Product Market Competition and Option Prices

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Abstract

Most firms face some form of competition in product markets. The degree of competition a firm faces feeds back into its cash flows and affects the values of the securities it issues. We demonstrate that, through its effects on stock prices, product market competition affects the prices of options on equity naturally and leads to an inverse relationship between equity returns and volatility, generating a negative volatility skew in option prices. Using a large sample of U.S. equity options, we provide empirical support for this finding and demonstrate the importance of accounting for product market competition when explaining the cross-sectional variation in option skew.

Keywords: Product market competition; Investment; Leverage effect; Option skew.

JEL Classification Numbers: G13; G31; G32.

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On September 29, 2016, *The Guardian* reported that “oil and share prices rose after OPEC members struck a deal to limit crude output for the first time since 2008, in an attempt to ease the global glut that [had] more than halved crude prices.” On the same day, Citigroup analysts indicated that “sustained higher oil prices, all else equal, could see U.S. [shale] production increase again, and hence limit the oil price move […], absent a demand driven move.” As this event starkly illustrates, firms interact in product markets to generate cash flows. These cash flows are in turn priced in financial markets, determining stock prices and returns. This direct link between product market competition and stock prices has been ignored in the equity option pricing literature. Our paper shows that, through its effects on stock prices, product market competition naturally leads to an inverse relationship between equity returns and subsequent volatility changes, thereby providing a potential explanation for the observed negative option skew. It also demonstrates the importance of accounting for competition when explaining the cross-sectional variation in option skew, defined as the difference between implied volatilities of out-of-the-money and at-the-money calls. To the best of our knowledge ours is the first paper that bridges the gap between corporate finance theory and the option pricing literature by endogenizing the underlying volatility process and linking its parameters to the intensity of competition in product markets.

The standard starting point for option pricing models is to specify an exogenous process for underlying stock prices. In the Black and Scholes (1973) model, stock prices are lognormally distributed and the volatility of stock returns is constant, but this specification has been empirically rejected. Notably, a robust pattern in the data is that stock return volatility increases after stock prices fall, a phenomenon coined as the leverage effect in the option pricing literature.\(^1\) In this paper, we show that product market competition provides a natural economic mechanism for this enduring empirical regularity and can thus potentially explain the negative option skew. We do so by constructing a dynamic model in which firms compete in product markets and by showing how product market competition affects the (endogenous) volatility of stock returns as well as option prices and implied volatilities.

We start by analyzing a setup in which firms face perfect competition. To do so, we consider

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\(^1\)This empirical regularity has been first attributed to financial leverage by Black (1976). The evidence on this financial leverage channel is mixed however. See the discussion of the related literature below.
a model in which, output and stock prices are lognormally distributed absent competition (so that there is no option skew absent competition), but allow for free and irreversible entry by new, homogenous firms at a cost. In this model, each firm’s optimal entry strategy depends on its expectation of future output prices. In turn, future output prices are contingent on the policies that firms pursue. We first derive the value of all-equity firms in this economy and show that product market competition implies that the stock return volatility is negatively related to stock price. Notably, as output and stock prices rise, the entry of new competitors becomes more likely. The anticipated increase in supply attenuates the effects of demand volatility on the output price and equity value, implying that stock return volatility decreases after equity value increases. Using the resulting endogenous stochastic process for equity prices, we then derive a closed-form formula for European call options on the firm’s equity and show that the mechanism described above naturally leads to negative option skew, in that the Black-Scholes implied volatility for at-the-money calls exceeds the implied volatility for out-the-money calls. Lastly, we also show with the model that the competition effect on option skew is stronger when the underlying economic uncertainty is larger.

After demonstrating the effects of perfect competition on option skew, we show that the intuition developed within the perfect competition model for all-equity firms also applies when firms are levered or face imperfect competition. Considering first the effects of financial leverage, we show that as demand for the firms’ output decreases, cash flows decrease and firms become more highly leveraged given a fixed level of debt outstanding, leading to a higher equity return volatility. We also show that this increase in volatility due to increased leverage is separate from the competition effect and mostly relevant for firms close to financial distress. Considering next imperfect competition, we relax our assumption of free entry and look instead at the effects of varying the number of firms in the industry on the relation between stock returns and volatility and on option skew. In this model, firms still compete to offer a homogenous product in a market where demand is stochastic. However, an increase in

\footnote{While we assume throughout our analysis that production costs are zero, similar intuition applies to operating leverage which increases equity risk following negative cash flow shocks when firms are not endowed with contraction options (i.e. when firms cannot scale down). See e.g. Carlson, Fisher, and Giammarino (2004), Aguerrevere (2009), or Lambrecht, Pawlina, and Teixeira (2016). Recent research by Hackbarth and Johnson (2015) shows that combining real options (e.g. expansion and contraction options) with operating leverage leads to a non-monotonic relation between profitability, operating leverage, and risk.}
demand does not lead to entry but to investment in capacity by incumbents at a cost. In this setup, we show that competition feeds back in the firms’ investment strategy and affects stock returns and prices. Notably, as demand for the good produced by firms increases, additional capacity is added via investment, which tends to reduce risk. At the same time, the firms’ growth options become more in the money, thereby increasing risk. As competition increases, the value of growth options decreases and the second effect weakens, implying that more competition decreases option skew. As in the model with perfect competition, this effect gets reinforced by the level of underlying uncertainty.

We proceed by empirically testing our main hypothesis for a negative relation between option skew and the intensity of product market competition. In this analysis, we use a large sample of individual U.S. equity options from 1996 to 2014 and define option skew as the difference between implied volatilities of out-of-the-money and at-the-money calls, where we use implied volatilities provided by IvyDB Optionmetrics. We then test whether option skew is related to product market competition, as measured by the product market fluidity measure of Hoberg, Phillips, and Prabhala (2014), the text based Herfindahl-Hirschman Index (HHI TNIC) of Hoberg and Phillips (2016), or the number of firms in the industry.

Consistent with our main hypothesis, we find that the effect of product market fluidity, our main proxy for competition, on option skew is negative and highly significant in all specifications. The effect of competition is also economically large – keeping everything else constant, a firm in a perfectly competitive industry has an option skew approximately 33 basis points below that in a monopoly industry. Our analysis also demonstrates the robustness of our main result to the use of alternative competition measures. In addition, consistent with the leverage effect, the coefficients on financial leverage are also negative and statistically significant.

In our model, option skew depends not only on the intensity of product market competition but also on the level of underlying uncertainty. In additional tests, we thus enrich our empirical specification by interacting our measures of competition with a dummy variable indicating a high volatility environment. Consistent with our prediction, we find that the coefficients on this interaction term are negative and statistically significant. In addition, the coefficient on the intensity of product market competition itself is also negative and significant. These
results demonstrate that while there is a negative effect of product market competition on the option skew, this effect is stronger when aggregate volatility is high. We also examine whether barriers to entry, which should limit competition, affect option skew. Consistent with our hypothesis, coefficients on the interaction terms of barriers to entry and fluidity are positive and highly statistically significant in all regressions specifications.

To strengthen the interpretation of the results, we also implement a differences-in-differences analysis around an exogenous shock to the competitiveness of the US manufacturing industries. The goal of this analysis is to validate our empirical results in a setting that, by design, reduces endogeneity concerns. To do so, we explore the effects of the U.S. granting of Permanent Normal Trade Relations (PNTR) to China, which was passed by Congress in October 2000 and became effective upon China’s accession to the WTO at the end of 2001. This PNTR status ended the uncertainty associated with annual renewals of China’s NTR status and reduced the expected import tariffs applied to China, thereby increasing competition for US manufacturing industries. Consistent with our main hypothesis of a negative relation between competition and option skew, we find that the option skew for firms in manufacturing industries decreased by about 50 to 90 basis points relative to firms in non-manufacturing industries following the granting of the PNTR status to China.

This paper is part of a larger literature that links industrial organization to issues in financial economics (see Lambrecht (2001), Garlappi (2004), or Miao (2005) for recent contributions). Most relevant to our work are the theoretical contributions by Leahy (1993) and Grenadier (2002) that examine how product market structure and investment decisions interact. Aguerrevere (2009) takes this literature one step further by showing that this interaction affects expected stock returns and by demonstrating that, depending on operating leverage, product market competition may increase or decrease expected stock returns.3 Carlson, Dockner, Fisher, and Giammarino (2014) show in a leader-follower equilibrium that own-firm and

3The empirical evidence on the relation between competition and expected stock returns is mixed. Early research by Hou and Robinson (2006) finds that equity returns are lower in more concentrated industries, where concentration is measured using Compustat-based measures. More recent research documents a negative relation between product market competition and equity returns, using measures of concentration that are not subject to the sample selection bias of public listing. See e.g. Bustamante and Donangelo (2016). In related research, Valta (2012) shows that the cost of bank debt also depends on a firm’s competitive environment.
competitor risks and required returns move together through contractions and oppositely during contractions, so that industry concentration is positively (respectively negatively) related to industry risk and expected returns during expansions (respectively recessions). Kogan (2004) develops a model of a production economy in which real investment is irreversible and subject to adjustment costs and shows that for firms with high-$q$ (respectively low-$q$) volatility and equity returns should be positively (respectively negatively) related. To the best of our knowledge, ours is the first paper that links product market competition to option pricing and option skew and demonstrates that competition yields a negative relation between volatility and equity returns that becomes more negative as competition intensifies. It is also the first paper that derives analytical solutions for the prices of financial options in a perfectly competitive industry as well as in a setting with imperfect competition.

It is common in the option pricing literature to assume an explicit exogenous stochastic process for stock volatility and a negative correlation between a stock’s past realized return and this stochastic volatility. Important papers that follow this approach include Heston (1993), Bates (2000), Heston and Nandi (2000), and Pan (2002). Our model takes option theory deeper into the theory of the firm and derives a rich and endogenous equity price process that depends on product market competition. The main advantage of an implicit endogenous stochastic process for the stock return volatility is that the stochastic changes in the stock’s volatility have known economic causes, which are the competitive structure of a firm’s industry and its capital structure.

Lastly, the model presented in this paper explains observed Black-Scholes implied volatility biases not only by product market characteristics but also by financial leverage. As a result, it relates to the large literature on the leverage effect, according to which the inverse relationship between stock prices and stock-return volatility is due to financial leverage (Black (1976)). Toft and Prucyk (1997) and Geske, Subrahmanyam, and Zhou (2016) derive option pricing models on levered equity and provide evidence consistent with this hypothesis. The validity of this leverage explanation has however been partly called into question by Figlewski and Wang (2000), who document that there is no effect on volatility when leverage changes because of
a change in debt or in the number of shares. Similarly, Hasanhodzic and Lo (2011) construct from Compustat a sample of 667 firms that they define as all-equity financed and find that the volatility of these all-equity firms exhibits the same negative relation between price and volatility that is characteristic of the leverage effect. Our paper provides an alternative mechanism for this relation, which does not rely on financial (or operating) leverage.\footnote{When firms have fixed costs of production and lack the ability to scale down, negative profitability shocks lead to an increase operating leverage and in equity risk. While this operating leverage channel could also potentially explain the negative relation between volatility and stock returns, Hackbarth and Johnson (2015) find that the data are best described by parameters with enough [investment] reversibility (i.e. ability to scale down) that operating leverage effects are muted.}

1. Model

1.1. Competition and option skew

In this section, we present a model based on Leahy (1993) that illustrates in the simplest possible way the effects of competition on option prices and option skew. The next section extends this model to consider the effects of imperfect competition and financial leverage.

We consider an economy with a large number of competitive firms. Each firm can undertake a single irreversible investment, requiring an initial sunk cost $I > 0$. Once this investment is made, it yields a flow of one unit of output forever with no variable cost of production. The output price is denoted by $P = (P_t)_{t \geq 0}$ and given by:

$$P_t = Y_t D(Q_t)$$

(1)

where $Y = (Y_t)_{t \geq 0}$ is an industry shock, $Q = (Q_t)_{t \geq 0}$ is the total industry output, and $D$ is a time-invariant inverse demand function relating price to industry supply. The industry shock is governed under the risk neutral probability measure $Q$ by the geometric Brownian motion

$$dY_t = (r - \delta)Y_t dt + \sigma Y_t dW_t,$$  

(2)
where \( r > 0 \) is the risk-free rate of return, \( \delta \) and \( \sigma \) are positive constants, and \( W = (W_t)_{t \geq 0} \) is a standard Brownian motion. We embed firms in an industry by assuming that each unit of output is very small compared to total industry output, so that each firm is an infinitesimal price taker. When \( Q \) firms are active, the short-run equilibrium price can be determined from equation (1) above.

In an interval of time when no entry takes place, total output is fixed, so the price is proportional to the industry shock and equations (1) and (2) give:

\[
dP_t = (r - \delta)P_t dt + \sigma P_t dW_t.
\] (3)

A potential entrant observes this price process and interprets a high price as a signal of a high level of demand. Since the entry cost is constant, it is natural to conjecture that there exists an upper threshold \( \overline{Y} \) for the industry shock which, if reached, triggers new entry. An entry policy \( \overline{Y} \) is associated with a price trigger \( \overline{P} \), which is its image according to equation (1). As soon as any one new firm enters, total output increases and the price decreases along the demand curve that applies for that instant. Thus, if the price ever reaches \( \overline{P} \), it is immediately brought back to a slightly lower level. Since all firms are identical and entry is free, the price process can never pass \( \overline{P} \). The threshold \( \overline{P} \) becomes an upper reflecting barrier for the price process, which is now given by:

\[
dP_t = (r - \delta)P_t dt + \sigma P_t dW_t - dU_t,
\] (4)

where the right-continuous, nonnegative, and non-decreasing process \( U = (U_t)_{t \geq 0} \) is defined by

\[
U_t = \sup_{0 \leq s \leq t} [(P^0_s - \overline{P}) \lor 0],
\] (5)

where \( P^0_t = Y_t D(Q_0) \) is the unregulated price process. The points of growth of \( U \) are located at the reflecting boundary \( \overline{P} \), where reflection is assumed to take place both instantaneously and with infinitesimal magnitude due to entry by firms. Figure 1 plots the dynamics of the
equilibrium output price in this perfect competition model.

\[ \text{Insert Figure 1 Here} \]

We define a competitive equilibrium as a symmetric Nash equilibrium in entry strategies: Given that all other firms follow a policy of entry at \( \overline{P} \), no individual firm can find it optimal to follow any other entry policy. Formally, an equilibrium is defined as follows:

**Definition.** An industry equilibrium is a diffusion process \( Y_t \) and a threshold \( \overline{P} \) such that

1. Equation (1) holds;
2. \( P_t \in (0, \overline{P}] \);
3. \( Q \) increases only when \( P_t = \overline{P} \);
4. Entry at \( \overline{P} \) maximizes the present value of profits;
5. The value of an idle firm is zero.

Competitive equilibrium involves the simultaneous determination of the price process and the entry policy of firms. Given the price dynamics in equation (4), we can derive the value of an active firm in the region \( (0, \overline{P}] \) in competitive equilibrium. Denote by \( P \) the initial value of the output price. In this region, a simple application of Itô’s lemma shows that firm value \( v_C(P) \) satisfies the second order differential equation

\[ rv_C(P) = P + (r - \delta)Pv'_C(P) + \frac{1}{2}\sigma^2P^2v''_C(P), \]

which is solved subject to \( \lim_{P \downarrow 0} v_C(P) = 0 \). The solution to equation (6) is given by

\[ v_C(P) = \frac{P}{\delta} + BP^\beta, \]

where \( B \) is a positive constant to be determined and

\[ \beta = \frac{1}{2} - \frac{r - \delta}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{r - \delta}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2} > 1.} \]
To find the value of the constant $B$, note that when the price is close to the reflecting barrier, it is almost sure to fall during the next time interval. To rule out the possibility of arbitrage, we must therefore have

$$v_C'(P) = 0,$$  \hspace{1cm} (9)

which implies that $B = -\frac{p^{1-\beta}}{\delta\beta}$. To better understand this condition, note that when the price hits the reflecting boundary, the behavior of the price process changes with upward movements in the unregulated price process being cancelled by offsetting movements in the stochastic regulator. The solution can satisfy the equilibrium condition $rv_C(P) = P + \frac{1}{dt} E dv_C(P)$ at $\bar{P}$ only if the infinite variation part in the equity value vanishes, i.e. if $v_C'(P) = 0$.

Combining these results shows that the value of an active firm in competitive equilibrium is given by

$$v_C(P) = \frac{P}{\delta} - \frac{1}{\delta\beta} P^\beta \overline{P}^{1-\beta}.$$

(10)

The first term on the right hand side of this equation gives the value of a monopolist. The second term gives the adjustment in firm value due to competitive entry. Entry implies that the range of prices facing a competitive firm is bounded, which reduces firm value.

To complete the determination of the competitive industry equilibrium, consider the optimal investment strategy of an idle firm. Assume that it is optimal for such a firm to invest when the price process reaches the trigger $P^* \leq \bar{P}$. In the inaction region $P < P^*$, standard derivations show that the value an idle firm is given by (see e.g. Dixit and Pindyck (1994)):

$$g(P) = AP^\beta,$$

(11)

where $A$ is a positive constant to be determined. The optimal entry threshold $P^*$ satisfies the usual value-matching and smooth pasting conditions: $g(P^*) = v_C(P^*) - I$ and $g'(P^*) = v_C'(P^*)$. These conditions require that the value of an active firm minus the cost of investing equals the value of an idle firm at the entry threshold and that the slopes of the pre- and
post-investment values are equal when \( P = P^* \). Solving these equations yields the following expression for the entry threshold:

\[
P^* = \frac{\beta}{\beta - 1} \delta I.
\]

(12)

To solve for the competitive equilibrium, we set \( P^* = \bar{P} \). This gives \( A = 0 \) so that the value of an idle firm is always zero. This condition also implies that the value of an active firm at \( \bar{P} \) is \( I \). That is, when \( P = \bar{P} \), each firm is just indifferent between entering and staying out.

We now consider the effects of competition on option prices and option skew, which we define as the difference between an out-of-the-money (OTM) and at-the-money (ATM) call option implied volatility. To do so, we consider that firms have a single share outstanding so that the value of this share in the competitive firm is given by (10). The value of this same share for a monopolist is given by the Gordon growth formula

\[
v_M(P) = \mathbb{E}_P \left[ \int_0^\infty e^{-rt} P^0_t n_t dt \right] = \frac{P}{\delta},
\]

(13)

where \( \mathbb{E}_P[\cdot] \) denotes the risk-neutral expectation conditional on an initial price level \( P \) and where \( P^0 \) is the unregulated price with dynamics given in (3). This equation shows that when the firm has monopoly power, there is no price ceiling and firm value is higher and governed by a geometric Brownian motion, as in the standard Black and Scholes (1973) model.

In the standard option pricing model without competition, the underlying stock price is then given by \( v_M(P) \) in equation (13) and the price a call option with maturity \( t \) and exercise price \( K \) written on the firm’s stock is given by:

\[
C_M(P,0,t) = \mathbb{E}_P \left[ e^{-rt} (v_M(P_t) - K)^+ \right],
\]

which yields the Black and Scholes (1973) formula:

\[
C_M(P,0,t) = \frac{P}{\delta} \Phi \left( \frac{\log P + (r - \delta)t}{\sigma \sqrt{t}} + \frac{\sigma \sqrt{t}}{2} \right) - Ke^{-rt} \Phi \left( \frac{\log P + (r - \delta)t}{\sigma \sqrt{t}} - \frac{\sigma \sqrt{t}}{2} \right),
\]

where

\[
\Phi(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2},
\]
where $\Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-\frac{1}{2}y^2} dy$ is the CDF of the standard Normal distribution. In this model, the volatility of stock returns is constant, given by $\sigma$, and there is no option skew.

In the model with (perfect) competition, the dynamics of the output price reflect entry by new firms. As a result, firm value is given by equation (10) and the call option price can be determined by integrating the option payoff function over a risk-neutral density function of the regulated price process:

$$
C_C(P, 0, t) = \int_{0}^{P} e^{-rt} \left[ \frac{y}{\delta} - \frac{1}{\delta \beta} y^\beta \overline{P}^{1-\beta} - K \right]^+ \mathbb{P}(P_t \in dy | P_0 = P, \overline{P})
$$

(14)

where $x^+ = \max\{0, x\}$ and $\mathbb{P}(P_t \in dp | P_0 = P, \overline{P})$ is the probability law of the underlying asset price at time $t$ given an initial value $P_0 = P$ at time 0 and a price ceiling at $\overline{P}$. This law can be obtained by evaluating the appropriate limit for the solution to the two-boundary setup derived in equation (57) below. This gives with $\mu \equiv r - \delta - \frac{\sigma^2}{2}$:

$$
\mathbb{P}(P_t \in dy | P_0 = P, \overline{P}) = \frac{2\mu}{y\sigma^2} e^{\frac{2y}{2\sigma^2} \log \frac{\mu t}{\overline{P}}} \Phi \left( \frac{\mu t + \log \frac{yP}{\overline{P}}}{\sigma \sqrt{t}} \right) dy
$$

(15)

$$
+ \frac{1}{y\sigma \sqrt{2\pi t}} \left[ e^{-\frac{1}{2\sigma^2} (\log \frac{\overline{P}}{\mu} - \mu)^2} + e^{-\frac{2\mu}{2\sigma^2} \log \frac{\overline{P}}{\mu} - \frac{1}{2\sigma^2} (\log \frac{yP}{\overline{P}} - \mu)^2} \right] dy
$$

In the model with perfect competition, option skew arises because the volatility of equity prices decreases as the price process approaches the reflecting barrier. Notably, an application of Itô’s lemma yields the following result:

**Proposition 1 (Perfect competition and option skew)** With perfect competition, the equity price process is characterized by an endogenous stochastic volatility function given by:

$$
\sigma_{vc}(P) \equiv P \frac{\partial v_C(P)}{\partial P} \sigma = \left[ 1 + \frac{1 - \beta}{\delta \beta} \frac{P^\beta \overline{P}^{1-\beta}}{v_C(P)} \right] \sigma.
$$

(16)

Equity volatility displays an endogenous, negative correlation with stock returns in that

$$
\frac{\partial \sigma_{vc}(P)}{\partial P} = - \left[ \frac{\beta(1 - \beta)^2 P^\beta \overline{P}^{1+\beta}}{(P^\beta \overline{P} - \beta PP^\beta)^2} \right] \sigma < 0,
$$

(17)
and satisfies \( \lim_{P \to 0} \sigma_{vc}(P) = \sigma \) and \( \sigma_{vc}(\bar{P}) = 0 \).

Proposition 1 shows that, in the model with perfect competition, the equity price process is characterized by an endogenous stochastic volatility function that depends on a set \( \Sigma = \{ \sigma, \delta, I \} \) of structural variables. In this model, competition limits price fluctuations and this effect gets stronger as the price process approaches the reflecting boundary. That is, the threshold at which competitors invest affects both option values and option sensitivities. Since \( \beta > 1 \), the second term in the square bracket of equation (16) is negative, showing that competition reduces equity volatility. In addition, equity volatility is stochastic and displays a negative correlation with (realized) stock returns (as in e.g. Heston (1993), Bates (2000), and Pan (2002) in which this relation is exogenously postulated). This in turn implies that competition leads to negative option skew in that volatility increases with the moneyness of the option. Lastly, as shown by Proposition 1, the total change in equity volatility due to competition increases with \( \sigma \), suggesting that an increase in underlying uncertainty should increase the effects of competition on option skew. Figure 2 plots the volatility of the stock price as a function of the output price in the monopoly and perfect competition models.

Before turning to the analysis of option skew, note that the payout rate in the model with competition \( R_C(P) \) is given by

\[
R_C(P) \equiv \frac{P}{v_C(P)} = \frac{\delta}{1 - \frac{1}{\beta} \left( \frac{P}{\bar{P}} \right)^{\beta-1}},
\]

and increases as the price process increases. Notably, we have \( \lim_{P \to 0} R_C(P) = \delta \) and \( R_C(\bar{P}) = \frac{\beta}{\beta-1} \delta \). Because this feature can affect the volatility skew, we consider two alternative scenarios for the calculation of implied volatilities. In the first scenario, we assume that dividends are paid and prices are given as as above. In the second, we assume that no dividends are paid before the option maturity and that cash flows are used to repurchase shares. This is turn implies that the number of outstanding shares decreases and satisfies \( dN_u = -N_u R_C(P_u) du \),
prior to the option maturity \( t \). In our numerical examples below, we thus present calculations of implied volatilities without and with an adjustment in the number of outstanding shares.

1.2. The effects of financial leverage and imperfect competition

1.2.1. Competition, financial leverage, and option skew

In this section, we incorporate financial leverage in the model. To do so, we follow Fries, Miller, and Perraudin (1997) and assume that, at the time of entry, each firm selects its capital structure by issuing infinite maturity debt with constant coupon payment \( c \geq 0 \). The net income of a firm after entry is then simply given by \( P - c \). As in the model without debt, it is natural to conjecture that there exists an upper threshold \( \overline{\gamma} \) for the industry shock which, if reached, triggers new entry. An entry policy \( \overline{\gamma} \) is again associated with a price trigger \( \overline{P} \) which, as before, becomes an upper reflecting barrier for the price process. Similarly, if the demand shock falls sufficiently, firms may default on their debt obligations and exit. An exit policy \( \underline{\gamma} \) is associated with a price trigger \( \underline{P} \), which is its image according to equation (1). As soon as a firm defaults and exits, total output decreases and the price increases. Thus, if the price ever reaches \( \underline{P} \), it is immediately brought back to a slightly higher level. The threshold \( \underline{P} \) thus becomes an lower reflecting barrier for the price process.

In equilibrium, the exit of firms generates a floor on the price process, just as their entry generates a ceiling. An active firm thus faces the price process (1) with barriers \( \overline{P} \) and \( \underline{P} \), with \( \overline{P} > \underline{P} \). We can now define a competitive equilibrium as a symmetric Nash equilibrium in entry and default strategies: Given that all other firms issue debt with coupon \( c \) and follow a policy of entry at \( \overline{P} \) and default at entry at \( P \), no individual firm can find it optimal to follow any other financing, entry, or default policy.

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\(^5\)The amount of debt chosen by firms is irrelevant to our results. As a result, we do not introduce frictions, such as corporate taxes, that could pin down an optimal capital structure for firms. The model can easily be extended in this direction; see the Appendix. The results in this section also apply to operating leverage if \( c \) is to be interpreted as a constant production cost. Under this interpretation operating leverage and risk increase following negative cash flow shocks.
Using the same steps as in section 1.1, it is possible to establish that in our competitive equilibrium with debt, the value of equity in an active firm is given by (see the Appendix):

\[
e_C(P) = \frac{P}{\delta} - \frac{c}{r} + E_1 P^\beta + E_2 P^\xi,
\]

where \( \beta \) and \( \xi \) are the positive and negative roots of the quadratic equation \( \frac{\sigma^2}{2} \nu (\nu - 1) + (r - \delta) \nu - r = 0 \), and \( E_1 \) and \( E_2 \) are constants given by

\[
E_1 = \frac{\xi - 1}{\beta - \xi} \frac{P^{1-\beta}}{\delta} + \frac{\xi}{\xi - \beta} \frac{P^{1-\beta}}{r}, \quad \text{and} \quad E_2 = \frac{\beta - 1}{\xi - \beta} \frac{P^{1-\xi}}{\delta} + \frac{\beta}{\beta - \xi} \frac{P^{1-\xi}}{r},
\]

where the entry and default thresholds \( \bar{P} \) and \( \underline{P} \) are derived in the Appendix.

In this model, option skew arises for two reasons. First, it arises because the volatility of equity prices decreases as the price process approaches the upper reflecting (entry) barrier, as in the all-equity financing model of section 1.1. Second, it arises because equity volatility increases as the price process goes down to the default barrier, reinforcing the skew. Notably, an application of Itô’s lemma shows that the equity price process is characterized by an endogenous stochastic volatility function \( \sigma_{eC}(P) \) given by

\[
\sigma_{eC}(P) \equiv \frac{P}{e_C(P)} \frac{\partial e_C(P)}{\partial P} \sigma = \left[ 1 + \frac{(\beta - 1) E_1 P^\beta + (\xi - 1) E_2 P^\xi + \frac{c}{r}}{e_C(P)} \right] \sigma.
\]

In equation (21), the term \( \frac{(\beta - 1) E_1 P^\beta}{e_C(P)} \) captures the effects of the price ceiling on equity volatility. Because \( \beta > 1 \) and \( E_1 < 0 \), this term is negative and becomes relatively larger as \( P \) increases, reducing equity volatility. When \( P = \bar{P} \), we can use the smooth-pasting and free entry conditions (43) and (46) given in the Appendix to show that

\[
\sigma_{eC}(\bar{P}) = \left[ 1 + \frac{d_{C}(\bar{P}) - I}{e_C(\bar{P})} \right] \sigma = 0,
\]

where \( d_C(\bar{P}) \) is the value of debt when \( P = \bar{P} \). The term \( \frac{(\xi - 1) E_2 P^\xi + \frac{c}{r}}{e_C(P)} \) in (21) captures the effects of financial leverage on equity volatility. Since \( \xi < 0 \) and equity value is an increasing function of \( P \), this term becomes larger as \( P \) decreases, increasing equity volatility. Our model therefore predicts that competition should decrease equity volatility as the firm’s fortunes
improve and that leverage should increase equity volatility as the firm’s fortunes deteriorate, thereby generating negative skew. Figure 3 plots the volatility of the stock price as a function of the output price in the monopoly and perfect competition models with debt.

The model derived in this section nests our model of competition for all-equity firms as a special case. We show in the Appendix that (when adding corporate taxes to the model) it also nests the Toft and Prucyck (1997) model, in which there is financial leverage but no competition, as a special case. Section 1.3 provides numerical examples illustrating the effects of competition and financial leverage on option skew.

1.2.2. Competition and option skew in an imperfect competition model

In this section, we show that the simple intuition developed in Section 1.1 on the effects of competition on option skew applies to imperfect competition. To do so, we consider a model in which the intensity of competition depends on the number of firms present in a given industry and look at the effects of varying the number of firms in the industry on option skew.

The model is based on Grenadier (2002). We consider an oligopolistic industry with $n$ identical firms producing a single, homogeneous good. At time $t$, firm $i$ produces $q_{i,t}$ units of output. The output price $P_t$ is a function of total industry output and a stochastic demand shock:

$$P_t = Y_t Q_t^{-\frac{1}{\gamma}}$$  \hspace{1cm} (23)

where $Y_t$ is an exogenous demand shock governed by equation (2), $Q_t = \sum_{i=1}^{n} q_{i,t}$, and the constant $\gamma > 1$ is the elasticity of demand.

\textsuperscript{6}Grenadier (2002) focuses on open-loop equilibria in investment strategies. Back and Paulsen (2009) discuss the implications of this assumption. Novy-Marx (2009) shows that the paths of investment and goods market prices under the closed-loop Markov perfect strategy in which the firm with the highest marginal valuation of capital preempts the preemptive investment of other firms coincide exactly with those in the open loop Cournot equilibrium in the long-run.
Each unit of installed capital produces a flow of one unit of output forever with no variable cost of production. At any time $t$, firms play a static Cournot game in which each firm chooses its size $q_{i,t}$ to maximize profits and conditions its choice on the choices of other firms. At each time $t$, each firm can increase its size by an increment $dq_{i,t}$. The price of a new unit of capacity is constant, denoted by $I > 0$, and investment is irreversible (implying that the process $q_{i,t}$ is non-decreasing). For each firm $i$, let $q_{-i} = \{q_1, \ldots, q_{i-1}, q_{i+1}, \ldots, q_n\}$ denote the output choices of firm $i$'s competitors. A $n$–tuple of strategies $\{q_1^*, \ldots, q_n^*\}$ is a Nash industry equilibrium if $q_i^* = q_i(Y, q_{-i}^*)$ for all $i$.

Because the industry is composed of $n$ identical firms, we have $q_{i,t} = \frac{Q_t}{n}$ and $q_{-i,t} = \frac{(n-1)Q_t}{n}$. This assumption also implies that firms only need to condition their investment decisions on the level of the demand shock $Y$ and total output $Q$. The optimal investment strategy for firm $i$ is then the solution to

$$v_n(Y, Q) = \max_{\{q_{i,t}: t > 0\}} \mathbb{E} \left[ \int_0^{+\infty} e^{-rt} \left( q_{i,t} Y_t Q_t^{\frac{1}{\gamma}} dt - Idq_{i,t} \right) \right].$$

In the Appendix, we solve for firm value in the symmetric industry equilibrium and show that it can be expressed as a function of the output price and total output as

$$v_n(P, Q) = \frac{1}{n} \left[ \frac{QP}{\delta} + \frac{\gamma Q}{\gamma - \beta} \left( I - \frac{(\gamma - 1)\nu_n}{\gamma\delta} \right) \left( \frac{P}{\nu_n} \right)^\beta \right],$$

where $\beta > 1$ is defined in equation (8). The first term on the right hand side of this equation is the present value of selling a fraction $\frac{1}{n}$ of total output forever. The second term reflects the effects of changing output on this present value, is negative, and reduces firm value. In equilibrium, total output $Q_t$ increases incrementally only when $Y_t = \nu_n Q_t^{\frac{1}{\gamma}}$ where

$$\nu_n = \frac{\gamma n}{\gamma n - 1} \frac{\beta}{\beta - 1} \delta I,$$

As a result, the price process $P_t = Y_t Q_t^{\frac{1}{\gamma}}$ is governed by a geometric Brownian motion with

---

7We assume that $\gamma < \beta$ to ensure the existence of an equilibrium. When this condition does not hold, future supply increases translates into an infinitely negative firm value, preventing the existence of the industry.
reflecting barrier at $\nu_n$. That is, the output price has similar dynamics as in the model with perfect competition of section 1.1.

Using equation (25), we can examine the effects of competition on stock price volatility. Notably, an application of Itô’s lemma yields the following result:

**Proposition 2 (Imperfect competition and option skew)** With imperfect competition, the equity price process is characterized by an endogenous stochastic volatility function $\sigma_{v_n}(P,Q)$ given by:

$$
\sigma_{v_n}(P,Q) \equiv \frac{P}{v_n(P,Q)} \frac{\partial v_n(P,Q)}{\partial P} \sigma = \left[ 1 + \frac{Q \frac{\gamma(\beta-1)}{\gamma-\beta} \left( I - \frac{(\gamma-1)\nu_n}{\gamma\delta} \right) \left( \frac{P}{\nu_n} \right)^\beta}{v_n(P,Q)} \right] \sigma. \quad (27)
$$

Equity volatility displays an endogenous, negative correlation with stock returns when $n > \frac{\beta-1}{\beta-\gamma}$ in that

$$
\frac{\partial \sigma_{v_n}(P,Q)}{\partial P} = -\frac{\gamma\delta(\beta-1)^2}{\beta-\gamma} \frac{\Omega(n)}{[P + \frac{\delta\gamma}{\gamma-\beta} \Omega(n)]^2} < 0, \quad (28)
$$

where $\Omega(n)$ is defined by $\Omega(n) \equiv \left( I - \frac{(\gamma-1)\nu_n}{\gamma\delta} \right) \left( \frac{P}{\nu_n} \right)^\beta$ and satisfies $\lim_{P \to 0} \sigma_{v_n}(P,Q) = \sigma$ and $\lim_{n \to +\infty} \sigma_{v_n}(\nu_n, Q) = 0$.

Several results follow from Proposition 2. First, competition limits price fluctuations and, as in the model with perfect competition, volatility is negatively related to stock returns. Notably, the stock price volatility converges to zero at the investment threshold when the number of firms tends to infinity in that:

$$
\lim_{n \to +\infty} \sigma_{v_n}(\nu_n, Q) = \frac{\beta \frac{\gamma}{\gamma-\beta} \left( 1 - \frac{\beta(\gamma-1)}{\gamma(\beta-1)} \right) + \frac{\beta}{\beta-1}}{\gamma \frac{\gamma}{\gamma-\beta} \left( 1 - \frac{\beta(\gamma-1)}{\gamma(\beta-1)} \right) + \frac{\beta}{\beta-1}} \sigma = 0. \quad (29)
$$

---

8Proposition 2 shows that, as in the model with perfect competition, product market competition reduces equity volatility, suggesting that competition should decrease equity returns. Aguerrevere (2009) shows that when adding fixed production costs to the Grenadier model, competition may increase or decrease equity returns. An early empirical study by Hou and Robinson finds that equity returns are lower in more concentrated industries, where concentration is measured using Compustat-based measures (i.e. including only firms that have decided to go public). More recent research using measures of concentration and markups that are not subject to the sample selection bias of public listing documents a negative relation between product market competition and equity returns, consistent with our model. See e.g. Bustamante and Donangelo (2016).
As in Proposition 1, the total change in equity volatility due to competition increases with \( \sigma \), suggesting that an increase in underlying uncertainty should increase the effects of competition on option skew. Second, because \( \Omega(n) \) in equation (28) is increasing in \( n \), we have that

\[
\frac{\partial \sigma_{vn}(P,Q)}{\partial P} > \frac{\partial \sigma_{vm}(P,Q)}{\partial P}
\]

for all \( m > n \), implying that an increase in the intensity of product market competition leads to a decrease in option skew.\(^9\) Figure 4 plots the volatility of the stock price as a function of the output price in the monopoly and imperfect competition models.

Figure 4 shows that for a monopolist equity volatility increases as the output price increases as the firm’s growth options (which are riskier than assets in place) get more in the money and, therefore, represent a larger fraction of total firm value. When the number of firms satisfies \( n > \frac{\beta-1}{\beta-\gamma} \) (which in our base case calibration is equivalent to \( n > 2 \)), volatility is negatively related to stock returns and the greater the intensity of product market competition, the more negative this relation. In an economy with \( n \) firms, the price process \( P_t = Y_tQ_t^{-\frac{1}{\gamma}} \) is governed by a geometric Brownian motion with reflecting barrier at \( \nu_n \).

### 1.3. Comparative statics

Our main prediction is about the negative relation between the intensity of product market competition and the option skew defined as the difference between implied volatilities of out-of-the-money and at-the-money calls. While the models in sections 1.1 and 1.2.1 are useful to demonstrate how negative skew arises in a perfectly competitive setting, the model in section 1.2.2 allows also to examine how the shape of the skew varies with the intensity of competition (proxied by the number of firms in the industry). It is also interesting to examine how the option skew depends on the key parameters of the model, such as the volatility and drift of

\(^9\)The term \( \Omega(n) \) represents the scaled value of changing output, as captured in the second term of equation (25). It is immediate to show that \( \frac{\partial \Omega(n)}{\partial n} = I \frac{(n-1)^{\beta}}{n(y-1)} \left( \frac{P}{\nu_n} \right)^{\beta} \geq 0 \).
the stochastic process $Y_t$. Below we provide comparative statics results from all three models: the perfectly competitive models in sections 1.1 (without financial leverage) and 1.2.1 (with financial leverage) as well as the imperfectly competitive model of section 1.2.2.

We define the option skew as the difference between implied volatilities of out-of-the-money (thereafter OTM) calls with $K/S_0 = 1.08$ (where $K$ is the strike price and $S_0$ is the underlying stock price) and at-the-money (thereafter ATM) calls. We use the same definition of the skew in our empirical tests in section 3 below. We set the model parameters as follows: the risk-free rate $r$ is set to 5%, the growth rate and volatility of $Y_t$ are set to $r - \delta = 1\%$ and $\sigma = 20\%$. The maturity of the options $T$ is set to one year. Lastly, the elasticity of demand in the imperfect competition model is set to $\gamma = 1.5$, as in Grenadier (2002).

**Perfect competition without leverage** We start our analysis with the perfectly competitive model of section 1.1. As we discuss above, the non-constant payout rate might potentially affect the volatility skew. We therefore compute the skew with and without the adjustment to the number of outstanding shares discussed in section 1.1. Figure 5 shows the relation between the option skew and the volatility $\sigma$ or the drift $r - \delta$ of the price process. The results in Figure 5 demonstrate that as expected, the skew is negative as OTM calls have lower implied volatilities than ATM calls. For our base set of model parameters the skew is -61.8 bp without the dividend adjustment and -51.7 bp with the adjustment. Furthermore, there is a negative relation between the skew and the underlying uncertainty as proxied by the volatility parameter $\sigma$. The relation between the skew and the growth parameter $r - \delta$ is also negative. Both higher volatility and higher drift parameter increase the probability of reaching the upper entry threshold and therefore triggering the hedging effect due to the entry of new firms. As shown in Figure 5, making an adjustment for the number of shares to eliminate dividend yield does not qualitatively affect the results.

**Perfect competition with leverage** We proceed by examining the effects of both leverage and competition on option skew in a perfectly competitive setting. As we show in section 1.2.1,
financial leverage creates optionality of equity and enhances volatility in low states while product market competition reduces volatility in high states. Thus the effect of competition is amplified by leverage and the negative skew that we observe in a perfectly competitive setting without leverage should become more pronounced for a firm with leverage. Figure 6 illustrates this intuition. The left plot presents the option skew as a function of volatility $\sigma$ for a firm in the industry when entering firms are 30% debt financed. The right plot displays the results when the leverage of entering firms is 50%. Two results emerge when comparing the panels of Figure 6. First, as expected, competition generates a negative skew and there is a negative relation between the skew and volatility $\sigma$. Second, the effect of competition on option skew is amplified by leverage. For example, when $\sigma = 0.3$ the skew decreases from -118 bp to -150 bp when leverage increases from 30% (left plot) to 50% (right plot).

**Imperfect competition** We next turn our attention to the imperfectly competitive industry analyzed in section 1.2.2. This model allows us to vary the degree of industry competitiveness and examine how the option skew reacts. According to (30) the effect of competition on the reduction in volatility at high demand states is stronger when there are more firms in the industry. We therefore expect a negative relation between option skew and the number of firms. The corresponding comparative statics result is presented in Figure 7, which plots the option skew as a function of the number of firms in the industry. As expected, the relation between the skew and the number of firms is negative —when there is more competition equity volatility is more sensitive to price changes, which widens the wedge between implied volatilities of OTM and ATM calls. As the number of firms increases, the skew converges to its value in the perfectly competitive model (which is -51.7 bp for the base set of parameters).
1.4. Testable hypotheses

In this section we summarize our main empirical hypotheses. Our key result is that there should be a negative relation between option skew and competition in product markets. As we show both in a perfectly competitive setting in sections 1.1 and 1.2.1, as well as in a model with imperfect competition in section 1.2.2, entry of new firms reduces equity volatility at higher states of demand. This reduction in volatility has a stronger effect on the prices of OTM calls than on the prices of ATM calls and therefore gives rise to a negative volatility skew in option prices.

**Hypothesis 1**: *Competition in product markets leads to negative option skew.*

We expect the option skew to be more negative in industries with more intense product market competition. In section 1.2.2, we analyze how varying the competitive landscape of an industry (proxied by the number of firms) affects the option skew. In particular, (30) shows that the sensitivity of volatility to price in product markets (that generates a negative option skew) is more negative when there are more active firms in the industry. This result is also illustrated in Figure 7 that presents the option skew as a function of a number of firms in an imperfectly competitive industry. Hypothesis 2 follows.

**Hypothesis 2**: *An increase in competition in product markets should decrease option skew.*

As we show in section 1.2.1 (see equation (21)), financial leverage amplifies volatility in low states of demand thereby generating a negative skew. This effect is consistent with the findings of Toft and Prucyk (1997), who demonstrate a similar result for a firm in a monopoly environment (see also the Appendix). Thus, leverage works alongside competition and has a negative effect on the skew. This leads to the following hypothesis.

**Hypothesis 3**: *An increase in financial leverage should decrease option skew.*

Next, as shown by Proposition 1 and Figures 5 and 6, the change in equity volatility due to competition increases with the volatility of the firm cash flows $\sigma$. We therefore expect the
option skew caused by competition to be more negative when the underlying uncertainty is high. This leads to the following hypothesis.

**Hypothesis 4:** *The effect of competition on option skew is higher when the underlying uncertainty is high.*

Finally, our analysis suggests that leverage has an effect on the skew by amplifying volatility in low states, while competition works by reducing volatility in high states. Therefore, the effect of leverage on the skew should be stronger while the effect of competition should be weaker if the skew is constructed from options whose prices are more sensitive to volatility in low states (i.e. out-of-the-money puts and in-the-money calls). Thus, leverage has a stronger effect in the left tail of the skew, while competition dominates in the right tail. This intuition is summarized in hypothesis 5.

**Hypothesis 5:** *The effect of leverage (competition) on option skew is stronger (weaker) for measures of the skew constructed from out-of-the-money puts or in-the-money calls.*

### 2. Data

Our main data source is IvyDB Optionmetrics that has comprehensive coverage of U.S. equity options from 1996 onwards. We obtain the necessary accounting data from Compustat and return and price data from CRSP. We start by excluding all options with zero open interest as quotes for such options are less likely to contain any useful information. We then compute the option skew, our main variable of interest, for every underlying option in our dataset on every trading day. Option skew is defined as the difference between implied volatilities of out-of-the-money and at-the-money calls. We use implied volatilities provided by Optionmetrics. For at-the-money options, we take the option with the strike closest to the underlying price, as long as the difference between the underlying price and the strike does not exceed 3%. We define out-of-the-money calls as the ones with strikes between 6% and 10% above the underlying price and choose the option closest to 8% out-of-the-money (our results are robust to variations of the out-of-the-money threshold.) We repeat this procedure
for all available option maturities. For any given maturity, we average the resulting skew values across all trading dates with available data within a calendar month. This gives us our final skew measure, available at a monthly frequency.

Our main proxy for the intensity of competition is the product market fluidity measure developed by Hoberg, Phillips, and Prabhala (2014), available in the Hoberg and Phillips data library starting in 1997. This proxy is based on product descriptions from firm 10-Ks and captures the structure and evolution of the product space occupied by firms. In particular, it captures competitive threats faced by firms and the changes in rivals’ products relative to the firm. In robustness tests, we use two alternative competition measures: the number of firms in SIC and GICs industries and the Herfindahl concentration measure constructed using text-based network industry classification (“TNIC3HHI”), developed by Hoberg and Phillips (2016). The TNIC measure is also based on textual analysis of firm 10K product descriptions and uses pairwise similarity scores to classify firms into industries. TNIC3 aims at developing an industry classification that is in general “as coarse” as the standard SIC3 classification.

In addition to our main variables of interest that proxy for the degree of industry competitiveness, we also construct a set of control variables that might affect the pricing of options and option skewness. Toft and Prucyk (1997) and Geske, Subrahmanyam, and Zhou (2016) show theoretically and empirically that financial leverage affects the pricing of options and the volatility surface. A similar mechanism works in our setting (see section 1.2.1 above and Hypothesis 3). Furthermore, Hypothesis 5 relates magnitudes of the competition and leverage effects on the option skew to alternative ways of constructing the skew. We therefore include market leverage as a control variable. Market leverage is defined as the book value of debt divided by the sum of the book value of debt and the market value of equity. Bakshi, Kapadia, and Madan (2003) develop a model in which return skewness of an individual stock depends on the skewness of the market return, the market exposure (beta), as well as the skewness of the idiosyncratic component. We therefore add idiosyncratic and market skewness constructed from daily returns and market betas as control variables. We compute betas using 36-month monthly rolling regressions of firm’s excess returns on the excess return on the SP500 index.
Grullon, Lyandres and Zhdanov (2012) show that firms with higher percentage value of growth options exhibit higher return skewness. To account for this potential effect on the volatility surface, we include market-to-book ratio and size as control variables. Higher market-to-book and smaller firms are likely to derive a higher percentage value from their growth options than from assets in place. Also, to the extent that (the inverse of) the market-to-book ratio proxies for financial distress, it should affect skewness in a manner similar to that discussed in Toft and Prucyk (1997). We define the market-to-book ratio as the ratio of market and book values of equity and size as the logarithm of the market value of equity. Because high momentum stocks may attract option traders wishing to speculate on subsequent price movement, we also include past six month equity returns as a control variable.

Table 1 presents the summary statistics of our main variables. Mean option skew, our main variable of interest is negative, consistent with the general prediction of our model (the average difference between OTM and ATM implied volatilities in our sample is about −1%). Our concentration measures indicate that our sample spans firms along the whole competition spectrum – from those in highly competitive industries (fluidity measure of 33.9, text-based Herfindahl of 0.015, and 783 firms in the 3-digit SIC industry) to highly concentrated ones (fluidity measure of 0, text-based Herfindahl of 1, and 1 firm in the 3-digit SIC industry). The average firm has a fluidity measure of about 6.6 and TNIC3HHI of about 13%. The mean (median) firm market capitalization in our sample is 17.6 billion (5.4 billion) as firms with listed options tend to be larger in general. The summary statistics for other variables are generally in line with existing studies.

As the universe of optionable stocks expands throughout our sample period, so does the set of stocks for which we are able to construct our skew measure. While it is only available for 961 stocks in 1996, this number grows to 1778 by 2014.
3. Empirical results

3.1. Option skew and competition

Our main hypothesis is for a negative relation between competition in product markets and the option skew. Option skew, our main variable, as well as control variables that use market prices and returns are available at a monthly frequency. However, fluidity, our main proxy for competitive threats, as well as the alternative competition measures are constructed at an annual frequency. Because both option skew and controls vary by month, we estimate our base empirical model using monthly observations. In the robustness section below we also estimate an alternative annual specification.

To test our main hypothesis, we run panel regressions of our option skew measure on proxies for the intensity of product market competition. Notably, we estimate the following model:

\[
Skew_{i,t} = \alpha + \beta_1 Competition_{i,t-1} + \beta_2 Y_{i,t-1} + \nu_t + \epsilon_{i,t},
\]

where the subscripts \(i\) and \(t\) represent firm and year, respectively. Equation (31) relates option skew to the intensity of competition. \(Competition_{i,t-1}\) is the competition measure for firm \(i\), as of the previous month.\(^{10}\) Our main focus is on the coefficient estimate \(\beta_1\). The set of control variables \(Y_{i,t-1}\) includes variables that are commonly believed to affect option skew that are discussed above. These include financial leverage, past cumulative six month return and the standard deviation of monthly returns measured over the previous 12 months, the market-to-book ratio, the logarithm of market capitalization, market beta, and idiosyncratic and market return skewness. We include monthly fixed effects \(\nu_t\) to account for potential aggregate shocks that affect options market in general (for example, one can argue that the skew might take different shapes in recessions versus expansions). In our main tests we do not include firm or industry fixed effects because we want our tests to capture cross-sectional differences in the option skew across firms and industries that are potentially related to differences in the

\(^{10}\)We follow common practice in the literature and skip six months when merging annual COMPUSTAT data and our competition data with monthly CRSP and option data.
competitive environment. However, in the robustness section below we also present alternative specifications with both time and industry fixed effects. Because both the option skew and product market fluidity, our main competition measure, are defined at the firm level, we cluster standard errors by firm to control for potential serial correlation in residuals.\footnote{Our results remain statistically significant if we cluster standard errors by 2, 3, or 4-digit SIC industries, as well as NAICs and GICs industries.}

We use product market fluidity developed in Hoberg, Phillips, and Prabhala (2014) as our main competition measure. We believe it is particularly relevant in our setting as it captures competitive threats from the product market space. In robustness tests below we use alternative industry concentration measures, in particular, text-based Herfindahl index, TNIC3HHI, and the number of firms in SIC and GICS industries.

We expect the relation between option skewness and competition to be stronger for options with longer maturities. Indeed, it is unlikely that the effect of competition plays a significant role at very short maturities (e.g. a few weeks) as a threat of new entry and/or significant investment by rivals is low for short time horizons. In our analysis we therefore focus on options with long-term maturities (one year and longer) and measures of the skew constructed from those options. Results from our regressions are presented in Table 2.

\footnotesize{Insert Table 2 Here}\normalsize

Consistent with our main hypothesis, product market fluidity, our main proxy for competition is negative and highly significant in all specifications. The effect of competition is also economically meaningful – keeping everything else equal, a firm in a perfectly competitive industry has an option skew approximately 33 basis points below that in a monopoly industry. Consistent with Hypothesis 3, coefficients on financial leverage are negative and statistically significant. Coefficients on past return are positive suggesting that option traders might be more inclined to buy out-of-the-money calls for stocks that have realized high returns in the past, thereby inflating the prices of such calls. Consistent with the notion that the market-to-book ratio identifies the growth option intensive firms with potentially positively skewed returns, the coefficients on market-to-book are positive albeit statistically insignificant.
3.2. Aggregate uncertainty

Our next hypothesis relates to the effect of uncertainty on the relation between option skew and product market competition. As our comparative statics results above demonstrate, the effect of competition on the skew is higher when the underlying uncertainty is high. To test this hypothesis, we define a new dummy variable HIGHVIX to indicate a high volatility environment. We set HIGHVIX equal to one whenever the VIX index is above its time-series mean in our sample, and set it to zero otherwise. To gauge the differential effect of HIGHVIX on the relation between competition and option skew, we interact HIGHVIX with product market fluidity, our main competition measure. The results from these tests are reported in Table 3. As before, we cluster standard errors by firm and include month fixed effects.\footnote{We do not include HIGHVIX by itself in the regression specification, as any variation of this dummy variable over time is already captured by the time fixed effects.}

Results in Table 3 support our Hypothesis 4. Coefficients on the interaction term of fluidity and the HIGHVIX dummy are negative and statistically significant (marginally significant in specifications 5 and 6). As before, coefficients on the fluidity measure itself are also negative and significant. These results demonstrate that while there is a negative effect of product market competition on the option skew, this effect is stronger when aggregate volatility is high as indicated by the HIGHVIX dummy.

3.3. Barriers to entry

Competitive threats are likely to be stronger in industries with lower barriers to entry. Therefore the effect of product market competition on option skew is also likely to be stronger in such industries. On the other hand, in industries with high entry costs the probability of entry during the lifetime of an option is lower and therefore we expect the volatility reduction due to potential entry to be attenuated. We argue that capital intensive industries pose stronger barriers to entry and proxy capital intensity by asset tangibility, defined as the
ratio of gross plant property and equipment (COMPUSTAT item \textit{ppegt}) and total assets (COMPUSTAT item \textit{at}).

To examine the effect of entry costs on options skewness, we run panel regressions of option skew on fluidity akin to those in Table 2, while augmenting our regression specification by including tangibility and its interaction it with fluidity. We then expect to see a positive coefficient on the interaction term.

Results from this exercise are reported in Table 4. Consistent with our conjecture, coefficients on the interaction terms of tangibility and fluidity are positive and highly statistically significant in all regressions specifications. Coefficients on tangibility itself are however statistically insignificant.

### 3.4. Relative magnitudes of the competitive and leverage effects

We argue (Hypothesis 5) that there is an asymmetry in both the leverage and competition effects in the lower versus upper states. In particular, we expect the leverage effect to be stronger on the left tail of the option skew and the competition effect to be stronger on the right tail. This section tests this prediction by constructing two alternative measures of the option skew. The first one is defined as the difference between implied volatilities of at-the-money and out-of-the-money puts. The second one is defined as the difference between implied volatilities of at-the-money and in-the-money calls. Both measures are sensitive to the volatility in low states of demand. We therefore expect the absolute values of the coefficients on leverage to be higher for this alternative skew measures compared to our main results in Table 2, and the absolute values of the coefficients on competition to be lower. To test Hypothesis 5, we repeat our main tests reported in Table 2, while replacing \textit{OptionSkew} with these two alternative measures. The results of these tests are reported in Table 5. Panel A presents results for the skew measure constructed from out-of-the-money puts, while panel B presents results for the measure derived from in-the-money calls.
The results in Table 5 support Hypothesis 5. While still statistically highly significant, the magnitude of the competition effect is weaker in both panels of Table 5 compared to our baseline results in Table 2. For example, in specification 6 that includes all control variables, the coefficients on fluidity for both alternative measures of the option skew are -0.006 (compared to -0.009 in our main tests). On the other hand, the coefficients on leverage in the same specification are -0.357 for the skew constructed from ITM calls and -0.521 for the skew constructed from OTM puts (compared to -0.317 in Table 2).

3.5. Alternative competition measures

In this section, we perform additional robustness tests for our main hypothesis of the negative relation between product market competition and option skew. While the fluidity measure is particularly relevant for our analysis as it is constructed to capture competitive threats, we also employ alternative industry concentration measures. Our first such measure is the TNIC3HHI of Hoberg and Phillips (2016). This measure is created using text based analysis of firm 10K filings to compute firm-by-firm pairwise similarity scores. The TNIC industry classification is then constructed with same degree of coarseness as the standard SIC3 classification. The TNIC3HHI is then computed as the Herfindahl index on the TNIC3 industry classification. Our second alternative competition measure is based on the number of firms in the industry. In particular, we use 2, 3 and 4-digit SIC industry definitions. Some authors argue that the more practitioner oriented GICS industry classification is superior to both SIC and NAICS. For example, Bhojraj, Lee, and Oler (2003) compare GICS, NAICS, and SIC industry classifications, and find that GICS classification is significantly better at explaining stock return comovement, as well as cross-sectional variation in valuation multiples, forecasted and realized growth rates, R&D expenditures, and various key financial ratios. We therefore also use a concentration measure based on the number of firms in the GICS industry.

To gauge the effect of these alternative competition measures on the option skew we repeat our analysis in Table 2 while replacing product market fluidity with TNIC3HHI and the number of firms in the SIC2/SIC3/SIC4/GICS industry. Table 6 reports the results from
these tests. Panel A of Table 6 uses TNIC3HHI as the measure of competition, while Panel B uses the number of firms.

The evidence in Table 6 demonstrates the robustness of our main result to the usage of alternative competition measures. Both TNIC3HHI and the number of firms are highly significant and have the predicted signs. Importantly, the positive sign on TNIC3HHI is expected because it is inversely related to industry competitiveness.

3.6. Alternative specifications

In this section we explore the robustness of our main results to alternative regression specifications. Product market fluidity, our main competition measure, varies both across firms and also in the time series. In our main tests we do not include industry fixed effects as they are likely to reduce the power of our tests by absorbing variation in the option skew across industries that is potentially related to differences in competition. It is however plausible that there are differences in option skew among industries not directly related to product market competition. For example, there is a lot of speculative option trading in the biotech industry and this might have an effect on the volatility surface. To alleviate this concern we re-estimate our main empirical model while augmenting it with SIC2 industry fixed effects.

As argued above, product market fluidity is constructed from annual statements and is therefore available at an annual frequency, while our main regression specification is based on monthly observations. As an additional robustness check, we average option skew and control variables for each firm within a year and re-run our main tests on these annualized data.

The results from these additional tests are presented in Table 7. To conserve space, we only report results from specifications without controls and with the full set of controls, corresponding to models (1) and (6) in Table 2. Regressions (1) and (2) in Table 7 are
estimated on monthly data with industry fixed effects. Regressions (3) and (4) use annual data. Industry fixed effects are also included in specifications (5) and (6).

The evidence in Table 7 displays the robustness of our main results to these alternative specifications. While slightly reduced in magnitude, the coefficients on the fluidity measure remain negative and highly statistically significant when industry fixed effects are included in the monthly model. Using annual data results in a sharp drop in the number of observations. However, coefficients on fluidity become even more negative while remaining highly significant.

4. Evidence from a natural experiment

To look deeper into the relation between product market competition and option skew we take advantage of an exogenous shock to the competitiveness of the US manufacturing industries associated with granting a Permanent Normal Trade Relations (“PNTR”) status to China in October 2000, which became effective upon China’s accession to WTO in 2001. As Pierce and Schott (2016) point out, US imports from nonmarket economies like China are subject to relatively high tariff rates originally set under the Smoot-Hawley Tariff Act of 1930. These rates (“non-NTR rates”) are substantially higher that the NTR rates enjoyed by WTO members. The case of China is unique as the United States had been applying the low NTR import tariffs rates to China since 1980. However, these rates required annual renewal and were subject to considerable political uncertainty. Without renewal, the US tariffs on Chinese goods would have jumped to the much higher non-NTR level. As Pierce and Schott (2016) argue, there was a high probability of revoking the low NTR tariffs applied to China with the average opposition to those rates in the House of 38%.

The change in China’s PNTR status had two effects. First, it ended the uncertainty associated with annual renewals of China’s NTR status and reduced the value of the option to wait for Chinese firms, thereby encouraging these firms to invest more in US-China trade. Second, it reduced the expected import tariffs applied to China by removing any possibility of returning to the higher non-NTR tariffs. Both effects lead to greater competition arising from Chinese imports within US manufacturing industries.
We analyze the effect of this exogenous shock to competition in two different ways. First, we use a difference-in-difference analysis to examine the resulting change in the option skew for firms in manufacturing industries (treated firms) versus firms in the other industries (control firms). Second, following Pierce and Schott (2016), we take advantage of the variation in tariffs across industries and study the relation between the skew and the NTR Gap, defined as the difference between industry’s non-NTR and NTR rates.

Feenstra, Romalis, and Schott (2002) compute NTR gaps as the difference between the non-NTR and NTR import tariffs at the 8-digit Harmonized System (HS) level for manufacturing industries. Following Pierce and Schott (2016), we use the NTR gaps for 1999 - the year before passage of PNTR in the United States. We use the concordance table also developed by Pierce and Schott (2016) to match HS codes to NAICs industries.

In our first test, to capture the effect of granting PNTR status to China on the option skew of US firms, we adopt a difference-in-difference methodology and define a Post NTR dummy that indicates whether or not an industry was subject to intensified competition with China in month $t$. We set the Post NTR dummy to one in the months after October 2000 in manufacturing industries (i.e. industries with available data on import tariffs) and set it to zero before October 2000 in manufacturing industries and in all months in the other (non-manufacturing) industries. Our empirical specification has the following form:

$$\text{Skew}_{i,t} = \alpha + \beta \text{Post NTR}_{i,t} + \delta X_{i,t-1} + v_t + \eta_i + \varepsilon_{i,t},$$

where $\text{Skew}_{i,t}$ is the option skew of firm $i$ in month $t$ and $X_{i,t-1}$ is a vector of control variables used in our main tests. We include time fixed effects $v_t$ to absorb potential impact of global time-varying economic conditions on the options market. We also include firm fixed effects $\eta_i$ to account for potential exogenous drivers of the skew at the firm level. To control for potential serial correlation in residuals, we cluster the standard errors at the firm level. Because we are interested in the effect of China’s PNTR status on the skew we limit our sample to the three year period around the PNTR approval in October 2000.

The results from these tests are presented in Table 8. Consistent with our main hypothesis of a negative relation between competition and option skew, these results demonstrate a
significant negative effect on the option skew of firms in manufacturing industries in all regression specifications. The results are also economically large and suggest that following China’s entry into WTO and obtaining the PNTR status the option skew of firms in manufacturing industries (that were subject to intensified competition with Chinese imports) decreased by about 50 to 90 basis points relative to firms in non-manufacturing industries.

In our second test, we follow Pierce and Schott (2016) and focus solely on manufacturing (treated) industries. We exploit the variation in the “tariff gap” defined as the difference between non-NTR and NTR tariff rates in an industry. The magnitude of the shock to competition intensity in an industry is likely to be higher when the tariff gap is larger as greater reductions in tariffs are likely associated with more aggressive penetration of China’s products. We therefore expect a negative relation between the tariff gap and the resulting effect on the option skew. Our empirical specification for this test has the following form:

\[ Skew_{i,t} = \alpha + \beta PostNTR_i \times NTRGap_i + \delta X_{i,t-1} + \nu_t + \eta_i + \varepsilon_{i,t}, \]  

where \( NTRGap_i \) is the difference between the non-NTR rate to which the tariffs would have risen if annual renewal had failed and the NTR rate that was locked by granting China the PNTR status. As before, the \( PostNTR \) dummy is set to one for dates after October 2000 and to zero otherwise.

The results from the second test are presented in Table 9. These results demonstrate a negative and statistically significant relation between the NTR gap and subsequent decline in the option skew of firms in manufacturing industries. This provides further evidence in support of a negative effect of product market competition on option skew, while addressing potential endogeneity concerns.

\section{Conclusion}

We show that competition in product markets is an important driver of the prices of financial options and of the option skew, defined as the difference between implied volatilities of out-of-the-money and at-the-money calls. We do so by modeling the effects of product
market competition on the dynamics of output and equity prices and by showing that, as output and stock prices rise, entry of new firms or investment by competitors becomes more likely, putting pressure on the equilibrium output price process and leading to a drop in the variance of stock returns. That is, we show that product market competition implies a specific stochastic process for the volatility of equity returns and produces a negative volatility skew in the prices of options on equity. We are able to derive analytical solutions for the prices of financial options for this volatility process. We also show that this effect, which produces negative skew by reducing volatility in high demand states, is separate from the effect of financial leverage, which generates a negative option skew by inflating volatility in low demand states. To the best of our knowledge ours is the first paper that models the effects of product market competition on the stochastic process driving the volatility of equity returns.

We complement our theory by empirically analyzing the relation between product market competition and the option skew. We find strong evidence in support of a negative relation. We also show that this effect is reinforced by the underlying uncertainty and is attenuated in industries with high barriers to entry.

Overall, our analysis suggests that an option pricing model capable of explaining the whole cross-section of option prices and volatility surfaces should account for firm fundamentals and, in particular, for the degree of competition that firms face in their product markets.
Appendix

A. Competition, financial leverage, and option skew

In this Appendix, we present a model based on Fries, Miller, and Perraudin (1997) and Zhdanov (2007) that illustrates in the simplest possible way the effects of competition and financial leverage on option prices and skewness. As in our base case model, we consider an economy with a large number of competitive firms. Each firm can undertake a single irreversible investment, requiring an initial sunk cost \( I > 0 \). Once this investment is made, it yields a flow of one unit of output forever with no variable cost of production. The output price is denoted by \( P = (P_t)_{t \geq 0} \) and given by:

\[
P_t = Y_t D(Q_t)
\]

(34)

where \( Y = (Y_t)_{t \geq 0} \) is an industry shock, \( Q = (Q_t)_{t \geq 0} \) is the total industry output, and \( D \) is a time-invariant inverse demand function relating price to industry supply. The industry shock is governed under the risk neutral probability measure by the geometric Brownian motion

\[
dY_t = (r - \delta)Y_t dt + \sigma Y_t dW_t,
\]

(35)

where \( r > 0 \) is the risk-free rate of return, \( \delta \) and \( \sigma \) are positive constants, and \( W = (W_t)_{t \geq 0} \) is a Brownian motion. We embed firms in an industry by assuming that each unit of output is very small compared to total industry output, so that each firm is an infinitesimal price taker.

Firms’ cash flows are subject to taxation at rate \( \tau \). As a result, firms have an incentive to issue debt to reduce taxes. To stay in a simple time-homogeneous setting, we consider debt contracts that are characterized by a perpetual flow of coupon payments \( c \geq 0 \). At the time of entry, each firm selects its capital structure by choosing \( c \). The net income of a firm after entry is then simply given by \( (1 - \tau)(P - c) \). Firms may default on their debt obligations following negative price (demand) shocks. We assume that default leads to exit and liquidation.

In an interval of time when no entry or exit takes place, total output is fixed, so the price is proportional to the industry shock and equation (35) gives:

\[
dP_t = (r - \delta)P_t dt + \sigma P_t dW_t.
\]

(36)

A potential entrant observes this price process and interprets a high price as a signal of a high level of demand. Since the entry cost is constant, it is natural to conjecture that there exists an upper threshold \( \overline{Y} \) for the industry shock which, if reached, triggers new entry. An entry policy \( \overline{Y} \) is associated with a price trigger \( \overline{P} \), which is its image according to equation (34). In equilibrium, the entry of new firms produces a ceiling on the price process. In this model with debt, the exit of firms generates a floor on the price process, just as their entry generates
a ceiling. An active firm thus faces the price process (34) with barriers \( \bar{P} \) and \( P \), with \( \bar{P} > P \). That is, the equilibrium price process is now given by:

\[
dP_t = (r - \delta)P_t dt + \sigma P_t dW_t - dU_t + dL_t, \tag{37}
\]

where the processes \( U = (U_t)_{t \geq 0} \) and \( L = (L_t)_{t \geq 0} \) are right-continuous, nonnegative, and non-decreasing and defined by

\[
U_t = \sup_{0 \leq s \leq t} (P^0_s - \bar{P} + L_s), \quad \text{and} \quad L_t = \sup_{0 \leq s \leq t} (P - P^0_s + U_s), \tag{38}
\]

where \( P^0_t = Y_t D(Q_0) \) is the unregulated price process. The points of growth of \( U \) and \( L \) are located at the reflecting boundaries \( \bar{P} \) and \( P \), where reflection is assumed to take place both instantaneously and with infinitesimal magnitude due to entry and exit by firms.

We can now define a competitive equilibrium as a symmetric Nash equilibrium in entry and default strategies: Given that all other firms issue debt with coupon \( c \) and follow a policy of entry at \( \bar{P} \) and default at entry at \( P \), no individual firm can find it optimal to follow any other financing, entry, or default policy. Formally, an equilibrium is defined as follows:

**Definition.** An industry equilibrium is a diffusion process \( Y_t \) and a pair of threshold \( \bar{P} \) and \( P \) such that

1. Equation (1) holds;
2. \( P_t \in [P, \bar{P}] \);
3. \( Q \) increases only when \( P_t = \bar{P} \) and decreases only when \( P_t = P \);
4. Firms issue debt with coupon \( c \geq 0 \);
5. Entry at \( \bar{P} \) and default at \( P \) maximize equity value, given the dynamics of the price process in (1) and (35);
6. The value of an idle firm is zero.

Competitive equilibrium involves the simultaneous determination of the price process and the entry and exit (default) policies of firms. Given the price dynamics in equation (37), we can derive the value of an active firm in the region \([P, \bar{P}]\) in a competitive equilibrium as follows. Denote by \( P \) the initial value of the output price. In the inaction (no entry, no exit) region, a simple application of Itô’s lemma shows that equity value \( e_C(P) \) satisfies the second order differential equation

\[
re_C(P) = (1 - \tau)(P - c) + (r - \delta)P e_C'(P) + \frac{1}{2} \sigma^2 P^2 e_C''(P), \tag{39}
\]
the solution to which is given by

\[ e_C(P) = (1 - \tau) \left( \frac{P}{\delta} - \frac{c}{r} \right) + E_1 P^\beta + E_2 P^\xi, \]  

(40)

where \( E_1 \) and \( E_2 \) are constants to be determined and \( \beta \) and \( \xi \) are the positive and negative roots of the quadratic equation \( \sigma^2 \nu (\nu - 1) + (r - \delta) \nu - r = 0 \). The first term on the right hand side of equation (40) is the present value of the cash flows to shareholders ignoring the price ceiling and the option to default. The second term captures the effects of the price ceiling and decreases equity value. The third term captures the effects of the option to default and increases equity value.

Now, denote the value of an inactive firm by \( v_I(P) \). Similar arguments as above imply that this value is given by

\[ v_I(P) = A_1 P^\beta + A_2 P^\xi, \]  

(41)

where the first term captures the value of the option to enter the market and the second term reflects the increase in value resulting from the floor on the price process. At the lower reflecting barrier, we have that the value an inactive firm satisfies:

\[ v'_I(P) = 0. \]  

(42)

Denote by \( P_E \leq \overline{P} \) the value of the price process at which inactive firms invest and enter the market. In addition, denote by \( P_D \geq \overline{P} \) the value of the price process at which active firms exit. The lower threshold together with the constants \( A_1, A_2, E_1, \) and \( E_2 \) can be determined using equations (42) and the following boundary conditions:

\[ v'_I(P_E) = e'_C(P_E), \]  

(43)

\[ v_I(P_D) = e_C(P_D), \]  

(44)

\[ v'_I(P_D) = e'_C(P_D). \]  

(45)

The first condition is a smooth-pasting condition that determines the optimal entry threshold. The second condition shows that equity value is zero at the default threshold. The third condition is a smooth-pasting condition which ensures the optimality of the default decision for shareholders. The upper (entry) and lower (default) thresholds can then be determined using the free entry condition:

\[ v_I(P_E) = e_C(P_E) + d_C(P_E) - I, \]  

(46)

in which we have used the fact that part of the investment expenditure is financed by issuing
debt, as well as the no-arbitrage condition

\[ e'_C(P) = 0. \] (47)

To better understand this last condition, note that when the price hits the reflecting boundary, the behavior of the price process changes with upward movements in the unregulated price process being cancelled by offsetting movements in the stochastic regulator \( U \). The solution can then satisfy the equilibrium condition \( r e_C(P) = (1 - \tau)(P - c) + \frac{1}{\delta} E d e_C(P) \) at \( \bar{P} \) only if the infinite variation part in the equity value vanishes, i.e. if \( e'_C(\bar{P}) = 0 \). Lastly, the fixed point requirements \( P_E = \bar{P} \) and \( P_D = \bar{P} \) complete the determination of the equilibrium.

Simple algebraic manipulations of these equations show that \( A_1 = A_2 = 0 \) so that the value of an idle firm is identically zero, as it should be given identical firms. In addition, the constants \( E_1 \) and \( E_2 \) capturing the effects of the price ceiling and the option to default can be derived using the fixed point requirements together with equations (44) and (45). This yields:

\[
E_1 = \frac{\xi - 1}{\beta - \xi} \delta^{-1} P^{1-\beta} + \frac{\xi}{\beta - \xi} \frac{(1 - \tau)c}{r} P^{-\beta}, \tag{48}
\]

\[
E_2 = \frac{\beta - 1}{\xi - \beta} \delta^{-1} P^{1-\xi} + \frac{\beta}{\xi - \beta} \frac{(1 - \tau)c}{r} P^{-\xi}. \tag{49}
\]

Lastly, to determine the entry and default thresholds (or the price ceiling and floor), we need to compute the value of corporate debt, as it enters the free entry condition (46). This value satisfies

\[
r d_C'(P) = c + (r - \delta) P d_C'(P) + \frac{1}{2} \sigma^2 P^2 d_C''(P), \tag{50}
\]

subject to

\[
d_C(P) = \nu P, \text{ and } d_C'(\bar{P}) = 0, \tag{51}
\]

where \( \nu \geq 0 \) and \( \nu \bar{P} \) is the liquidation value of assets. Solving for the value of debt yields

\[
d_C(P) = \frac{c}{r} + \frac{\xi(\nu P - \xi)}{\beta - \xi z^{1-\beta}} P^{1-\beta} + \frac{\beta(\nu P - \xi)}{\beta - \xi z^{1-\xi}} P^{-\xi}. \tag{52}
\]

where \( z \equiv \frac{P}{\bar{P}} \). Plugging this expression in the free entry condition (46), and using the fixed point requirements together with equation (47) allows us to derive two new expressions for \( E_1 \) and \( E_2 \). Combining these with (48) and (49) shows that the entry and default thresholds \( \bar{P} \) and \( \bar{P} \) are given by

\[
P = z \bar{P}, \tag{53}
\]
and
\[
\mathcal{P} = \frac{\xi \left[ I - \frac{\tau c}{r} - \frac{(1-\tau)c}{r}z^{-\beta} \right] + \xi \frac{\xi(\xi-\beta)}{\xi z^{\beta} - \beta \xi}}{(1 - \xi) \frac{1-\tau}{\delta} (z^{1-\beta} - 1) + \frac{\xi(\xi-\beta)\nu z}{\xi z^{\beta} - \beta \xi}}.
\]

where \( z < 1 \) is the solution to the non-linear equation
\[
\xi \left[ I - \frac{\tau c}{r} - \frac{(1-\tau)c}{r}z^{-\beta} \right] + \frac{\xi(\xi-\beta)}{\xi z^{\beta} - \beta \xi} = \beta \left[ I - \frac{\tau c}{r} - \frac{(1-\tau)c}{r}z^{-\xi} \right] + \frac{\beta(\xi-\beta)\nu z}{\xi z^{\beta} - \beta \xi}.
\]

We now consider the effects of competition and financial leverage on option prices. Assume with no loss in generality that the firm has a single share outstanding and that the firm defaults the first time its interest coverage ratio falls below one (alternative default rules, such as endogenous default, can also be considered with no effect on our qualitative predictions). In the model with perfect competition and financial leverage, the dynamics of the state variable (i.e. the output price) reflect entry and exit decisions. As a result, equity value is given by equation (19) and the call option price can be determined by integrating the option payoff function over a risk-neutral density function of the regulated price process:
\[
C_C(P, 0, t) = \mathbb{E} \left[ e^{-rt} \left[ \mathcal{C}_C(y) - K \right]^+ \mathbb{P}(P_t \in dy \mid P_0 = P, P, \mathcal{P}) \right]
\]

where \( x^+ = \max\{0, x\} \) and \( \mathbb{P}(P_t \in dp \mid P_0 = P, P, \mathcal{P}) \) is the probability law of the underlying asset price at time \( t \), given an initial value \( P_0 = P \) at time 0 and reflecting barriers at \( \mathcal{P} \) and \( P \). This law can be obtained by applying a simple change of variable to the density derived in Veestraeten (2004) for a reflected Brownian motion. This gives
\[
\mathbb{P}(P_t \in dy \mid P_0 = P, P, \mathcal{P}) = \sum_{y=0}^{+\infty} \left[ \frac{1}{y\sigma \sqrt{2\pi t}} e^{\frac{2\mu y}{\sigma^2} (y-P)} e^{-\frac{(\mu y + 2n\mathcal{P} - \mu t)^2}{2\sigma^2 y}} \right] dy
\]

\[
+ \sum_{y=0}^{+\infty} \left[ \frac{1}{y\sigma \sqrt{2\pi t}} e^{\frac{2\mu y}{\sigma^2} (y-P)} e^{-\frac{(\mu y + 2n\mathcal{P} - \mu t)^2}{2\sigma^2 y}} \right] dy
\]

\[
+ \frac{2\mu}{\sigma^2} \sum_{y=0}^{+\infty} \left[ \frac{1}{y} e^{\frac{2\mu y}{\sigma^2} (y-P) + \log y} \Phi \left( \frac{\mu y - 2(n+1)\mathcal{P} + 2n\mathcal{P} + \log y + \log P - \mu t}{\sigma \sqrt{t}} \right) \right] dy
\]

\[
- \frac{2\mu}{\sigma^2} \sum_{y=0}^{+\infty} \left[ \frac{1}{y} e^{\frac{2\mu y}{\sigma^2} (y-P) + \log y} \left( 1 - \Phi \left( \frac{\mu y + 2n\mathcal{P} - 2(n+1)\mathcal{P} + \log y + \log P}{\sigma \sqrt{t}} \right) \right) \right] dy
\]

where \( \mu = r - \delta - \frac{\sigma^2}{2}, \mathcal{P} = \log \mathcal{P}, P = \log P \) and \( \Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-\frac{1}{2}y^2} dy \).
The model derived above nests two well known models as special cases, the Black and Scholes (1973) model in which there is no competition nor financial leverage and the Toft and Prucyk (1997) model in which there is financial leverage but no competition. Since the Black and Scholes model is presented in the main text, we focus here on the Toft and Prucyk (1997) model. In this model, there is no price ceiling and the price process evolves in $[P_D, +\infty)$, where $P_D$ is the default threshold. Using standard arguments, it is immediate to show that in our model the value of equity if there is no competition is given by:

$$v_{TP}(P) = (1 - \tau) \left( \frac{P}{\delta} - \frac{C}{r} \right) + (1 - \tau) \left( \frac{C}{r} - \frac{P_D}{\delta} \right) \left( \frac{P}{P_D} \right)^\xi.$$  \tag{58}$$

The first term on the right hand side of equation (58) is the present value of the cash flows to shareholders, ignoring the option to default. The second term captures the value of the option to default and increases the value of equity.

In this model without competition, it is possible to obtain a closed-form solution for the price of a European option written on the firm’s equity. Indeed, since leverage creates the possibility of default before the maturity of the option, the option is akin to a “down-and-out” European call option. The price a call option with maturity $t$ and exercise price $K$ written on the firm’s stock is given by:

$$C_{TP}(P, 0, t) = \mathbb{E}_P \left[ e^{-rt} \mathbb{1}_{\theta > t} (v_{TP}(P_t) - K)^+ \right],$$

where $\theta$ is the default time. This can also be written as

$$C_{TP}(P, 0, t) = e^{-rt} \mathbb{E}_P \left[ \mathbb{1}_{v_{TP}(P_t) > K} \mathbb{1}_{\theta > t} v_{TP}(P_t) \right] - e^{-rt} K \mathbb{E}_P \left[ \mathbb{1}_{v_{TP}(P_t) > K} \mathbb{1}_{\theta > t} \right].$$

Define $B_t = W_t + \alpha t$, where $\alpha \equiv \frac{1}{2} \left( r - \delta - \frac{\sigma^2}{2} \right)$, and

$$\frac{d\tilde{Q}}{d\tilde{Q}} \bigg| _{\mathcal{F}_t} = e^{\frac{\alpha^2}{2} - \alpha B_t}.$$

$B$ is a $\tilde{Q}$-Brownian motion and we have

$$P_t = P_0 e^{\sigma B_t},$$

and

$$\theta = \inf\{ s > 0 : B_s = b \}, \text{ with } b = \frac{1}{\sigma} \log \left( \frac{P_D}{P} \right).$$

\footnote{Our model is also related to the Geske, Subrahmanyam, and Zhou (2016) in which there is no competition and the firm has issued a debt contract with a single payment due at some future date $T > t$. In this case, the value of the option on equity is given by the Geske (1979) formula for compound options.}
We can now write

\[ A = \mathbb{E}_P \left[ 1_{\mathbb{V}_T P_t > K} 1_{\theta > t} e^{-\frac{\alpha^2 t}{2} + \alpha B_t} \right] = \tilde{\mathbb{E}}_P \left[ 1_{\mathbb{V}_T P_t > K} 1_{\theta > t} e^{-\frac{\alpha^2 t}{2} + \alpha B_t} \right] \]

\[ = e^{-\frac{\alpha^2 t}{2}} \tilde{\mathbb{E}}_P \left[ 1_{\mathbb{V}_T P_t > K} 1_{\theta > t} e^{\alpha B_t} \right] = e^{-\frac{\alpha^2 t}{2}} \int_{x^*}^{+\infty} e^{\omega^2} \tilde{Q}(\theta > t, B_t \in d\omega) \]

where \( x^* \) is the smallest solution to

\[ \frac{K}{1 - \tau} = \frac{P}{\delta} e^{\sigma x} - \frac{c}{r} + \left( \frac{c}{r} - \frac{P_D}{\delta} \right) \left( \frac{P}{P_D} \right)^{\xi} e^{\sigma x}. \]

To compute the joint law in the integral, note that

\[ \tilde{Q}(\theta > t, B_t \in d\omega) + \tilde{Q}(\theta < t, B_t \in d\omega) = \tilde{Q}(B_t \in d\omega). \]

Using the reflection principle (see e.g. Karatzas and Shreve (1991, pp79-80)), we have

\[ \tilde{Q}(\theta < t, B_t \in d\omega) = \tilde{Q}(B_t \in d(2b - \omega)). \]

This implies

\[ A = e^{-\frac{\alpha^2 t}{2}} \int_{x^*}^{+\infty} e^{-\frac{1}{2}(\omega^2 - 2t\omega)} d\omega = e^{-\frac{\alpha^2 t}{2}} \int_{x^*}^{+\infty} e^{-\frac{1}{2}((\omega - 2b)^2 - 2t\omega)} d\omega. \]

Using a simple change of variables to compute the above integrals, we finally get

\[ A = \Phi \left( -\frac{x^*}{\sqrt{t}} + \alpha \sqrt{t} \right) - \left( \frac{P_D}{P} \right)^{2\alpha/\sigma} \Phi \left( -\frac{x^* + 2b}{\sqrt{t}} + \alpha \sqrt{t} \right). \]

Similarly, we can compute

\[ B = \mathbb{E}_P \left[ 1_{\mathbb{V}_T P_t > K} 1_{\theta > t} P_t \right] = P\tilde{\mathbb{E}}_P \left[ 1_{\mathbb{V}_T P_t > K} 1_{\theta > t} e^{-\frac{\alpha^2 t}{2} + (\alpha + \sigma) B_t} \right] \]

\[ = Pe^{\frac{(\sigma^2 + 2\alpha \sigma) t}{2}} e^{-\frac{(\alpha + \sigma)^2 t}{2}} \tilde{\mathbb{E}}_P \left[ 1_{\mathbb{V}_T P_t > K} 1_{\theta > t} e^{(\alpha + \sigma) B_t} \right] \]

\[ = Pe^{(r - \delta) t} e^{-\frac{(\alpha + \sigma)^2 t}{2}} \tilde{\mathbb{E}}_P \left[ 1_{\mathbb{V}_T P_t > K} 1_{\theta > t} e^{(\alpha + \sigma) B_t} \right]. \]

The third term on the right hand side of this equation is similar to \( A \) with \( \alpha \) replaced by \( \alpha + \sigma \). We thus have

\[ B = Pe^{(r - \delta) t} \Phi \left( -\frac{x^*}{\sqrt{t}} + (\alpha + \sigma) \sqrt{t} \right) - \left( \frac{P_D}{P} \right)^{2\alpha/\sigma + 2} \Phi \left( -\frac{x^* + 2b}{\sqrt{t}} + (\alpha + \sigma) \sqrt{t} \right). \]
Similar calculations can be used to compute \( \mathbb{E}_P \left[ 1_{\nu_P(P_t) > K} 1_{\theta > \xi} P_t^\xi \right] \). Define \( y^* = \frac{\mu}{\sqrt{t}} - \alpha \sqrt{t} \).

Combining the above calculations shows that the European call option price is given by:

\[
C_{TP}(P, 0, t) = (1 - \tau) \frac{P e^{-\delta t}}{\delta} \left[ \Phi(-y^* + \sigma \sqrt{t}) - \left( \frac{P_D}{P} \right)^{\frac{2\mu}{\sigma^2} + 2} \Phi \left( -y^* + \sigma \sqrt{t} + \frac{2b}{\sqrt{t}} \right) \right] \\
- \left( 1 - \tau \right) \frac{c}{r} + K \right) e^{-rt} \left[ \Phi(-y^*) - \left( \frac{P_D}{P} \right)^{\frac{2\mu}{\sigma^2}} \Phi \left( -y^* + \frac{2b}{\sqrt{t}} \right) \right] \\
+ (1 - \tau) \left( \frac{c}{r} - \frac{P_D}{\delta} \right) \left( \frac{P}{P_D} \right)^{\xi} e^{(\xi(r - \delta) + \frac{\sigma^2}{2}\xi(\xi - 1) - \tau) t} \\
\times \left[ \Phi(-y^* + \xi \sigma \sqrt{t}) - \left( \frac{P_D}{P} \right)^{\frac{2\mu}{\sigma^2} + 2\xi} \Phi \left( -y^* + \xi \sigma \sqrt{t} + \frac{2b}{\sqrt{t}} \right) \right]
\]

(59)

where \( \mu = r - \delta - \frac{\sigma^2}{2} \) and \( y^* \) is the smallest solution to:

\[
K = \frac{1}{1 - \tau} \frac{P e^{\mu t + \sigma \sqrt{t} y} - c}{r} + \left( \frac{c}{r} - \frac{P_D}{\delta} \right) \left( \frac{P}{P_D} \right)^{\xi} e^{(\mu t + \sigma \sqrt{t} y)}. \]

(60)

Equation (60) equates the exercise price of the option to the equity price and is used to determine the minimum value of \( y \) that ensures that the option is in the money at the time to maturity. This implies for example that the term \( \Phi(-y^*) - \left( \frac{P_D}{P} \right)^{\frac{2\mu}{\sigma^2}} \Phi \left( -y^* + \frac{2b}{\sqrt{t}} \right) \) in equation (59) is the probability that the option ends up in the money on the maturity date \( t \) and that there is no default prior to time \( t \) (the second term capturing the “down-and-out” feature of the option on leveraged equity). The other terms in equation (59) admit a similar interpretation and additionally reflect the stochastic changes in \( P \).

Applying Itô’s lemma shows that the volatility of equity prices \( \sigma_{v_C}(P) \) satisfies

\[
\sigma_{v TP}(P) \equiv \frac{P}{\nu_{TP}(P)} \frac{\partial \nu_{TP}(P)}{\partial P} \sigma = \left[ 1 + \frac{(1 - \tau)^{\xi} + (\xi - 1)(1 - \tau)(\xi - \frac{P_D}{\delta}) \left( \frac{P}{P_D} \right)^{\xi}}{\nu_{TP}(P)} \right] \sigma. \]

(61)

It is easy to check that

\[
\frac{\partial \sigma_{v TP}(P)}{\partial P} = \frac{c(\xi - 1)\delta \left( rP(\xi - 1) + (c\xi^2\delta - rP(1 - \xi)^2) \left( \frac{P}{P_D} \right)^{\xi} \right)}{P \left( rP(1 - \xi) + c(\xi - 1) + c \left( \frac{P}{P_D} \right)^{\xi} \right)^2} \sigma < 0. \]

(62)

The denominator of this expression is obviously positive. The numerator is equal to zero when \( P = P_D \) and is otherwise negative. That is, financial leverage leads to negative skewness.
B. Competition and option skew in an imperfect competition model

In the model with imperfect competition, firm value is the solution to

$$v_n(Y,Q) = \max_{\{q_{i,t}: t > 0\}} \mathbb{E} \left[ \int_0^{+\infty} e^{-rt} \left( q_{i,t} Y_t Q_t^{-\frac{1}{\gamma}} dt - I d_0 Q_t \right) \right].$$

To determine this value, we first consider the value of investing in a marginal unit of capital in the symmetric industry equilibrium. Standard derivations show that the value $G_n(Y,Q)$ of the option to invest in a marginal unit of capital satisfies:

$$rG_n(Y,Q) = (r - \delta)Y G_n'(Y,Q) + \frac{1}{2}\sigma^2 Y^2 G_n''(Y,Q),$$

which is solved subject to the value-matching and smooth-pasting conditions

$$\begin{align*}
G_n(Y_n^*(Q),Q) &= \frac{n\gamma}{n\gamma - 1} \frac{Y_n^*(Q) Q^{-\frac{1}{\gamma}}}{\delta} - I \\
G_n'(Y_n^*(Q),Q) &= \frac{n\gamma}{n\gamma - 1} Q^{-\frac{1}{\gamma}}.
\end{align*}$$

where $Y_n^*(Q)$ is the equilibrium investment threshold and where we have used the fact that a marginal unit of capital produces a continuous flow of profit given by: $\frac{n\gamma}{n\gamma - 1} Y Q^{-\frac{1}{\gamma}}$. Solving these equations yields:

$$Y_n^*(Q) = \frac{\gamma n}{\gamma n - 1} \frac{\beta}{\beta - 1} \delta IQ^{\frac{1}{\gamma}},$$

where

$$\beta = 1 - \frac{r - \delta}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{r - \delta}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} > 1.$$ (66)

Consider next the value of the firm $v_n(Y,Q)$. Given the optimal investment threshold $Y_n^*(Q)$, the value of the firm satisfies in the inaction region:

$$rv_n(Y,Q) = (r - \delta)Y v_n'(Y,Q) + \frac{1}{2}\sigma^2 Y^2 v_n''(Y,Q) + \frac{Q}{n} Y Q^{-\frac{1}{\gamma}}.$$ (67)

At the investment trigger, total output increases from $Q$ to $Q + dQ$ and the firm pays the exercise price $\frac{I_n}{n} dQ$. As a result, firm value satisfies the value matching condition: $v_n(Y_n^*(Q),Q) = v_n(Y_n^*(Q),Q + dQ) - \frac{I_n}{n} dQ$. Dividing $dy$ by $dQ$ and taking the limit as $dQ$, this value matching
condition can be written in derivative form as:
\[
\frac{\partial v_n(Y_n^\ast(Q),Q)}{\partial Q} = \frac{I}{n}.
\] (68)

The solution to equation (68) is given by
\[
v_n(Y,Q) = A_n(Q)Y^\beta + \frac{Y}{n\delta}Q^{\gamma - 1},
\] (69)
where \(\beta\) is defined in equation (66). Plugging this expression in equation (69) yields
\[
A'_n(Q) = \left[ I - \left( \frac{\gamma - 1}{\gamma} \right) \frac{\nu_n}{\delta} \left( \frac{\nu_n^{-\beta}}{\nu_n} \right) Q^{-\frac{\gamma}{\delta}} \right].
\] (70)

Integrating \(A'_n(z)\) between \(Q\) and \(+\infty\), the value of each firm can then be expressed as a function of the output price and total output as
\[
v_n(P,Q) = \frac{1}{n} \left[ \frac{QP}{\delta} + \gamma Q \left( I - \frac{(\gamma - 1)\nu_n}{\gamma\delta} \right) \left( \frac{P}{\nu_n} \right)^\beta \right].
\] (71)

Consider now the effects of competition on option prices. In the industry equilibrium with \(n\) firms, both the output price and total output vary through time as firms optimally invest in new capacity. As a result, firm value is given by equation (71). Because the firm invests when \(Y_t\) reaches a new high, the process of equilibrium output can be written as
\[
Q_t = \max \left[ Q, \left( \frac{M_t}{\nu_n} \right)^\gamma \right],
\] (72)
where \(Q\) is the initial output and \(M_t \equiv \sup \{Y_s : 0 \leq s \leq t\}\) is the running maximum of the demand shock at time \(t\). This also implies that we can write the equilibrium output price as
\[
P_t = Y_tQ_t^{-\frac{1}{\gamma}} = Y_t \min \left[ Q^{-\frac{1}{\gamma}}, \left( \frac{M_t}{\nu_n} \right)^{-1} \right].
\] (73)

Equations (72) and (73) imply that we can express the option price as a function of the industry shock and its running maximum, instead of the regulated price process \(P\) and \(M\). Notably, the price at time 0 of a European option maturing at time \(t\) is given by:
\[
C_n(Y,M,0,t) = \int_0^\infty \int_0^\infty e^{-rt} \frac{1}{N_t} [v_n(y,m) - K]^+ \mathbb{P}(Y_t \in dy, M_t \in dm | Y_0 = Y, M_0 = M) \) (74)
\]
where \(N_t\) is the number of shares at time \(t\), \(v_n(y,m)\) is firm value expressed as a function of the industry shock and its running maximum and \(\mathbb{P}(Y_t \in dy, M_t \in dm | Y_0 = Y, M_0 = M)\) is
their joint law at time \( t \) given starting values \( Y \) and \( M \) at time 0. Using equation (71) and the fact that \( \gamma < \beta \), it is immediate to show that

\[
v_n(y, m) = \frac{y \max \left[ Q^{1-\gamma}, \left( \frac{m}{\nu_n} \right)^{\gamma-1} \right]}{n\delta} + \frac{\gamma \min \left[ Q^{1-\frac{\beta}{\gamma}}, \left( \frac{m}{\nu_n} \right)^{\frac{\beta}{\gamma}} \right]}{n(\gamma - \beta)} \left( I - \frac{(\gamma - 1)\nu_n}{\gamma \delta} \right) \left( \frac{y}{\nu_n} \right)^{\beta}.
\]

Because total output does not change between time 0 and time \( t \) if the unregulated process does not reach a new maximum, we can rewrite the option price as

\[
C_n(Y, M, 0, t) = \int_0^M e^{-rt} \left[ v_n(y, M) - K \right]^+ \mathbb{P}(Y_t \in dy, T(M_0) > t | Y_0 = Y, M_0 = M) \nonumber \\
+ \int_0^M \int_0^t e^{-rt} \frac{1}{N_t} \left[ v_n(y, m) - K \right]^+ \nonumber \\
\times \int_0^{T(M_0) \in du | Y_0 = Y, M_0 = M} \mathbb{P}(Y_t \in dy, M_t \in dm | Y_u = M_u = M_0 = M). \quad (75)
\]

The first term on the right hand side of (75) captures the option price if total output does not change before the option matures. The second term captures the option price if total output increases before the option matures due to the demand shock reaching a new high before time \( t \). In this equation, \( T(M_0) \) is the first time that \( Y \) reaches \( M_0 \): \( T(M_0) = \inf \{ s > 0 : Y_s \geq M_0 \} \). The law \( \mathbb{P}(Y_t \in dy, T(M_0) > t | Y_0 = Y, M_0 = M) \) is given by

\[
\mathbb{P}(Y_t \in dy, T(M_0) > t | Y_0 = Y, M_0 = M) = \mathbb{P}(Y_t \in dy | Y_0 = Y) - \mathbb{P}(Y_t \in dy, M_t \geq M_0 | Y_0 = Y, y \leq M_0 = M) \\
= \frac{1}{y \sigma \sqrt{2\pi t}} e^{-\frac{(y-\delta-u^2/2)^2}{2\sigma^2 t}} \left[ e^{-\frac{1}{2\sigma^2 t} \log^2 \frac{u}{\nu_n}} - e^{-\frac{1}{2\sigma^2 t} \log^2 \frac{u^2}{\nu_n^2}} \right] dy. \quad (76)
\]

where the last equality follows from Borodin and Salminen (2002, chapter 9). Lastly, the laws \( \mathbb{P}(T(M_0) \in du | Y_0 = Y, M_0 = M) \) and \( \mathbb{P}(Y_t \in dy, M_t \in dm | Y_u = M_u = M_0 = M) \) can be computed as (see e.g. Jeanblanc, Yor, and Chesney (2009, chapter 3))

\[
\mathbb{P}(T(M_0) \in du | Y_0 = Y, M_0 = M) = \frac{1}{\sigma \sqrt{2\pi u^3}} \log \frac{M}{Y} e^{-\frac{1}{2\sigma^2 u} \left( \log \frac{M}{Y} - (r-\delta-u^2/2)u \right)^2} 1_{u > 0} du,
\]

and

\[
\mathbb{P}(Y_t \in dy, M_t \in dm | Y_u = M) = \frac{2}{\sigma^3 \sqrt{2\pi (t-u)^3}} e^{-\frac{\log^2 \frac{m^2}{Y^2 M}}{2\sigma^2 (t-u)^2} + \frac{(r-\delta-u^2/2)^2}{2\sigma^2} \log \frac{M}{Y} - \frac{(r-\delta-u^2/2)^2}{2\sigma^2}} dudy.
\]
References


**Figure 1.** Equilibrium output price dynamics with perfect competition

This figure presents the dynamics of the output price in the perfect competition setting in which reflection takes place instantaneously and with infinitesimal magnitude at $P$.

**Figure 2.** Equilibrium volatility

This figure plots the volatility of stock returns as a function of the output price in the monopoly and perfect competition models.
Figure 3. Equilibrium volatility with leverage

This figure plots the volatility of stock returns as a function of the output price in the monopoly and perfect competition models when the firm is levered. $P_D$ is the default threshold for a monopolist with debt.

Figure 4. Equilibrium volatility with imperfect competition

This figure plots the volatility of stock returns as a function of the output price in the monopoly and in the imperfect competition models.
Figure 5. Options skew in a perfectly competitive model

This figure presents the option skew as a function of volatility $\sigma$ and growth rate $\mu = r - \delta$ in a perfectly competitive model without leverage. Parameter values are set as follows: $T = 1$, $r = 0.05$, $\sigma = 0.2$, $\mu = r - \delta = 0.01$. Right plots include adjustments to the number of shares to eliminate dividend yield.

Panel A: Option skew and underlying uncertainty

Panel B: Option skew and drift
Figure 6. Options skew in a perfectly competitive model with leverage

This figure presents the option skew as a function of volatility $\sigma$ in a perfectly competitive model with leverage. Parameter values are set as follows: $T = 1$, $r = 0.05$, $\mu = r - \delta = 0.01$. The market leverage of entering firms is 30% (left plot) and 50% (right plot).

Figure 7. Options skew in the model with imperfect competition

This figure presents the option skew as a function of the number of firms in the model with imperfect competition of section 1.2.2. Parameter values are set as follows: $T = 1$, $r = 0.05$, $\sigma = 0.2$, $\mu = r - \delta = 0.01$, $\gamma = 1.5$. 
Table 1
Summary Statistics

Table 1 reports summary statistics of the main variables. *Option Skew* is the difference between implied volatilities of OTM and ATM calls. *Fluidity* is the fluidity measure of industry competitiveness. *Tnic3hhi* is the text-based Herfindahl concentration measure. *Number of firms* is the number of firms in the 3-digit SIC industry. *Market leverage* is the book value of debt divided by the sum of the book value of debt and market value of equity. *Market-to-Book* is the ratio of market and book values of equity. *Size* is the market capitalization in million dollars. *Cumulative return* is past six month cumulative return. *Sdret* is the standard deviation of monthly returns. *Beta* is the market beta from 36-month rolling regressions. *IdSkew* is idiosyncratic skewness of daily returns. *MktSkew* is market skewness of daily returns.

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Table 2 reports results from the regressions of option skew on product market fluidity. *Option Skew* is the difference between implied volatilities of OTM and ATM calls (in percentage points). *Fluidity* is the fluidity measure of industry competitiveness. *Market leverage* is the book value of debt divided by the sum of the book value of debt and market value of equity. *Market-to-Book* is the ratio of market and book values of equity. *Size* is the logarithm of market cap. *Cumulative return* is past six month cumulative return. *Sdret* is the standard deviation of monthly returns. *Beta* is the market beta from 36-month rolling regressions. *IdSkew* is idiosyncratic skewness of daily returns. *MktSkew* is market skewness of daily returns. Table 2 presents results from options with maturities longer than 12 months. Standard errors are clustered by firm. Monthly fixed effects are included.

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54
Table 3
The effects of aggregate uncertainty

Table 3 reports results from the regressions of option skew on product market fluidity and an interaction term of HIGHVIX dummy and fluidity. HIGHVIX is the dummy variable equal to 1 in months when VIX is above its time-series mean. See table 2 for other variable definitions. Standard errors are clustered by firm. Monthly fixed effects are included.

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Table 4 reports results from the regressions of option skew on product market fluidity, tangibility and an interaction term of tangibility and fluidity. Tang is tangibility defined as the ratio of property plant and equipment and total assets. See Table 2 for other variable definitions. Standard errors are clustered by firm. Monthly fixed effects are included.

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Table 5
Alternative measures of option skew

Table 5 reports results from the regressions of alternative measures of option skew on product market fluidity. In panel A Option Skew is defined as the difference between implied volatilities of ATM and OTM puts. In panel B Option Skew is defined as the difference between implied volatilities of ATM and ITM calls. See table 2 for other variable definitions. Standard errors are clustered by firm. Monthly fixed effects are included.

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Panel B: Using ITM calls to construct Option Skew

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Table 6
Alternative competition proxies

Table 6 reports results from the regressions of option skew on alternative competition measures. Panel A reports results for \( TNIC3HHI \). Panel B reports results for the number of firms in the 2/3/4-digit SIC industry and GICS industry. See table 2 for other variable definitions. Standard errors are clustered by firm. Monthly fixed effects are included.

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Panel B: Number of firms in the 2/3/4-digit SIC industry and GICS industry

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60
Table 7 reports results from the regressions of option skew on product market fluidity. See table 2 for variable definitions. Standard errors are clustered by firm. Specifications (1) and (2) use monthly data and include month and industry fixed effects. Specifications (3)-(6) use annual data and include year fixed effects. In addition, specifications (5) and (6) include industry fixed effects.

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Table 8
The effect of granting the PNTR status to China on the option skew

Table 8 reports results from the regressions of option skew on the Post NTR dummy. Option Skew is the difference between implied volatilities of OTM and ATM calls. Post NTR dummy is set to 1 for dates after October 2000 (the date when congress granted PNTR status to China) for manufacturing industries and set to zero otherwise. Leverage is the book value of debt divided by the sum of the market values of debt and equity. Market-to-Book is the ratio of market and book values of equity. Size is the logarithm of market cap. Cumulative return is past six month cumulative return. Sdret is the standard deviation of monthly returns. Beta is the market beta from 36-month rolling regressions. IdSkew is idiosyncratic skewness of daily returns. MktSkew is market skewness of daily returns. Standard errors are clustered by firm.

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Table 9 reports results from the regressions of option skew on the interaction of the Post NTR dummy and the NTR Gap. Option Skew is the difference between implied volatilities of OTM and ATM calls. Post NTR dummy is set to 1 for dates after October 2000 (the date when congress granted PNTR status to China.) NTRGap is the gap between non-NTR and NTR tariffs. PostNTRxNTRGap is the interaction term of Post NTR dummy and NTRGap. Leverage is the book value of debt divided by the sum of the market values of debt and equity. Market-to-Book is the ratio of market and book values of equity. Size is the logarithm of market cap. Cumulative return is past six month cumulative return. Sdret is the standard deviation of monthly returns. Beta is the market beta from 36-month rolling regressions. IdSkew is idiosyncratic skewness of daily returns. MktSkew is market skewness of daily returns. Standard errors are clustered by firm.

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<td>1,386</td>
<td>1,422</td>
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<td>R-squared</td>
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</tr>
<tr>
<td>Time fixed effects</td>
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