squared	0.410	0.411	0.411	0.435	0.412	0.412	0.435
<b>Panel C: Floor trading volume, log</b>							
SLIM Share [t – 1]	0.046 (1.62)		0.168*** (5.35)	0.148** (2.23)		0.056** (1.96)	0.117* (1.82)
D(SLIM buy imbalance) [t – 1]		–0.212*** (–6.11)	–0.289*** (–7.53)	–0.091 (–1.49)			
D(MM sell imbalance) [t – 1]					–0.579*** (–6.71)	–0.582*** (–6.74)	–0.296*** (–3.23)
Adjusted R-squared	0.551	0.552	0.552	0.479	0.552	0.552	0.480
Sample	All	All	All	Top profit tercile	All	All	Top profit tercile
Observations	72,132	72,132	72,132	23,103	72,132	72,132	23,103

This table reports estimates of (13) in our dividend play sample. Floor trading share is the contract-level volume share of trades executed on the trading floor in the total traded volume on the last cum-dividend date. SLIM Share is the contract-level volume share of SLIM trades, one day before the last cum-dividend date. D(SLIM buy imbalance) = 1 if there was a buy imbalance in SLIM volume as of the day before the dividend play date, and 0 otherwise. D(MM sell imbalance) = 1 if there was a sell imbalance in market maker trades in PHOTO data as of one day before the last cum-dividend date, and 0 otherwise. All regressions include ticker-by-date fixed effects and contract controls (log OI, EEV, log dollar trading volume, log contract trading volume, relative spread, IV, moneyness, and days to expiration). Top profit tercile includes contracts in the top tercile of total potential profits. *t*-statistics are based on standard errors clustered by contract and date (in parentheses). \*\*\* *p* < 0.01, \*\* *p* < 0.05, \* *p* < 0.1.

expect arbitrageurs to enter contracts with a larger SLIM share, all else equal, as dividend play is more profitable in these contracts. However, this is not the case. Remarkably, our two proxies for natural markets do predict entry. Consistent with the natural markets interpretation, arbitrageur activity in a contract is *negatively* related to the SLIM buy imbalance, and this result is statistically significant across all specifications in Table 5, irrespective of the measure of arbitrageur activity (Panels A–C). The same is true for our second proxy for natural markets, market maker sell imbalances. Arbitrageurs are less likely to engage in dividend play in a profitable contract in which market makers are set to receive a windfall gain at zero cost, provided that no arbitrageurs enter and compete it away. The tests in Panel A are particularly aligned with the model, indicating that arbitrageurs are less likely to enter the natural markets of other intermediaries.

The specifications in columns (4) and (7) of Table 5 restrict the sample to the top tercile of most profitable contracts (by total profits) for dividend play arbitrageurs. Standard theories of limits-to-arbitrage imply that we should see more arbitrage activity in those contracts. This is not what our estimation reveals. We still see a strong negative effect of SLIM buy imbalance. The latter is inconsistent with standard limits-to-arbitrage theories but consistent with the hypothesis that arbitrageurs selectively enter different contracts, even the most profitable ones, avoiding those that represent natural markets for market makers.

#### 4.6. Alternative explanations and further discussion

Other theories could potentially rationalize the phenomena that we document. In the rest of this section, we explore alternative explanations of arbitrageurs' selective entry based on the existing limits-to-arbitrage literature.

Trading costs are the most natural alternative explanation. First, per-contract exchange fees might prevent arbitrageurs from fully exploiting available arbitrage opportunities. However, there exist dividend-play specific fee caps on PHLX and, more recently, BOX exchanges, in which most of the dividend play activity takes place (Table 2).<sup>30</sup> Those fee caps limit the total costs paid by a market maker or other arbitrageur on a particular day at the options class level: Harvesting the profit from an additional contract would not increase payments once the limit is reached. Second, given that dividend play usually requires two participating parties, it is highly likely that they would agree on the transaction price that allows for mutually beneficial profit sharing. Therefore, there is no clear reason why they would omit any particular contract from their agreement due to its lower market liquidity. Finally, in the analysis above, we always either control for contract liquidity or match contracts on their relative spreads. It is, therefore, unlikely that the contracts in which arbitrageurs do not engage in dividend play are systematically less liquid. There can also be financing costs, which would likely be increasing in the time to expiration, yet we do not see significant differences in arbitrageur participation across time to expiration in our sample.

Our data shows that traders simultaneously establish offsetting long and short positions, and so they are (ex ante) almost fully hedged. However, since options exercise orders are submitted before the close on the last cum-dividend date, while option assignment becomes known only in the morning, this implies that a symmetric long-short position

<sup>30</sup> See the PHLX pricing schedule: <https://listingcenter.nasdaq.com/rulebook/phlx/rules/phlx-options-7> and BOX fee schedule: <https://boxoptions.com/regulatory/fee-schedule/>.

in the neighboring contracts could still be exposed to two types of residual (largely) overnight risk: (a) a slight mismatch in risk between the long and short legs of the strategy due to the use of neighboring contracts, and (b) the exposure to the price of the underlying via options that remain unassigned in the morning and liquidated later. The latter exposure is similar to that of a short covered call position held overnight (see Figure B.10 in the Appendix for a detailed illustration.) To test the impact of this residual risk, we sort dividend play contracts based on various dimensions of risk to see whether this could explain the lack of arbitrageurs' entry.

Table 6 reports our findings. Panel A (Panel B) presents the fraction of harvested trades (profits, respectively) in contracts sorted by various dimensions of contract risk (delta, gamma, and other Greeks) and that of the underlying (stock's beta and idiosyncratic volatility). None of the sorts reveal a strong relationship between arbitrageur entry and contract characteristics, making a risk-based explanation for their lack of entry unlikely. Figure B.11 further supports these findings by showing the cumulative realized profits from the dividend play strategy. They remain remarkably stable under various assumptions regarding the trade size. Furthermore, Panels C and D in Table 6 demonstrate that none of the risk characteristics could explain the small number of participating arbitrageurs, conditional on at least one entry. Model risk, introducing uncertainty in expected profits, is unlikely to explain arbitrageur activity either. The lack of market participants' entry in the contracts belonging to the top group by delta (moneyness), where model uncertainty is likely to be fully eliminated, is striking. We report these results for delta in Table 6 and for moneyness in Table B.12 in Appendix.

It is also possible that the arbitrageurs' capital constraints bind. Most regulatory requirements involve netted positions, which are relatively low given the symmetric and (ex ante) virtually fully hedged nature of the strategy. Nevertheless, to test this channel and the importance of the residual overnight exposure, we create a risk–return tradeoff proxy for the strategy, equal to the ratio of potential profits to that of the total potential delta exposure. (See Figure B.10 in the Appendix for a detailed illustration.) Table B.18 (Panels A–D) reveals that similar to other dimensions of risk, this exposure does not explain arbitrageurs' activity. Therefore, capital constraints are unlikely to drive arbitrageurs' contract selection.

Our proxies for the natural markets channel, introduced in Section 4.5, remain robust after controlling for contract risk (see Table B.17 in the Appendix). Specifically, in columns (1) and (2) of Table B.17, we test our proxies for the natural markets, controlling for the contract-level values of delta, gamma, and other Greeks. Furthermore, given the sensitivity of some of the Greeks to the choice of the option pricing model used for calibration, in columns (3) and (4), we also present results controlling for the quartile of the contract Greeks instead of their raw values. This specification is less likely to be affected by potential measurement error and model-dependent calibration of the Greeks by OptionMetrics.

Table 17 in the Appendix confirms all our existing results on the natural markets interpretation. In particular, even after controlling for various measures of risk, arbitrageur activity in a contract is strongly negatively related to both proxies of the natural markets, SLIM buy imbalance and the market maker sell imbalance. In particular, arbitrageurs are less likely to enter a profitable contract in which market makers are already set to receive a windfall gain at zero cost, provided that no arbitrageurs enter and compete it away. Columns (5)–(8) and (9)–(12) further report the results of estimating Eq. (13) on contracts within a particular quartile of delta, using both proxies for the natural markets. Even within each bucket of contracts, arbitrageurs do not engage in dividend play in contracts that are likely to be the natural markets of market makers.

Large trades implemented during dividend play could be associated with high operational risks. According to SIFMA, Bank of America Merrill Lynch incurred a \$10 million loss due to a human error when

Table 6

Contract-level risk and arbitrageur activity.

	Quartile			
	(1)	(2)	(3)	(4)
Panel A: Fraction of harvested trades, %				
Delta	49.6	58.9	59.3	60.7
Gamma	57.7	61.0	58.9	50.5
Vega	58.0	58.8	55.9	55.5
Theta	58.7	57.8	56.5	55.1
IV	47.7	56.3	63.1	61.3
Potential profits/Delta exposure	51.5	61.6	58.6	63.1
CAPM beta	56.5	59.5	58.8	52.5
CAPM IVOL	54.9	61.9	59.7	52.7
Panel B: Fraction of harvested profits, %				
Delta	45.3	54.8	55.1	56.5
Gamma	53.5	57.0	54.7	46.1
Vega	54.1	54.4	51.5	51.3
Theta	53.8	53.3	52.5	51.7
IV	43.7	52.3	58.8	56.7
Potential profits/Delta exposure	47.8	57.3	54.3	58.2
CAPM beta	51.6	55.4	55.1	49.3
CAPM IVOL	50.3	57.3	55.9	49.5
Panel C: Conditional on entry, fraction of only 1 arbitrageur, %				
Delta	49.8	48.8	48.2	49.9
Gamma	50.2	47.7	48.8	50.0
Vega	51.8	48.8	48.3	47.5
Theta	47.6	49.2	48.7	51.3
IV	49.5	48.4	47.3	51.5
Potential profits/Delta exposure	60.8	44.0	41.1	44.3
CAPM beta	47.3	47.9	50.2	55.8
CAPM IVOL	48.7	46.7	49.2	54.7
Panel D: Conditional on entry, fraction of $\leq 4$ arbitrageurs, %				
Delta	91.1	91.6	92.1	92.9
Gamma	93.7	91.5	91.2	91.3
Vega	93.1	91.9	91.7	90.9
Theta	92.9	92.2	91.4	91.2
IV	91.3	91.2	91.8	93.3
Potential profits/Delta exposure	96.8	88.3	88.3	90.5
CAPM beta	91.5	91.2	91.8	95.1
CAPM IVOL	92.1	91.4	91.4	93.1

This table reports the characteristics of the arbitrage activity among the contracts, which are sorted into quartiles by different measures of risk: contract delta, gamma, vega, and theta, the contract-level ratio of potential dividend plays profits to the dividend play exposure to the underlying risk, contract's implied volatility (IV), CAPM beta of the underlying stock/ETF, and its CAPM-based idiosyncratic volatility (CAPM IVOL). Delta exposure is computed as (1-delta) of the contract (see Figure B.10 for the detailed illustration). CAPM beta and IVOL are computed using daily data over the previous 63 trading days, using CRSP index as the market rate of return. Panel A and B report the percentage of harvested trades and profits. Panels C and D report the fraction of contracts with only 1 arbitrageur and  $\leq 4$  arbitrageurs.

executing the dividend play strategy.<sup>31</sup> Still, such explanations cannot produce the variation in floor trader activity within and across tickers that we document: Table 4 illustrates that there are many profitable contracts in which floor traders do not participate at all.

We also rule out an alternative explanation based on arbitrageurs' inattention, which could be a characteristic of even sophisticated market players (Kacperczyk et al., 2016). Indeed, there may be hundreds of potentially profitable contracts available to dividend play on each cum-dividend day (thousands, in the case of SPY), making it difficult to keep track of all the relevant information. First, this hypothesis does not explain the puzzling amount of variation in contract entry within a given ticker. All of our results also contain ticker-date fixed effects. Nevertheless, we also used the number of stock-level EPS (Hirshleifer et al., 2009) and macroeconomic announcements (Savor and Wilson,

<sup>31</sup> See

<https://www.reuters.com/article/us-usa-options-apple-idUSKBN0IQ2FA20141106>.



2014) as proxies for limits to attention and did not find that those mattered for floor trader activity.

Some profits could also be left unexploited because of the stigma and reputational costs associated with the dividend play strategy. The SEC clearly signaled its disapproval of the strategy in its 2014 rule (see footnote 6). Reputational costs could explain the lack of entry of new arbitrageurs. However, they cannot explain why arbitrageurs who regularly engage in this strategy and hence are willing to incur reputation costs do not enter the most profitable contracts first.

Finally, there could be an explanation related to clearing fees. While we do not observe all the information regarding clearing fees because they are often negotiated bilaterally, we can put an upper bound on these fees based on the sizes of the positions arbitrageurs take. As a result, any position with a positive profitability net of such fees should be exploited, still implying a pecking order in contract selection based on profitability. Yet, we do not observe arbitrageur entry even in the top tercile of the most profitable contracts.

A few remarks are in order. Identifying profitable dividend play contracts does not require a very accurate forecast of the fraction of options left unexercised. Given that the fee cap is fairly low, as long as some of the contracts are not unexercised optimally, it would still be profitable to engage in dividend play. Furthermore, if uncertainty in this quantity had any practically relevant impact on the arbitrageur's decision to enter, we would expect to see more entry into the contracts recently bought by retail investors, not less.

It may seem puzzling that the arbitrageurs sometimes harvest less than 100% in a given contract. On one hand, this could mean that the remaining share of the profit was earned by other option writers, with arbitrageurs not taking large enough positions to fully divert the windfall gain from competitors. There is also a small chance that these other option writers simply got lucky and happened to hold the contracts that were not assigned to deliver the underlying. Last but not least, there could also be a measurement error in the arbitrageur's share of harvested profit. This measurement error could be driven by the fact that we do not observe the arbitrageur's original position and, hence, how much they need to engage in dividend play on top of the existing exposure to collect all the potential gains. Given that the puzzle of the arbitrageur's lack of participation in dividend play is largely in the contract selection, it seems that this measurement error should not affect the key empirical findings of the paper.

Some dividend play contracts, especially those very deep in the money and close to expiration, occasionally lack the data on implied volatility and Greeks in OptionMetrics. We impute missing Greeks from those of the nearby contracts on the same underlying with the same time to expiration, available on that day and subject to economic constraints (e.g., the delta of an option cannot be above one in absolute value). To make sure our results are not affected by the interpolation of the Greeks, we also run the analysis on the subsample of contracts with fully observed Greeks. Tables 18 and 19 in the Appendix test the risk-based explanation of arbitrageurs' activity on this dataset and find that the results are identical. There is no notable pattern consistent with the risk–return tradeoff that could explain arbitrageurs' behavior. Instead, all of our key empirical results remain consistent with the notion of natural markets of arbitrageurs and the model presented in Section 2.

## 5. Difficulties of devising effective regulation and further discussion

The dividend play arbitrage does not serve any particularly useful purpose in financial markets. It neither improves liquidity nor aids price discovery. It simply reallocates profits from the original option writers to arbitrageurs. In the process of doing so, however, it dramatically inflates trading volume and hence skews various important statistics that market participants rely on while exposing arbitrageurs and potentially exchanges to large operational risk. With its 2014 regulation, the SEC attempted to put an end to this strategy.

**Table 7**

Arbitrageur activity in neighboring contracts by strike.

	Floor trading measure on last cum-date			
	D(floor share > 0)		Floor imbalance	
	(1)	(2)	(3)	(4)
D(floor share > 0), $K - 1$	0.036*** (5.04)	0.019*** (2.86)		
D(floor share > 0), $K + 1$	0.066*** (10.04)	0.041*** (6.34)		
D(floor share > 0), $K - 2$		0.039*** (5.73)		
D(floor share > 0), $K + 2$		0.073*** (11.56)		
Floor imbalance, $K - 1$			−0.077*** (−8.69)	−0.106*** (−9.14)
Floor imbalance, $K + 1$			−0.085*** (−10.02)	−0.115*** (−9.20)
Floor imbalance, $K - 2$				−0.044*** (−3.71)
Floor imbalance, $K + 2$				−0.057*** (−4.96)
Observations	60,306	52,383	18,694	10,565
Adjusted R-squared	0.399	0.404	0.055	0.056

This table compares floor entry (D(floor share > 0)) or floor buy imbalance (Floor imbalance) in a given contract with strike  $K$  with floor entry or floor imbalance in contracts with neighboring strikes  $K - 2$ ,  $K - 1$ ,  $K + 1$ , and  $K + 2$  (within ticker and date but across expiration dates). We only consider contracts in which dividend play is profitable in our dividend play sample. All regressions include ticker-by-date fixed effects and contract controls (log OI, EEV, log dollar trading volume, log contract trading volume, relative spread, IV, moneyness, and days to expiration).  $t$ -statistics are based on standard errors clustered by contract and date (in parentheses). \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

Our paper demonstrates that market participants found a way around the 2014 SEC regulation. Two previous papers on dividend play, Hao et al. (2009) and Pool et al. (2008), written before the SEC regulation, argue that arbitrageurs engage in dividend play by simultaneously opening long and short positions in the *same* call option contract. The 2014 regulation affected clearing rules of netting positions and execution of options contracts, and it was no longer beneficial for arbitrageurs to long and short the same contract.

In our transaction-level data, we clearly see that after the regulation, dividend play arbitrageurs simultaneously long and short contracts with *neighboring* strikes. Table 7 presents supportive evidence of this change in arbitrageur behavior. If arbitrageurs enter a profitable contract with a strike  $K$ , they are highly likely to enter profitable contracts with neighboring strikes  $K - 2$ ,  $K - 1$ ,  $K + 1$ , and  $K + 2$  on the same underlying (columns (1)–(2)). Columns (3)–(4) of Table 7 reveal that the trade directions in the neighboring contracts tend to be the opposite, consistent with the fact that arbitrageurs simultaneously originate long and short positions in the neighboring strikes. We observe the same pattern as in columns (3)–(4) if we instead use a dummy equal to one if there is a buy imbalance in floor trades and zero if there is a sell imbalance in floor trades, indicating that the result is driven by the extensive margin. All coefficients in Table 7 are highly statistically significant.

For the purposes of computing regulatory risk exposures, an arbitrageur's positions in the neighboring strikes in the same underlying are simply netted to zero. There is some economic risk exposure resulting from this trade since the deltas of the long and short positions are not exactly the same (as we discussed in Section 4.6), but the short-horizon nature of the trade and the ability of arbitrageurs to delta hedge their economic exposure, if desired, still makes it a worthwhile strategy.

How quickly did arbitrageurs find a way around the 2014 SEC regulation? Examining abnormal trading volume on dividend play dates from 2014 onwards, we find that it took little time for arbitrageurs to switch to a new implementation of the dividend play strategy. Figure

B.12 in the Appendix shows that already in 2014 abnormal trading volume in the strategy was sizeable, albeit lower than during its peaks of the previous years. This experience highlights the difficulties in designing effective regulation in financial markets.

We propose an alternative way to curtail the strategy. The problem lies in the OCC's random assignment of contracts to options writers who are required to deliver the underlying. Dividend play relies on this random assignment. An alternative would be the First-in, First-out (FIFO) rule, similar to a regulation imposed by the National Futures Association (NFA) in the U.S. on trading international currencies and currency derivatives.<sup>32</sup> It requires that currency traders close out their oldest positions first, before closing out more recent positions. This rule would favor the original option writers over the dividend play arbitrageurs.<sup>33</sup> We should acknowledge, however, the added complexity and data requirements that come with FIFO rules, in that one would be required to keep track of the time a position was established.

Another possible way to make the strategy impractical is to encourage exchanges to remove fee caps for dividend play trades, which would make this high-trading-volume strategy very expensive. Most exchanges, possibly in response to regulatory concerns, removed the fee caps around the time of the 2014 SEC regulation or just prior to it.<sup>34</sup> PHLX remained the only venue with explicit fee caps until 2019, when BOX entered the space and introduced similar caps. In our main sample that starts in 2019, we observe little trading volume in dividend play in all exchanges except for BOX and PHLX.

Our final point concerns investor protection. The new generation of investors may be lacking in financial education that is required to trade options. Investor mistakes in sophisticated financial decisions, such as failures to exercise options early, generate transfers to arbitrageurs or market makers. It is not clear whether retail investing platforms have the right incentives to prevent their customers from making trading mistakes. The question of optimal options exercise requires knowledge of option pricing models, which retail investors are likely to lack. One possibility would be to require retail brokerages to report options' early exercise values to investors. The early exercise value could be computed from the Black–Scholes model. Another possibility is to make *automatic* early exercise on last cum-dividend dates when it is optimal to do so, a default option for investors, from which they can opt out if they wish. This simple enhancement would prevent retail investor losses of over \$360 million in our sample.<sup>35</sup> More generally, the literature on investor protection has long been concerned about complex investment products and incentives of intermediaries.<sup>36</sup> The complexity of options contracts from the viewpoint of an average retail investor and the potentially misaligned incentives of intermediaries call for enhancements to investor protection on retail trading platforms.

## 6. Conclusion

In this paper, we contribute to the literature on arbitrage in financial markets by introducing repeated game considerations. Arbitrageurs in our model are large and their number is limited because of economies of scale and entry costs, and they interact repeatedly with each other. Repeated game considerations enlarge the set of possible equilibrium outcomes and, in particular, give rise to tacit collusion. Arbitrageurs enter into only a subset of markets, which reduces their combined entry

costs and thus increases social welfare.

Our empirical application mimics the setup of the model. We consider dividend play, a specific arbitrage strategy in the options market for which we can accurately track arbitrageur activity. Dividend play arbitrageurs execute their trades on the floor of the exchange, which is typically populated by a limited number of players, and they interact repeatedly. Needless to say, there are entry costs associated with floor trading, although these costs are lower for intermediaries who are already present in the options markets, such as for example market makers. We document that arbitrageurs routinely do not take part in dividend play in a large number of exploitable options contracts, even the most profitable ones. Moreover, if arbitrageurs do decide to engage in a dividend play in a given contract, their number is usually limited to only one arbitrageur. These implications are consistent with our model. We also consider alternative explanations for the selective entry of arbitrageurs, most of which we are able to rule out.

While we do not provide any direct proof that a tacit collusion equilibrium indeed occurs in dividend play, our paper presents a cautionary tale about its potential presence in financial markets, in this and other circumstances. Dividend play arbitrage is not the only setting that satisfies our model's assumptions. For example, in the options market, there are five further arbitrage strategies, facilitated by exchanges via fee caps, which are also executed on the floor. More broadly, financial markets with entry costs and natural economies of scale, intermediated by a limited number of players, may present other applications of our model, as strategic interactions cannot be ruled out in such markets. More opaque and concentrated markets, for example, over-the-counter markets, may also present suitable applications, as repeated game considerations are more likely to arise in those environments. For example, Bolton and Oehmke (2013) conjecture that there may be scope for tacit collusion in credit derivative markets,<sup>37</sup> while the 2012 LIBOR fixing scandal has exposed collusion in the interbank lending market (Hou and Skeie, 2014).

Whether tacit collusion indeed explains partial market segmentation and other patterns we see in financial markets is, of course, an open question. Given its crucial importance for market participants and regulators, it requires significant follow-up work, both theoretical and empirical.

## CRedit authorship contribution statement

**Svetlana Bryzgalova:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Anna Pavlova:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Taisiya Sikorskaya:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

<sup>32</sup> See <https://www.nfa.futures.org/rulebooksql/rules.aspx?Section=4&RuleID=RULE%202-43>.

<sup>33</sup> We thank Terry Hendershott for suggesting this idea to us.

<sup>34</sup> See <https://www.tradersmagazine.com/departments/options/dividend-trades-cease-at-three-options-exchanges/>.

<sup>35</sup> While \$365 million is the total potential profit to be exploited by dividend play arbitrageurs, a large fraction of it is likely coming from retail investors, as sophisticated investors are likely to exercise their options optimally.

<sup>36</sup> See e.g., Barbu (2022), Bhattacharya et al. (2019), Egan (2019), Heimer and Simsek (2019), C  l  rier and Vall  e (2017), and Campbell et al. (2011).

<sup>37</sup> The number of dealers in these markets is typically small. For the U.S. credit default swap market, Eisfeldt et al. (2023a) estimate it to be around 13 and that the volumes are highly concentrated.

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