Convertible bond arbitrage and short-selling activity

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Abstract

The objective of this study is to examine the impact of convertible bond arbitrage activity on short-selling levels of the underlying equity. We exploit changes in Reg SHO reported short sale data to identify convertible bond arbitrage related short-selling activity. By further scrutinizing 335 convertible bonds around the issuance as well as for the period following issuance. Results provide considerable evidence of arbitrage-induced short-selling for both the period around the issuance and the post-issue period. Moreover, deal-specific characteristics capturing hedging demand and attractiveness of the arbitrage opportunity strongly relate to convertible arbitrage short-selling. Given our identification of short-selling with daily accuracy near the issuance, our paper highlights the benefits of applying empirical precision to the study of convertible bond arbitrage activity.

Keywords: Short-selling, hedge funds, convertible bond arbitrage, offering discount, long-run returns, delta-hedging

Contents

1 Introduction

The past decades have witnessed unprecedented growth in convertible bond issuance by US corporations. Choi, Getmansky, and Tookes (2009), for instance, reported a sixfold increase in convertible issuance, from $7.8 billion in 1992 to $50.2 billion in 2006. Alongside such development, convertible arbitrage hedge fund involvement grew. In 2004, 80% of the convertible bonds were estimated to be bought by hedge funds (Pulliam, 2004). In pointing to a continuation of such pattern, researchers state that by 2007 hedge funds purchased 75% of all new issues, thereby becoming the primary buyer of convertible bonds (Mitchell, Pedersen, & Pulvino, 2007).

Against this backdrop, scholarly interest in convertible bonds and hedge funds involvement has grown. Conceptually, convertible bonds are complex financial instruments, including a wide range of different terms and conditions. Rather than being static, such terms and conditions are the results of an on-going process of creativity geared towards keeping up with changes in financial markets. Hedge funds, as profit maximising investors, may further impact the design of convertible bonds, introducing theoretical and empirical questions about the nature of their increased involvement, and how such involvement develops over time.

Several scholars have outlined and investigated the heterogeneity mentioned above in the design of convertible bonds. Hillion and Vermaelen (2004), for instance, study floating-priced known as death spirals, which are convertible securities that embed a conversion price set at a discount. Korkeamaki (2005) examines call protection terms (soft and hard calls), which firms can use to adjust their convertible issue to be more debt-like or equity-like. Lewis and Verwijmeren (2011) analyse the method of payments choice for convertible bond settlements, specifically cash settlement features. Grundy and Verwijmeren (2018) provide evidence that security design reflects the interplay of a capital supplier, mainly hedge-funds, and security issuer preferences. For example, a steep decrease of call provision features can be a direct result of the domination of arbitrage hedge funds in the convertible bond market. Following the disappearance of call provisions, Verwijmeren and Yang (2020) study the increase in issues with shorter maturities.

Similar to the design of convertible bonds, the inner workings of and outcomes associated with convertible bond arbitrage have received substantial scholarly attention. Convertible bond arbitrage stems from the tendency of convertible bonds to be underpriced at issuance due to small issue size, valuation complexities and illiquidity (Kang & Lee, 1996; Ammann, Kind, & Wilde, 2003; Loncarski, Horst, & Veld, 2008; Choi, Getmansky, Henderson, & Tookes, 2010). In echoing and explicating such underpricing, recent studies (Henderson, 2005; Jong, Dutordoir, &

Verwijmeren, 2011; Hackney, Henry, & Koski, 2018) point to it as a fundamental characteristic of convertible bonds that seem to be persistent over time.

Underpricing, in literature interchangeably referred to as discount or mispricing, is exploited with convertible bond arbitrage. In other words, when buying the undervalued convertible bond, a short position is simultaneously taken in the underlying equity.[1] Generally, convertible bond arbitrage employs delta-neutral hedging by taking a long position in the convertible bond and a short position in the underlying equity. Delta measures the sensitivity of the convertible bond to changes in the underlying equity price, thereby informing the calculation of the number of shares expected to be sold short for hedging purposes.[2]

Alongside being delta-neutral, a convertible bond arbitrage strategy typically consists of two distinct time frames. The first is referred to as the initial position, occurring at the issuance of the convertible bond, where the underlying aim is to not generate profit or loss from small movements in the underlying equity price. In pursuit of such an aim, the holder possessing a long call position shortens the underlying equity.[3] Income is generated from the convertible bond's coupon and the interest rebate of the short position. The second time frame is known as the dynamic hedging period and follows straight after the initial delta neutral position is established. If the price of the underlying equity decreases, the delta decreases, and the arbitrageur buys stock to cover part of the short position. Likewise, if the underlying equity price increases, the arbitrageur adds to his current short position as the delta increased.

This thesis seeks to understand and explain the impact of convertible bond arbitrage activity on short-selling in the underlying equity. As such short-selling is an essential component of the arbitrage strategy, we expect significant changes in short-selling levels of the underlying equity for convertible bonds with convertible bond arbitrage activity. Short-selling levels around the issuance, and more importantly, for the dynamic hedging period, have hitherto received scant attention by scholars, partly due to the limited availability of high-frequency short-selling data. We address this lacuna by identifying convertible bond arbitrageurs and consequently examine the influence the arbitrage activity has on short-selling of the underlying equity in the dynamic hedging period.

[1] A convertible bond is a hybrid debt security that can be broken down in two separate components: a debt and an equity-component. The debt component acts identical to straight debt: it pays interest with a fixed frequency. The equity component provides the possibility to convert the bond to a fixed amount of shares (conversion option), and can be compared to a call option on the equity and provides upside potential for the convertible bondholder in the case the equity value increases. Besides, due to guaranteed fixed bond payments, bondholders enjoy a level of downside protection from the debt component.

[2] Delta can be mathematically expressed as follows: $\Delta = \Delta V / \Delta S$ with ΔV being the change in value of the convertible bond and ΔS the change in price of the underlying equity, see Option Greeks: Delta and Gamma. In addition to the Delta, the sensitivity of the convertible bond to changes in the underlying equity price is also dependant on other parameters such as the volatility of the underlying equity, the conversion price and the time until maturity of the convertible bond.

[3] A long call position means that the investor only benefits if the price of the stock goes up. When the price of the stock goes down, the option does not provide any payoff.

We use a novel dataset of Reg SHO daily short volume data for the period 2011 to 2018, to test the hypothesis that short-selling levels increase significantly around the issuance date and post-issue due to dynamic hedging. The issuance date, conceptualised as the moment the initial position is taken, can function as a proxy for arbitrageur activity and behaviour during this period. Consequently, we are also able to measure dynamic hedging by studying changes in short-selling levels for convertible bonds which are expected to have increased delta hedging activity (higher gamma).[4]

Consistent with our hypothesis, results indicate that short-selling levels increase by an average of 702% around the issuance compared to shorting levels for a pre-issue period.[5] Besides, we observe short-selling levels to be significantly higher in the dynamic hedging period compared to pre-issuance. For convertible bonds with a higher gamma, which are expected to have an increased level of hedging activity, we observe no increase in short-selling levels.

The aggregated data and respective results allow us to capture the arbitrage strategy effects. Alternatively, for our analysis, hedge fund data could be used as a proxy for arbitrage activity. However, hedge fund databases have several limitations which do not allow us to accurately measure the positions taken by convertible bond arbitrageurs in the underlying equity. First, fund flows data are self- reported and can, therefore, be an incomplete measure. The hedge fund databases only partially represent the hedge fund universe, since many large hedge funds do not report their fund flows data. Second, the style of hedge funds can be misclassified, or hedge funds report their strategy under multiple styles.[6] Third, hedge funds use extensive leverage. Even if the assets of the hedge funds could accurately be observed, it would be impossible to observe the actual position of the hedge fund (Choi et al., 2009).

Our study sheds new light on the influence convertible arbitrage has on short-selling levels of the underlying equity. We find robust evidence of arbitrage activity near the issuance and for the period following the bond issuance. Moreover, these short-selling changes in the post-issue period are positively and significantly related to our proxy for convertible bond arbitrage. Additionally, we hypothesise that the gamma profile of convertible bonds affects short-selling levels in the post-issue period. Contrary to expectations, we observe a significant negative relationship between short-selling and the gamma profile.

[4] See Option Greeks: Delta and Gamma for a thorough explanation on the option Greek Gamma (Γ) and Delta (Δ)

[5] The average short-selling shows an increase of 1.56% around the issuance relative to the shares outstanding. In the pre-issue period, short-selling levels are on average 0.22%.

[6] Hedge funds differentiate themselves by their investment style or investment strategy. Certain hedge funds focus solely on one specific investment style, while others may focus on multiple at once. Examples of hedge fund styles include arbitrage strategies such as convertible bond arbitrage or fixed-income arbitrage. One can also think of event-driven strategies such as risk arbitrage or distressed securities. Lastly, global macro strategies are also possible, which evolve around global market trends. See Hedge Fund Research (HFR) for an example of a hedge fund database with defined investment styles.

Additionally, we observe that the offering discount, the value of the embedded option and changes in volatility and market capitalisation is positively related to increases in short-selling for the post-issue period. Finally, we briefly touch upon the liquidity and price efficiency effects of short-selling in the post-issue period. Together, our results show that short-selling positively affects liquidity, but has no relation with price efficiency. Our results are robust to using different pre- and post-issue period to measure changes in short-selling.

This study contributes to the academic literature in three ways. First, our study sheds new light on convertible bond arbitrage and its influence on short-selling of the underlying equity near the issuance. We build upon and extend the analyses of Benchmann (2004) and Hackney et al. (2018) who analyse convertible bond arbitrage effects on short-selling and market quality. Such previous research has mostly been restricted to the use of monthly frequency short-selling data in the form of short interest. Instead of showing short-sell changes near the issuance, the monthly frequency shows a change in short-selling for the month after the issuance compared to the month before. Conversely, we introduce a dataset of daily short volume observations to observe short-selling with daily accuracy near the issuance. Given such empirical precision, our study is the first to show that convertible arbitrageur fuels a significant increase in short-selling for the two days before and after the issuance.

Second, our focus lies on further contextualising the dynamic hedging period by examining changes in short-selling. In contrast, earlier studies (e.g. Choi et al., 2009) mostly studied if convertible arbitrageurs impact market quality during such period. Through such empirical contextualisation, we can show that increased short-selling is a direct effect of delta hedging by the arbitrageurs. Thus, this is the first report relating short-selling to the dynamic hedging period.

Third, we investigate variations of short-sell level, as well as determinants related to such variations. We find considerable evidence that particular issues (e.g. delta, offering discount and gamma) and issuer characteristics (e.g. amihud and turnover) impact the short-selling levels near the issuance and in the dynamic hedging period. Taken together, we interpret our findings as evidence that convertible bond arbitrage activity tends to affect short-selling levels near the issuance and in the dynamic hedging period. Our findings contribute to the academic discussion around convertible bond arbitrage theories.

The remaining part of the paper proceeds as follows. Section 2 outlines the rationale for the hypothesised changes in short-selling levels. Section 3 describes the data and provides initial observations on short-selling levels. In Section 4, the results of our analysis are described and discussed. Lastly, we conclude our paper and findings in Section 5.

2 Related Literature

2.1 The underlying rationale for convertible debt

In pursuit of the aim mentioned above, it is essential to understand the underlying rationale for firms issuing convertible debt. One of these rationales mentioned by past empirical research (e.g., Green, 1984; Constantinides & Grundy, 1989; Mayers, 1998) is the idea that convertibles allow the bondholder to partake in upside potential of the underlying equity. In doing so, the value of the option reduces the value of limited liability, thereby mitigating the so-called risk-shifting problem.[7] Thus, by being neither debt or equity but rather a combination of both, convertibles can function as an efficient financing instrument in cases of uncertainty about a firm's risk (Brennan & Kraus, 1987; Brennan & Schwartz, 1988). Its efficiency lines in the thee lines of thought, which are described next.

First, convertibles may serve as an alternative to straight debt for issuers, especially for issuers that already have ruled out equity and thus lean towards a debt-like financing structure. Second, efficiency comes as through the issuance of convertible debt firms can raise *backdoor equity* as a substitute for common equity and can minimize the cost related to direct equity offerings (Brennan & Schwartz, 1992). Third, convertible debt allows for financing in the presence of information asymmetry (Constantinides & Grundy, 1989).

Alongside being found to be efficient by past empirical research, convertible bonds have also been found to relate to the inner workings of firms, for instance reducing issue costs in light of the overinvestment incentive (Mayers, 1998) or unveiling a firms' potential to attract and retain capital (Kang & Lee, 1996).

2.2 short-selling as a proxy of arbitrageur activity

Researchers differ in the way they conceptualise, and measure arbitrageur activity, notably as such activity can differ at any given time. Hanson and Sunderam (2014), for instance, use time variation in short interest to infer the amount of capital allocated to arbitrage strategies. The importance of these time variations is increasingly becoming evident in the scientific debate on arbitrageur activity, albeit not yet related to specific event dates. Thus, although such specific event dates, for instance, earnings announcements or convertible bond issuance, have been investigated before (see, e.g., Christophe and Ferri (2004); Benchmann (2004); Hackney

[7] The risk-shifting problem, originating from Jensen and Meckling (1976), postulates that shareholders of a firm with high leverage have an incentive to partake in riskier projects. The shareholders have unlimited upside potential and face limited downside potential due to limited liability. Bondholders are expected to anticipate this misalignment in incentives and will therefore demand a higher compensation for this risk. The higher asked yield is the imposed cost of risk-shifting on the shareholders.

et al. (2018))[8], they have not been related to arbitrageur activity.

Of particular interest is the notion that short-sellers contribute to market quality and incorporate (negative) information to correct stock prices. The specifics of such either positive or negative contribution depends on the level of information a short seller has, with the possibility of being informed or uninformed, referred to as valuation and arbitrage, respectively.[9] Whereas informed short-selling may negatively impact market quality through adverse selection, uninformed short-selling may positively impact market quality through enhanced liquidity.

We assume that the change in short-selling primarily to be a direct result of convertible bond arbitrage. Thus, notwithstanding the difficulties of measurement, of particular interest to the conceptual repertoire of this paper is the level of information a trader has when executing a short sale.[10] Drawing from existing empirical evidence, we find it likely that valuation short-sellers are active around the announcement date since this is the moment new information is released. Following a similar logic, arbitrageurs may be active around the issuance date, serving as the moment to initiate delta-hedging. Therefore, with our specific date approach, we can further identify arbitrage shorting activity without the noise of valuation shorting.

2.3 Hypotheses

Above, we outline existing empirical research related to short-selling and arbitrageur activity. This section outlines the rationale for our hypotheses.

Several relevant papers use short-selling activity near an event to study the behaviour and impact of a particular type of trader. In studying the announcement of convertible bond calls, the study of Benchmann (2004), for instance, provides evidence that hedging-induced short-selling causes at least part of the short-run price pressure around said announcement date. Mitchell, Pulvino, and Stafford (2004) use short-selling activity around merger announcements to identify the impact of risk arbitrageurs. Choi et al. (2010) examine convertible bond issuance to determine the impact of convertible bond arbitrageurs on the underlying equity market, such as liquidity and price pressure. Hackney et al. (2018) test for the relative importance of informed and uninformed short sellers and the increase in short-selling around convertible bond issues and

[8] Benchmann (2004) and Hackney et al. (2018) focus on price pressure induced by short sales around convertible bond issuance and provide evidence of steep stock price declines caused by hedging activities of convertible bond arbitrageurs at the issuance date.

[9] Engelberg, Reed, and Ringgenberg (2012) find that a substantial portion of informed short-sellers' trading advantage comes from their ability to analyze and incorporate publicly available information. They show that the negative relation between short sales and stock returns is twice as substantial on news days and four-time as ample on days with negative news.

[10] Boehmer, Charles, and Xiaoyan (2008) attempt to distinguish the type of seller by using proprietary system order data from the New York Stock Exchange and by looking at the type of account (system short sales can be partitioned into six different accounts) that exercises the short sale. Boehmer, Huszar, Wang, and Zhang (2015) use eight alternative short sale measures to examine the informativeness of short sales on a global scale (38 countries) and analyze which type of information predicts high future stock returns.

earnings announcements for the same firms over the same period.[11] Similarly to these studies, we focus on the impact of arbitrage related short-selling on the underlying equity, represented by the following hypothesis:

> $\boldsymbol{H_{0_1}}$ ***(Issuance)***: Changes in short-selling of the underlying near convertible bond issuance are correlated with convertible bond arbitrage activity.

As previously illustrated, evidence suggests that hedge funds can play a significant role in convertible bonds and related markets. Although such a role can be examined in various ways, our approach is novel in many ways. We, for instance, assert that with the increase in the supply of stock due to short-selling, significant changes will be present at issuance for those convertible bonds with active convertible bond arbitrageurs. The moment a convertible is issued and distributed to the buyer, the arbitrage hedge funds holds a long open position and is expected to hedge this position directly. Thus, we expect the increase in short-selling to peak exactly on the issuance day. Additionally, we analyse the impact of convertible bond arbitrageurs on short-selling levels for the dynamic hedging period, resulting in the following, second, hypothesis:

> $\boldsymbol{H_{0_2}}$ ***(Dynamic hedging)***: Changes in short-selling in the dynamic hedging period are correlated with convertible bond arbitrage activity.

For the dynamic hedging period, we expect short-selling to be at elevated levels compared to before the convertible bond issuance due to active delta-neutral hedging. Henderson (2005) studies the underpricing of convertible bonds at issuance and finds that excess returns occur shortly after issuance. With excess returns dissipating, incentives for the arbitrageurs to stay exposed to the convertible bond and underlying equity decreases. This finding is relevant when examining the dynamic hedging period and influenced setting our dynamic hedging window for our analysis.

Of specific interested are the firm and deal-specific determinants of the different changes in short-selling. Firm-specific determinants such as share price, liquidity (e.g. measured with Amihud (2002)), and firm size are a proxy for the cost of short-selling (Hackney et al., 2018). Deal-specific characteristics such as Delta, Gamma, 144A and conversion premium are positively related to hedging demand (Choi et al., 2009; Hackney et al., 2018). As the magnitude of underpricing could play a role in the amount of short-selling, we are also interested in what determinants may drive the underpricing in the first place.

Alongside studying the potential issue and firm characteristics, we test whether short-selling affects convertible offering discounts under the rationale that short-sellers may trade before

[11] Benchmann, 2004; Mitchell et al., 2004; Choi et al., 2010; Hackney et al., 2018 use (monthly) short interest as a proxy of short-selling activity.

seasoned equity offering to manipulate prices, resulting in more substantial issue discounts (Gerard & Nanda, 1993). We draw from the Tsiveriotis and Fernandes framework (Tsiveriotis & Fernandes, 1998) to obtain the theoretical offering price, which is deducted from the offering price to obtain the offering discount.[12].

Lastly, we examine the effect convertible bond arbitrage has on market quality. If demand curves for the underlying stock are downward sloping, and the short-selling is due to the convertible bond arbitrageur (uninformed), higher levels of short-selling should be related to higher negative returns on the day of issuance. Benchmann (2004) finds a complete price reversal within days after the shock, which is in line with the notion that the demand curves for stocks are only in the short run inelastic. Contrary, Lynch and Mendenhall (1997) find a permanent price effect, echoing the notion that demand curves are downward-sloping in the long-run (Shleifer, 1986). Brophy, Ouimet, and Sialm (2009) examine the role of hedge funds as investors in public companies raising equity privately. Hedge funds tend to finance companies that have relatively shaky fundamentals and pronounced information asymmetries. They argue that after hedge funds finance a company, they enter into short positions of the underlying. Using data from 5244 transactions between 1995 and 2002, the authors find that, even after controlling for security structure, investments by hedge funds relate to negative long-run of the underlying equity.

Thus, previous studies have presented inconsistent findings on the impact of uninformed' (various arbitrageurs) supply or demand shocks on stock prices and market quality. To advance the field, we assert that if convertible bond arbitrageurs activity is identified in the dynamic hedging period, an observation can be made whether the presence of the (uninformed) arbitrageurs affects stock prices.

3 Data Description

The initial sample consists of all public and 144A convertible debt issues by US publicly traded firms for the period January 2011 to December 2018, where 2011 is the earliest date for which daily short volume data availability holds. We collect issue dates and other relevant issue characteristics from the Mergent Fixed Income Securities Database (FISD). Mergent FISD contains 1053 fixed-coupon convertible bonds that were offered in our sample period. We remove convertible bond offerings that are double-counted in the sample.[13] We exclude convertible offerings by financial institutions and utility firms. Convertible bond offerings with missing

[12] See in the Appendix for a detailed description.

[13] A number of convertible bonds are registered as a 144A offering and are on a later date registered as a public offering.

offering data (e.g., offering price) are also removed. The sample consists of 381 convertible bonds.

To be able to examine short-selling levels, we match the convertible bond offerings with short-selling data for the issuing firms. We obtain daily short volume data directly from FINRA.[14] We encounter insufficient short-selling data for 33 firms, which leads to a merged sample between Mergent FISD and FINRA with 348 observations.

Lastly, in order to analyse firm-specific variables, we obtain stock daily stock prices from the Center for Research in Security Prices (CRSP) database. We require non-missing data and lose another 13 observations. Our final sample concludes 335 observations.[15]

Choi et al. (2009) use monthly short-interest as a proxy for the presence of arbitrageurs in the equity market. The authors argue that short-interest data are solely available monthly, therefore being partly insensitive to the existence of short-sales transactions. To mitigate such shortcoming, Choi et al. (2009) find further evidence of convertible bond arbitrage by using Reg-SHO pilot 2005-2006 data.[16] Such efforts illustrate the ability of daily short-volume from FINRA to provide an accurate measure of short volumes exactly around the issuance and the dynamic hedging period.

3.1 Understanding the short-sale volume data

In recent years, the availability of daily-sale volume data has sustainably increased. On November 9, 2009, FINRA set foot on uncharted territory by publishing daily short-sale volume files under Regulation SHO. This regulation provides aggregate daily short sale volume data by security for off-exchange trades in listed stocks, as well as for trades in non-exchange-listed (or OTC equity) securities. FINRA's public database includes short-sale volume files dating back as far as to January 4, 2011. Such data is derived from transactions that are reported to its equity trade reporting facilities. The exchanges - in particular NASDAQ Chicago, NYSE and NASDAQ - publish their short sale volume data in the same format relating to trades executed on their markets.

The data is published separately by FINRA for each FINRA trade reporting facility and by

[14] FINRA provides a publicly available short volume data on `http://regsho.finra.org/regsho-Index.html`. Historical data can be accessed by modifiying the date URL. To demonstrate: `http://regsho.finra.org/FNQCshvol20200221.txt` provides data for 21 February, 2020, for the FNQC reporting facility (symbol FNQC represents NASDAQ TRF Chicago). A modification of the date in the URL allows access to different dates. By using a custom web scraper we can efficiently create our offline-database.

[15] Figure 6 in the Appendix describes the time series of convertible bond issuance for our sample. Issuance is reasonably volatile over the sample period, with a low number of issues for the years 2011 and 2012, followed by the highest issues per year in 2013 and 2014.

[16] The Securities and Exchange Commission adopted Regulation SHO on June 23, 2004. The pilot program began on May 2, 2005, and ended on April 28, 2006. The purpose of the Reg-SHO pilot was to make trading data publicly available for researchers to study. The data contains information on each executed short sale involving all exchange-listed securities.

each exchange and is not consolidated. Thus, to obtain a comprehensive overview of the total short sale volume for a particular listed stock, data published by FINRA for each of its trade reporting facilities (TRF) must be combined. FINRA's TRFs receive data from exclusively off-exchange venues. Since off-exchange volume accounts for about a third of all trade volume, the data should suffice as a representative market proxy. The short-interest data reflects short positions held by market participants at a specific moment in time on one or two discrete days each month (dependent on whether one uses monthly or bi-monthly data). The daily short volume files reflect the aggregate volume of trades executed as short sales on each trade date. Therefore, whereas the two data sets are related (e.g., short sale volume may ultimately result in a reportable short interest position), they are not necessarily correlated. For example, if a firm sells short 5,000 shares of security ABC, then purchases 5,000 shares of ABC later the same day, the short sale volume in the daily short volume will include the 5,000 shares that were sold short. Because the firm sold short and purchased an equivalent number of shares that day, it did not establish or accumulate a short position in ABC; thus, its short-sale has no impact on the reported short-interest in ABC. Therefore, instead, inspecting short volume data will give us a reasonably accurate picture of the short trade action by arbitrageurs surrounding a convertible bond issue.

3.2 Capturing changes in short-selling

Figure 1 illustrates the timeline of the arbitrage strategy. An initial observation of the short-selling data shows a pattern as we would expect. Figure 2 illustrates the average scaled daily short volume. Consistent with Choi et al. (2009), short-selling increase around the issuance.[17] Furthermore, it seems that short-selling levels are higher in the post-issue period compared to pre-issuance levels.

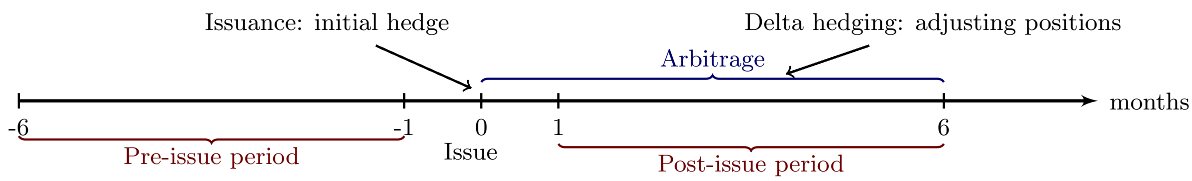

Figure (1) This figure presents the timeline of the convertible bond arbitrage strategy. At issuance, the convertible bond arbitrageur buys the convertible bond and shorts the underlying. The amount to be shorted is determined by the delta of the embedded option of the convertible bond. After the issuance, the arbitrageur adjusts his position based on stock price changes (to stay delta-neutral). When the stock price increases, the arbitrageur will short additional stock and when the stock price decreases, the arbitrageur will buy additional stock.

Following Choi et al. (2009), we define two relative measures to proxy for arbitrage activity.

[17] In Figure 8 in the Appendix, we present short-selling changes for 144A and public offerings separately. We observe no differences between 144a or public offerings. We also display the short volume relative to total volume in smaller time windows, see Figure 9.

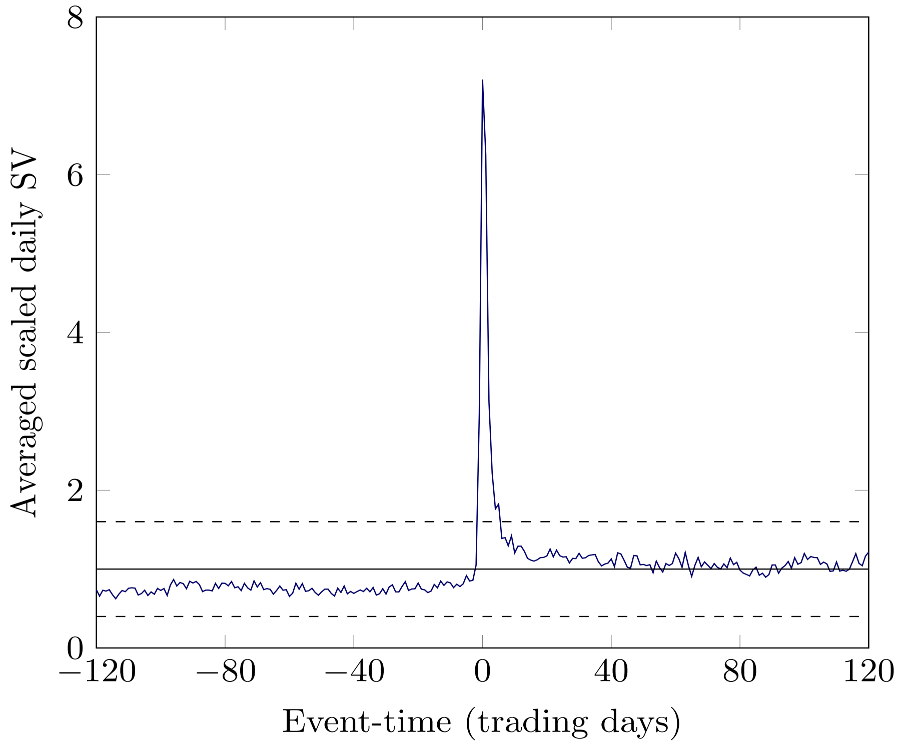

Figure (2) Average scaled daily short volume with day 0 as the issuance day. The short volumes for the underlying equity are divided by their mean for the same period (-120 and +120 days around issuance). The dashed lines give the one standard deviation band around the mean. The horizontal line (at 1) shows the mean of the average scaled daily trade volumes. The short volume relative to the total volume is a relative measure of the increase in short-selling. Number of observations = 335.

The first measure, $SV\_\%Shrout_{\mathrm{t}}$ is the short volume on day t, scaled by the total shares outstanding for day t. Second, $SV\_\%Issue_{\mathrm{t}}$ is the dollar value of the short volume during day t, divided by the issue size (face value of the convertible bond times the offer price). The first measure, $SV\_\%Shrout_{\mathrm{t}}$, provides a relative measure for the short volume as a percentage of the shares outstanding. The second measure, $SV\_\%Issue_{\mathrm{t}}$, provides a relative measure for the amount of short-selling activity relative to the issue size. The issue size is directly linked to the hedging activity as a larger issuance with a similar delta will need a larger amount of underlying equity to be shorted.

Figure 3 shows that both $SV\_\%Shrout_{\mathrm{t}}$ and $SV\_\%Issue_{\mathrm{t}}$ capture short-selling activity around the issuance. The mean $SV\_\%Shrout_{\mathrm{t}}$ and $SV\_\%Issue_{\mathrm{t}}$ at the issuance increases to 1.56% and 23.77%, respectively. For our main analysis, we use $SV\_\%Shrout_{\mathrm{t}}$ as a proxy for convertible bond arbitrage activity as this measure is directly linked to the underlying equity.

Moreover, we want to capture the change around the issuance compared to a normalised shorting volume of the underlying equity. Therefore, we obtain the average daily short volume scaled by the daily shares outstanding from the six months (120 trading days) ending one month (20 trading days) before the issuance. Subsequently, we obtain the average daily short volume scaled by the daily shares starting from two days before and ending two days after the issuance.[18] The difference between the two periods we refer to as $\Delta SV\_\%Shrout$ and is the change in short-selling activity around the issuance. For notional convenience, we denote the proxy for convertible bond arbitrage activity from now on as ΔSV_{Iss}.[19]

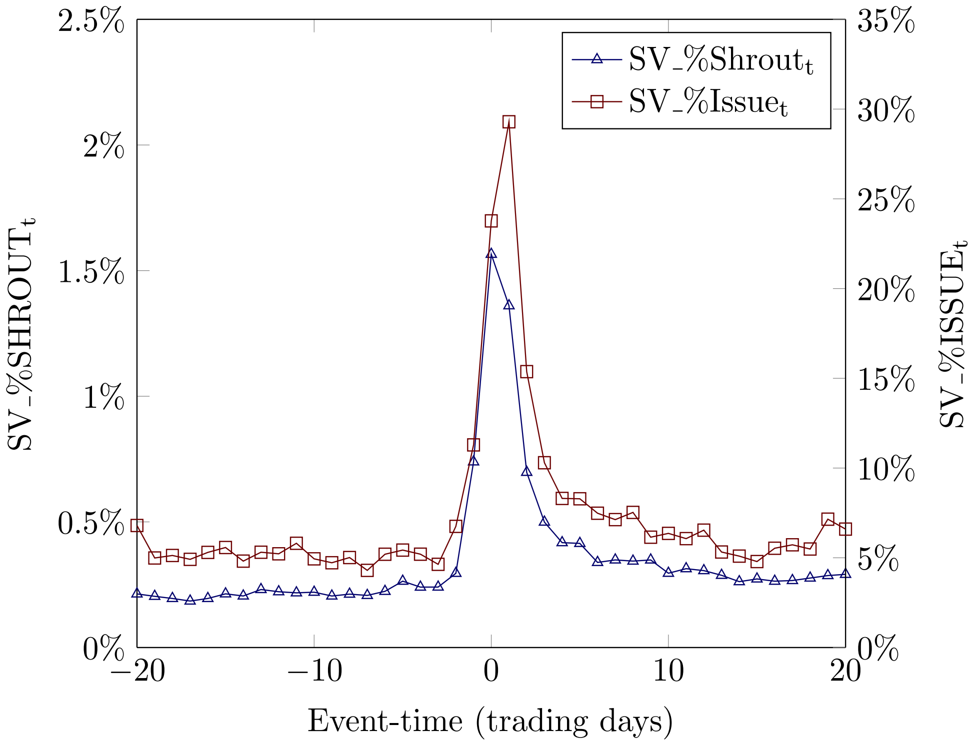

Figure (3) Mean change in short volume. This figure shows the mean change in short volume during the event window (trading days -20 to +20). $SV\_\%Shrout_{\mathrm{t}}$ is the change in short volume during day t divided by the number of shares outstanding on day $t-1$. $SV\_\%Issue_{\mathrm{t}}$ is the dollar value of the change in short volume during day t, divided by the Issue size (face value of the convertible bond times the offer price). Number of observations = 335.

3.3 Short-selling in the dynamic hedging period

We have mentioned that convertible arbitrageurs use the mispricing of the convertible bond and delta hedging to generate profits. However, an additional strategy that arbitrageurs would typically deploy is gamma scalping. A gamma scalper makes a profit if the realized volatility of the underlying equity is higher than that of the implied volatility of the option (in this case the implied volatility of the convertible bond's embedded option). A higher gamma profile is, therefore, more likely to have increased gamma scalping activity. Consequently, with increased gamma scalping activity, delta hedging will be higher as well (see Gamma Scalping for an

[18] Robustness checks show a difference in results for the periods $(-20,+20)$, $(-10,+10)$,$(-5,+5)$ or $(-2,+2)$ around the issuance. To capture the increase in the short volume surrounding the issuance, the window $(-2,+2)$ returns the best results. Short-selling activity post-issue decreases significantly after two trading days. This window is in line with Hackney et al. (2018). They conclude that short-selling to establish and adjust hedge positions around convertible bond offerings occurs predominately on the issue day and for two subsequent days before largely tapering off

[19] The mathematical expression of ΔSV is: $\Delta SV = \frac{\bar{SV}_{\text{-2,+2}}}{\bar{SV}_{\text{-120,-20}}} \times \frac{\bar{Shrout}_{\text{-120,-20}}}{\bar{Shrout}_{\text{-2,+2}}}$ with SV as the daily short volume and $Shrout$ as the daily shares outstanding.

educational example of gamma scalping). Specifically, for our analysis, we put a substantial focus on the gamma profile of convertible bonds. For that reason, we will put additional focus on the gamma profile of convertible bonds and expect the difference in shorting levels to be higher for convertible bonds with higher gamma's.[20]

At the outset, we construct four portfolio's sorted from the lowest gamma (Group 4) to the highest gamma (Group 1). We calculate gamma (Γ) on a daily frequency for the post-issue period (the 20 trading days to 120 trading days after the issuance). The mean gamma for group 4 and group 1 is 0.07 and 0.005 respectively. Figure 4 depicts an increase in short-selling in the post-issuance period. We observe a greater change in short-selling in group 1 convertible bonds. From Figure 4a, we can observe that higher gamma bonds have a larger change in short-selling around the issuance. For the post-issue period, We cannot distinguish whether there is a greater change in short-selling for higher/lower gamma convertible bonds. Therefore, we measure the change in short volume relative to the shares outstanding for the pre-issue and post-issue period (ΔSV). For Figure 4b, the mean ΔSV for high gamma and low gamma convertible bonds are 1.38x and 1.16x, respectively (the mean short over shares level is 1.38 times as high in comparison to pre-issue levels). Findings show that high gamma convertible bonds have a greater change in short-selling compared to low gamma convertible bonds. In the results section, we replicate the quartile approach but instead segregate our sample in four quartiles based on ΔSV_{Iss}. Based on the quartile approach, we can distinguish for which type of issue or issuing firms convertible arbitrageurs are most evident (at issuance).

3.4 Issuing firms and issue characteristics

Based on the literature, we identify several firm-specific and deal-specific characteristics that may affect arbitrage short-selling. For our initial analysis of the changes in short-selling near the issuance, we include the following deal-specific variables; *144A*, *Maturity*, *Discount*, *Delta*, *Delta-neutral*, *Gamma*, *Conversion ratio*, *Conversion premium*, and *Issue size*. According to Choi et al. (2009), arbitrageurs may prefer stocks with lower conversion premiums because they imply lower credit risk and interest rates. Hackney et al. (2018) discuss that liquidity may be lower for private deals, so we include the indicator *144A*. *Delta-neutral* controls for the number of shares that arbitrageurs need to short to obtain a delta neutral-hedge.[21] We include

[20]In addition to the gamma scalping strategy, gamma is important in regards to delta hedging. Gamma (Γ) is the sensitivity of Delta concerning the underlying stock price. If Gamma is small, then Delta changes are less sensitive to stock price changes. Fewer changes in Delta means the portfolio requires less frequent adjustments in the hedge-ratio. Consequently, a lower hedge-ratio implies that we should observe a lower short volume since there has to be shorted less to maintain a delta neutral position. See Option Greeks: Delta and Gamma in the Appendix for a detailed explanation.

[21]The Delta-neutral short position is the total number of shares that buyers of the convertible bond have to short to obtain a delta-neutral position. The delta neutral short position is then scaled by the number of shares outstanding. The delta-neutral short position is calculated as follows:

the variable *Gamma* because of it's relation with Delta and to measure the attractiveness for post-issue gamma scalping (see subsection 3.3 above). We include the offering discount (see Offering discount), since a higher discount may attract more short-selling (Hackney et al., 2018). Variables such as *Delta*, *Conversion ratio* and *Maturity*, may either indirectly (associated with a higher or lower offering discount) or directly affect short-selling.

Next to deal-specific variables, we include the following firm-specific variables; *NYSE*, *NASDAQ*, and *Market cap*. Hirshleifer, Teoh, and Yu (2011) argue that short arbitrage constraints vary by exchange, so we include an indicator for firms listed on the NASDAQ or *NYSE*. Besides, we include firm size (*log Market cap*) as short-selling can be more constrained for small stocks (D'Avolio, 2002). Choi et al. (2009) and D'Avolio (2002) argue that short-selling is more constrained for illiquid stocks with low price levels. We, therefore, include the variables *Turnover*, Dollar volume and *Amihud* to proxy for liquidity. Furthermore, we include variable *Volatility*, since Choi et al. (2009) observe higher convertible bond arbitrage activity in stocks with a standard deviation of returns.

Finally, we include three short-selling measures for the underlying equity; *short volume/shares outstanding*, *short volume/total volume* and *short volume/shares outstanding st.dev.* Hackney et al. (2018) show that arbitrage short-selling is higher in stock with higher short-selling levels before the issuance.

Besides, we also control for multicollinearity between the variables. Multicollinearity occurs when there are high correlations among the explanatory variables, which may lead to unstable and unreliable estimates of the regression coefficients. We include a correlation matrix (see Table 11 in the Appendix) to test for multicollinearity between our variables. We observe a number of variables with high correlations (e.g., *LogProceeds* and *LogMktcap* correlate 0.767). Such high correlations may indicate the presence of multicollinearity. To test for multicollinearity, we calculated the variance inflation factor (VIF) for some of the relevant regression models. Results show that none of the independent variables exceeded the threshold of 10 (see Table 10 in the Appendix). A number of independent variables are close to the threshold, for instance *LogMktcap*. The stepwise deletion of each independent variable did, however, not result in an improvement of explained variance or overall model fit. Therefore, and partly due to their conceptual relevance to our research, we do not remove any of our initial set of independent variables.

Finally, although we primarily aim attention to changes in short-selling, we include com-

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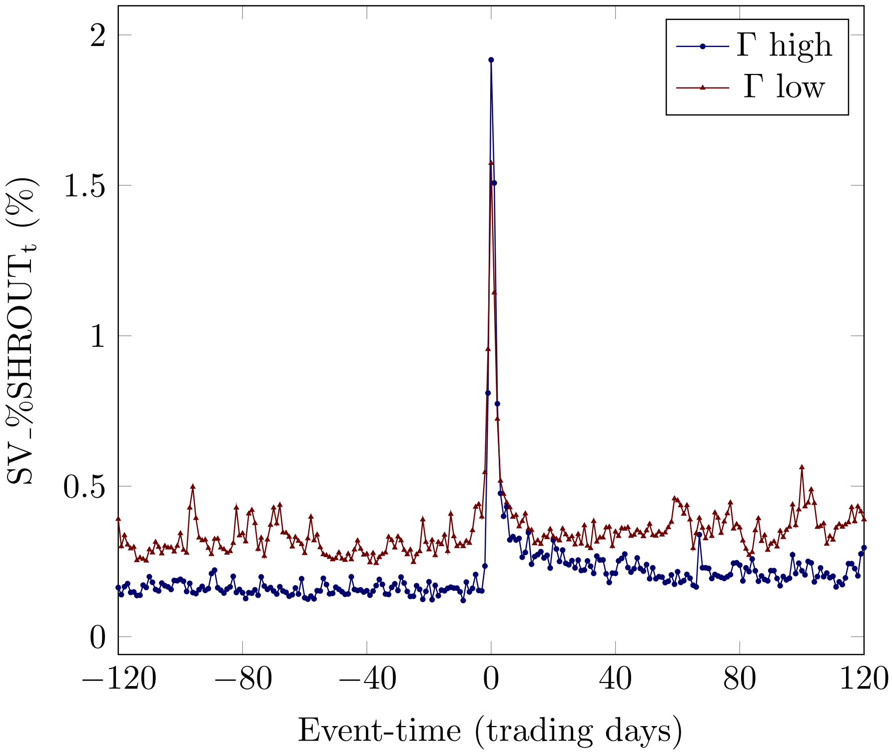
$$\text{Delta-neutral short position} = \frac{\text{face value of entire issue}}{\text{conversion price}} \times \text{Delta}$$

plimentary tests in regards to the offering discount and price efficiency. With our novel daily short volume dataset, we are interested if we can observe any differences compared to previous studies.

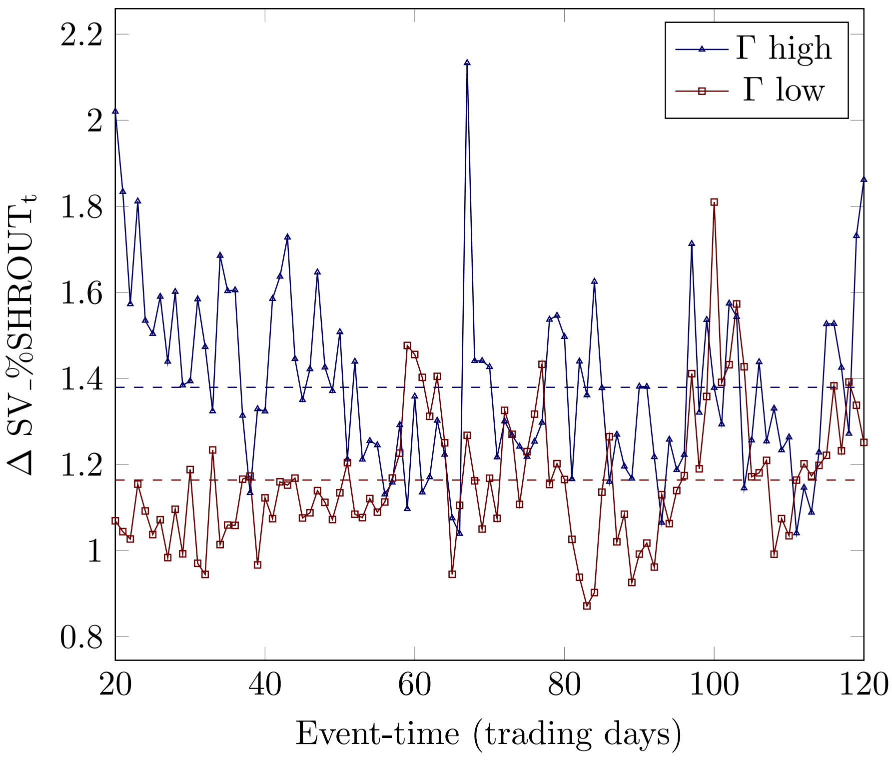
Table 1 provides summary statistics for selected issuing firm and deal characteristics. We examine the median and mean for several characteristics, such as the market capitalization, daily dollar volume, and change in short volume. We observe a considerable difference between the median and the mean. This divergence comes from several large firms in our data sample. We observe that deal-specific characteristics such as maturity, discount, issue size and volatility do not have large discrepancies. Finally, we observe that the short measures have deviating means and medians. We make a distinction between those convertible bonds with a greater or lesser change in short-selling so that we can observe the determinants of these deviations.

Table (1)
Summary statistics of firm and issue characteristics
This table presents summary statistics for the sample of convertible bond issues between January 2011 and December 2018. *Market cap* is the issuing firm's equity market capitalization, based on the daily shares outstanding and the average of the closing stock price for day_t and day_{t-1}. *NYSE* and *NASDAQ* are dummy variables indicating the exchange the issuing firm is listed. *Daily dollar volume* is the average daily dollar stock volume. *Issue size* is the total offering size of the convertible bond at issuance. *Short volume/shares outstanding* is the average daily short volume (in per cent) divided by the daily shares outstanding before the issuance. ΔSV_{Iss} is the change in short-selling activity compared to average short-selling pre-issue (measured by short volume/shares outstanding). The average change is 7.02 times. *Short volume over total volume* is the average daily short volume relative to the total volume (based on the FINRA data, the total volume represents all trades, short and long). *Maturity* is the time-to-maturity of the convertible bond at issuance. *Discount* is the amount (in percent) by which the offering price differs from the theoretical price (see [Offering discount]Offering discount). *Volatility* is the annualized volatility of the underlying stock for the period $(-240, -40)$. All daily measures are calculated using data from calculated using daily data from the six months (120 trading days) ending one month (20 trading days) before the issuance.
Number of observations = 335.

	Mean	Median	Standard deviation
Market cap (mln)	3,224	1,372	6,155
NYSE	0.33	0.00	0.47
NASDAQ	0.66	1.00	0.47
Daily dollar volume (mln)	53.58	15.61	156.76
Issue size (mln)	299.52	225.00	270.35
Issue size/market cap (%)	17.62	15.84	10.25
Short volume/shares outstanding (%)	0.21	0.14	0.22
ΔSV_{Iss}	7.02	4.68	6.85
Short volume/total volume (%)	43.03	42.84	7.63
Maturity	6.15	5.04	3.52
Discount (%)	11.96	12.18	16.75
Volatility (%)	52.79	46.83	50.55



(a) short-selling levels for low and high gamma convertible bonds



(b) short-selling change in the post-issue period for low and high gamma convertible bonds

Figure (4) Change in short-selling for the post-issue period for low and high gamma (Γ) sorted portfolio's. For a, the SV_%SHROUT$_t$ is the daily short volume relative to the daily shares outstanding. For b, Δ SV_%SHROUT$_t$ is the relative change between the daily short volume relative to the daily shares outstanding for the post-issue period and the average for the pre-issue period. The pre-issue is the period from the six months (120 trading days) ending one month (20 trading days) before the issuance. Γ high is the portfolio with the highest average daily Γ for the post-issue period. Γ low is the portfolio of the lowest average daily Γ for the post-issue period. The post-issue period from one month (20 trading days) after the issuance to six months (120 trading days) after the issuance. Number of observations: 335.

4 Results

In this section, we examine links between changes in short-selling near the issuance and dynamic hedging period for issuing firm characteristics and deal characteristics.

4.1 Univariate Analysis

We start our analysis by comparing convertible bond issues with a different change in short-selling. As illustrated in Table 1, there are between-level discrepancies in the amount of short-selling within our (aggregated) sample. Furthermore, the positions taken by the arbitrageurs at issuance act as a proxy for their presence in the post-issue market for the underlying equity. Therefore, for convertible bonds with low convertible bond arbitrage (low ΔSV_{Iss}) at issuance, lower arbitrage activity in the delta hedging period is expected (and vice versa).

Table 2 provides summary statistics of all firm and issue characteristics before issuance.[22] Quartile 4 and 1 correspond to the smallest and most substantial change in short volume around the issuance, respectively. A number of observations can be made. First, smaller firms and smaller issues seem to experience higher ΔSV. Second, issues with a higher delta and gamma, calculated for the day of issuance, see the largest ΔSV. Third, as expected, the delta-neutral short position (*DeltaNeutral*) is larger for a higher ΔSV_{Iss}. Finally, stocks that have lower pre-issue short-selling experience higher convertible bond arbitrage. Panel B of Table 2 reports the average gamma and delta in the post-issue period. Thus, our results indicate that convertible bonds remain to have a similar gamma or delta profile as they initially had at issuance.

We conduct a similar univariate analysis as in Table 2 but focus on pre-issue and post-issue short-selling levels. Table 3 presents the short-selling statistics for the pre and post-issue period. Panel A of Table 2 reports short-selling measures pre-issuance. Both short volume relative to shares outstanding and short volume relative to total volume indicate that stocks with the highest ΔSV_{Iss} have a significantly lower number of short-selling before the issuance. The short volume relative to shares outstanding st.dev shows that the standard deviation of short-selling before the issuance is significantly higher (thus more volatile) for high ΔSV_{Iss} issues. Panel B shows that post-issue short-selling measures remain similar to the pre-issue period. However, we can observe that the relative number of short-selling to total trades (SV/TV_{post}) has now increased significantly for the higher ΔSV_{Iss} quartile.

In Panel C, we find strong evidence of an increase in short-selling based on both ΔSV and SV/TV_{post}. The mean ΔSV and SV/TV_{post} for the largest ΔSV_{Iss} quartile is 0.175% and 7.116% higher than that for the smallest ΔSV_{Iss} quartile, respectively. Additionally, the

[22] All measures are calculated using daily data from the six months (120 trading days) ending one month (20 trading days) before the issuance.

Table (2)
Univariate analysis of firm and issue characteristics sorted by ΔSV_{Iss} quartile sorts. ΔSV_{Iss} proxies for convertible bond arbitrage activity. In Panel A, *NYSE* and *NASDAQ* are dummy variables indicating the exchange the issuing firm is listed. *144A* is a dummy if the convertible bond is a rule 144A offering (1 if 144A, and 0 if public). *Market cap* is the equity market capitalization, based on the daily shares outstanding and the average of the closing stock price for day_t and day_{t-1}. *Conversion ratio* is the number of shares of common stock one convertible bond can be converted for. *Conversion premium* is the amount by which the conversion price exceeds the stock price of the common stock at issuance. *Discount* is the amount (in percent) by which the offering price differs from the theoretical price (see Offering discount). *Delta* is the delta of the embedded option of the convertible bond at issuance. *Gamma* is the gamma of the embedded option of the convertible bond at issuance. *Delta-neutral/shares outstanding* is the number of common shares (in '000s) that buyers of the convertible issue have to short to obtain a delta-neutral position relative to the shares outstanding (see Delta-neutral short position). *Maturity* is the time-to-maturity of the convertible bond at issuance. *Issue size* is the total offering size of the convertible bond at issuance. *Turnover* is the average daily volume divided by the daily shares outstanding. *Amihud* is the average ratio of absolute daily return to dollar volume (Amihud, 2002).
In Panel B, $Gamma_{post}$ and $Delta_{post}$ are the average daily gamma and delta calculated for the post-issuance period (+20 to +120 trading days), respectively. The daily gamma and delta are calculated with volatility for day_t as the annualized volatility for the period day_{t-240} to day_{t-40} and stock price for day_t with the average stock price for the period day_{t-12} to day_{t-2}. All measures in Panels B are calculated using daily data from the six months (120 trading days) ending one month (20 trading days) before the issuance. The last two columns show the mean measures of quartile 4 (the smallest ΔSV_{Iss}) minus quartile 1 (the largest ΔSV_{Iss}) and the corresponding *t*-statistics. *, ** and *** denote 10%, 5% and 1% significance, respectively. The sample period is from January 2011 to December 2018.
Number of observations = 335.

	Quartiles based on ΔSV_{Iss}						
	All	Q4	Q3	Q2	Q1	(Q1 - Q4)	t-stat
		(Smallest)			(Largest)		
Panel A: Firm and Issue characteristics							
NYSE	0.331	0.345	0.321	0.310	0.349	0.004	(0.056)
NASDAQ	0.657	0.631	0.679	0.679	0.639	0.008	(0.101)
144A	0.663	0.643	0.714	0.631	0.663	0.020	(0.267)
log Market cap	9.180	9.376	9.289	9.123	8.930	-0.446*	(-1.954)
Conversion Ratio	6.478	6.434	4.732	6.301	8.467	2.033	(1.257)
Conversion premium (%)	30.592	30.953	35.673	28.430	27.274	-3.680*	(-1.636)
Discount (%)	11.961	11.650	9.665	12.689	13.861	2.211	(0.764)
Delta	0.673	0.700	0.651	0.675	0.667	-0.034*	(-1.661)
Gamma	0.022	0.019	0.019	0.023	0.028	0.009**	(2.255)
DeltaNeutral	0.094	0.076	0.074	0.102	0.125	0.049***	4.192
Issue size	299.52	355.39	310.36	287.02	244.69	-110.70**	(-2.376)
Maturity	6.150	6.621	5.664	6.406	5.906	-0.715	(0.993)
log Turnover	-1.956	-1.791	-1.867	-2.003	-2.167	-0.377***	(-8.477)
log Amihud	-8.900	-9.199	-9.104	-8.835	-8.458	0.741***	(6.426)
Panel B: Post-issue characteristics							
$Gamma_{post}$	0.028	0.023	0.021	0.030	0.037	0.015**	(2.395)
$Delta_{post}$	0.648	0.677	0.642	0.650	0.623	-0.053***	(-2.733)
log Turnover	-1.865	-1.828	-1.796	-1.879	-1.957	-0.128***	(-3.004)
log Amihud	-9.016	-9.250	-9.194	-8.969	-8.645	0.605***	(5.136)

standard deviation of the short volume/shares outstanding between the largest ΔSV_{Iss} and smallest ΔSV_{Iss} is 0.168 higher, indicating that short sell levels got more volatile in comparison to the pre-issue period. Interestingly, we observe a negative ΔSV for the smallest quartile, which indicates that short-selling has decreased. However, when we examine the change in short-selling for the smallest quartile, we only observe a slight increase around the issuance,

Table (3)
Univariate analysis of short-selling measure sorted by ΔSV_{Iss} quartile sorts. Quartiles are based on ΔSV_{Iss}, which is the change in average short volume scaled by the shares outstanding (ΔSV) for the period around the issuance (-2 to +2 trading days around the issue) compared to short volume for the period before the issuance (-120 to -20 trading days). ΔSV_{Iss} proxies for convertible bond arbitrage activity.
In Panel A, SV_{pre} is the average daily short volume (in percent) divided by the daily shares outstanding before the issuance. SV/TV_{pre} is the average daily short volume relative to the total volume (based on the FINRA data, total volume represents all trades, short and long). SV_{pre} vola is the standard deviation of the average short volume over the daily shares outstanding. In Panel B, the measures for Panel A are replicated, but for the post-issue period. In Panel C, the difference between the pre and post-issue characteristics are shown. All measures in Panels A and B are calculated using daily data from one month (20 trading days) ending six months (120 trading days) before or after the issuance. The last two columns show the mean measures of quartile 4 (the smallest ΔSV_{Iss}) minus quartile 1 (the largest ΔSV_{Iss}) and the corresponding *t*-statistics. *, ** and *** denote 10%, 5% and 1% significance, respectively. The sample period is from January 2011 to December 2018.
Number of observations = 335.

	Quartiles based on ΔSV_{Iss}						
	All	Q4	Q3	Q2	Q1	(Q1 - Q4)	t-stat
		(Smallest)			(Largest)		
Panel A: Pre-issue short-selling							
SV_{pre}	0.207	0.352	0.233	0.151	0.090	-0.262***	(-6.896)
SV/TV_{pre}	43.030	44.372	44.849	42.963	39.899	-4.473***	(-3.986)
SV_{pre} vola	0.986	0.948	0.930	0.982	1.083	0.136*	(1.810)
Panel B: Post-issue short-selling							
SV_{post}	0.266	0.297	0.313	0.242	0.210	-0.087***	(-2.618)
SV/TV_{post}	47.383	45.184	48.547	47.979	47.827	2.643**	(2.468)
SV_{post} vola	0.974	0.853	0.912	0.978	1.157	0.304***	(4.995)
Panel C: difference pre-and post-issue short-selling							
ΔSV	0.059***	-0.055***	0.081***	0.091***	0.120***	0.175***	
	(6.181)	(-2.754)	(3.791)	(8.582)	(6.955)	(6.580)	
$\Delta SV/TV$	4.353***	0.812	3.697***	5.016***	7.928***	7.116***	
	(11.407)	(1.103)	(5.231)	(8.275)	(9.994)	(6.633)	
ΔSV vola	-0.011	-0.095	-0.018	-0.004	0.073	0.168*	
	(-0.398)	(-1.386)	(-0.398)	(-0.083)	(1.278)	(1.881)	

which suggest hardly any convertible arbitrage activity.[23] We therefore expect this finding to be likely driven by a factor other than arbitrage activity. Consistent with our prediction (for H_{0_2}), short-selling increases systematically in the post-issuance period with ΔSV_{Iss} as a proxy for arbitrage activity.

Overall, the univariate analysis allows for a number of compelling initial observations. Contrary to our predictions, we observe that smaller issues and smaller firms experience greater arbitrage activity, This may indicate that the cost of short-selling is not a relevant factor of convertible bond arbitrage. We also find delta to be lower for higher ΔSV_{Iss}. Interestingly, even though *deltaneutral* is positively related, *delta*, which is the driving factor for *deltaneutral*, is negatively related to short-selling. A possible explanation could be that convertible bonds with higher delta's tend to be smaller issues. Subsequently, for smaller issues less shares

[23]The mean ΔSV_{Iss} for quartile 1 and 4 is 1.29% and 0.61%, respectively. For quartile 1, the ΔSV_{Iss} increases by 15.83 times compared to the pre-issue period short-selling levels, while the ΔSV_{Iss} only increases by 1.77x times for quartile 4.

need to be shorted. The results also indicate that higher gamma convertibles experience greater short-selling. This finding could be explained by the higher gamma providing attractive gamma scalping opportunities, therefore increasing arbitrage-activity. Looking at the post-issue characteristics, the relation between short-selling and the respective variable initially observed at issuance, does not seem to change. Finally, the univariate analysis does not allow to take confounding factors into account. Hence, in the next section we perform a multivariate analyse to examine the cross-sectional relation between short-selling an convertible bond characteristics.

4.2 Multivariate analysis

To control for factors other than ΔSV_{Iss} we examine the cross-sectional relation between the change in short-selling and convertible bond characteristics using several regression specifications. The regressions include year and industry fixed effects. Results are reported in Table 4, where several findings stand out.

First, consider, the coefficients on the firm-specific variables. Short-selling seems to be higher for firms that are less liquid (based on the *Amihud* and *LogTurnover* measures). This finding differs from the notion that the cost of short-selling, proxied by the liquidity of the stock, plays a negative role for arbitrage activity Hirshleifer et al., 2011;Choi et al., 2009;Jong et al., 2011). However, in previous studies, such as that Choi et al. (2009), this counter-intuitive finding has also been found. A possible explanation for this, is that issuing firms that experience large arbitrage activity tends to be smaller, therefore making the direct comparison of the level of liquidity inappropriate.

Multiple deal-specific characteristics appear to be significant, for instance, deal maturity. Furthermore, the delta of the embedded option is positively related to short-selling. Consequently, the number of shares that need to be shorted to obtain a delta-neutral position (*DeltaNeutral*), is also positively related to higher short-selling. Convertible arbitrage is also higher when the gamma profile of the convertible bond is lower. This notion accords the general relationship between a high call delta is being associated with lower gamma's.

Issue discounts are negatively and significantly related to short-selling. This finding is in contrast with Hackney et al. (2018). They argue that short-selling serves to hedge out the directional risk of the convertible arbitrage and is caused by factors related to the delta-neutral hedge rather than the magnitude of the offering discount. However, Brown, Grundy, Lewis, and Verwijmeren (2012) find that offering discounts are smaller, although insignificantly, when the majority of the issue is sold to hedge fund investors. The issue discount result is also surprising because this measure showed a significant positive change based on portfolio sorts. Besides, the issue discount has a positive coefficient without including issue-specific characteristics. It is difficult to explain this result, but it might be, for instance, that short-selling is primarily driven by other factors such as *gamma* or *deltaneutral*, and that the issue-discount is an irrelevant factor for short-selling activity.[24] Alternatively, offering discount and issue-specific characteristics are confounded, causing a change in sign.[25]

Finally, we consider the R-squared for the different regression specifications, as a measure of explained variance. Such a statistic is considerably higher when we include both firm-specific and issue-specific characteristics. There is a significant increase in the explanatory power when we control for fixed effects (columns (5) and (6) include Year and Industry fixed effects).

4.2.1 Short-selling post-issuance

Table 3 shows a significant increase in short-selling in the post-issue period when controlling for ΔSV_{Iss} (as a proxy of arbitrage activity), a notion confirmed by Table 5, where other control factors are also included.

Returning to our expectation of a positive role for ΔSV_{Iss} and gamma in short-selling changes, we can now use the findings to discuss our expectation.

Control variables include a change in equity market capitalization and stock return volatility. We anticipate that higher volatility in the post-issue period can increase the frequency an arbitrageur would have to hedge, resulting in higher short volumes. We also control for the exchange, whether the underlying equity is listed and if the issue is private (144A) or public. Additional control variables are the issue discount and embedded option value at issuance. Controlling for the issue discount, we can observe if convertible bonds with greater issue discount experience higher arbitrage activity in the post-issue period.

When controlling for the average gamma in the post-issue period, we find that a higher gamma profile indicates that there might be significant changes in the delta. So arbitrageurs often buy and sell short more frequent to monetize these movements in delta (Brown et al., 2012). Lastly, we include month, year and industry dummies based on the Fama and French 12 industry classification.

A higher embedded option value may illustrate an issue's equity-like behaviour, as the higher value of the option is related to a higher probability of exercise. Higher embedded option value (at issuance) directly relates to the option being deep(er) in the money. Arbitrageurs could be more likely to hold these, as these convertible bonds can act as cheap put options. However, it could be that since this paper is so in the money, the gamma profile is much lower. So

[24] We compare the predictive power with and without the *issue discount* variable, and find a neglectable improvement. This indicates that the variable may not be that important to the overall model, thus not being a driving factor for short-selling activity.

[25] From the correlation matrix in the appendix, we can observe a high correlation between issue discount and delta and deltaneutral, see Table 11.

Table (4) This table presents the results of six OLS regressions. The dependent variable, ΔSV_{Iss} is the change in average short volume scaled by the shares outstanding for the period around the issuance (-2 to +2 trading days around the issue) compared to short volume for the period before the issuance (-120 to -20 trading days). ΔSV_{Iss} proxies for convertible bond arbitrage activity. The independent variables are listed in the Appendix at . *Industry* dummies are based on the Fama and French 12 industry classification (Fama & French, 1997). Heteroskedasticity-consistent t-statistics are in the parentheses. *, ** and *** denote 10%, 5% and 1% significance, respectively. The sample period is from January 2011 to December 2018. Number of observations = 335.

	Dependent Variable: ΔSV_{Iss}					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	26.899***	-2.149	25.735**	-4.447	-9.982	-7.938
	(2.660)	(-0.110)	(2.460)	(-0.230)	(-0.510)	(-0.400)
Firm-Specific						
SV_{pre}	-25.586	181.015	-34.717	214.135	382.285	430.381
	(-0.070)	(0.550)	(-0.100)	(0.650)	(1.120)	(1.270)
LogMktcap	-4.473***	-2.105	4.337***	-2.052	-1.602	-1.677
	(-5.380)	(1.130)	(-4.880)	(-1.100)	(-0.870)	(-0.910)
Volatility	-6.284	-14.750	-9.812	-12.165	-19.758	-25.100
	(-0.270)	(-0.510)	(-0.400)	(-0.420)	(-0.680)	(-0.870)
Amihud	-21.240*	-29.580**	-21.444*	-27.208**	-25.742**	-21.600*
	(-1.690)	(-2.410)	(-1.700)	(-2.221)	(-2.090)	(-1.770)
LogTurnover	-10.777***	-12.871***	-10.629***	-13.107***	-14.263***	-14.031***
	(-4.82)	(-5.97)	(-4.79)	(-6.09)	(-6.49)	(-6.37)
DollarVolume	0.006***	0.007*	0.007**	0.005	0.005	0.004
	(2.110)	(1.800)	(2.140)	(1.490)	(1.230)	(1.110)
NYSE	0.945	1.030	0.903	1.206	1.072	1.201
	(1.360)	(1.520)	(1.290)	(1.770)	(1.560)	(1.550)
Issue-specific						
DeltaNeutral		22.801***		29.744***	33.256***	33.579***
		(0.680)		(3.200)	(3.560)	(3.590)
Delta		0.533		4.731	6.758	10.378*
		(0.110)		(0.870)	(1.240)	(1.880)
Issue Discount			1.047	-6.303*	-8.314**	-10.899***
			(0.430)	(-1.790)	(-2.340)	(-2.980)
Maturity		0.014		-0.101	-0.152	-0.227*
		(0.130)		(-0.800)	(-1.180)	(-1.750)
ConvPrem		0.393		0.211	0.537	0.404
		(0.350)		(0.190)	(0.480)	(0.360)
Gamma		-44.554***		-39.406***	-35.337**	-28.762**
		(0.002)		(-2.730)	(-2.480)	(-1.970)
OptionValue		-0.036		-0.036	-0.035	-0.332
		(0.293)		(-1.600)	(-1.040)	(-0.990)
LogProceeds		0.001		0.001	0.001	0.000
		(0.500)		(0.250)	(0.250)	(0.060)
RelOfrSize		9.326		6.260	60.552	3.950
		(13.600)		(0.890)	(0.860)	(0.560)
144A		-0.635		-0.884	-0.866	-0.898
		(-0.940)		(-1.290)	(-1.110)	(-1.280)
Observations	335	335	335	335	335	335
R^2	0.287	0.377	0.270	0.383	0.416	0.453
Year Dummies	No	No	No	No	Yes	Yes
Industry Dummies	No	No	No	No	No	Yes height

arbitrageurs will not adjust their deltas as much (therefore lower delta hedging in the post-issue period). The arbitrageur might just buy the convertible bond, sell short the delta-neutral amount of the underlying equity and does not re-balance (hedging) his position until the stock makes a significant jump, for instance, fuelled by an event.

Table 5 provides an overview of the main results. Based on such results, several observations can be made. The measure ΔSV_{Iss} is positively and significantly related to the change in short-selling for the post-issue period. This reconfirms our earlier (significant) finding based on quartile sorts. Besides, this finding supports our second hypothesis, that increased short-selling in the dynamic hedging period is driven by arbitrage activity. With ΔSV_{Iss}, our proxy for arbitrage activity, we can argue that increased short-selling is indeed driven by arbitrage-induced short-selling.

The change in volatility and equity market capitalization (which captures a price change), are also both positively related increased short-selling. An arbitrageur's dynamic hedging strategy can be inherently profitable and hedging a more volatile stock provides more opportunities to trade profitably (Brown et al., 2012). This understanding is in line with our result for the change in volatility, for which short-selling is higher. Since the equity market capitalization is positively related to short-selling, we can make an assumption about the informativeness of the short-selling. If short-selling were to be performed by informed short-sellers, a negative relation between the equity market capitalization (which captures a price change) and short-selling

Table (5)
This table presents the results of three OLS regressions. The dependent variable, ΔSV, is the change in average short volume scaled by the shares outstanding between the period before the issuance (-120 to -20 trading days) and after the issuance (+20 to +120 trading days). The independent variables are defined in the Appendix, see Explanatory variables. *Industry* dummies are based on the Fama and French 12 industry classification. Heteroskedasticity-consistent t-statistics are in the parentheses. *, ** and *** denote 10%, 5% and 1% significance, respectively. The sample period is from January 2011 to December 2018.
Number of observations = 335.

Dependent Variable: ΔSV			
Constant	0.048	0.048	0.038
	(1.580)	(1.220)	(0.440)
Firm-Specific			
ΔSV_{Iss}	0.006***	0.006***	0.006***
	(4.110)	(4.410)	(4.210)
ΔVolatility	1.022***	0.788**	0.728**
	(2.800)	(2.150)	(1.930)
ΔMarket Cap	0.072***	0.089***	0.089***
	(1.010)	(1.220)	(1.190)
NYSE	-0.009	0.001	0.013
	(-0.450)	(0.040)	(0.550)
Issue-Specific			
RelOfrSize	0.033	0.057	0.066
	(0.320)	(0.540)	(0.600)
Issue Discount	0.076	0.063	0.062
	(1.230)	(1.020)	(0.950)
Option Value	-0.003***	-0.003***	-0.002***
	(-3.740)	(-3.550)	(-3.400)
Gamma	-0.578**	-0.599**	-0.524*
	(-2.030)	(-2.130)	(-1.780)
144A	0.005	-0.009	-0.012
	(0.2400)	(-0.450)	(-0.580)
Year Dummies	No	Yes	Yes
Industry Dummies	No	No	Yes
R^2	0.147	0.196	0.206
Observations	335	335	335

should be observed. Our finding contradicts this, which may indicate that short-selling in the dynamic hedging period is mostly related to uninformed short-selling.

Besides, we find evidence that gamma is negatively related to the change in short-selling. A general assumption of convertible bond arbitrage is that after an arbitrageur obtains the convertible bond at issuance, the arbitrageur holds it throughout the post-issue period. Consequently, while holding the high gamma convertible bond, the arbitrageur would have to delta-hedge more often. However, in practice, it could be that the arbitrageur is active in the convertible bond during the post-issue period but simply does not hold it at all times. Typically, higher gamma convertible bonds imply a shorter time to maturity and/or are at the money. Arbitrageurs could trade them near term events to benefit from the convexity of the embedded option. If this would be the case for the majority of the convertible bonds, convertible bonds might not be held for subsequent periods. This might explain the negative relationship between gamma and higher short-selling for the post-issue period.

For option value, as we have pointed out before, the arbitrageur might buy the convertible bond, sell short the delta-neutral number of the underlying equity and does not re-balance (hedging) his position until the stock makes a large jump. Therefore, less delta-hedging activity could be observed.[26] Our results provide evidence that certain deal-characteristics, most-notably gamma, are related to short-selling in the dynamic hedging period. We also conclude that the initial change in short-selling near the issuance is directly positively related to short-selling levels in the post-issue period. Lastly, based on the change in equity market capitalization, short-selling is more likely to be a result of uninformed short-selling.

4.3 Additional Tests

This section examines the determinants of the offering discount and the relationship between specific firm and issue characteristics on stock returns.

4.3.1 Issue Discount

In line with previous studies (e.g. Chan and Chen (2007), Loncarski et al. (2008), and Jong et al. (2011)), we observed that convertible bond offerings are underpriced at issuance. In subsection 4.2, we already examined the relationship between short-selling and offering discounts. As we are also interested in which convertible bond determinants affect the offering discount, we test for firm-specific and issue-specific characteristics on offering discount. Table 6 reports the results of the regressions. Results show that firm-specific characteristics are not related to

[26] In Table 2, we observed the significant positive relationship between the theoretical delta-neutral short position and increased in short-selling around the issuance.

the issue discount. Only firms that are listed on the NYSE have a significant higher offering discount. Additionally, the amount of short-selling before the issue (SV_{pre}) is significant and negatively related when not controlling for fixed effects. A potential reason that most firm-specific characteristics are not significant is that short-selling takes place in the market of the underlying equity, while offering discount are established in the convertible bond market. Arbitrageurs are therefore not able to gain from covering their short positions at a discounted price in the convertible bond market. Lastly, we measure the presence of convertible bond arbitrageur on offering discount with the SV_{Iss}. Surprisingly, results indicate that a higher presence of arbitrageurs has a adverse effect on the offering discount. We established the negative relation between offering discount and arbitrage-activity already in Table 4.

Table (6) This table presents the results of three OLS regressions. The dependent variable, Issue Discount, is the amount (in percent) by which the offering price differs from the theoretical price (see Offering discount). The independent variables are defined in the Appendix, see Explanatory variables. *Industry* dummies are based on the Fama and French 12 industry classification. Heteroskedasticity-consistent t-statistics are in the parentheses. *, ** and *** denote 10%, 5% and 1% significance, respectively. The sample period is from January 2011 to December 2018.
Number of observations = 335

	Dependent Variable: Issue Discount		
	(1)	(2)	(3)
Constant	-0.193	-0.195	-0.231
	(-0.880)	(0.890)	(-1.070)
Firm-specific			
SV_{Iss}	-0.001	-0.001	-0.002*
	(-0.590)	(-0.930)	(-1.730)
SV_{Pre}	-7.288	-6.082	-4.566
	(-1.630)	(-1.320)	(-1.010)
LogMktcap	-0.011	-0.002	0.021
	(-0.270)	(-0.060)	(0.500)
Volatility	-0.446	-0.660	-0.680
	(-0.940)	(-1.360)	(-1.450)
Amihud	0.196	0.184	0.197
	(0.930)	(0.870)	(0.960)
Dollarvolume	-0.011	-0.021	-0.036
	(-0.300)	(-0.570)	(-0.970)
NYSE	0.033***	0.032***	0.041***
	(2.810)	(2.720)	(3.110)
Issue-specific			
RelOfrSize	-0.046	-0.024	-0.054
	(-0.56)	(-0.280)	(-0.650)
Delta	1.029***	1.045***	1.058***
	(14.890)	(15.060)	(15.470)
Gamma	0.874***	0.835***	0.889***
	(3.600)	(3.3450)	(3.650)
Maturity	-0.022***	-0.022***	-0.021***
	(-11.960)	(-11.820)	(-11.330)
ConvPrem	-0.063***	-0.058***	-0.055***
	(-3.230)	(-3.010)	(-2.920)
144A	-0.337***	-0.034***	-0.029**
	(-3.100)	(-2.860)	(-2.370)
Observations	335	335	335
R^2	0.670	0.683	0.712
Year Dummies	No	Yes	Yes
Industry Dummies	No	No	Yes

The offering discount is significantly related to all issue-specific characteristics. The offering discount is higher for a smaller relative offering size (*RelOfrSize*). The relative offer size captures price pressure related to the market's ability to absorb short-selling. At issuance, arbitrageurs short the underlying equity and may increase the supply of shares. Similar to Hackney et al. (2018), underpricing is positively related to a higher delta. Additionally, underpricing is higher for gamma. Furthermore, underpricing is negatively related to the maturity of the bond. Grundy and Verwijmeren (2015) and Hackney et al. (2018) also find that maturity is negatively related to offering discount. For convertible bonds that are issued privately (*144A*), underpricing is significantly lower. A potential explanation could be that liquidity might be lower for private deals, therefore allowing for smaller offering discount. As of last, the conversion premium is negatively related to the offering discount. A lower conversion premium indicates that the embedded option is less deep in the money (or closer at the money).

Our overall conclusion is that offering discount is related to issue specific characteristics. Furthermore, more equity-like convertible bonds are related to a lower offering discount,[27] Some of findings are line with what has previously found in past empirical research. For example, echoing our findings is the study of Hackney et al. (2018), who find that delta is positively related to underpricing and a 144A placement is negatively related. Interestingly, firm-specific factors do not affect the magnitude of underpricing, except for a NYSE exchange listing. Lastly, a novel result, is that a more prominent presence of arbitrageurs may lead to a lower offering discount.

4.3.2 Short and long-run returns

To examine whether short-selling effects price efficiency, we analyse the long-run returns. In our analysis, we assume that short sellers are taking positions in the equity market only to hedge out their directional exposure. If this is the case, convertible bond arbitrageurs are uninformed, and their presence would not impact efficiency on equity prices.

[27]Issuers can make a convertible bond more equity-like by choosing a relatively low conversion premium (Brown et al., 2012).

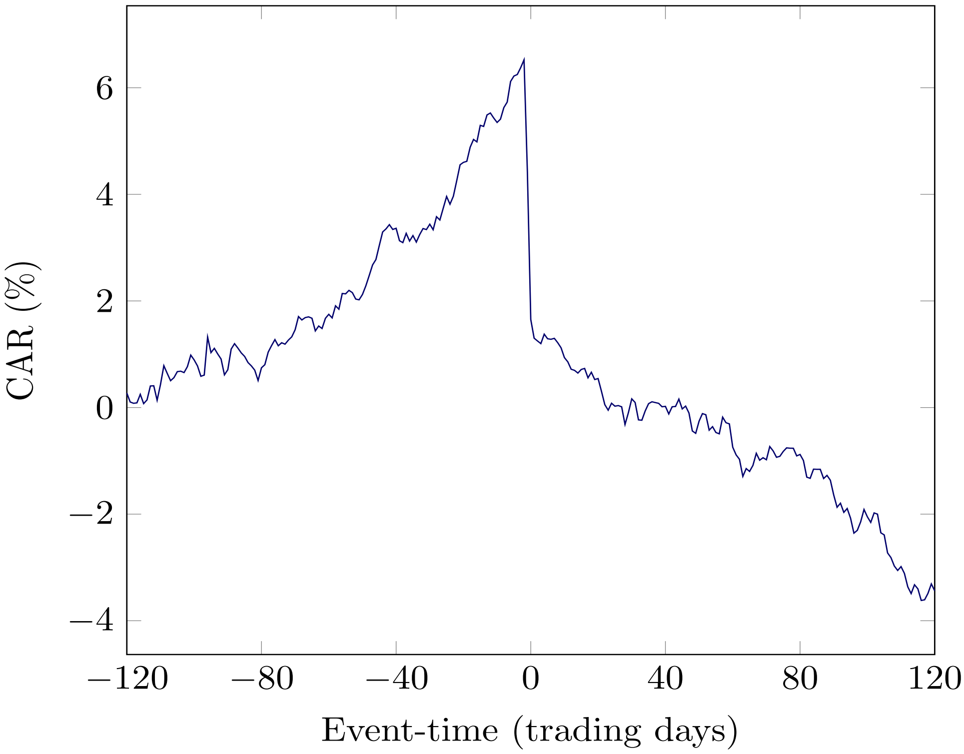


Figure (5) The cumulative abnormal return (CAR) from the event study. Abnormal returns are based on a standard market model, which uses CAPM. Day 0 is the issuance day. Number of observations = 332.

In Figure 5, we show the cumulative abnormal return using a standard market model. We observe a large decrease in CAR around the issuance (see Figure 10 in the Appendix for a smaller observation window). Interestingly, we observe a negative CAR for the post-issue period as well. In Table 7, we can observe a negative average CAR of -5.13% in the days around the issuance. This finding is in line with previous studies (e.g. Duca, Dutordoir, Veld, and Verwijmeren (2012) and Jong et al. (2011)). We can also observe a short term stock price reversal since the CAR for the period of three to five days after issuance ($CAR_{3,5}$) shows positive abnormal returns.

The short-term price reversal indicates that negative issue-date ARs are primarily attributable to hedging-related price pressure. In the long-term, the price reversal does not persist, since the long-term cumulative abnormal returns for the post-issue period are considerably negative (-3.97% for $CAR_{20,120}$).

Next, we examine if firm-specific and issue-specific characteristics affect abnormal returns. Results are reported in Table 8. Consider, first, the abnormal returns around the issuance

Table (7) Univariate analysis of abnormal stock returns following convertible bond issuance

	$CAR_{-2,2}$	$CAR_{3,5}$	$CAR_{3,10}$	$CAR_{20,120}$
Mean	-5.13%	0.04%	-0.31%	-3.97%
Median	-3.11%	-6.19%	0.00%	-6.19%
St.dev	10.94%	4.74%	7.85%	37.17%
Observations	332	332	332	332

($CAR_{-2,2}$). Convertible arbitrage characteristics such as ΔSV_{Iss} and *Delta* are negatively related to abnormal returns, reflecting the price pressure of short sales (Benchmann, 2004). Lower abnormal returns are also related to higher offering discounts. For the periods directly after the issuance, the explanatory power of the variables diminishes considerably. For both $CAR_{3,5}$ and $CAR_{3,10}$, the gamma profile of the convertible bond at issuance is significantly related to higher abnormal returns. A convertible with a high gamma offers more frequent dynamic hedging opportunities.

In the post-issue period ($CAR_{20,120}$), we observe a number of significant determinants. First, the initial offering discount and absolute short-selling amount post-issuance (SV_{post}) are

Table (8) This table presents the results of four OLS regressions. The dependent variable is different windows of cumulative abnormal returns. Abnormal returns are estimated by using a standard market model. The independent variables are defined in the Appendix, see Explanatory variables. Heteroskedasticity-consistent t-statistics are in the parentheses. *, ** and *** denote 10%, 5% and 1% significance, respectively. The sample period is from January 2011 to December 2018.
Number of observations = 332

Dependent Variable	$CAR_{-2,2}$ (1)	$CAR_{3,5}$ (2)	$CAR_{3,10}$ (3)	$CAR_{20,120}$ (4)
Constant	0.124***	0.004	-0.006	-0.718***
	(3.11)	(0.200)	(-0.180)	(-5.29)
Panel A: Firm and issue characteristics				
ΔSV_{Iss}	-0.004***	0.001	0.001	0.003
	(-5.090)	(0.490)	(0.700)	(1.090)
Issue Discount	-0.152***	-0.007	-0.026	-0.368**
	(-3.000)	(-0.260)	(-0.610)	(-2.28)
Delta	-0.251***	0.005	0.049	
	(-3.540)	(0.150)	(0.800)	
DeltaNeutral	0.000	-0.000	-0.000	0.000
	(1.310)	(-0.890)	(-0.260)	(0.740)
Gamma	-0.285	0.125	(-0.004)	
	(-1.210)	(1.030)	(-0.020)	
RelOfrSize	0.018	-0.028	-0.051	0.442**
	(0.290)	(-0.910)	(-0.980)	(1.980)
ConvPrem	0.007	0.016	0.003	-0.051
	(0.460)	(1.630)	(0.170)	(-0.710)
Maturity	0.003	-0.001	-0.003	-0.274***
	(0.124)	(-0.890)	(-1.500)	(-4.010)
NYSE	0.005	-0.002	0.001	0.079*
	(0.470)	(-0.31)	(0.040)	(1.84)
144A	0.019*	-0.004	-0.008	-0.029
	(1.760)	(-0.710)	(-0.860)	(-0.680)
Panel A: Post-issue measures				
Amihud_{post}				-2.521
				(-1.540)
SV_{post}				-20.079**
				(-2.160)
Delta_{post}				1.289***
				(5.530)
Gamma_{post}				1.484**
				(1.990)
Volatility_{post}				-0/911
				(-0.870)
Observations	332	332	332	332
R^2	0.300	0.024	0.014	0.138

negatively related. In subsection 4.2.1, we observed that a higher offering discount results in lower arbitrage activity. These results indicate that a different type of short-selling might affects the abnormal returns over the post-issue period. Second, positively related issue characteristics such as the *delta* and *gamma* reinforce our theory that convertible bonds might be more subject to gamma scraping. We argue that if delta and gamma are greeks of interest to arbitrageurs, these greeks should be positively related to abnormal returns. This would be in line with our expectation that arbitrage-induced short-selling does not affect price-efficiency, thus short-selling should not lead to lower returns which is the case in our results.

The negative returns in the long-run could be explained by the findings of Brophy et al. (2009). They argue that companies that receive equity financing from hedge fund investors experience substantial negative returns in the long-run. Moreover, they argue that hedge funds might be more willing to invests in firms that otherwise are constrained from raising capital (due to weak fundamentals and pronounced information asymmetries). Puzzling to this argumentation is that our measures for arbitrage activity (thus hedge-fund activity), is not significantly related to the returns. Therefore, although short-selling negatively affects returns (SV_{post}), we are unable to determine if the short-selling is due to arbitrage-induced short-selling or other types of short-sellers.

Overall, since no positive abnormal returns follow after the issuance, convertible bond arbitrageurs are not able to make money from their equity market positions. Therefore, in line with Choi et al. (2010), we conclude that convertible bond arbitrageurs do not play a role in stock price efficiency. However, in line with Brophy et al. (2009), we argue that firms with a higher presence of hedge funds, measured by short-selling, experience substantial negative performance.

4.3.3 Robustness

We conduct several robustness checks to show that our conclusions are not dependent on methodological choices such as the assumed time window (six months) to measure short-selling levels. Table 9, for instance, contains the replications of the results from Table 5. In regressions (1) and (2), we conduct regressions using a pre-issue window of five (100 trading days) and four (80 trading days) months before the issuance, respectively. For regressions (3), (4) and (5), we change the post-issue window to five, four and three months after the issuance, respectively. Overall, we find that using a shorter pre-issue or dynamic hedging period to compare short-selling changes to, does not affect the direction of strength of the found relationships. Besides, based on our robustness checks, we conclude that the dynamic hedging period significantly affects short-selling for at least six months post-issuance.

Table (9)
This table reports results for regressions of the change in short-selling with different pre- and post-issue windows. Column (1) and (2), report results when the change in short-selling is measured with a pre-issue period of -100 tradings days to -20 trading days and -80 trading days to -20 trading days, respectively. Column (3), (4) and (5) report results when the change in short-selling is measured with a post-issue period of +20 trading days to +100, +80, and +60 trading days, respectively. Explanatory variables are defined in Explanatory variables. Results are including year-month and industry fixed effects. Heteroskedasticity-consistent t-statistics are in the parentheses. *, ** and *** denote 10%, 5% and 1% significance, respectively. The sample period is from January 2011 to December 2018.
Number of observations = 335.

Dependent Variable:	$\Delta SV_{pre_{-100,-20}}$ (1)	$\Delta SV_{pre_{-80,-20}}$ (2)	$\Delta SV_{post_{20,100}}$ (3)	$\Delta SV_{post_{20,80}}$ (4)	$\Delta SV_{post_{20,60}}$ (5)
Constant	-0.021	-0.029	0.004	0.032	0.006
	(-0.210)	(-0.300)	(0.040)	(0.360)	(0.070)
ΔSV	0.006***	0.006***	0.006***	0.007***	0.006***
	(4.200)	(3.990)	(4.480)	(4.790)	(4.620)
ΔVolatility	0.917**	0.744*	0.839**	0.692*	0.735**
	(2.360)	(1.910)	(2.270)	(1.940)	(2.230)
ΔMarket Cap	0.000***	0.000***	0.000***	0.000***	0.000***
	(3.340)	(2.850)	(4.310)	(4.700)	(3.900)
NYSE	0.017	0.015	0.015	0.015	0.004
	(0.710)	(0.640)	(0.690)	(0.690)	(0.200)
144A	-0.001	-0.006	-0.008	-0.196	-0.019
	(-0.060)	(-0.290)	(-0.400)	(-1.010)	(-1.030)
Discount	0.123*	0.135**	0.126**	0.114*	0.076
	(1.830)	(2.000)	(1.960)	(1.840)	(1.320)
Option Value	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***
	(-4.130)	(-3.710)	(-4.330)	(-4.650)	(-4.580)
Gamma	-0.612**	-0.622**	-0.657**	-0.686**	-0.561**
	(-2.080)	(-2.110)	(-2.350)	(-2.540)	(-2.250)
Issue size	0.079	0.073	0.097	0.092	0.110
	(0.720)	(0.670)	(0.930)	(0.920)	(1.190)
R^2	0.255	0.234	0.280	0.298	0.295
Observations	335	335	335	335	335

5 Conclusion

This paper set out to investigate the link between convertible bond arbitrage and changes in short-selling around the issuance and in the dynamic hedging period. We define the dynamic hedging period as the period from one month ending six months after the issuance. Departing from the concept of delta-neutral hedging, where arbitrageurs have the option to short or buy additional stock to remain delta-neutral, our central hypothesis was that arbitrageurs affect short-selling levels of the stock. Such expectation is tested using a high-frequency short sale dataset, being superior to existing, less precise, datasets.

The first major finding was that the initial position taken by convertible bond arbitrageurs substantially affects short-selling levels at issuance. This finding confirms the theory that convertible bond arbitrageurs start delta-hedging their exposure at the moment of issuance. Besides, our finding allows us to understand the drivers of increases in short-selling better, and subsequently, what issue-specific characteristics (such as delta and gamma) and issuer-specific characteristics (such as liquidity) affect the magnitude of short-selling.

The second major finding was that we find evidence that increased convertible bond arbitrage short-selling is associated with specific deal characteristics. Contrary to one of our main predictions, we find that the gamma profile of convertible bonds is negatively related to post-issue short-selling. We argue that arbitrageurs could use high gamma convertible bonds solely near term events to benefit from the convexity of the embedded option, instead of holding the convertible bonds and performing delta-neutral hedging. Furthermore, we find that changes in short-selling in the dynamic hedging period are substantially related to convertible bond arbitrage.

Our study builds upon and extends that of Hackney et al. (2018) in that we analyse determinants of the underpricing of the convertible bond. We find underpricing to be positively related to a higher delta. Additionally, we find underpricing to also be higher for a higher gamma. Furthermore, underpricing is negatively related to the maturity of the bond. Grundy and Verwijmeren (2015) and Hackney et al. (2018) similarly find that maturity is negatively affected to offering discount. Moreover, our results indicate a negative relationship between an increased presence of hedge funds and the offering discount. Taken together, these findings support strong recommendations that underpricing is affected by the characteristics of the issuance, but is not related to firm-specific characteristics and hedge fund presence.

We also analyse the short and long-run returns. Our results differ from what we would expect based on existing literature. The long-run returns are substantially negative for our sample. Brophy et al. (2009) argue that the presence of hedge funds as investors may lead to severely negative performance. However, our findings do not show a significant relation between hedge fund activity and returns. Additionally, our control variables do not allow us to explain what drives the negative returns. Therefore, more research is needed to fully comprehend the drivers of these negative long-run returns.

Our first two findings highlight the impact convertible bond arbitrageurs have on short-selling. However, there still seems to be a source of uncertainty, as for our results (especially the results for the dynamic hedging period) we are unable to explain the variations of our dependent variables to the fullest extent. This indicates that we are not controlling for factors that may substantially influence short-selling. For example, for our analysis, we have not included variables that are related more generally to the supply of capital (e.g. Duca et al., 2012 and Choi et al., 2010). When more capital is available to convertible arbitrage hedge funds, arbitrage should be noticeably easier. Besides, there might be a bidirectional relationship between some of our variables. For instance, our finding that gamma is negatively related to arbitrage activity near the issuance could be explained due to model bias. It could also be that there are real underlying economics at play which we are simply unable to observe.

More research is needed examining the role of gamma for arbitrage-induced short-selling. Such research can, for instance, apply structural equation modeling to build a path model, including covariances between independent variables and examine model fit for competing models (Chang, Lee, & Lee, 2009).

We conclude that our findings provide new insights in short-selling around the issuance by using a novel short-selling dataset. Furthermore, our results add to existing literature by shedding additional empirical light on short-selling in the dynamic hedging period.

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Appendix

Tsiveriotis-Fernandes model

The Tsiveriotis-Fernandes (TF) model makes a distinction between two parts of the convertible bond. First, the bond-like or cash only part, and second, the equity-like part. The bond-like or cash only part provides cash payments and no equity flows. The value of convertible bond, denoted as V is the sum of the bond-like or cash only part, denoted as, V^{CO}, and the equity-like part, (V - V^{CO}). The price of the stock is assumed to follow a continuous time process, $dS = rSdt + \sigma Sdw$, where σ is the standard deviation of the stock returns, r is the risk-free interest rate, and w is a Wiener process. The bond-like part can default, TF propose to use the credit spread as a measure of default risk. The equity-like part is assumed to be default-free and is therefore discounted only at the risk-free interest rate. In the event of a default, TF assume a proportion p can be recovered of the bond face value. The convertible bond value is derived from a pair of coupled partial differential equations:

$$\text{For } V\text{: } \tfrac{1}{2}V_{ss}\sigma^2 V^2 + (r-d)SV_s + V_t - r(V - V^{CO}) - (r + r_c)V^{CO} = 0$$

$$\text{For } V^{CO}\text{: } \tfrac{1}{2}V_{ss}^{CO}\sigma^2 V^2 + (r-d)SV_s^{CO} + V_t^{CO} - r(V - V^{CO}) - (r + r_c)V^{CO} = 0$$

With S is the underlying stock price, r_c is the credit spread (represents the default risk), and d is the dividend yield of the underlying stock. By solving the system of partial differential equations, the value of the convertible bond can be found. At each step (point in time), the convertible bond prices should meet boundary conditions. The boundary condition at maturity date should hold: $V(S,T) = max(aS, F + Coupon)$, $V^{CO}(S,T) = max(F, 0)$ where F is the face value of the bond and a is the conversion ratio. The boundary condition at the conversion points are: $V(S,t) \geq aS$; $V^{CO} = 0$ if $V(S,T) \leq aS$. The callability boundary conditions are $V \leq max(CallPrice, aS)$; $V^{CO} = 0$ if $V \geq CallPrice$. A binomial tree is used to calculate the prices of the convertible bond. Therefore, the prices of the convertible bond are first calculated for different stock prices at the maturity date. For the equity-like part where the conversion value is higher than the face value of the bond and the accrued coupons combined, the price of the convertible is equal to the conversion value. For this range, the value of the convertible bond is discounted at the risk-free rate (r) one period/step back. When the conversion value is lower than the face value of the bond and the accrued coupons combined, the value of the convertible bond is discounted at the risky rate ($r + r_c$) one period/step back. Through a stepwise backwards approach, the convertible bond values are calculated and periods are found where the issuer can call the bond. Iterations continue until the valuation date (t_0) is reached.

Option Greeks: Delta and Gamma

Delta and Gamma are so-called Greeks, and are quantities representing the sensitivity of the value of an option to a change in underlying parameters on which the value of an option depends. Delta is the Greek that has the most considerable influence over the option value. Delta is a reflection of how the options premium will change as the price of the underlying stock changes. Take, for instance, a call option on a stock with a cost of $100 with a delta of 0.35. The premium of the option is expected to go up by 35 cents if the price of the underlying stock goes up by $1, to $101. Gamma, or Γ, is the second derivative of the value function concerning the underlying stock price and is, therefore the derivative of Delta. Gamma is the instantaneous rate of change for each consecutive increase or decrease in the underlying stock price relative to the value of the option and is non-linear. For example, if the call option mentioned above has a gamma of 0.05, and the stock goes up by $1, the premium of the option is expected to go up by 35 cents, and the delta will go up to 0.40, which means that the next $1 increase for the underlying stock price will increase the premium by 40 cents instead of 35 cents.

The Delta and Gamma for a European call option can be calculated with the *Black-Scholes Model* (Black & Scholes, 1972)(Black & Scholes, 1973). The mathematical expression of the Black-Scholes formula is as follows:

$$d_1 = \frac{\log(S/K) + (r + \sigma^2/2)(T - t)}{\sigma\sqrt{T - t}}$$
$$d_2 = \frac{\log(S/K) + (r - \sigma^2/2)(T - t)}{\sigma\sqrt{T - t}}$$

and then

$$V_C(S, t) = S\Phi(d_1) - Ke^{-r(T-t)}\Phi(d_2)$$

Note that $d_2 = d_1 - \sigma\sqrt{T - t}$.

S is the stock price of the underlying; K is the strike price of the option; r is the risk-free rate; T is the maturity date; t is the day of valuation (T - t is therefore the time to maturity); σ is the volatility; V_C is the value of the option. Delta is calculated as follows:

$$\Delta = \frac{\partial V_C}{\partial S}$$
$$= \Phi(d_1)$$

With Φ as the standard normal cumulative distribution function. The sensitivity of the financial derivative value with respect to the asset value, denoted Δ, gives the hedge-ratio, The hedge-ratio is the number of short units of the underlying asset which combined with a call option will offset immediate market risk. After a change in the stock price, $\Delta(S)$ also changes. Next, the hedge-ratio needs to be dynamically adjusted, in order to keep up with the changing asset value. Thus $\Delta(S)$ as a function of S provides a dynamic strategy for hedging against risk. The Gamma (Γ) of a derivative is the sensitivity of Δ concerning the underlying stock price:

$$\Gamma = \frac{\partial^2 V}{\partial S^2}.$$

The concept of Gamma matters when the hedged portfolio cannot be adjusted continuously in time, according to $\Delta(S(t))$. If Gamma is small then Delta changes slightly with S. This means the portfolio requires only infrequent adjustments in the hedge-ratio. However, if Gamma is large, then the hedge-ratio Delta is sensitive to changes in the price of the underlying security. According to the Black-Scholes formula:

$$\Gamma = \frac{\Phi(d_1)}{S\sigma\sqrt{T-t}}$$

Gamma scalping

Gamma scalping is one of the many strategies an option trader can use. Since convertible bonds contain an embedded option, certain option strategies, such as gamma scalping, are applied by arbitrageurs. We provide an example to understand how gamma scalping works and how it affects delta hedging.

T_0

100 calls strike \$65; 60 days expiration; 31% volatility; 3.25% interest rate; 0 div; at \$3.44

Greeks; delta +0.54; gamma +0.05; theta -0.03; vega; +0.105

Original delta-neutral hedge are 5400 stocks at \$65

T_1

Goes up to \$66, delta changes to +0.59

Short 500 stocks at \$66 to be delta-neutral

Total delta-neutral short is 5900 stocks

T_2

Goes down to \$64, delta is now +0.49

Buy 1000 stocks at \$64 Total delta-neutral short is 4900 stocks

T_3

Stock goes up to \$65, delta is now +0.54

Short 500 stocks at \$65 to be delta-neutral

Total delta-neutral short is 5400 stocks

The arbitrageur bought 1000 stocks at \$64 and sold 500 stocks at \$65 and 500 stocks at \$66, resulting in a gross profit of \$1500. Over the three days of holding the option, the arbitrageur pays three days of theta, which is \$900 ($0.09 \times 100 \times 100$). Gross profit minus theta is the net profit. In this case; \$1500 minus \$900 = \$600. The gamma scalper needs the stock to move more than the 31% (the implied volatility of the option) to make money. The long gamma scalper is making money as the stock price changes, with the profits coming from delta-neutral hedging. The arbitrageur paid for 31% implied volatility for the option and hopes to gamma scalp at higher volatility. Specifically, the arbitrageur wants the underlying stock to trade at higher volatility than 31%.

Offering discount

In line with Chan and Chen (2007) and Jong et al. (2011), we define the offering discount (OD) for a convertible bond Issue as follows:

$$OD = \frac{TheoreticalPrice - OfferingPrice}{TheoreticalPrice}$$

To calculate the theoretical price we use a pricing model by Tsiveriotis and Fernandes (1998), which is in line with previous studies (Chan & Chen, 2007)(Loncarski, Horst, & Veld, 2006). Tsiveriotis and Fernandes (1998) break a convertible bond down in two separate components, an equity component and a straight debt component.[28] A binomial tree approach is used to obtain a value for equity component, which essentially represents a call option on the underlying equity. We use the module Quantlib[29] for modelling the Tsiveriotis and Fernandes (1998) model. Our theoretical price calculations use the following inputs: stock return volatility; risk free-rate (the yield on US treasury bills with the maturity linked as closely as possible to the maturity of the convertible bond); stock price; coupon rate; stock return volatility; coupon payment frequency; offering price; call schedule; maturity date; settlement days and credit spread. All security-related information is obtained from Mergent, including the ratings from the convertible bonds. The credit spread is based on Standard and Poor's (S&P) ratings for corporate bonds with, similar to the risk-free rate, a maturity linked as closely as possible to the maturity of the convertible bond. The majority of our sample does not contain an S&P rating (83%) at issuance. In line with Jong et al. (2011), Loncarski et al. (2006), we assign a BBB rating to convertible bonds that are unrated. The risk-free rate is obtained from the Federal Reserve Bank of St. Louis. In line with Jong et al. (2011), we define stock return volatility as the annualized historical volatility estimated from daily stock return over trading days -240 to -40 before the issuance. Stock price is the average stock price for -12 to -2 trading days before the issuance (to avoid potential stock price drop resulting from short-selling activity near the issuance). Dividends are omitted, as the majority of convertible bonds tend to be dividend protected (Grundy & Verwijmeren, 2015). In total, our sample holds 335 convertible bonds for which we can calculate the offering discount.

[28] A detailed explanation of the Tsiveriotis and Fernandes can be found in the appendix, see

[29] https://github.com/lballabio/QuantLib

Explanatory variables

Short-selling measures:

- ΔSV the change in average short volume scaled by the shares outstanding between the period before the issuance (-120 to -20 trading days) and after the issuance (+20 to +120 trading days). Short volumes are from FINRA. The daily shares outstanding are from CRSP.

- ΔSV_{Iss} is the change in average short volume scaled by the shares outstanding (ΔSV) for the period around the issuance (-2 to +2 trading days around the issue) compared to short volume for the period before the issuance (-120 to -20 trading days). Short volumes are from FINRA. The daily shares outstanding are from CRSP.

- SV/TV is the average daily short volume relative to the total volume (based on the FINRA data, total volume represents all trades, short and long).

- *SV vola* is the daily standard deviation of short volumes. Short volumes are from FINRA.

Firm-specific variables:

- *NYSE* is a dummy variable, equal to one in the case the firm is listed on NYSE and zero otherwise. Data on exchange listing are from Mergen FISD.

- *Amihud* is the average ratio of daily absolute return to dollar volume (Amihud, 2002). Stock returns and volumes are from CRSP.

- *Dollar volume* is the average daily dollar stock volume. Stock volumes are from CRSP.

- *Volatility* is the standard deviation of the returns for the pre-issue period (-120 to -20 trading days). Daily returns are from CRSP.

- *Marketcap* is the equity market capitalization, based on the daily shares outstanding and the average of the closing stock price for day_t and day_{t-1}. Data are from CRSP.

- *Turnover* is the average daily volume divided by the daily shares outstanding. Data are from CRSP.

- $\Delta Volatility$ is the change between the pre- (-120 to -20 trading days) and post-issue (+20 to +120 tradings days) standard deviation of the daily returns. Data from CRSP.

- $\Delta Marketcap$ is the change between the pre- (-120 to -20 trading days) and post-issue (+20 to +120 tradings days) equity market capitalization. Data are from CRSP.

Deal-specific variables:

- *Delta* is the delta of the embedded option of the convertible bond at issuance. Input data are from CRSP and Mergent FISD.
- *Proceeds* are the total proceeds of the issue (Principal × Offering Price). Data are from Mergent FISD.
- *RelOfrSize* is defined as (Principal × Offering Price)/MarketCap at issuance. Issue characteristics are from Mergent FISD, MarketCap from CRSP.
- *144A* is a dummy variable, equal to one if the convertible bond was a 144A issue and zero otherwise (public). Data are from Mergent FISD.
- *Maturity* is the time-to-maturity of the convertible bond at issuance, from Mergent FISD.
- *ConvPrem* is the amount by which the conversion price exceeds the stock price of the common stock at issuance. Conversion price is from Mergent FISD. Stock price is from CRSP.
- *DeltaNeutral* is the amount of common shares (in '000s) that buyers of the convertible issue have to short to obtain a delta-neutral position relative to the shares outstanding (see Delta-neutral short position). Variable is defined as (Face value of entire issue)/conversion price × Delta (following Jong et al. (2011)). Input parameters are defined in this Appendix.
- *Gamma* is the gamma of the embedded option of the convertible bond at issuance. Input data are from CRSP and Mergent FISD.
- *OptionValue* s the theoretical value of the embedded option (based on the Black-Scholes Model, see Option Greeks: Delta and Gamma) of the convertible bond at issuance. Input data are from CRSP and Mergent FISD.
- *Issue discount* is the amount (in percent) by which the offering price differs from the theoretical price (see). Components of this calculation are defined in Offering discount.
- *Year* are year fixed effects, indicating the timing of the convertible bond issues. Data is from Mergent FISD.
- *Industry* refers to the industry fixed effects, based on the Fama and French 12 industry classification, indicating the industry of the convertible bond issuer. Data is from Mergent FISD.

Issue period distribution

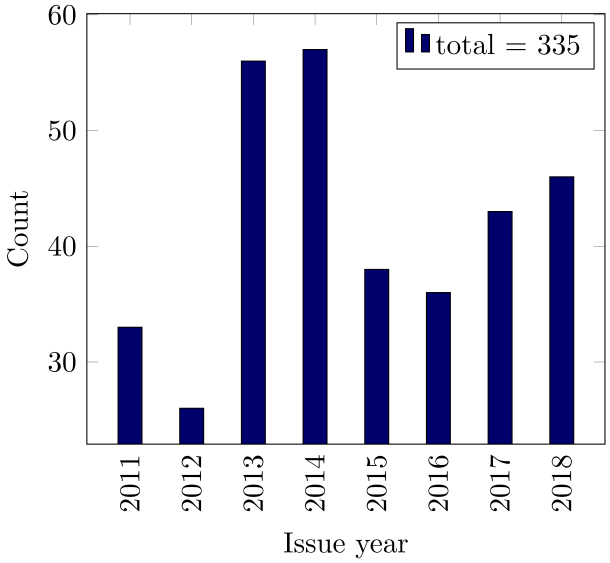

Figure (6) This figure presents the convertible bond issues per year. Issuance is fairly volatile over the sample period, with a low number of issues for the years 2011 and 2012, followed by the highest issues per year in 2013 and 2014. Number of observations = 335.

Offering discount distribution

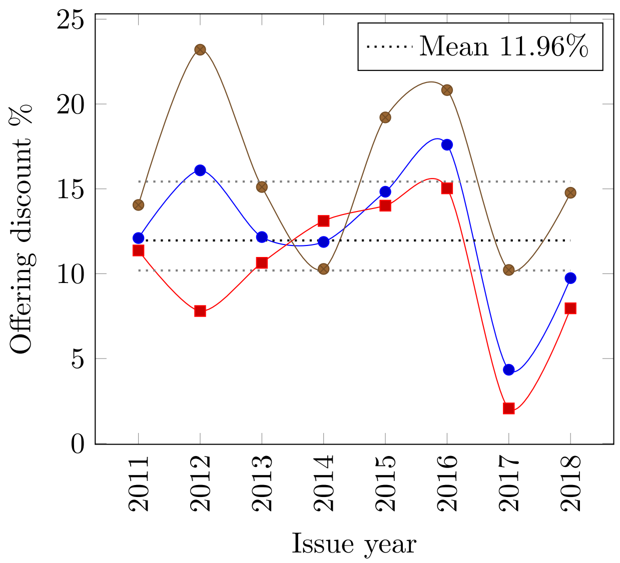

Figure (7) Offering discount distributed per year for the sample. The mean offering discount is 11.96%. The offering discount is volatile and shifts over the years. The blue line is the mean discount each year. The brown and red line show the mean offering discount for public and 144A offerings, respectively. The mean offering discount for 144A offerings is 10.19%. The mean offering discount for public offerings is 15.43%. Number of observations = 335.

144A and public short-selling

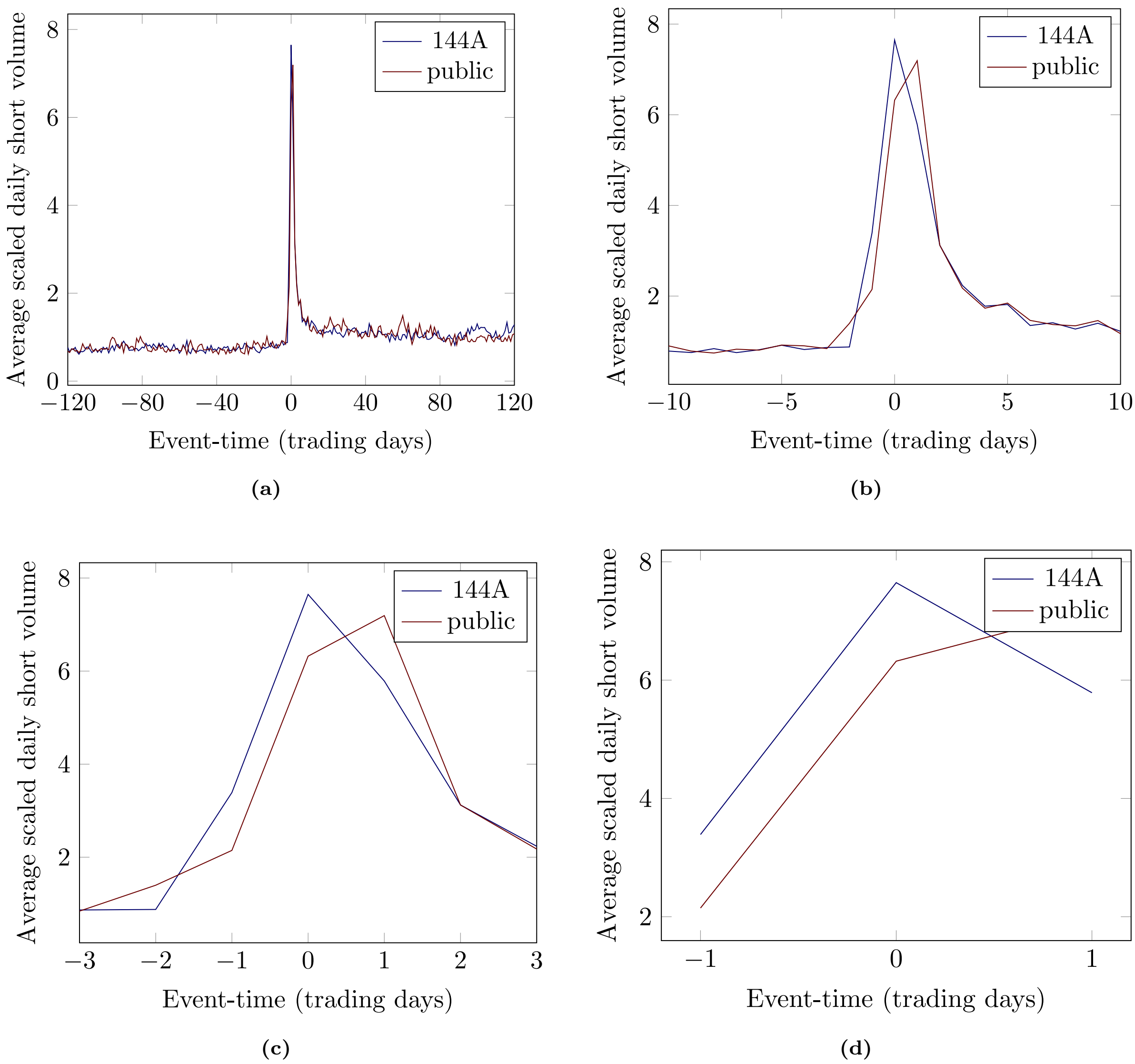

Figure (8) Average scaled daily short volume for public and 144A offerings with day 0 as the issuance day. The short volumes for the underlying equity are divided by their mean for the same period (-120 and +120 days around issuance). Different windows around the issuance are shown to display the difference in short volume between 144A and public offerings. Number of observations = 335.

Short volume relative to total volume

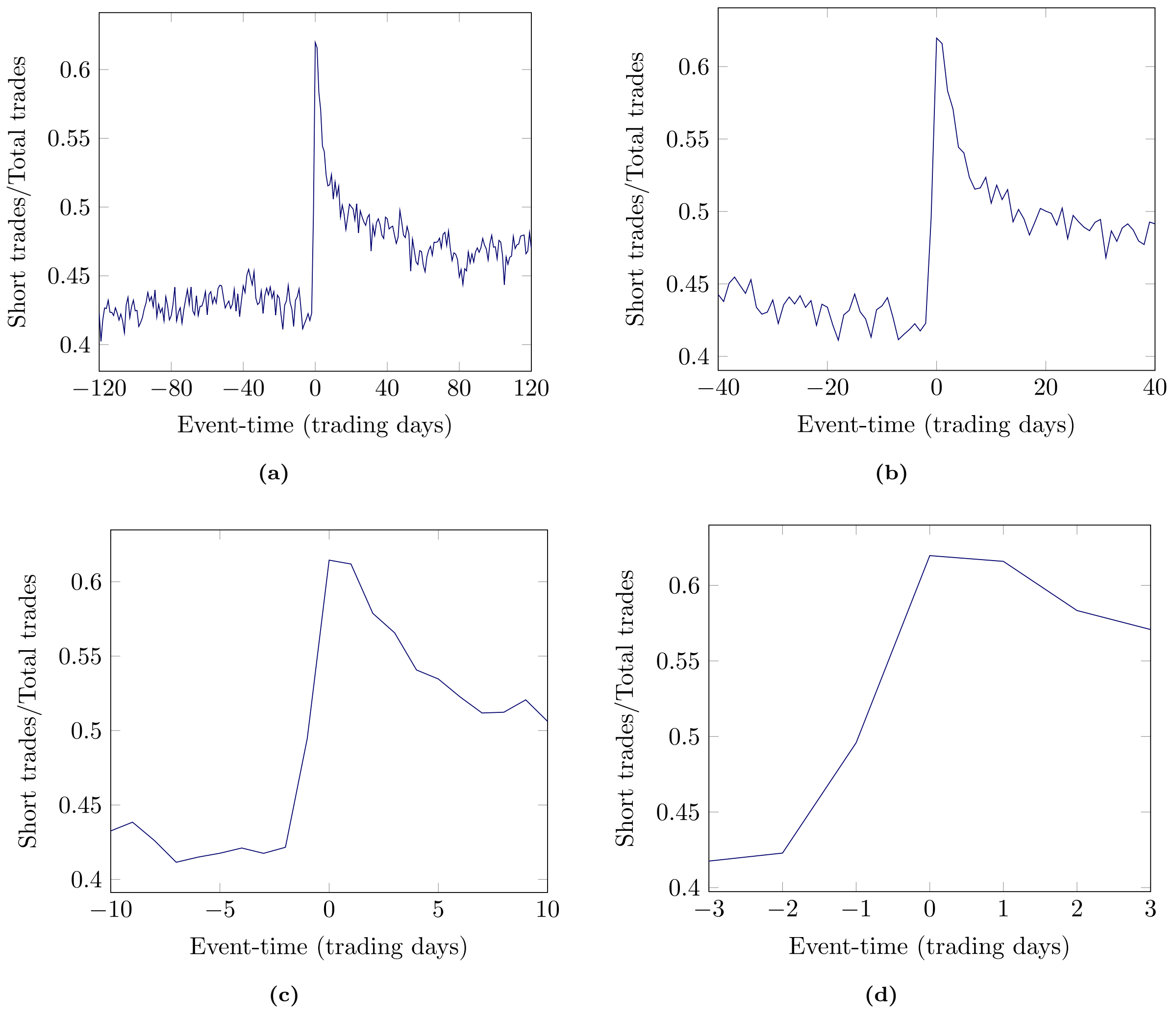

Figure (9) Short trade volume relative to the total trade volume is taken. We winsorize values below the 5th percentile to remove outliers followed by taking the mean for all short and total trade volumes. Different windows around the issuance are shown. Number of observations = 335.

Mean cumulative abnormal returns

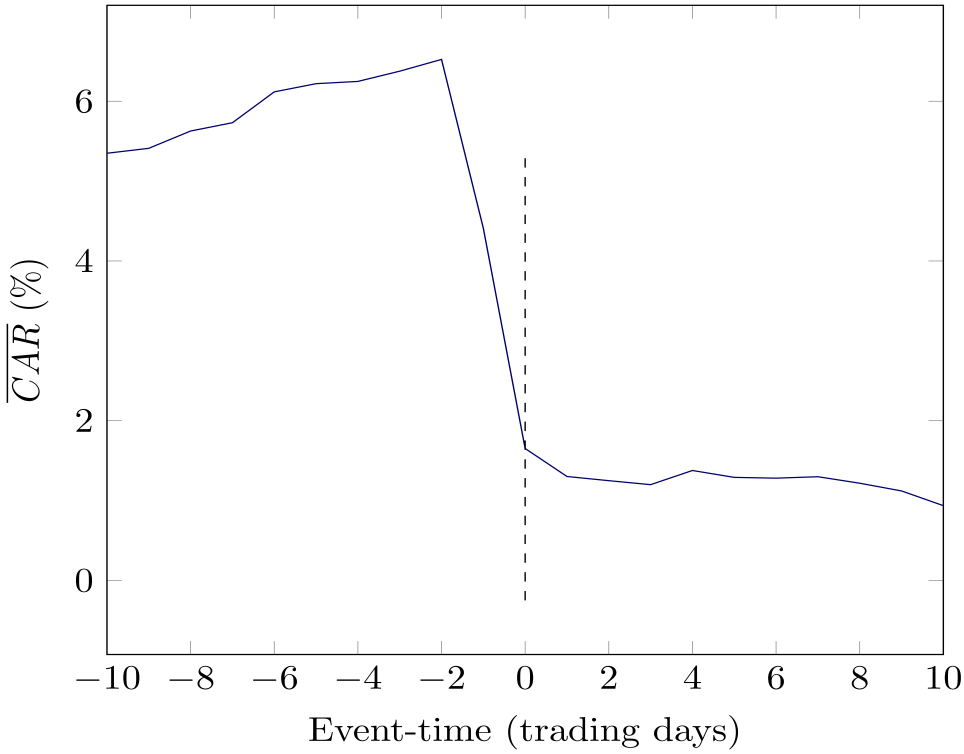

Figure (10) The cumulative abnormal return (CAR) from the event study. Abnormal returns are based on a standard market model, which uses CAPM. Day 0 is the issuance day. Number of observations = 332.

VIF statistics

Table (10) The VIF statistics for the ΔSV regression (see Table 5) and the ΔSV_{Iss} (see Table 4).

	ΔSV		ΔSV_{Iss}	
	VIF	$\frac{1}{VIF}$	VIF	$\frac{1}{VIF}$
$\Delta MarketCap$	1.23	0.81		
$\Delta Volatility$	1.05	0.95		
ΔSV_{Iss}	1.21	0.83		
Issue discount	1.32	0.75	3.80	0.26
RelOfrSize	1.46	0.68	5.69	0.18
144A	1.07	0.93	1.16	0.86
NYSE	1.09	0.92	1.13	0.89
OptionValue	1.31	0.76	2.50	0.40
Gamma			1.61	0.62
ConvPrem			1.14	0.88
Amihud			1.39	0.72
Maturity			2.17	0.46
Delta			5.23	0.19
$Gamma_{post}$			1.37	0.73
LogMktcap			9.32	0.11
SV_{pre}			5.80	0.17
DollarVolume			3.66	0.27
DeltaNeutral			5.01	0.20
LogTurnover			4.33	0.23
LogProceeds			4.03	0.25
Volatility			2.44	0.41
Mean	1.23		3.55	

Table (11) This table presents a correlation matrix of all independent variables used in Table 4.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) Amihud	1.000																
(2) Dollar Volume	-0.064	1.000															
(3) Volatility	0.201	0.032	1.000														
(4) LogMktcap	-0.302	0.487	-0.234	1.000													
(5) NYSE	-0.046	0.005	-0.093	0.099	1.000												
(6) SV_{pre}	-0.104	0.640	0.341	0.224	0.007	1.000											
(7) LogTurnover	-0.275	0.399	0.326	0.253	-0.064	0.817	1.000										
(8) Delta	0.147	-0.007	0.630	-0.321	-0.112	0.266	0.247	1.000									
(9) LogProceeds	-0.151	0.463	-0.171	0.767	0.033	0.185	0.171	-0.277	1.000								
(10) RelOfrSize	0.319	-0.291	0.190	-0.726	-0.128	-0.127	-0.136	0.195	-0.304	1.000							
(11) 144A	0.056	-0.122	-0.110	-0.105	-0.115	-0.128	-0.083	0.000	-0.100	0.027	1.000						
(12) Maturity	-0.049	0.028	0.028	0.084	-0.059	0.065	0.073	0.406	0.017	-0.099	0.108	1.000					
(13) ConvPrem	-0.038	0.053	0.005	0.142	-0.063	-0.037	-0.004	-0.077	0.103	-0.091	0.087	0.047	1.000				
(14) DeltaNeutral	0.224	-0.208	0.241	-0.614	-0.106	-0.054	-0.067	0.482	-0.277	0.761	0.023	-0.017	-0.215	1.000			
(15) Gamma	0.138	-0.158	-0.050	-0.394	0.017	-0.138	-0.242	-0.130	-0.181	0.341	-0.083	-0.203	-0.105	0.227	1.000		
(16) OptionValue	-0.077	0.610	0.281	0.418	-0.133	0.393	0.320	0.209	0.314	-0.269	-0.083	0.090	0.184	-0.177	-0.406	1.000	
(17) Issue discount	0.223	-0.233	0.433	-0.501	0.046	0.021	-0.016	0.568	-0.414	0.338	-0.148	-0.211	-0.234	0.611	0.219	-0.116	1.000