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Intermediary frictions and convertible bond pricing

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ABSTRACT

Buy-and-hedge intermediaries are important investors in the convertible bond market as they intermediate between firms that require capital quickly and investors requiring time to assess the security. Their strategy requires them to manage the trade-offs involved with the costs and benefits of hedging. We find that prices of convertible securities reflect the costs that intermediaries incur when managing their positions. Especially cross-sectional and within-bond variation of intermediaries' loan costs helps explain variation in convertible bond underpricing.

1. Introduction

With over 250 billion USD of convertible debt outstanding in the U.S. in 2022, convertible bonds are an important source of financing for corporations. A majority of convertible bonds are privately placed, which exempts newly-issued securities from certain registration requirements and thereby allows firms to raise capital quickly. The buy-side of the convertible bond market is characterized by two different types of investors. The first type, "buy-and-hedge" intermediaries, such as convertible arbitrage hedge funds, are frequent initial purchasers of convertible bond issues (Brown et al., 2012). They are known to make their decisions quickly, typically overnight, without requiring a discussion with the convertible issuing firm's management as they hedge the equity risk by shorting the underlying stock (Mitchell and Pulvino, 2012; Dong et al., 2018). Over time, convertible bond ownership gradually transfers to the second type of buyer, namely "buy-and-hold" investors, such as banks and mutual funds, that invest in convertible bonds with a view to profiting from the upside potential of the equity component of the convertible.

In this paper, we examine whether the hedging costs associated with the strategy of the buy-and-hedge intermediaries affect convertible bond prices. Their large initial involvement in convertible securities makes them the marginal investor in the initial period of the convertible's life. Buy-and-hedge intermediaries will be willing to acquire and hedge a convertible when its price reflects the costs they expect to incur in managing their short positions. For market prices to reflect these costs, the convertible must be priced at a discount to the value of an otherwise equivalent package of stock and bonds.

We construct a model that shows how the degree of convertible bond underpricing depends on the loan costs involved with intermediaries' hedging strategy. Loan costs relate to buy-and-hedge intermediaries' optimal short position in the convertible issuer's stock, which is typically substantial and aims to create a delta-neutral hedged portfolio. Our model shows that, besides loan fees, the degree of convertible bond underpricing is related to the sensitivity of the convertible bond's value to a change in the convertible's issuer's stock price (as measured by the convertible's elasticity) and the time since the convertible's issuance.

We use the Trade Reporting and Compliance Engine (TRACE) database to track the pricing of 1098 convertibles in the secondary market between 2002 and 2020. The underpricing, or discount, on a convertible is defined as the percentage difference between the observed market price and the theoretical price. On average, we estimate a discount of 1.6%. We examine the relation between the size of discounts in the seasoned market and measures of shorting costs that link closely to our

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theoretical model. By using panel regressions that allow us to control for heterogeneity across issuers and time, we find that hedging costs are important in explaining variation in underpricing, with post-issue convertible bond underpricing decreasing when the present value of the future cost of hedging the underlying stock decreases.

We also focus on bond-specific measures of the cost of hedging in analyses that keep firm-level factors in a given month constant. We perform a regression with time-varying firm fixed effects in a subsample of firms that have multiple convertible bonds outstanding, effectively comparing convertible bonds that are issued by the same firm but with differing hedging costs due to their differing elasticities. The bond-specific measures of short-selling costs have the predicted relation to underpricing and corroborate our conclusion that financial intermediaries' loan costs are transmitted to asset prices.

Our model further predicts that hedging costs have a smaller effect on convertible bond pricing when the convertible has been trading for a longer time. The reason is that the fraction of the convertible held by buy-and-hedge funds and the anticipated time until the position is fully closed out will both be reducing with the age of the convertible. Our evidence shows that hedging costs indeed have a smaller effect on convertible bond pricing as the time since issuance increases.

In addition to borrowing costs, buy-and-hedge intermediaries face trading costs when they hedge their positions dynamically. Trading costs relate to the adjustments that buy-and-hedge intermediaries need to make to their initially established positions after changes in the issuer's stock prices, as after an increase (decrease) in stock price, the optimal delta-neutral hedge ratio increases (decreases) and the optimal short position becomes larger (smaller). We find evidence that these trading costs also matter for convertible prices, even though borrowing costs are a more robust determinant of convertible underpricing.

In the final analysis of the paper, we exploit the fact that hedging is challenging when short selling is banned. Between September 18th and October 9th in 2008, the SEC banned the short selling of most financial stocks. While the intention of the ban was to prevent excessive short selling by speculators, the ban introduced challenges for existing convertible arbitrageurs in maintaining their hedges and prevented new arbitrageurs from entering the market. We estimate a difference-in-difference regression and document a significant increase of 3 percentage points in underpricing for convertibles issued by companies whose stock could not be short sold during the period of the ban.

Our study links to the literature on underpricing around corporate financing events, which focuses mostly on IPOs and SEOs. Our focus on convertible bond financing allows us to analyze underpricing in a setting where ownership transfers from buy-and-hedge intermediaries to buy-and-hold investors, which provides both cross-sectional predictions as well as within-firm and within-bond predictions about the importance of short-selling frictions during a security's life. The large presence of arbitrageurs in the convertible bond market makes it a natural setting in which to study the effects of frictions in financial intermediation. The focus of much of the empirical literature on intermediary asset pricing has been on the financial health of intermediaries, with periods of intermediary distress leading to low asset prices (e.g., Mitchell et al. 2007, He and Krishnamurthy 2013, 2018, Haddad and Muir 2021). In this paper, we ask whether intermediary frictions in the convertible market affect pricing when financial intermediaries are not in distress.

Lamont (2012) provides examples of firms implementing a variety of methods to impede short selling. Our results highlight how firms can benefit from relatively low short-sale constraints on their stock. We show that a reduction in the cost of short selling can reduce firms' cost of capital in the case of convertible issuance. This finding is also relevant for regulators, who have been implementing policies to regulate short selling since 1610, a few years after the first stock market developed (Bris et al., 2007). Our results imply that when regulators are contemplating the introduction of a (temporary) short-sale ban, they should seriously consider providing an exemption for short sales relating to convertible arbitrage activity.

2. A model of borrowing costs

The strategy employed by buy-and-hedge intermediaries involves short selling, which requires locating stocks available for borrowing, paying loan fees, and posting collateral (D'Avolio, 2002). Potentially, investing in a delta-hedged convertible bond strategy requires substantial discounts to compensate for these costs. In this section, we provide a simple model of a relation between stock loan rates and discounts on convertible bonds.

Suppose a firm with assets of V_t at time t has a simple capital structure of common shares and a convertible bond. Assume no dividends will be distributed during the life of the bond.[1] The zero-coupon convertible promises to pay K at its time T maturity when it becomes convertible into a fraction of the post-conversion equity. Let S_t and CB_t denote the respective values of a share and of the convertible.

Let x_t denote the fraction of the convertible held by buy-and-hedge funds at time t and for simplicity assume that buy-and-hedge funds reduce their positions evenly through time such that their positions are completely closed by time $T^{'} \leq T$. Thus for $t \leq \tau \leq T^{'}, x_\tau = \left(\frac{T^{'}-\tau}{T^{'}-t}\right)x_t$. The buy-and-hedge funds short the quantity of shares that hedges changes in the value of the convertible holdings associated with changes in the value of the underlying shares. At time $t < T^{'}$ the funds will short Q_t shares, with Q_t determined as the solution to $-Q_t + \frac{\partial x_t CB_t}{\partial S_t} = 0$.

The larger the present value of the anticipated future cost of borrowing stock to sell short, the lower the price at which a buy-and-hedge fund would be willing to sell the bond on to a buy-and-hold investor. The effective cost of borrowing stock in order to short sell is the rate charged by the stock lender less any interest earned on the short sale proceeds. Let θ denote the effective borrowing rate, which for simplicity is assumed to be constant. The value of the stock borrowed in order to hedge is then $Q_t S_t = x_t \frac{\partial CB_t}{\partial S_t} S_t$ and the instantaneous cost of borrowing stock to hedge at time t is $\theta x_t \frac{\partial CB_t}{\partial S_t} S_t$. The aggregate stochastic future borrowing cost associated with hedging between times t and $T^{'}$ will be $\int_t^{T^{'}} \theta x_\tau \frac{\partial CB_\tau}{\partial S_\tau} S_\tau d\tau$. Thus, the present value at time t of this stochastic future borrowing cost is $\int_t^{T^{'}} \theta x_\tau PV_t\left(\frac{\partial CB_\tau}{\partial S_\tau} S_\tau\right) d\tau$, where $PV_t(\cdot)$ denotes the present value operator at time t. Online Appendix A proves that $PV_t\left(\frac{\partial CB_\tau}{\partial S_\tau} S_\tau\right)$ is equal to $\frac{\partial CB_t}{\partial S_t} S_t$ for all τ provided the payoff to the convertible can be replicated through a self-financing trading strategy involving the underlying stock and bonds. Thus, the present value at time t of the stochastic future cost of borrowing stock in order to implement a hedge between times t and $T^{'}$ is

$$\int_t^{T^{'}} PV_t\left(\theta x_\tau \frac{\partial CB_\tau}{\partial S_\tau} S_\tau\right) d\tau = \theta \int_t^{T^{'}} x_\tau PV_t\left(\frac{\partial CB_\tau}{\partial S_\tau} S_\tau\right) d\tau$$

$$= \theta \int_t^{T^{'}} \left(\frac{T^{'}-\tau}{T^{'}-t}\right) x_t \frac{\partial CB_t}{\partial S_t} S_t d\tau$$

$$= \theta \left(\frac{T^{'}-t}{2}\right) x_t \frac{\partial CB_t}{\partial S_t} S_t.$$

If buy-and-hedge investors' diminished willingness to intermediate due to the costs of borrowing stock were to reduce the convertible's market value by the present value of the future borrowing costs, then underpricing associated with borrowing costs would be

[1] Grundy and Verwijmeren (2016) demonstrate that nearly all convertible bonds issued since 2003 have been dividend-protected.

$$\begin{aligned} Underpricing_t &\equiv \frac{CB_t - market\ price\ of\ convertible_1}{CB_t} \\ &= \frac{PV_t(future\ stock\ borrowing\ costs)}{CB_t} \\ &= \theta\left(\frac{T' - t}{2}\right)x_t\frac{\frac{\partial CB_t}{\partial S_t}S}{CB_t} \\ &= \theta\left(\frac{T' - t}{2}\right)x_t\,\Omega_S^{CB}(t), \end{aligned} \tag{1}$$

where $\Omega_S^{CB}(t) \equiv \frac{\partial CB_t}{\partial S_t}\frac{S_t}{CB_t}$ is the elasticity at time t of the value of the convertible with respect to the stock price. In the remainder of the paper, we refer to the product $\theta\Omega_S^{CB}(t)$ as *Loan Costs*.

3. Data and methodology

3.1. Convertible bond sample

The Mergent Fixed Income Securities Database (FISD) contains information on 1226 plain-vanilla U.S. convertible bonds issued between July 2002 and December 2018, including details of design features and the bonds' credit ratings. The sample starts in July 2002. This is when the TRACE database of the Financial Industry Regulatory Authority (FINRA) began reporting transaction-level bond data.[2] The sample ends in 2018 to facilitate the analysis of post-issuance underpricing until 2020. The Mergent dataset is complemented with hand-collected information on put schedules and call prices from prospectuses available on the SEC Electronic Data Gathering, Analysis, and Retrieval (EDGAR) system and online news announcements. We delete 128 convertibles for which we are unable to determine the call schedule or which we could not match with CRSP stock price information on the issuing firm. After applying these filters, our sample consists of 1098 convertible bonds.

3.2. Empirical estimates of underpricing

Following prior convertible studies, our measure of convertible bond underpricing is the difference between the theoretical price of the convertible bond determined by a valuation model and the bond's market price, with the difference expressed as a fraction of the theoretical price. Like most studies of convertible bond pricing, we obtain our baseline results using theoretical prices based on a binomial-tree adaption of the Tsiveriotis and Fernandes (1998) model (henceforth, the TF model), which is also mostly used by practitioners (Zabolotnyuk et al., 2010). The TF model incorporates common design features like call and put provisions, which are redemption rights at the option of the issuer and the security holder, by adjusting the value function at nodes in a manner consistent with the call and put schedules at the node-date.

The main input parameters of the theoretical model are the risk-free rate, the credit spread, and the volatility of stock returns. The risk-free rate is set to the U.S. Treasury rate with a maturity closest to the maturity of the convertible bond. The credit spread is determined using yields of U.S. corporate bonds matched by the convertible's most recently observed credit rating. Treasury rates and corporate bond yields are obtained from St. Louis Federal Reserve Economic Data (FRED). For unrated convertible bonds, we use the most likely credit rating from an ordered logit model in which we regress the observed credit ratings in our sample on a convertible's offering amount, moneyness, maturity, whether it is privately placed, and the set of firm characteristics from Altman and Rijken (2004), Ashbaugh-Skaife et al. (2006), and Bae et al. (2015). Stock volatility is measured as the annualized standard deviation of daily stock returns measured over the year prior to the valuation date.

3.3. Costs of short selling

The main prediction of our study is that convertible bond discounts compensate arbitrage investors for the cost of subsequently maintaining the short positions necessary to hedge their holding of convertibles. Following from Section 2, our main variable of interest is *Loan Costs*, which is the product of the loan fee, being the rate that the arbitrageur pays the lender for borrowing the stock as available on Markit, and the convertible's elasticity, which represents the sensitivity of the value of the convertible bond in percentage terms with respect to percentage changes in the stock price.

In practice, loan fees only represent a fraction of total short-selling costs. One dimension of search costs that is difficult to theoretically model is the search cost involved in identifying and negotiating with stock lenders. Intuitively, search costs reduce the willingness of an intermediary to distribute the security. These costs will be determined by the supply of stocks available for shorting. From Markit, we therefore collect the active number of shares made available for borrowing scaled by total shares outstanding (*Loan Supply*).

Underpricing could also link to the relative liquidity of the convertible security. More precisely, underpricing might be affected by a difference in the liquidity of the convertible and that of the replicating stock-bond portfolio. The effects of stock and non-convertible bond illiquidity are automatically built into the TF model price of a payoff-equivalent portfolio of stock and non-convertible bonds. Any greater illiquidity of convertible bonds will not be reflected in the TF model price. Hence, our analysis includes a measure of the liquidity of the convertible itself, with the prediction that underpricing could in part be compensation to convertible investors for holding the relatively illiquid convertible.

The academic literature has proposed various measures of liquidity in corporate bond markets (Schestag et al., 2016). Since most convertible bonds are privately placed under SEC Rule 144A (Huang and Ramirez, 2010) and the buy/sell indicator is often missing for bonds traded on the SEC Rule 144A market, we focus on a measure that does not rely on this. We estimate the actual transaction costs using the Imputed Roundtrip Costs (*IRC*) measure developed by Feldhutter (2012). Bid-ask spreads are derived from consecutive trades occurring within short time intervals and with identical par volumes. These trades typically represent pre-matched roundtrip trades between investors and dealers combined with interdealer trades. The *IRC* is then calculated as the difference between the highest and lowest price among the roundtrip trades, divided by the midpoint price.

3.4. Sample characteristics

Table 1 reports summary statistics of our sample with all continuous variables winsorized at the 1% and 99% levels. Variable definitions appear in Appendix A. The typical convertible bond in our sample pays a coupon of 2.875%, has been outstanding for 2.5 years, and still has almost five years remaining until its stated maturity. Roughly half of the convertibles in our sample have a credit rating, which is consistent with convertible bonds being a popular choice for lower-quality firms with limited financing alternatives. Although prior to 2002 most convertible bonds were callable, only 38% of the convertibles in our sample of post-2002 issues are callable. This is consistent with the post-2000 role of arbitrageurs as buyers of newly-issued convertibles and arbitrageurs' preference for protection from calls (Grundy and Verwijmeren, 2018). The average *Elasticity* of the convertible's value with respect to the stock price is 0.473.

[2] The system was implemented in phases and completed by 2004. Beginning in 2014, the TRACE database started to also systematically cover transactions in bonds privately issued under SEC Rule 144A. The TRACE data is cleaned following the data filters described by Dick-Nielsen (2009, 2014). These filters delete double-reporting, cancellations and corrections, reversals, and agency trades that would otherwise bias market liquidity upwards.

Table 1
Sample Summary Statistics, This table shows monthly summary statistics of our sample of 1098 convertible bonds. Observations are at the bond-month level. Variable definitions are contained in Table A of the Appendix.

Variable	N	Mean	Median	$Q_{0.25}$	$Q_{0.75}$
Coupon (%)	34,120	3.040	2.875	1.750	4.000
Age (Years)	34,120	2.794	2.500	1.333	4.000
Time to Maturity (Years)	34,120	8.963	4.699	2.704	16.493
Moneyness	34,120	1.153	0.275	−0.068	0.900
Rated	34,120	0.478	0	0	1
Callable	34,120	0.382	0	0	1
Puttable	34,120	0.325	0	0	1
Underpricing (%)	34,120	1.601	0.546	−3.206	6.067
Elasticity	34,120	0.473	0.461	0.206	0.712
Vega / Theoretical price	34,120	0.313	0.333	0.154	0.465
Volatility	34,120	0.432	0.347	0.238	0.512
Loan fee (%)	32,168	1.294	0.375	0.375	0.500
Stock bid-ask spread (%)	34,120	0.149	0.077	0.039	0.149
Loan costs (%)	32,168	0.349	0.204	0.099	0.337
Trading costs (%)	34,120	0.037	0.021	0.008	0.044
Loan supply	31,409	0.194	0.202	0.123	0.270
# Trades	34,120	46.93	25.00	9.00	64.00
Volume ($M)	34,120	28.53	13.02	4.69	29.96
Turnover	34,120	0.076	0.054	0.025	0.100
Zero	34,120	0.472	0.478	0.150	0.773
IRC (%)	30,284	1.032	0.733	0.409	1.315

The average discount in the secondary market, defined as the volume-weighted average of daily underpricing within a month, is 1.60%. This discount is significantly different from zero (with a t-statistic, unreported, of 20.89). The average loan fee is 1.294%. The average fee is substantially higher than the median fee of 0.375%, indicating that a small number of firms have stocks that are particularly costly to borrow. Although the current loan fee on a firm's stock is correlated with expected future loan fees on that stock, there is also within-stock variation in loan fees (Engelberg et al., 2018), which facilitates a within-firm analysis of loan costs and underpricing.

The average effective bid-ask spread estimated with the *IRC* measure for our sample of convertible bonds is approximately 1%. Using the filtered TRACE data, we calculate several low-frequency liquidity measures. These measures are the number of trades, par value of bonds traded, the turnover ratio, and the probability that the bond is not traded on a given day. We denote this latter probability by *Zero* and estimate it as the fraction of trading days on which the convertible bond is not traded. The average (median) convertible bond is traded 47 (25) times per month. The average (median) monthly trading volume is 28.5 (13.0) million USD, corresponding to a turnover ratio of 7.6% (5.4%). The probability that a convertible bond does not trade on any given trading day is 47%. Interestingly, convertible bonds do not appear particularly illiquid when compared to non-convertible corporate bonds. Friewald et al. (2012) report that the average corporate bond is traded around 73 times per month, with a total volume of approximately 28 million USD, and has an estimated average effective bid-ask spread of 1.3%. Finally, the average supply of stocks available for shorting is 19.4% of the shares outstanding.

3.5. Implications of mean level loan costs for observed underpricing

Intermediary frictions are unlikely to be the only source of convertible underpricing. Chan and Chen (2007) argue that underpricing may be driven by the risk that the firm might renegotiate the convertible's covenants. Henderson and Tookes (2012) show that the network of the underwriter affects convertible discounts at issuance. In this section, we consider whether buy-and-hedge intermediaries' loan costs can explain a sizeable fraction of observed convertible bond underpricing by building on our theoretical model and using simple summary statistics.

Intuitively, the present value of the total future stock lending fees on the shares sold short to hedge (as a fraction of the convertible's theoretical price) is approximately the product of the annual loan rate on the stock borrowed to short sell and the current value of the shares sold short to hedge times the number of years before the short position is closed out. In order to hedge the entire issue against a 1% change in the stock's value, which would be associated with a $\Omega_S^{CB}(t)$% change in the convertible's value, one would need to short stock with a value equal to the fraction $\Omega_S^{CB}(t)$ of the value of hedge fund's position in the convertible. If hedge funds reduce their positions evenly through time, then an estimate of the average number of years over which short positions will be held is one half the number of years taken for the hedge fund to completely close out its position. Suppose hedge funds initially acquire 75% of the typical new convertible bond issue (Mitchell et al., 2007; Brown et al., 2012) and close out their positions evenly through time. From Table 1 we see that the mean stated life at the time of issue is the sum of the mean age and the mean time to maturity, i.e., 2.794 + 8.963 = 11.757 years. In practice, the majority of convertibles are no longer outstanding after five years (Brown et al., 2012). If we take five years as a measure of the practical life of a convertible, an estimate at a random point during a convertible's life of the expected number of years over which some portion of a convertible will continue to be held by hedge funds is ½ × 5 = 2.5 years. The fraction of the convertible held by hedge funds at that random point is ½ × 75% = 0.375. Given the Table 1 values of mean loan fees of 1.294% and mean convertible bond *Elasticity* of 0.473, an estimate of the expected future borrowing costs incurred by hedge funds as a fraction of the theoretical value of a convertible is

$$1.294\% \times 2.5 \times 0.375 \times 0.473 = 0.574\%.$$

The observed mean *Underpricing* level reported in Table 1 is 1.601%. Thus, based on these simple calculations, hedge funds' borrowing costs can potentially explain a sizeable fraction (0.574 / 1.601 = 36%) of observed convertible bond underpricing.

3.6. Alternative model specifications

Our use of the TF model is motivated by its popularity among academic researchers and practitioners (Zabolotnyuk et al., 2010). Nevertheless, the output of the model is sensitive to methodological choices. Credit spreads and stock return volatility are two important input parameters of the TF pricing model. In the baseline analysis, the credit spread is derived from bond yields matched to the credit rating of the convertible. These bond yields may not fully incorporate the effect of embedded options on the effective yield on a bond. We use the "Option-Adjusted Spread" (OAS) matched by credit rating as an alternative estimate of the credit spread. The OAS adjusts the credit spread for embedded options. It might thus be a more suitable input measure when valuing convertible bonds, as these bonds contain conversion rights, call provisions, and put provisions. We obtain OAS data from the St. Louis FRED. In addition, in the baseline analysis we estimate the most likely rating for unrated bonds. For an alternative measure of underpricing, we follow De Jong et al. (2011) and assign the credit spread of BBB-rated bonds to unrated convertible bonds.

In the baseline analysis, we measure stock return volatility using the historical standard deviation of stock returns over the year prior to the convertible's issue. An alternative volatility measure is the implied volatility of at-the-money stock options with maturities that provides the closest match with the convertibles' maturities. Implied volatility is forward-looking and can be viewed as a gauge of investor beliefs about future volatility. Option data is obtained from OptionMetrics. A shortcoming of using option-implied volatility is that the sample size is reduced, as some convertible issuing firms do not have listed options.

Table 2 contains summary statistics of underpricing calculated using alternative measures of theoretical prices. We refer to these alternative measures as OAS, BBB, and IVOL. The average level of underpricing

Table 2
Convertible Underpricing with Alternative Theoretical Prices, This table shows statistics of the distribution of convertible bond underpricing measures calculated using alternative theoretical price estimators. In the upper (first) panel, theoretical prices are estimated using the Tsiveriotis and Fernandes (1998) model with option-adjusted spread. In the second panel, theoretical prices are estimated using the Tsiveriotis and Fernandes (1998) model when unrated convertible bonds are assigned a BBB credit rating. In the third panel, theoretical prices are estimated using the Tsiveriotis and Fernandes (1998) model with the option-implied volatility. In the lower panel, the model of Finnerty (2015) is used to determine theoretical prices. ρ is the correlation of the alternative underpricing measures with the baseline underpricing measure.

Variable	N	Mean	Median	$Q_{0.25}$	$Q_{0.75}$	ρ
OAS:						
Secondary Market Underpricing	34,120	2.911%	1.352%	−2.125%	7.439%	0.995
BBB:						
Secondary Market Underpricing	34,120	4.396%	2.202%	−1.449%	9.150%	0.931
IVOL:						
Secondary Market Underpricing	27,421	0.178%	0.160%	−3.186%	4.456%	0.928
Finnerty:						
Secondary Market Underpricing	34,120	3.519%	1.885%	−1.683%	8.098%	0.970

tends to be affected by the specific choices that we make. Importantly though, the alternative measures of underpricing are highly correlated with our baseline measure, with correlation coefficients of 0.928 or higher.

Finally, we use the theoretical model developed by Finnerty (2015) to estimate convertible bond underpricing. The Finnerty (2015) model incorporates stochastic interest rates and credit spreads, whereas the TF model assumes these to be constant. Finnerty (2015) derives a closed-form solution for the value of the exchange option and uses iterative procedures to adjust the value of the convertible bond for call and put provisions. Table 2 shows that underpricing estimates with the Finnerty model prices are higher than our baseline measure, but they remain highly correlated (0.970).

In the next section, we turn to an investigation of panel data on *Underpricing*, borrowing costs, and proxies for search costs and the relative liquidity of convertibles. Online Appendix B includes robustness tests that employ the alternative price measures described above.

4. Results

4.1. Determinants of convertible bond underpricing

We start our analysis by examining the link between underpricing in the secondary market and metrics for the borrowing costs of hedging. We construct a monthly panel of convertible bond underpricing using volume-weighted average daily underpricing during the five years after issuance. This approach controls for movements in convertible bond prices driven by movements in equity prices, credit spreads, and interest rates after the issuance of the convertible. In Model 1 of Table 3, the main explanatory variable of interest is *Loan Costs*, following from Section 2. The other explanatory variables in the regression specification are proxies for search costs (*Loan Supply*) and the relative liquidity of convertibles (*IRC*).

Although explaining cross-firm differences in underpricing has been the focus of much of the underpricing literature examining corporate financing (see, e.g., Corwin 2003, Cai et al. 2007, Ljungqvist 2007), an analysis of convertible underpricing allows for model estimations that include firm fixed effects. These firm fixed effects control for time-invariant heterogeneity and allow us to study within-firm variation. Model 2 adds firm fixed effects and year-month fixed effects to the regression specification. In addition, as our analysis is on a monthly level, Model 2 includes controls that can vary on a monthly level. These variables are stock return volatility, the convertible's moneyness, credit rating dummies, and firm size as measured by the natural logarithm of the market value of equity. For completeness, we also include the monthly stock return, even though this variable is largely captured by changes in moneyness and firm size.

Table 3
Regression Results of Secondary Market Underpricing, This table shows the results of multivariate regressions of monthly convertible bond underpricing. Variable definitions are contained in Table A of the Appendix. Standard errors are two-way clustered at the firm and year-month-level. *, ** and *** indicate significance at the 10% level, 5% level, and 1% level, respectively.

	(1)	(2)	(3)
Loan Costs	1.677***	0.896***	0.766***
	(0.413)	(0.264)	(0.208)
Loan Supply	−0.214***	−0.097*	−0.139***
	(0.032)	(0.052)	(0.034)
IRC	2.179***	0.859***	0.767***
	(0.404)	(0.166)	(0.123)
Volatility		0.052***	0.038***
		(0.010)	(0.008)
Moneyness		0.006***	0.007***
		(0.001)	(0.001)
Firm size		−0.029***	−0.031***
		(0.007)	(0.007)
Stock return		0.020**	0.016**
		(0.008)	(0.008)
Rating dummies	No	Yes	Yes
Time FE	No	Yes	Yes
Firm FE	No	Yes	No
Bond FE	No	No	Yes
Observations	24,565	24,560	24,540
Adj. R^2	0.085	0.578	0.687

Table 3 shows the results of these estimations. Standard errors are two-way clustered at the firm- and year-month-level.

We find that the relation between *Loan Costs* and secondary market underpricing is positive, indicating that higher fees are associated with higher underpricing, in line with a relevance of convertible arbitrageurs in setting prices in the secondary market for convertible bonds. This relation is statistically significant at the 1% level across specifications. The economic magnitude of the relation reduces as more controls are added to the regression specification. The coefficient of 0.896 in Model 2 suggests that a one percentage point increase in the fee to borrow a stock would be expected to lead to an increase in the underpricing of a convertible bond with an elasticity equal to the sample mean by $0.896 \times 0.473 = 0.424\%$.

Due to search costs, underpricing is expected to depend on the supply of stocks available for shorting. The relation between *Loan Supply* and secondary market underpricing is negative and significant at the 1% level in Model 1, indicating that the higher search costs implicit in a lower lending supply is associated with higher underpricing. This result is also in line with short-selling frictions being an important cost of intermediation. The relation remains apparent in Model 2, although the statistical significance drops, and we can only reject the null hypothesis of no relation at a 94% confidence level. The estimated coefficient on the *Loan Supply* variable of −0.097 implies that a one percentage point increase in *Loan Supply* is expected to lead to a decrease in the underpricing of a convertible bond of 0.097%.

We predict and observe a positive relation between the convertible bond's illiquidity as measured by *IRC* and our measure of underpricing. This relation is statistically significant at the 1% level, also after controlling for firm and year-month fixed effects. We further find that underpricing is particularly severe when stock price volatility and moneyness is high and when the market value of equity and stock returns are relatively low.

Our sample includes 540 different firms, which means that some firms have multiple convertible bonds outstanding over our sample period. In Model 3 of Table 3, we re-estimate the regression specification by replacing firm fixed effects with bond fixed effects. This specification absorbs fixed differences across bonds over time. We find similar results. In terms of statistical significance, the only difference is that *Loan Supply* has a statistically more significant effect in the specification with bond fixed effects than with firm fixed effects. The main takeaways from the results remain the same.

The main conclusion from Table 3 is that both cross-sectional and within-firm or within-bond variation of intermediaries' loan costs over time helps explain the observed variation in convertible bond underpricing. The supply of stocks available for shorting and the convertible's liquidity also appear to play a role in explaining convertible underpricing.

5. Exploiting within-firm-month differences

The baseline analyses in Section 4 control for both firm- or bond-specific differences and time-varying variables. A potential concern that affects the interpretation of our findings is that the measure of *Loan Costs* may reflect an information asymmetry surrounding the firm, or that loan costs relate to temporarily overpriced stocks. To facilitate the interpretation of our findings, subsequent sections compare the *Underpricing* of different convertible bonds by the same firm with each other at the same time, so that the information asymmetry surrounding a firm and potential stock overpricing can be held constant. Our sample contains 114 firms that have multiple convertible issues outstanding in at least one month during the sample period.

To test our predictions, we perform a regression with firm-month fixed effects. These fixed effects capture time-varying firm-level heterogeneity, such that we have the cleanest setting and are effectively comparing different convertible bonds by the same firm at the same time. Based on Section 2, variation within a firm-month can be caused by variation in a bond's *Elasticity* so the relation of *Underpricing* with *Loan Costs* can be investigated holding the firm-month fixed. Other variables, such as *Loan Supply,* drop out when we include firm-month fixed effects, as they have no variation within a firm-month and are fully absorbed by the firm-month fixed effects. Table 4 shows the results.

In line with our predictions, we find that the coefficient of the bond-level *Loan Costs* measure in Model 1 is positive. The estimate implies that a one percentage point increase in the fee to borrow a stock would be expected to lead to an increase in the underpricing of a convertible with an elasticity equal to the sample mean of $2.227 \times 0.473 = 1.053\%$. The effect is statistically significant at the 5% level. This result relies on bond-specific characteristics linked to the cost of shorting and are consistent with our results being driven by intermediary frictions rather than by firm characteristics, i.e., short-selling costs are a relevant determinant of pricing among different convertible bonds issued by the same firm.

The other variables that were included in Table 3 and that can vary within a firm-month are the liquidity of a convertible and the moneyness of a convertible. Neither variable has a significant relation with underpricing once we control for firm-month fixed effects.

Table 4
Within-Firm-Month Analysis, This table shows the results of multivariate regressions of monthly convertible bond underpricing in the secondary market. Variable definitions are contained in Table A of the Appendix. The regressions include rating dummies and firm-month fixed effects. Standard errors are two-way clustered at the firm and year-month-level. *, ** and *** indicate significance at the 10% level, 5% level, and 1% level, respectively.

	(1)	(2)	(3)	(4)
Loan Costs	2.227**	1.790**	5.819***	4.068***
	(1.002)	(0.800)	(1.330)	(1.247)
*Loan Costs * Age*			−1.412***	−0.850**
			(0.384)	(0.340)
IRC	0.048	0.113	0.046	0.095
	(0.418)	(0.415)	(0.415)	(0.415)
Moneyness	−0.007	−0.008	−0.008	−0.008
	(0.007)	(0.007)	(0.007)	(0.007)
Age		−0.011***		−0.008*
		(0.004)		(0.004)
Observations	6579	6579	6579	6579
Adj. R^2	0.761	0.770	0.768	0.772

6. The convertible's age

Two convertibles of the same firm observed at the same time can differ in their time since issuance. More specifically, when the intermediation process involves buy-and-hedge intermediaries reducing their position in a bond through time, the percentage of an issue held by intermediaries will differ between differentially aged convertibles issued by the same firm.

Our predictions on the effects of a convertible's age follow from our theoretical model in Section 2. The borrowing cost component of underpricing at time *t* can be viewed intuitively as the product of the length of the hedge and the annual cost of the hedge. The appropriate measure of the length of the hedge is the weighted average number of years over which the hedgers' position at time *t* is expected to be closed out, with weights given by the fraction of the position still held at each point in time. When arbitrageurs reduce their positions evenly through time, the weighted average length of the hedge is $(\frac{T'-t}{2})x_t$, where x_t is the fraction of the convertible held at time *t*. *Underpricing* at a point in time will reflect the fraction of the bond still held by buy-and-hedge intermediaries and the expected time to fully close out the position. Since the fraction of the convertible held by buy-and-hedge funds at time *t* and the anticipated time until the position is fully closed out will both be reducing with the age of the convertible, the model in Section 2 predicts that the positive link between *Loan Costs* and secondary market underpricing decreases as the time since issuance increases. The setup in Table 4 is well suited to examining predictions on the convertible's age, as it allows us to keep other factors constant within a firm-month.

In Model 2 of Table 4, we simply add the convertible's *Age*, measured in years, to the regression specification. This addition does not change our conclusions on the effect of *Loan Costs*, which remains positive and statistically significant at the 5% level. The convertible's age itself is negatively linked to secondary convertible underpricing, in line with findings in Chan and Chen (2007).

In Model 3, we test the prediction of our model that the positive effect of *Loan Costs* decreases as the convertible's age increases. To link closely to the theoretical model in Section 2, we include the standalone *Loan Costs* variable and the interaction term of *Loan Costs* and *Age.* We observe a positive effect of the standalone *Loan Costs* variable, while the interaction term of *Loan Costs* and *Age* obtains a negative coefficient. The estimates of Model 3 imply that a one percentage point increase in the fee to borrow a stock would be expected to lead to an increase in the underpricing of a two-year old convertible with an elasticity equal to the sample mean of $5.819 \times 0.473 - 1.412 \times 0.473 \times 2 = 1.42\%$.

In Model 4, we add the standalone variable *Age.* Even though our model in Section 2 assigns no specific role for this standalone variable, including *Age* separately facilitates the interpretation of the interaction term between *Loan Costs* and *Age*. The standalone variable *Age* has a negative coefficient. In line with our predictions, and similar to the results in Model 3, we find a positive effect of the standalone *Loan Costs* variable and a negative effect of the interaction term of *Loan Costs* and *Age*.

7. Trading costs

The dynamic nature of convertible arbitrage requires that short positions be rebalanced frequently (Calamos, 2003; Choi et al., 2009). More specifically, buy-and-hedge intermediaries need to adjust their positions after changes in the issuer's stock prices. After an increase in the stock price, the optimal delta-neutral hedge ratio increases, and the optimal short position becomes larger. Vice versa, after a decrease in the stock price, the optimal delta-neutral hedge ratio decreases, and the optimal short position becomes smaller. These adjustments lead to trading costs, which could influence observed discounts due to a reduced willingness by buy-and-hedge intermediaries to acquire and hedge a convertible when trading costs are substantial.

The cost of trading to hedge the value of the convertible depends on the frequency with which the hedge is adjusted. To perfectly hedge would require trading continuously and, at any positive level of transactions costs, the transactions costs would be infinite. The transactions costs of a feasible hedge will depend on the quality of the hedge. Leland (1985) determines an approximation for the costs of hedging when the interval between revisions is Δ and the percent transactions cost of trading the hedging instrument is k. Using this approximation, the present value of the per annum future transactions costs of hedging a convertible's right to convert expressed as a fraction of CB_t is $k\frac{\frac{\partial CB_t}{\partial \sigma}}{\sqrt{2\pi\Delta}}/CB_t$, where $\frac{\partial CB_t}{\partial \sigma}$ is the convertible's vega at time t. When hedge funds hold the fraction x_t of the convertible at time t and their convertible holdings are reduced evenly through time to zero at time $T^{'}$, then *Underpricing* as a result of the trading costs of future hedging is

$$\left(\frac{T^{'}-t}{2}\right)x_t k\frac{\frac{\partial CB_t}{\partial \sigma}}{\sqrt{2\pi\Delta}}\Bigg/CB_t. \quad (2)$$

As such, the annual costs of the hedge relate to annual transactions costs measured as a fraction of the convertible's price, i.e., to $k\frac{\frac{\partial CB_t}{\partial \sigma}}{\sqrt{2\pi\Delta}}/CB_t$.

Table 5
Trading Costs, This table shows the results of multivariate regressions of monthly convertible bond underpricing in the secondary market. Variable definitions are contained in Table A of the Appendix. The regressions include rating dummies and firm-month fixed effects. Standard errors are two-way clustered at the firm and year-month-level. *, ** and *** indicate significance at the 10% level, 5% level, and 1% level, respectively.

	(1)	(2)	(3)
Trading Costs	33.718*	36.151**	10.269
	(19.373)	(17.854)	(19.009)
*Trading Costs * Age*		−10.789**	−3.667
		(4.433)	(4.811)
Loan Costs	1.982**		4.058***
	(0.890)		(1.233)
*Loan Costs * Age*			−0.847**
			(0.345)
IRC	0.005	0.152	0.093
	(0.408)	(0.361)	(0.403)
Moneyness	−0.006	−0.009	−0.008
	(0.006)	(0.007)	(0.007)
Age			−0.007
			(0.005)
Observations	6579	7100	6579
Adj. R^2	0.763	0.756	0.772

We denote the $k\frac{\frac{\partial CB_t}{\partial \sigma}}{CB_t}$ measure as *Trading Costs*.

Empirically, we calculate *Trading Costs* as the cost of trading the underlying stock as a consequence of managing a dynamically-hedged position multiplied by the bond's vega scaled by the theoretical price of the convertible bond. Vega is the sensitivity of the value of the convertible bond with respect to stock return volatility. We proxy the cost of trading the stock with the CRSP bid-ask spread, which, as shown by Chung and Zhang (2014), should provide an informative spread estimate.

To get a sense of whether buy-and-hedge intermediaries' trading costs can explain a sizeable fraction of observed convertible bond underpricing, we first examine sample means. From Table 1 we observe that an estimate of mean transactions costs given by the stock's bid-ask spread is 0.149% and the mean value of *Vega* relative to the convertible's theoretical value is 0.313. If the hedge is adjusted once each trading day, then expression (2) yields an estimate at a random point during a convertible's life of the expected future transactions costs incurred by hedge funds as a fraction of the theoretical value of the convertible as

$$\frac{2.5 \times 0.375 \times 0.149 \times 0.313}{\sqrt{2\pi/250}} = 0.276\%.$$

Given the observed mean *Underpricing* level of 1.601%, trading costs potentially explain roughly 17% (0.276% / 1.601%) of observed convertible bond underpricing.

In Model 1 of Table 5, we add *Trading Costs* to our paper's main specification, which was shown in Model 1 of Table 4. Hence, this specification includes proxies for both *Loan Costs* and *Trading Costs*, firm-month fixed effects, and other controls. We find that *Trading Costs* has a positive relation to convertible underpricing. Statistically, the relation is marginally significant, at the 10% level. A coefficient of 33.718 implies that a tenth of a percentage point increase in the round-trip trans actions cost of trading stock to hedge a convertible would be expected to lead to an increase in the underpricing of a convertible whose vega relative to market value equals the sample mean of this ratio by $(33.718 \times 0.1 \times 0.313)\% = 1.056\ \%$. The relation between *Loan Costs* and underpricing remains statistically significant at the 5% level.

In Model 2 of Table 5, we link more closely to Eq. (2) and include the interaction between *Trading Costs* and *Age,* without considering loan costs. In line with an importance of buy-and-hedge intermediaries' trading costs, *Trading costs* as a standalone variable obtains a positive coefficient, whereas this positive effect reduces as the convertible's age increases, as the interaction term of *Trading Costs* and *Age* obtains a negative coefficient. Both the standalone variable *Trading Costs* and the interaction with *Age* have effects that are statistically significant at the 5% level. The estimates of Model 2 imply that a tenth of a percentage point increase in the round-trip transactions cost of trading stock to hedge a convertible would be expected to lead to an increase in the underpricing of a two-year old convertible whose vega relative to market value equals the sample mean of this ratio by $(36.151 - 10.789 \times 2) \times 0.313 \times 0.1\% = 0.456\%$.

In Model 3 of Table 5, we add *Trading costs* and the interaction between *Trading Costs* and *Age* to Model 4 of Table 4, so that the specification includes the standalone variables *Trading Costs, Loan Costs*, and *Age*, and the interactions of *Trading Costs* and *Loan Costs* with *Age*. The results show that *Loan Costs* and *Loan Costs* x *Age* remain to have statistically significant effects in this specification. The other variables' coefficients continue to have the expected signs but are not statistically significant. As such, when comparing the relevance of the trading costs of the hedge to the loan costs of the hedge, the loan costs involved in convertible arbitrage appear to be a more robust determinant of convertible underpricing. Estimates for the effects of loan costs and trading costs based on Eqs. (1) and (2) also indicate that loan costs are a more important determinant of underpricing, as we estimated that *Loan Costs* could explain about 36% of observed convertible bond underpricing (see Section 3.5), which is more than double the estimated extent to which trading costs potentially explain convertible underpricing (17%).

8. Causality and robustness tests

8.1. The 2008 short-sale ban

In this section, we study convertible underpricing when there is a shock to the costs of following the strategy of buy-and-hedge intermediaries. Between September 18 and October 8 of 2008, U.S. regulators prohibited the short selling of the stock of financial firms. The 2008 short-sale ban aimed to prevent speculators from driving down stock prices, but simultaneously introduced challenges for convertible arbitrageurs in implementing their hedging strategy. If convertible bond discounts compensate arbitrageurs for the cost of managing their short positions, we predict that the underpricing of convertible bonds issued by firms whose stock were subject to the ban would be higher during the ban period.

To isolate the effect of the short-sale ban on the pricing of convertible bonds issued by firms subject to the short-sale ban, we use a difference-in-difference regression to examine daily measures of convertible bond underpricing around the ban period. The sample starts on September 1, 2008, and ends on the last day of the short-sale ban. We include convertible bond fixed effects to account for heterogeneity across bonds and trading-day fixed effects to absorb general trends in underpricing in the convertible bond market.

The key result from our analysis, which we report in more detail in Online Appendix C, is that the interaction effect between the short-sale ban dummy and the banned stock dummy is significantly positive. Our estimates indicate that the disruption of arbitrageurs' ability to short sell the stocks of a firm coincided with a 3 percentage point increase in the underpricing of convertible bonds issued by firms subject to the ban.

8.2. Robustness analysis

The Online Appendix also contains robustness analyses in which we re-estimate the specifications in this paper. In a first test, we analyze whether our observed effects are representative of normal periods and are not unique to crisis periods in the convertible bond market. The second to fifth robustness tests use the alternative measures of underpricing discussed in Section 3.6. The alternative underpricing measures are based on option-adjusted spreads, BBB credit ratings for unrated convertibles, implied volatilities, and the Finnerty (2015) valuation model. We find that our main results are robust to excluding crises periods and to the choice of underpricing measure.

9. Conclusion

This paper investigates the importance of frictions in financial intermediation by examining the pricing of convertible bonds. Buy-and-hedge convertible arbitrage hedge funds are important players in the convertibles market. These convertible arbitrage funds distribute the security, intermediating between firms that require capital quickly and investors requiring time to assess the security.

We model the effect of arbitrageurs' hedging costs, in particular costs related to stock loan fees, on convertible underpricing and find that observed convertible bond prices reflect the stock loan fees that the arbitrageurs incur when managing their positions. Our empirical analysis establishes that underpricing is significantly higher for bonds convertible into stock that is more expensive to short sell. We also find some evidence that underpricing is higher when loan supply is lower, the convertible bond is more illiquid, and the transactions costs of the stock trading necessary to hedge are higher. As predicted by our model, the sensitivity of underpricing to stock loan fees diminishes significantly as convertibles age, i.e., when arbitrageurs face a shorter time over which they will bear the future costs of hedging their remaining holdings.

A causal interpretation of our findings is supported by a within-firm-month analysis that compares different bonds issued by the same firm and by a difference-in-difference analysis of the effect of the 2008 short-sale ban-induced increase in the cost of hedging. Our results suggest that regulators should seriously consider providing an exemption for short sales relating to convertible arbitrage activity when they are contemplating the introduction of a new short-sale ban.

CRediT authorship contribution statement

Bruce D. Grundy: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Conceptualization. **Patrick Verwijmeren:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antti Yang:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

Data availability

The authors do not have permission to share data.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jfi.2024.101085.

Appendix A

Table A
Variable definitions. This table contains definitions of the underpricing, short-selling costs, liquidity, and control variables that are used throughout the paper.

Variable	Definition
Coupon (%)	The annual coupon rate that the issuer must pay to the holder of the convertible
Age	Number of years that have elapsed since the bond was issued
Time to Maturity	The number of years to the stated maturity of the convertible bond
Moneyness (%)	The difference between the conversion price and the stock price as a percentage of the stock price
Rated	A dummy indicating whether the convertible is rated by a credit rating agency
Callable	A dummy indicating whether the convertible can be called at the discretion of the issuer
Puttable	A dummy indicating whether the convertible contains a put provision
Underpricing	The difference between the convertible's theoretical value determined using the Tsiveriotis and Fernandes (1998) model and the market price, divided by the theoretical value

(continued on next page)

Table A (*continued*)

Variable	Definition
Elasticity	$Elasticity = \frac{\ln(Theoretical\ Price_{TF,\ Up}\ /\ Theoretical\ Price_{TF,\ Down})}{\ln(Stock\ Price_{Up}\ /\ Stock\ Price_{Down})}$, where $Stock\ Price_{Up}$ ($Stock\ Price_{Down}$) represents the stock price following a 1 % increase (decrease) and $Theoretical\ Price_{TF,\ Up}$ ($Theoretical\ Price_{TF,\ Down}$) represents the corresponding convertible bond values according to the TF model.
Vega/Theoretical Price	$Vega/Theoretical\ Price = \frac{\ln(Theoretical\ Price_{TF,\sigma+0.1}\ /\ Theoretical\ Price_{TF})}{0.1}$, where $Theoretical\ Price_{TF,\ \sigma+0.1}$ represents the convertible bond value with a standard deviation that increases with 0.1.
Volatility	The annualized standard deviation of daily stock returns
Loan Fee (%)	The rate that the short seller must pay to the lender in return for borrowing the stock
Bid-Ask Spread Stock (%)	The CRSP quoted bid-ask spread of the stock
Loan Costs	The product of the Loan Fee (%) and Elasticity
Trading Costs	The product of Bid-Ask Spread Stock (%) and Vega/Theoretical Price
Loan Supply	The number of stocks actively made available for lending divided by total stocks outstanding
# Trades	The number of times a convertible bond was traded over a given time period
Volume ($M)	The par trading volume of a convertible bond over a given time period
Turnover	The par trading volume of a convertible bond over a given time period divided by the offering amount
Zero	The number of trading days that the convertible remained untraded over a given time period, expressed as a percentage of the total number of trading days
IRC (%)	The imputed roundtrip costs measure of the bid-ask spread proposed by Feldhutter (2012)

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