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ABSTRACT

We develop a model in which an entrepreneur learns about the average profitability of a private firm before deciding whether to take the firm public. In this decision, the entrepreneur trades off diversification benefits of going public against benefits of private control. The model predicts that firm profitability should decline after the IPO, on average, and that this decline should be larger for firms with more volatile profitability and firms with less uncertain average profitability. These predictions are supported empirically in a sample of 7,183 IPOs in the U.S. between 1975 and 2004.

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1. Introduction

The decision to go public is one of the most important decisions made by privately held firms. This decision can have various motives, such as to diversify the entrepreneur's holdings, to raise capital for investment, to exploit favorable market conditions, to facilitate acquisitions, to improve the liquidity of the firm's shares, to find the firm's market value, and to make the firm more visible. One complicating factor in the IPO decision is that the private firm's future cash flow is highly uncertain. This uncertainty makes it difficult for both the entrepreneur and the outside investors to value the private firm. We examine the effect of this uncertainty on the decision to go public and on firm profitability around the IPO.

We develop a model of the optimal IPO decision in the presence of learning about average profitability. In the model, the profitability of a private firm mean-reverts around an unknown mean and agents learn about this mean by observing realized profits. There are two types of risk-averse agents: investors, who are well diversified, and an entrepreneur, whose entire wealth is tied up in the private firm. The entrepreneur suffers from under-diversification but enjoys benefits of private control. If he takes his firm public, he forfeits the private benefits but achieves better diversification by investing the IPO proceeds in publicly-traded stocks and bonds. It is optimal for the entrepreneur to take his firm public when the market value of the firm (value to investors) exceeds the private value of the firm (value to the entrepreneur). We show that an IPO is more likely for firms with higher expected and current profitability, more volatile profitability, more uncertain average profitability, and lower benefits of private control.

In this model, it is optimal for an IPO to take place when the firm's expected future profitability is sufficiently high. The entrepreneur's benefits of private control are derived from assets in place rather than from future growth opportunities. The firm's private value is therefore less sensitive to expected future profitability than the firm's market value is. When expected profitability rises, the market value rises faster than the private value, and when expected profitability rises high enough, it becomes optimal for the firm to be owned publicly (by investors) rather than privately (by the entrepreneur).

The model predicts that firm profitability should drop after the IPO, on average, and that this drop should be larger for firms with more volatile profitability and firms with less uncertain average profitability. These predictions follow from the endogeneity of the IPO and from learning. For an IPO to take place, the agents' expected profitability must go up before the IPO, as explained in the previous paragraph. According to Bayes' rule, agents revise their expectations upward only if they observe realized profitability that is higher than expected. As a result, realized profitability exceeds expected future profitability at the time of the IPO, and hence profitability is expected to drop after the IPO. The implications for volatility and uncertainty also follow from the basic properties of Bayesian updating. These results come through most clearly in the context of a toy model in Section 2.

To analyze the implications of our model, we calibrate the model and compute the expected post-IPO drop in profitability for a wide range of plausible parameter values, using a closed-form solution for this expected drop. We incorporate the endogeneity of the IPO by computing expectations conditional on an IPO being optimal. We also incorporate the endogeneity of the private firm's existence, recognizing that for some sets of parameter values it is not optimal for the entrepreneur to start the private firm in the first place. The results show that the basic intuition from the toy model applies to our richer model as well.

We test the model's predictions empirically in a sample of 7,183 IPOs in the U.S. between 1975 and 2004. Our evidence supports the model. Firm profitability, measured as return on equity (ROE), declines significantly after the IPO. The average decline in quarterly ROE is 2.7% after one year and 4.3% after three years. A post-IPO decline in profitability has already been reported by Degeorge and Zeckhauser (1993), Jain and Kini (1994), Mikkelson, Partch, and Shah (1997), and Pagano, Panetta, and Zingales (1998) but our sample is much larger.[1] More important, we also find that the post-IPO decline is larger for stocks with more volatile profitability and firms with less uncertain average profitability. These findings, which do not seem to appear in the literature, are consistent with our model.

While the volatility of profitability can be estimated directly from realized profits, uncertainty about average profitability is more difficult to measure. The common proxies for uncertainty also proxy for volatility. To separate uncertainty from volatility, we estimate the stock price reaction to earnings announcements, which should be stronger for firms with higher uncertainty and lower volatility. We find that firms with weaker price reactions tend to experience larger post-IPO drops in ROE, as predicted by the model.

The model also predicts that firm profitability increases before the IPO. We do not test this prediction due to the lack of pre-IPO data, but supporting evidence is provided by Degeorge and Zeckhauser (1993) who study 62 reverse LBOs that went public between 1983 and 1987. They find that profitability increases sharply before LBOs return to public ownership and decreases thereafter, consistent with our model.

[1] Degeorge and Zeckhauser (1993) analyze 62 reverse leveraged buyouts (LBOs) in 1983–1987, Jain and Kini (1994) study 682 IPOs in 1976–1988, Mikkelson, Partch, and Shah (1997) examine 283 IPOs in 1980–1983, and Pagano, Panetta, and Zingales (1998) investigate 69 Italian IPOs in 1982–1992.

Our model generates a rise and fall in profitability around the IPO without asymmetric information. In contrast, many IPO models assume that the entrepreneur has private information about her own firm (e.g., Chemmanur and Fulghieri, 1999). Asymmetric information may well explain some of the observed post-IPO declines in profitability, but it is not clear how it would generate higher declines for firms with more volatile profits and firms with less uncertain average profits. Another possible explanation for the profitability pattern is earnings management. Teoh, Welch and Wong (1998) argue that firms opportunistically inflate their earnings through discretionary accruals shortly before going public. However, firms that are willing to manipulate their earnings around the IPO are likely to manipulate them after the IPO as well. Such firms are likely to smooth their post-IPO earnings, given the apparent market preference for less volatile earnings.[2] Therefore, the earnings management hypothesis would seem to predict that the post-IPO decline in profitability should be larger for firms with less volatile post-IPO earnings, but we find the opposite result.[3]

The key motive for an IPO in our model is diversification. This motive is empirically important according to Bodnaruk, Kandel, Massa, and Simonov (2006), who study all Swedish IPOs in 1995–2001 and find that firms held by less diversified shareholders are more likely to go public. In the model of Benninga, Helmantel, and Sarig (2005), the IPO decision is also driven by the tradeoff between diversification benefits and private benefits, but there are important differences between their paper and ours. First, the models are different: in their model, there is no learning, the cash flow process is different (binomial with known up and down probabilities), and so are the agents' preferences. Second, Benninga et al do not examine post-IPO profitability, which is the subject of our analysis. Finally, their contribution is theoretical whereas ours is both theoretical and empirical.

This paper is also related to the theory of "rational IPO waves" of Pástor and Veronesi (2005). In their model, the entrepreneur observes time-varying market conditions before deciding when to go public. IPO waves arise because many entrepreneurs find it optimal to go public after market conditions improve (e.g., after the equity premium falls).[4] Unlike in that model, we hold market conditions constant, for simplicity, and focus instead on learning about the private firm itself. In our model, unlike in theirs, observing the private firm's profits allows the agents to learn about the firm's average future profitability. In their model, the IPO proceeds are invested in the firm to start production, whereas in our model,

[2]For example, Graham, Harvey and Rajgopal (2005) survey 401 financial executives and find that more than three quarters of them would give up economic value in exchange for smooth earnings.

[3]Ball and Shivakumar (2006) argue that the evidence of Teoh et al is unreliable and that IPO firms actually supply more conservative and higher-quality financial reports than other firms.

[4]Consistent with this argument, CFOs identify overall stock market conditions as "the single most important determinant of timing" of an IPO in Brau and Fawcett's (2006) survey.

they are invested in stocks and bonds for diversification reasons. Finally, while they focus on optimal IPO timing, we focus on the dynamics of profitability around the IPO.

The paper is organized as follows. Section 2. presents a toy model that illustrates how learning affects the post-IPO dynamics of profitability. Section 3. develops the full model. Section 4. analyzes the dynamics of profitability implied by the full model, with a focus on the expected post-IPO drop in profitability. Section 5. presents an empirical test of the main implications of the model. Section 6. concludes. All proofs are in the Appendix.

2. A Toy Model

In this section, we present a simple model that illustrates the effect of learning on the behavior of profitability after an IPO. There are two periods, 0 and 1, in which an entrepreneur decides whether to take his private firm public. This decision is made based on a cutoff rule: an IPO takes place if the firm's expected profitability exceeds a given cutoff. (This type of rule is shown to be optimal in the full model in Section 3.) Let $\underline{\rho}$ denote the cutoff, which is known, and $\overline{\rho}$ denote the firm's average profitability, which is unknown.

At time 0, the entrepreneur's prior beliefs about $\overline{\rho}$ are given by the normal distribution,

$$\overline{\rho} \sim N\left(\widehat{\rho}_0, \widehat{\sigma}_0^2\right). \tag{1}$$

At time 1, the entrepreneur observes a signal about average profitability $\overline{\rho}$, namely realized profitability ρ, whose distribution conditional on $\overline{\rho}$ is given by

$$\rho \sim N\left(\overline{\rho}, \sigma_\rho^2\right). \tag{2}$$

Result 1. Firm profitability is expected to fall after an IPO at time 1.

To prove this result, we first compute the entrepreneur's posterior beliefs after observing the signal. Using Bayes' rule, the posterior distribution of $\overline{\rho}$ is given by

$$\overline{\rho} \mid \rho \sim N\left(\widehat{\rho}, \widehat{\sigma}^2\right), \tag{3}$$

where

$$\widehat{\rho} = w_0\widehat{\rho}_0 + (1 - w_0)\rho \tag{4}$$

$$w_0 = \frac{1/\widehat{\sigma}_0^2}{1/\widehat{\sigma}_0^2 + 1/\sigma_\rho^2}. \tag{5}$$

An IPO takes place at time 1 if expected profitability exceeds the cutoff $\underline{\rho}$:

$$\widehat{\rho} > \underline{\rho}\,. \tag{6}$$

Since the IPO takes place at time 1, there is no IPO at time 0, so that

$$\widehat{\rho}_0 < \underline{\rho}\ . \tag{7}$$

Combining equations (6) and (7), we have $\widehat{\rho} > \widehat{\rho}_0$. It then follows from equation (4) that

$$\rho > \widehat{\rho}\ . \tag{8}$$

In words, for an IPO to take place at time 1, realized profitability ρ must exceed expected future profitability $\widehat{\rho}$. As a result, the post-IPO profitability is expected to be lower than ρ. At time 0, the expected post-IPO drop in profitability is $\mathrm{E}_0(\rho - \widehat{\rho} \mid \text{IPO at time 1}) > 0$.

To simplify the algebraic exposition, add the assumption that $\widehat{\rho}_0 = 0$.

Result 2. The post-IPO drop in profitability is expected to be large when the volatility of profitability (σ_ρ) is high and when prior uncertainty about average profitability ($\widehat{\sigma}_0$) is low.

To prove this result, rewrite equation (4) as

$$\rho - \widehat{\rho} = w_0\,(\rho - \widehat{\rho}_0)\ . \tag{9}$$

The assumption $\widehat{\rho}_0 = 0$ implies $\rho > 0$, so the expected percentage drop in profitability is

$$\mathrm{E}_0\left(\frac{\rho - \widehat{\rho}}{\rho} \mid \text{IPO at time 1}\right) = w_0. \tag{10}$$

From equation (5), w_0 increases with σ_ρ and decreases with $\widehat{\sigma}_0$. As a result, the expected percentage drop in profitability after the IPO is high when profitability is highly volatile and when there is low uncertainty about average profitability.

The intuition behind both results is simple. For an IPO to take place at time 1, expected profitability must go up between times 0 and 1, so realized profitability at time 1 must exceed expected profitability to "pull it up" via Bayesian updating. Since realized profitability exceeds expected profitability at the IPO, profitability is expected to fall after the IPO (Result 1). If volatility is higher, realized profitability is a less precise signal, so it must rise by more to pull expected profitability above the IPO cutoff. Similarly, if uncertainty is lower, realized profitability must rise by more to overcome stronger prior beliefs. In both cases, the gap between realized and expected profitability widens, so the post-IPO drop in profitability is larger (Result 2). This intuition applies not only to the percentage drop but also to the absolute drop in profitability. Note that our arguments rely only on the endogeneity of the IPO decision (equation (6)), the endogeneity of the private firm's existence before the IPO (equation (7)), and Bayesian updating (equation (3)).

In the next section, we develop a richer model with more realistic dynamics for profitability and additional assumptions about agent preferences and investment opportunities. In that model, we show that a version of the IPO rule in equation (6) is optimal, with an endogenous cutoff $\underline{\rho}$ that depends on uncertainty and volatility. The endogeneity of $\underline{\rho}$ complicates the analysis, but we show that Results 1 and 2 hold also in the full model for plausible parameter values. For the reader's convenience, the full model uses some of the same notation as the toy model to denote the same concepts, but none of the above equations apply outside of Section 2.

3. The Full Model

We consider an economy with two types of agents, investors and an entrepreneur. The agents can invest in two assets, risky public equity ("stocks") and a risk-free bond ("bonds"). A third asset, risky private equity, can be created by the entrepreneur at time 0.

At time 0, investors are endowed with a large amount of stocks and bonds. The entrepreneur is endowed with a patent-protected technology and the initial wealth W_0. To produce a stream of profits, the technology requires an initial lump-sum investment of $B_0 = W_0$. The entrepreneur has three choices at time 0: start a private firm that implements the technology, sell the patent, or discard the patent. If the entrepreneur chooses to start a firm, he invests his wealth in the technology and begins producing. He also acquires an option to take the firm public at a future time τ, $0 < \tau < T$. We assume that τ is exogenously given, for simplicity, and that this is the only time when an IPO can take place. If the entrepreneur chooses to go public at time τ, he sells the firm to investors for its fair market value.[5] The entrepreneur's decisions at times 0 and τ are irreversible.

The firm owning the patent-protected technology uses capital B_t to produce earnings at the rate Y_t. The firm's profitability $\rho_t = Y_t/B_t$ follows the mean-reverting process

$$d\rho_t = \phi\left(\overline{\rho} - \rho_t\right)dt + \sigma_{\rho,1}dX_{1,t} + \sigma_{\rho,2}dX_{2,t}, \qquad 0 \le t \le T, \tag{11}$$

where $\overline{\rho}$ denotes average profitability, ϕ denotes the speed of mean reversion, and $X_{1,t}$ and $X_{2,t}$ are uncorrelated Brownian motions that capture systematic ($X_{1,t}$) and firm-specific ($X_{2,t}$) shocks to firm profitability.[6] The firm reinvests all of its earnings. The patent expires at time T, at which point the firm's market value equals the book value, $M_T = B_T$.[7]

[5] In reality, the entrepreneur often retains a substantial part of equity after an IPO. Assuming that the entrepreneur sells the whole firm simplifies both the calculations and the exposition. We believe that none of our qualitative results would change if we allowed the entrepreneur to retain some equity.

[6] Empirically, firm profitability is mean-reverting, e.g., Beaver (1970) and Fama and French (2000).

[7] See Pástor and Veronesi (2003) for a more detailed justification of the terminal value assumption.

Both the entrepreneur and investors are fully rational utility-maximizing agents. Investor preferences are characterized by a pricing kernel π_t, which follows the stochastic process

$$\frac{d\pi_t}{\pi_t} = -rdt - \sigma_{\pi,1} dX_1, \tag{12}$$

where r is the risk-free rate and dX_1 is perfectly correlated with the return on public equity. The entrepreneur's preferences at time t are given by

$$\max \; E_t \left[\int_t^T e^{-\beta(u-t)} \frac{c_u^{1-\gamma}}{1-\gamma} du + \eta e^{-\beta(T-t)} \frac{W_T^{1-\gamma}}{1-\gamma} \right] \tag{13}$$

where c_u denotes consumption, $\gamma > 1$ is the local curvature of the utility function, β is the intertemporal discount, η is a constant, and W_T is the entrepreneur's terminal wealth. For simplicity, we assume that the entrepreneur retires at time T (when the patent expires).

As long as the entrepreneur owns the private firm, he consumes benefits of private control. These benefits include any costs saved by a firm that is not publicly traded (e.g., the costs of separating ownership from control, reporting costs, administrative costs, auditing costs, etc.) as well as benefits commonly referred to as private benefits of control (e.g., Dyck and Zingales, 2004). We distinguish benefits of private control from private benefits of control because the latter benefits can be consumed not only by entrepreneurs but also by managers of publicly traded firms. There are no benefits of private control if the firm is owned by (disperse) investors. For simplicity, we assume that the consumption flow from benefits of private control is proportional to the size of the firm as measured by assets in place,

$$c_t = \alpha B_t, \tag{14}$$

and that the entrepreneur consumes nothing else while managing the private firm. The entrepreneur cannot alter this consumption path by borrowing or lending.[8]

There is no asymmetric information. Average profitability $\overline{\rho}$ in equation (11) is unknown to all agents, investors and entrepreneurs alike. All other parameters are known. Agent beliefs about $\overline{\rho}$ at time $t = 0$ are represented by the normal prior distribution,

$$\overline{\rho} \sim N\left(\widehat{\rho}_0, \widehat{\sigma}_0^2\right). \tag{15}$$

All agents observe realized profitability ρ_t as well as π_t and they update their beliefs about $\overline{\rho}$ dynamically following Bayes' rule.

Under the assumptions detailed above, we solve for the following:

[8] Allowing limited borrowing and lending would not alter our basic intuition (and hence the conclusions) but it would significantly complicate the calculations.

(a) The dynamics of the agents' beliefs about $\overline{\rho}$ (Section 3.1.)

(b) The value of the firm to investors (Section 3.2.)

(c) The value of the firm to the entrepreneur (Section 3.3.)

(d) The conditions under which the entrepreneur finds it optimal to take the firm public at time τ (Section 3.4.)

(e) The conditions under which the entrepreneur finds it optimal to start a private firm at time 0 (Section 3.5.)

(f) The dynamics of firm profitability after the IPO (Section 4.)

3.1. Learning

Following standard results on Bayesian updating in continuous time, the agents' posterior beliefs about average profitability $\overline{\rho}$ at time t are summarized by the normal distribution,

$$\overline{\rho} \sim N\left(\widehat{\rho}_t, \widehat{\sigma}_t^2\right), \tag{16}$$

where the posterior mean and variance evolve over time according to

$$d\widehat{\rho}_t = \widehat{\sigma}_t^2 \frac{\phi}{\sigma_{\rho,2}} d\widehat{X}_{2,t} \tag{17}$$

$$\widehat{\sigma}_t^2 = \frac{1}{\frac{1}{\widehat{\sigma}_0^2} + \left(\frac{\phi}{\sigma_{\rho,2}}\right)^2 t}, \tag{18}$$

and $d\widehat{X}_{2,t}$ is a Brownian motion defined as the normalized expectation error of the idiosyncratic shock. See Lemma 1 of Pástor and Veronesi (2003).

3.2. Value of the Firm to Investors ("Market Value")

The outside investors value the firm as the present value of the terminal payoff B_T. Given the investors' preferences, the market value of the firm at any time t is given by $M_t = E_t\left[\pi_T B_T\right]/\pi_t$, where π_t follows the process in equation (12) and B_t follows the process

$$dB_t = \rho_t B_t dt. \tag{19}$$

Our assumptions allow us to obtain a closed-form solution for the firm's market value:

$$M_t = B_t\, e^{Q_0(T-t)+Q_1(T-t)\rho_t+Q_2(T-t)\widehat{\rho}_t+\frac{1}{2}Q_2(T-t)^2\widehat{\sigma}_t^2}\ , \tag{20}$$

where the functions of time $Q_0(s)$, $Q_1(s)$, $Q_2(s)$, and $Q_3(s)$ are given in the Appendix. This result corresponds to Proposition 2 of Pástor and Veronesi (2003). At this point, the overlap with Pástor and Veronesi (2003) ends.

3.3. Value of the Firm to the Entrepreneur

At time τ, the entrepreneur must decide whether to take his private firm public. This decision is made by comparing two utility values:

1. The utility resulting from selling the firm in an IPO at time τ and investing the proceeds in stocks and bonds until time T
2. The utility resulting from owning the firm between times τ and T

We compute the two utility values in Sections 3.3.1. and 3.3.2., respectively.

3.3.1. Utility Value of Selling the Firm in an IPO

If the entrepreneur sells the firm at time τ, he receives the fair market value M_τ given in equation (20) and invests M_τ in publicly-traded stocks and bonds. To compute the utility value of selling the firm, we first compute the utility value of any generic amount of wealth W_t under the assumption that this wealth is invested in stocks and bonds. This task is made simple by the fact that we have complete markets, in which the stock and bond investment opportunities are captured by the state price density π_t in equation (12). Cox and Huang (1989) show that the dynamic maximization problem of an agent deciding between consumption and investment at time t can be written in a static form as

$$\max_{c,W_T} E_t\left[\int_t^T e^{-\beta(u-t)}\frac{c_u^{1-\gamma}}{1-\gamma}du+\eta e^{-\beta(T-t)}\frac{W_T^{1-\gamma}}{1-\gamma}\right]$$

subject to the static budget constraint

$$E_t\left[\int_t^T \frac{\pi_u}{\pi_t}c_u du+\frac{\pi_T}{\pi_t}W_T\right]\le W_t.$$

The optimal consumption stream and final wealth are given by

$$c_u = \left(\frac{\pi_u}{\pi_t}\right)^{-\frac{1}{\gamma}}\lambda^{-\frac{1}{\gamma}}e^{-\frac{\beta}{\gamma}(u-t)} \qquad \text{and} \qquad W_T=\left(\frac{\pi_T}{\pi_t}\right)^{-\frac{1}{\gamma}}\lambda^{-\frac{1}{\gamma}}\eta^{\frac{1}{\gamma}}e^{-\frac{\beta}{\gamma}(T-t)},$$

where λ is the constant Lagrange multiplier from the maximization problem. The resulting value function for the intertemporal utility is given in the following proposition.

Proposition 1: Let W_t denote the entrepreneur's financial wealth, which can be allocated to stocks or bonds in any proportions. The value function from optimal investment is

$$\begin{aligned} V\left(W_t,t\right) &= \max E_t\left[\int_t^T e^{-\beta(u-t)}\frac{c_u^{1-\gamma}}{1-\gamma}du+\eta e^{-\beta(T-t)}\frac{W_T^{1-\gamma}}{1-\gamma}|W_t\right] \\ &= \frac{W_t^{1-\gamma}}{1-\gamma}\left(\frac{\left(1+\eta^{\frac{1}{\gamma}}\frac{1-\gamma}{\gamma}\left(r-\frac{\beta}{1-\gamma}+\frac{1}{2}\frac{1}{\gamma}\sigma_{\pi,1}^2\right)\right)e^{\frac{1-\gamma}{\gamma}\left(r-\frac{\beta}{1-\gamma}+\frac{1}{2}\frac{1}{\gamma}\sigma_{\pi,1}^2\right)(T-t)}-1}{\frac{1-\gamma}{\gamma}\left(r-\frac{\beta}{1-\gamma}+\frac{1}{2}\frac{1}{\gamma}\sigma_{\pi,1}^2\right)}\right)^{\gamma} \qquad (21)\end{aligned}$$

Thus, selling the firm at time τ gives the entrepreneur utility equal to $V\left(M_\tau,\tau\right)$.

3.3.2. Utility Value of Keeping the Firm Private

If the entrepreneur decides not to go public at time τ, he will continue consuming benefits of private control and his final wealth will be equal to B_T. Thus, according to equations (13) and (14), his utility is given by

$$V^O(B_\tau,\tau) = E_\tau\left[\int_\tau^T e^{-\beta(u-\tau)}\frac{(\alpha B_u)^{1-\gamma}}{1-\gamma}du + \eta e^{-\beta(T-\tau)}\frac{B_T^{1-\gamma}}{1-\gamma}\right].$$

This utility is characterized explicitly in the following proposition.

Proposition 2: The utility from owning the firm from time τ to time T is given by

$$V^O(B_\tau,\tau) = \frac{B_\tau^{1-\gamma}}{1-\gamma}\left\{\alpha^{1-\gamma}\int_\tau^T Z^O\left(\rho_\tau,\widehat{\rho}_\tau,\widehat{\sigma}_\tau^2;u-\tau\right)du + \eta Z^O\left(\rho_\tau,\widehat{\rho}_\tau,\widehat{\sigma}_\tau^2;T-\tau\right)\right\}, \quad (22)$$

where the function Z^O is given in the Appendix.

3.4. The IPO Decision

The IPO decision reflects the tradeoff between diversification benefits of going public and benefits of private control. The entrepreneur will sell the firm at time τ if the utility from investing the IPO proceeds in stocks and bonds is higher than the utility from continuing to run the firm and consume private benefits. The entrepreneur will go public if and only if

$$V(M_\tau,\tau) > V^O(B_\tau,\tau), \quad (23)$$

where $V(M_\tau,\tau)$ is given in Proposition 1 and $V^O(B_\tau,\tau)$ is given in Proposition 2. Let

$$P_\tau = V^{-1}\left(V^O(B_\tau,\tau),\tau\right) \quad (24)$$

define the firm's "private value" at time τ. (The entrepreneur is indifferent between owning the private firm and having P_τ dollars optimally invested in stocks and bonds.) We can then restate condition (23) as $M_\tau > P_\tau$. That is, an IPO takes place if and only if the firm's market value exceeds the private value.

Proposition 3: An IPO takes place at time τ if and only if

$$f(T-\tau,\widehat{\sigma}_\tau,\sigma_\rho) < \alpha^{1-\gamma}\int_\tau^T \widehat{Z}(\rho_\tau,\widehat{\rho}_\tau,\widehat{\sigma}_\tau,\sigma_\rho;u-\tau;T)\,du, \quad (25)$$

where $f(T-\tau,\widehat{\sigma}_\tau,\sigma_\rho)$ and $\widehat{Z}(\rho_\tau,\widehat{\rho}_\tau,\widehat{\sigma}_\tau,\sigma_\rho;u-\tau;T)$ are functions given in the Appendix. Note that f is decreasing in both $\widehat{\sigma}_\tau$ and $\sigma_{\rho,2}$, $\widehat{Z}$ is increasing in both ρ_τ and $\widehat{\rho}_\tau$, and $\widehat{Z} > 0$.

Corollary 1: An IPO at time τ is more likely when

(a) benefits of private control, α, are lower

(b) uncertainty about average profitability, $\widehat{\sigma}_\tau$, is higher

(c) the idiosyncratic component of the volatility of profitability, $\sigma_{\rho,2}$, is higher

(d) current and/or expected profitability, ρ_τ and $\widehat{\rho}_\tau$, are higher

Part (a) follows immediately from the fact that private benefits can be consumed by the entrepreneur but not by the disperse group of investors. Mathematically, the right-hand side of (25) decreases with α but the left-hand side does not depend on α.

The intuition behind parts (b) and (c) is also simple. If the firm is privately owned, higher uncertainty $\widehat{\sigma}_\tau$ or idiosyncratic volatility $\sigma_{\rho,2}$ make the entrepreneur's future consumption more volatile. The risk-averse entrepreneur dislikes this volatility because he is not diversified (formally, V^O is decreasing in both $\widehat{\sigma}_\tau$ and $\sigma_{\rho,2}$), and the only way he can diversify is by selling the firm in an IPO. Since investors are well diversified, they are in a better position to bear the risk associated with the private firm's cash flow process. (The firm can be thought of as small relative to the investors' other holdings since π_t in equation (12) does not depend on $\widehat{\sigma}_\tau$ or $\sigma_{\rho,2}$.) In fact, if the firm is publicly owned, its market value in equation (20) increases with both uncertainty and idiosyncratic volatility, due to the convexity effect discussed in Pástor and Veronesi (2003, 2006). In short, parts (b) and (c) follow because the entrepreneur dislikes uncertainty and idiosyncratic volatility but investors don't.

For most plausible parameter values, part (c) holds not only for idiosyncratic volatility $\sigma_{\rho,2}$ but also for total volatility $\sigma_\rho \sigma_\rho' = \sigma_{\rho,1}^2 + \sigma_{\rho,2}^2$. When $\sigma_{\rho,2}$ increases, the left-hand side of (23) increases while the right-hand side decreases, making an IPO more likely. When $\sigma_{\rho,1}$ increases, both sides of (23) tend to decrease because systematic volatility generally reduces market value. The right-hand side typically decreases by more, so an IPO is usually more likely also after $\sigma_{\rho,1}$ increases. Combining the effects of $\sigma_{\rho,1}$ and $\sigma_{\rho,2}$, we find for most parameter values that an IPO is more likely when total volatility $\sigma_\rho \sigma_\rho'$ is higher.

Although the right-hand side of (25) is always positive, the left-hand side becomes negative when uncertainty and/or volatility are sufficiently high. That is, for any α, there exist levels of uncertainty and volatility above which an IPO always takes place.

Part (d) follows from the fact that the right-hand side of (25) is increasing in both ρ_τ and $\widehat{\rho}_\tau$ (because $\partial \widehat{Z}/\partial \rho_\tau > 0$ and $\partial \widehat{Z}/\partial \widehat{\rho}_\tau > 0$) while the left-hand side is independent of both quantities. Put differently, the market value of the firm increases with ρ_τ and $\widehat{\rho}_\tau$ more rapidly than the private value does. The effect of expected future profitability, $\widehat{\rho}_\tau$, is stronger and easier to explain. Recall from equation (14) that benefits of private control are derived from assets in place (B_t) rather than from future growth opportunities. The firm's private value is therefore less sensitive to $\widehat{\rho}_\tau$ than the firm's (more forward-looking) market value is. Increases in $\widehat{\rho}_\tau$ push up the private value (because B_t grows at the rate of ρ_t) but they push up the market value even more. Therefore, higher $\widehat{\rho}_\tau$ makes an IPO more likely: The entrepreneur becomes more willing to forego private benefits in exchange for financial wealth, because doing so moves him to a more valuable consumption path.

The new consumption path is more valuable in part because it is smoother over the entrepreneur's lifetime. When $\widehat{\rho}_\tau$ increases, the entrepreneur expects higher consumption in the future. He wants to smooth his consumption by consuming more today but he cannot; his consumption is given by private benefits in equation (14). If $\widehat{\rho}_\tau$ is sufficiently high, the entrepreneur's consumption path under private ownership becomes so unattractively steep that he finds it optimal to sell the firm. After cashing out in an IPO, the entrepreneur can smooth his consumption by trading stocks and bonds.

3.4.1. The Endogenous Cutoff Rule for an IPO

Next, we modify the condition in Proposition 3 to obtain an equivalent condition that resembles the cutoff rule in the toy model in Section 2. Define 'excess profitability' as $x_\tau = \rho_\tau - \widehat{\rho}_\tau$. The condition (25) can be restated in terms of x_τ as follows:

$$f\left(T-\tau,\widehat{\sigma}_\tau,\sigma_\rho\right) < h\left(x_\tau,\widehat{\rho}_\tau\right) \equiv \alpha^{1-\gamma}\int_\tau^T \overline{Z}\left(x_\tau,\widehat{\rho}_\tau,\widehat{\sigma}_\tau^2,u-\tau,T\right)du, \tag{26}$$

where $\overline{Z}\left(x_\tau,\widehat{\rho}_\tau,\widehat{\sigma}_\tau,\sigma_\rho,u-\tau,T\right)$ is a function similar to $\widehat{Z}$ (see Appendix). We show in the Appendix that $h\left(x_\tau,\widehat{\rho}_\tau\right)$ is monotonically increasing in x_τ and $\widehat{\rho}_\tau$. Assuming that $f\left(T-\tau,\widehat{\sigma}_\tau,\sigma_\rho\right)$ is sufficiently large, we can define the cutoff $\underline{\rho}\left(x_\tau;\widehat{\sigma}_\tau,\sigma_\rho\right)$ such that

$$h\left(x_\tau,\underline{\rho}\left(x_\tau;\widehat{\sigma}_\tau,\sigma_\rho\right)\right) = f\left(T-\tau,\widehat{\sigma}_\tau,\sigma_\rho\right).$$

If $f\left(T-\tau,\widehat{\sigma}_\tau,\sigma_\rho\right)$ is too low for such a cutoff to exist, we set $\underline{\rho}\left(x_\tau;\widehat{\sigma}_\tau,\sigma_\rho\right) = -\infty$.

Corollary 2: An IPO takes place at time τ if and only if

$$\widehat{\rho}_\tau > \underline{\rho}\left(x_\tau;\widehat{\sigma}_\tau,\sigma_\rho\right). \tag{27}$$

In words, an IPO takes place if expected profitability is sufficiently high. This rule is similar to the cutoff rule assumed in the toy model in Section 2. except that the cutoff $\underline{\rho}\left(x_\tau;\widehat{\sigma}_\tau,\sigma_\rho\right)$ here is endogenous: it depends on the model parameters including uncertainty and volatility, and it is also decreasing in x_τ. (If the current excess profitability x_τ is high, the expected long-run profitability $\widehat{\rho}_\tau$ need not be as high for an IPO to occur.) The intuition behind Corollary 2 is the same as that behind Corollary 1(d). When $\widehat{\rho}_\tau$ rises, the market value rises faster than the private value because the former value is more sensitive to $\widehat{\rho}_\tau$. When $\widehat{\rho}_\tau$ rises sufficiently, it becomes optimal for the firm to be owned publicly rather than privately.[9]

In Section 4., we use Corollary 2 to compute the expected drop in profitability after an IPO, or $E_t\left[x_\tau|\widehat{\rho}_\tau > \underline{\rho}\left(x_\tau;\widehat{\sigma}_\tau,\sigma_\rho\right)\right]$. But first, we step back to time 0. Having characterized the optimal decision at time τ, we can solve for the optimal decision at time 0.

3.5. The Decision to Start a Private Firm

In this section, we solve for the conditions under which the entrepreneur finds it optimal to start a private firm at time 0. These conditions restrict the parameter space, allowing us to incorporate the endogeneity of the private firm's existence in the following section.

At time $t = 0$, the entrepreneur has three choices:

(A) Start a private firm. (Invest W_0 in the technology to start production, keep the firm.)

(B) Sell the patent to investors. (Invest W_0 in the technology to start production, sell it to investors for its fair market value M_0, invest M_0 in stocks and bonds.)

(C) Discard the patent. (Invest W_0 in stocks and bonds.)

The entrepreneur makes a utility-maximizing choice between (A), (B), and (C). Under choice (C), his expected utility is $V(B_0, 0)$, where V is given in Proposition 1 (recall that $B_0 = W_0$). Under choice (B), his utility is $V(M_0, 0)$, where M_0 comes from equation (20). Under choice (A), his expected utility, which we denote by $V_0^O(B_0, 0)$, is given by

$$\begin{aligned} V_0^O(B_0,0) &= E_0\left[\int_0^T e^{-\beta t}\frac{c_t^{1-\gamma}}{1-\gamma}dt + \eta e^{-\beta T}\frac{W_T^{1-\gamma}}{1-\gamma}\right] \\ &= E_0\left[\int_0^\tau e^{-\beta t}\frac{(\alpha B_t)^{1-\gamma}}{1-\gamma}dt\right] + e^{-\beta\tau}E_0\left[V(M_\tau,\tau)\,|\widehat{\rho}_\tau > \underline{\rho}\right]\Pr\left(\widehat{\rho}_\tau > \underline{\rho}\right) \\ &\quad + e^{-\beta\tau}E_0\left[V^O(B_\tau,\tau)\,|\widehat{\rho}_\tau < \underline{\rho}\right]\Pr\left(\widehat{\rho}_\tau < \underline{\rho}\right), \end{aligned} \tag{28}$$

where "Pr" stands for "probability" as of time 0. There are three terms on the right-hand side. The first term reflects the benefits of private control that the entrepreneur consumes while running the firm between times 0 and τ. The second term is the present value of

[9] Ours is unlikely to be the only mechanism that can deliver a cutoff rule for an IPO. For example, consider a model a la Leland and Pyle (1977) in which an entrepreneur seeking IPO financing must signal high effort to outside investors. It seems plausible for high average profitability to serve as a signal of high effort, which could make an IPO optimal if average profitability exceeds a cutoff. Our primary interest is in the implications of the cutoff rule, however this rule is rationalized, for firm profitability around the IPO.

expected utility conditional on an IPO taking place at time τ, which happens if and only if $\widehat{\rho}_\tau > \underline{\rho}$ (see Corollary 2). Recall that in an IPO, the entrepreneur sells the firm to investors for M_τ and invests the proceeds in stocks and bonds. The third term is the utility obtained if no IPO takes place, in which case the entrepreneur remains non-diversified after time τ but continues enjoying private benefits until time T. The calculation of $V_0^O(B_0, 0)$ in equation (28) is challenging, but we have obtained a closed-form solution. Since the formula for $V_0^O(B_0, 0)$ takes up a full page of text, we relegate it to the Appendix.

The necessary and sufficient condition for (A) to be the optimal choice is

$$V_0^O(B_0, 0) > \max\{V(M_0, 0), V(B_0, 0)\}. \tag{29}$$

This is the condition that we impose in the calibration. Due to the complicated formula for $V_0^O(B_0, 0)$, this condition is not transparent. To gain more insight into the decision at time 0, we examine a simpler sufficient condition for (A) to be the optimal choice:

$$V^O(B_0, 0) > \max\{V(M_0, 0), V(B_0, 0)\}. \tag{30}$$

This condition is identical to condition (29) except that $V_0^O(B_0, 0)$ is replaced by $V^O(B_0, 0)$. The left-hand side of condition (30) is the entrepreneur's expected utility from running the private firm between times 0 and T. If the inequality (30) holds, then choice (A) is superior to both (B) and (C) even without taking into account the value of the entrepreneur's option to sell the firm at time τ. This option makes choice (A) more attractive, so that $V_0^O(B_0, 0) > V^O(B_0, 0)$, making condition (30) sufficient but not necessary. We do not use condition (30) for anything other than providing intuition through the following corollary.

Corollary 3: Condition (30) is more likely to be satisfied if

- (a) benefits of private control, α, are higher
- (b) uncertainty about average profitability, $\widehat{\sigma}_0$, is lower
- (c) the idiosyncratic component of the volatility of profitability, $\sigma_{\rho,2}$, is lower

The entrepreneur is more likely to start a private firm if benefits of private control are larger and if the cash flow stream is more stable. The intuition is similar to that behind Corollary 1. When private benefits increase, private value increases relative to market value because these benefits can be consumed by the entrepreneur but not by the outside investors. Private value also increases relative to market value when uncertainty and volatility decrease, because the entrepreneur is not diversified whereas the investors are. However, the negative effects of uncertainty and volatility are likely to be mitigated by the fact that uncertainty and volatility increase the value of the IPO option that is omitted from condition (30).

4. Profitability Dynamics Around an IPO

In this section, we analyze the evolution of profitability around an IPO. Without conditioning on an IPO, profitability ρ_t follows the simple mean-reverting process in equation (11) and expected profitability $\widehat{\rho}_t$ follows the martingale process in equation (17). Conditioning on an IPO changes the dynamics of ρ_t and $\widehat{\rho}_t$ in an interesting way, as we show below.

4.1. Endogeneity of an IPO

To analyze the profitability dynamics around an IPO, we simulate many paths of shocks from the model, and then we average the profitability paths across those simulations in which it is optimal for an IPO to take place. Such an approach produces the model-implied expected pattern in profitability while incorporating the endogeneity of the IPO decision.

Table 1 reports the baseline parameter values used in the simulations. The parameters for the profitability process ($\sigma_{\rho,1}$, $\sigma_{\rho,2}$, and ϕ) are taken from Pástor and Veronesi (2003) who estimate them from the return on equity data of all U.S. public firms in 1962–2000. We also choose the same risk-free rate $r = 0.03$ per year, the same pricing kernel volatility $\sigma_\pi = 0.6$, and the same horizon $T = 15$ years as Pástor and Veronesi. These authors report the grand median of profitability of 0.11 per year for public firms. For a typical private firm, the average profitability $\overline{\rho}$ should be lower than 0.11 because only private firms whose average profitability is perceived to be sufficiently high go public in the model. Therefore, we choose a lower prior mean of $\overline{\rho}$, $\widehat{\rho}_0 = 0.07$. We set the prior uncertainty equal to $\widehat{\sigma}_0 = 0.05$, so the two-standard-deviation prior bounds for $\overline{\rho}$ are -0.03 and 0.17 per year. We pick $\tau = 5$ years, which is close to the median age of IPO firms in the 1990s (Loughran and Ritter, 2004). We choose risk aversion $\gamma = 2$ and the subjective discount rate $\beta = 0.03$. We consider two values of initial profitability, $\rho_0 = \widehat{\rho}_0 = 0.07$ and $\rho_0 = 0$. The latter choice is motivated by the fact that private firms typically do not produce any profits when they are started. Measuring the benefits of private control is difficult. We choose $\alpha = 0.10$, a round number.[10] Later on, we analyze the sensitivity of our results to α and we also average across many plausible values of α when analyzing the expected post-IPO drop in profitability.

We conduct simulations as follows. First, we draw $\overline{\rho}$ from its prior distribution in equation (15). Starting from ρ_0, we simulate the realizations of ρ_t between times 0 and T by discretizing the process (11) and randomly drawing the Brownian shocks $dX_{1,t}$ and $dX_{2,t}$. Analogously, we simulate the realizations of the pricing kernel π_t from the process (12). Given the series of ρ_t and π_t, we compute the dynamics of the posterior beliefs from equa-

[10] Benninga et al (2005) use a range of private benefits centered on 10% of cash flow in their simulations.

tions (17) and (18). We then check whether the IPO condition (23) is satisfied at time τ. If it is, we keep the simulated path; otherwise we discard it. We repeat this procedure until we generate 10,000 simulated paths for which an IPO occurred at time τ.

Figure 1 plots the average paths of realized profitability (ρ_t; solid line) and expected profitability ($\widehat{\rho}_t$; dashed line), where the averages are computed across the 10,000 simulations in which an IPO takes place at time $\tau = 5$. Given the large number of simulations, these paths represent the expected patterns in ρ_t and $\widehat{\rho}_t$ conditional on an IPO. In Panel A, the initial profitability $\rho_0 = \widehat{\rho}_0$; in Panel B, $\rho_0 = 0$. In both panels, the figure shows that realized profitability ρ_t rises sharply before the IPO and declines after the IPO, on average. Expected profitability $\widehat{\rho}_t$ also rises before the IPO but it remains flat after the IPO.

To understand the pattern in expected profitability, $\widehat{\rho}_t$, recall from Corollary 2 that in order for an IPO to take place at time τ, $\widehat{\rho}_\tau$ must exceed a cutoff: $\widehat{\rho}_\tau > \underline{\rho}$. Ex ante, $\widehat{\rho}_t$ is a martingale (equation (17)), but the ex-post conditioning on $\widehat{\rho}_\tau > \underline{\rho}$ implies that $\widehat{\rho}_t$ is expected to increase before the IPO. Indeed, in Figure 1, $\widehat{\rho}_t$ rises from 0.07 to almost 0.09 between times 0 and τ. After the IPO, there is no more conditioning on an ex post event, so $\widehat{\rho}_t$ is constant in expectation due to its martingale property.

The pattern in realized profitability, ρ_t, is also intuitive. As discussed above, expected profitability $\widehat{\rho}_t$ increases before the IPO, on average. In a rational model of learning, an expectation is revised upward only if the realization is higher than expected. To cause upward revisions in $\widehat{\rho}_t$, realized profitability must rise faster than expected under its mean-reverting process. This is why ρ_t rises so sharply before the IPO.

Why does ρ_t typically fall after the IPO? We answer in two steps: first, we explain why it is likely that $\rho_\tau > \widehat{\rho}_\tau$, and second, why $\rho_\tau > \widehat{\rho}_\tau$ implies a post-IPO decline in ρ_t. First, as argued above, ρ_t must rise before the IPO to cause upward revisions in $\widehat{\rho}_t$ so that $\widehat{\rho}_\tau$ can exceed the IPO cutoff. When $\rho_0 = \widehat{\rho}_0$ (Panel A), realized profitability must rise above expected profitability in order to "pull it up" via Bayesian updating, making $\rho_\tau > \widehat{\rho}_\tau$ very likely. When $\rho_0 = 0$ (Panel B), ρ_t must rise faster than expected given its rate of mean reversion. Given the parameter values in Table 1, ρ_t rises so fast that it "catches up" with $\widehat{\rho}_t$ (i.e., $\rho_t = \widehat{\rho}_t$) before time τ. After that point, the only way for ρ_t to pull $\widehat{\rho}_t$ higher toward the cutoff is for ρ_t to rise above $\widehat{\rho}_t$. Again, $\rho_\tau > \widehat{\rho}_\tau$ seems likely. Second, $\rho_\tau > \widehat{\rho}_\tau$ means that ρ_τ exceeds its expected long-run mean, $\widehat{\rho}_\tau$, at the time of the IPO. Since $\widehat{\rho}_t$ has no expected drift after the IPO, $\rho_\tau > \widehat{\rho}_\tau$ implies that ρ_t is expected to fall after the IPO.

Note that the same basic pattern in ρ_t can obtain even in the absence of learning, simply as a result of mean reversion in profitability and the endogeneity of the IPO decision.[11] The case of no learning is a special case of our framework in which average profitability $\overline{\rho}$ is a known constant, so that $\widehat{\rho}_t = \overline{\rho}$ and $\widehat{\sigma}_t = 0$ for all t. In that case, it is useful to restate the condition (26) in terms of ρ_τ. Since $h\left(x_\tau, \widehat{\rho}_\tau\right)$ is monotonically increasing in x_τ, there exists a cutoff $\underline{\underline{\rho}}\left(\overline{\rho}\right)$ such that an IPO takes place at time τ if and only if ρ_τ exceeds this cutoff:

$$\rho_\tau > \underline{\underline{\rho}}\left(\overline{\rho}\right). \tag{31}$$

For many plausible parameter values, this cutoff is larger than ρ_0, $\underline{\underline{\rho}} > \rho_0$, which implies that ρ_t must rise between times 0 and τ to exceed $\underline{\underline{\rho}}$. Whether ρ_t falls after the IPO is not clear but for many parameter values it does. If $\underline{\underline{\rho}} > \overline{\rho}$ then ρ_t is almost guaranteed to fall after the IPO in the long run because its value at the IPO exceeds its long-run mean: $\rho_\tau > \underline{\underline{\rho}} > \overline{\rho}$. Even if $\underline{\underline{\rho}}$ is smaller than $\overline{\rho}$ but not much smaller, ρ_t will fall after the IPO, on average.

Also note that if we average ρ_t and $\widehat{\rho}_t$ across the simulations in which no IPO takes place at time τ, the resulting patterns are opposite to those in Figure 1: $\widehat{\rho}_t$ falls before time τ and stays constant after time τ, on average, and ρ_t also falls before time τ but rises slowly after time τ, mean-reverting toward the higher value of $\widehat{\rho}_t$.

We also examine the sensitivity of the profitability pattern to changes in the baseline parameters from Table 1. We change one parameter at a time, rerun the simulations, compute averages across the simulations in which an IPO took place, and plot the resulting average paths of ρ_t in Figure 2. For comparison, the solid line plots the baseline case, already described in Figure 1. The dash-dot line plots ρ_t for a higher value of private benefits, $\alpha = 0.11$. The pattern in realized profitability is more pronounced than in the baseline case: a steeper pre-IPO increase in ρ_t is followed by a larger post-IPO decrease. As α increases, the private value of the firm increases but the market value does not, so the entrepreneur becomes less willing to sell the firm in an IPO (see Corollary 1). To induce the entrepreneur to sell, $\widehat{\rho}_t$ must rise by more than in the baseline case because it must exceed a higher hurdle in Corollary 2. A larger increase in $\widehat{\rho}_t$ can only be induced by a larger increase in ρ_t, hence ρ_t rises by more than in the baseline case. Given the basic properties of Bayesian updating, the pre-IPO increase in ρ_t must also be larger than the pre-IPO increase in $\widehat{\rho}_t$, so the post-IPO decline in ρ_t (toward its long-run mean $\widehat{\rho}_t$) is steeper.

The dotted line plots ρ_t for a lower value of prior uncertainty, $\widehat{\sigma}_0 = 0.04$. The post-IPO fall in ρ_t is slightly larger than in the baseline case. This result is driven by learning: when uncertainty is lower, prior beliefs about $\overline{\rho}$ are stronger, so ρ_t must rise higher relative to $\widehat{\rho}_t$ in

[11] Similar mean-reversion arguments have been proposed by Degeorge and Zeckhauser (1993) for reverse LBOs and by Li, Livdan, and Zhang (2006) for SEOs. Mean reversion does not have the same predictions as learning, e.g., it does not predict a larger post-IPO drop in ROE for firms with lower uncertainty.

order to pull $\widehat{\rho}_t$ above any given IPO cutoff. One complication is that this cutoff endogenously depends on uncertainty. Lower uncertainty makes private ownership more valuable to the entrepreneur (Corollary 1), which raises the IPO cutoff for $\widehat{\rho}_t$. The higher cutoff typically amplifies the post-IPO drop in profitability.[12]

The dashed line plots ρ_t for more volatile profitability, which we obtain by increasing both $\sigma_{\rho,1}$ and $\sigma_{\rho,2}$ to 0.065. The rise and fall in ρ_t are steeper than in the baseline case. The main reason for this result is learning: higher volatility makes ρ_t a less precise signal about $\overline{\rho}$, so ρ_t must rise higher relative to $\widehat{\rho}_t$ in order to pull $\widehat{\rho}_t$ above a given IPO cutoff. We also recognize that this cutoff endogenously depends on volatility. When $\sigma_{\rho,2}$ increases, the firm's private value is reduced relative to its market value, making an IPO more attractive, thus reducing the IPO cutoff. The cutoff also depends on $\sigma_{\rho,1}$, but this dependence is ambiguous. Overall, the dependence of the cutoff on volatility typically weakens the tent-shape pattern in ρ_t around the IPO. In subsequent analysis, we work with total volatility of profitability, in part because the empirical separation of $\sigma_{\rho,1}$ from $\sigma_{\rho,2}$ is difficult and in part because the theoretical effect of $\sigma_{\rho,1}$ on the IPO decision is ambiguous.

4.2. Endogeneity of the Private Firm's Existence

In Section 4.1., we analyze IPO profitability for plausible sets of parameter values. Some parameter sets are inadmissible, though, because the condition (29) is not satisfied, meaning that it is not optimal to start a private firm at time 0. For example, it is optimal to start the private firm for the parameters in Panels A of Figures 1 and 2, but not for the parameters in Panels B (where it is optimal to discard the patent at time 0). This consideration can affect the expected post-IPO drop in profitability. For example, Figure 2 shows that this drop is lower if private benefits are lower. However, if private benefits are too low, it is not optimal for the entrepreneur to start a private firm at time 0. Therefore, private firms characterized by very low benefits of private control do not exist, and the fact that the post-IPO drop would be low for such firms is nothing more than an intellectual curiosity.

In this section, we account for the endogeneity of the private firm's existence by averaging results across sets of parameters for which it is optimal to start a private firm at time 0. The quantity whose average we calculate is the expected post-IPO drop in profitability. We compute this expectation in closed form and analyze its dependence on the key parameters,

[12]Interestingly, uncertainty has an ambiguous effect on the long-run expectation of ρ_t, which is equal to $\mathrm{E}(\widehat{\rho}_\tau | \widehat{\rho}_\tau > \underline{\rho})$. On one hand, lower uncertainty raises the IPO cutoff $\underline{\rho}$, which pushes $\mathrm{E}(\widehat{\rho}_\tau | \widehat{\rho}_\tau > \underline{\rho})$ up. On the other hand, for any given cutoff, lower uncertainty pushes $\mathrm{E}(\widehat{\rho}_\tau | \widehat{\rho}_\tau > \underline{\rho})$ down due to basic properties of the truncated normal distribution (because the dispersion of $\widehat{\rho}_\tau$ is smaller). The relative importance of the two effects depends on the sensitivity of $\underline{\rho}$ to uncertainty. In Figure 2, the second effect prevails.

uncertainty and volatility. The expected post-IPO drop in profitability is given by

$$E_t\left[\rho_\tau - \widehat{\rho}_\tau | \text{IPO at } \tau\right] = E_t\left[x_\tau | \widehat{\rho}_\tau > \underline{\rho}\left(x_\tau; \widehat{\sigma}_\tau, \sigma_\rho\right)\right], \tag{32}$$

where $x_\tau = \rho_\tau - \widehat{\rho}_\tau$ and the IPO condition is from Corollary 2. Since x_t mean-reverts around zero, a positive expected value of x_τ implies that x_τ is expected to fall after the IPO, so that ρ_τ is expected to fall toward the expectation of its long-run mean, $\widehat{\rho}_\tau$. We do not focus on the expected percentage drop as in equation (10) because profitability can be negative.

Proposition 4: At time $t < \tau$, the expected post-IPO drop in profitability is given by

$$E_t\left[\rho_\tau - \widehat{\rho}_\tau | \text{IPO at } \tau\right] = \frac{e^{-\phi(\tau - t)} x_t - \int x_\tau \mathcal{N}\left(k\left(x_\tau, \tau; t, x_t, \widehat{\rho}_t, \widehat{\sigma}_t^2\right)\right) \Phi\left(x_\tau; \mu_x, \sigma_x^2\right) dx_\tau}{1 - \int \mathcal{N}\left(k\left(x_\tau, \tau; t, x_t, \widehat{\rho}_t, \widehat{\sigma}_t^2\right)\right) \Phi\left(x_\tau; \mu_x, \sigma_x^2\right) dx_\tau} \tag{33}$$

where $\mathcal{N}(.)$ is the cumulative density function of the standard normal distribution and $\Phi\left(.; \mu_x, \sigma_x^2\right)$ is the probability density function of the normal distribution with mean μ_x and variance σ_x^2. The formulas for $k(.)$, μ_x, and σ_x^2 are given in the Appendix.

Proposition 4 provides a closed-form expression for the expected post-IPO drop in profitability. The expected drop depends mostly on uncertainty, volatility, and $\tau - t$. Since this dependence is too complicated to be characterized analytically, we examine it by computing the expected drop as of time $t = 0$ for a wide range of parameter values. We vary uncertainty $\widehat{\sigma}_0$ from 0 to 10% per year, and both components of volatility, $\sigma_{\rho,1} = \sigma_{\rho,2}$, from 1% to 10% per year. We average the results across a range of values for benefits of private control, α, and the prior mean, $\widehat{\rho}_0$ (because these two parameters seem the hardest to choose a priori). We assume that α is uniformly distributed in $[5\%, 15\%]$ and $\widehat{\rho}_0$ is uniformly distributed in $[-20\%, 40\%]$. We take $\rho_0 = 0$ and the remaining parameters are from Table 1. For each set of parameters, we check whether the condition (29) is satisfied; if it is, we compute the expected post-IPO drop in profitability following Proposition 4 with $t = 0$ and $\tau = 5$. For each combination of uncertainty and volatility, we average the expected drops across all values of α and $\widehat{\rho}_0$ for which the condition (29) is satisfied. This calculation produces the expected drop that accounts not only for the endogeneity of the IPO decision but also for the endogeneity of the private firm's existence and for uncertainty about α and $\widehat{\rho}_0$.

Table 2 shows the results. Almost all entries in Panel A are positive, confirming that the expected post-IPO drop in profitability is generally positive. The expected drop can be as large as 23.5% per year, which obtains for $\widehat{\sigma}_0 = 2\%$ and $\sigma_{\rho,1} = \sigma_{\rho,2} = 10\%$. However, there exist parameter values for which the expected drop is zero or even slightly negative; when profitability exhibits very little volatility ($\sigma_{\rho,1} = \sigma_{\rho,2} = 1\%$), we expect profitability to increase after the IPO, although only by less than 1%. The reason is that when volatility is low, signals are precise, so learning is fast and $\widehat{\rho}_t$ rises rapidly toward the IPO cutoff.

Realized profitability ρ_t, which is initiated at $\rho_0 = 0$, may not "catch up" with $\widehat{\rho}_t$, in which case we have $\rho_\tau < \widehat{\rho}_\tau$ at time τ, after which we expect an increase in profitability.

Panel A also shows that the expected drop in profitability tends to be high when volatility is high and when uncertainty is low, as expected from Sections 2. and 4.1. The volatility pattern is stronger and it obtains even for $\widehat{\sigma}_0 = 0$ when the main force is mean reversion in profitability. Both effects are non-monotonic, though. For example, when volatility increases from 9% to 10%, the expected drop decreases in some cases, as it does when uncertainty drops below 2%. This non-monotonicity is largely due to the endogeneity of the private firm's creation at time 0. For example, when uncertainty is higher, a private firm is less likely to be created at time 0, at least according to the sufficient condition (Corollary 3). The firms that are created tend to compensate for the higher uncertainty with higher values of α, for which the drop is generally larger. This firm-selection effect contributes to the reversal of the basic pattern in Table 2 for the lowest values of $\widehat{\sigma}_0$. The firm-selection effect is complicated, in part because we do not have explicit comparative statics for the necessary and sufficient condition (29); we can only partially characterize the sufficient condition (Corollary 3). Panel A of Table 2 provides an imperfect but useful substitute for this intractable theoretical analysis. The basic patterns in the table confirm the implications of the toy model.

In addition to some sets of parameters being inadmissible due to failing the condition (29), other sets of parameters seem implausible because they imply unrealistic properties for the dynamics of the firm's market value. To analyze these properties, Panel B of Table 2 reports the average volatility of the firm's stock returns and Panel C reports the average expected excess return on the firm's stock. Both averages are computed as in Panel A, across all admissible values of α and $\widehat{\rho}_0$, conditional on an IPO at time τ and also on the creation of a private firm at time 0. Note that the expected excess return, which is given by $Q_1(T - t)\sigma_{\rho,1}\sigma_\pi$, does not depend on uncertainty. Panels B and C show that many combinations of volatility and uncertainty in which volatility exceeds 3% produce reasonable properties for stock returns, with return volatility ranging from 14% to 45% per year and the expected excess return ranging from 5.9% to 14.8% per year. However, lower values of the volatility of profitability seem implausible. For example, for $\sigma_{\rho,1} = \sigma_{\rho,2} = 1\%$, return volatility ranges from only 3.5% to 6.6% and the expected excess return is only 1.5%. These values seem unrealistically low, suggesting that profitability must be more volatile than $\sigma_{\rho,1} = \sigma_{\rho,2} = 1\%$ per year. Since the expected drop in Panel A is non-positive only for the lowest values of the volatility of profitability, this additional return-based evidence strengthens the conclusion that the expected drop is positive in this model.

Table 3 is a counterpart of Table 2 with $\tau = 5$ replaced by $\tau = 7$.[13] The results are quite similar to those in Table 2. Although the expected drop is generally smaller than in Table 2, it is overwhelmingly positive. The only exceptions occur for the smallest values of the volatility of profitability, which seem implausible because they produce stock returns whose volatility is less than 10% per year and whose mean is less than 3% in excess of the risk-free rate. Although there are some non-monotonicities due to the private-firm selection at time 0, the expected drop generally increases with volatility and decreases with uncertainty.

5. Empirical Analysis

In this section we test the main predictions of our model: Firm profitability drops after the IPO on average, and this decline is larger for firms with more volatile profitability and lower uncertainty about average profitability.

5.1. Data

Our data sources include CRSP, Compustat, IBES, SDC, and Jay Ritter's IPO database. Our sample contains 7,183 firms that had IPOs in the U.S. from 1975–2004. We include an IPO firm in the sample if it meets all of the following criteria: (1) it appears in either Jay Ritter's 1975-1984 IPO database or in SDC's U.S. Public Common Stock New Issues database with an offer date between 1/1/1985 and 12/31/2004; (2) it had a firm-commitment IPO; (3) it is not a closed-end fund, trust, unit, ADR, ADS, or REIT; and (4) the IPO's offer price was at least one dollar per share.

Guided by the model, we measure profitability as earnings scaled by the book value of equity, or return on equity (ROE). $ROE_{i,s}$ is computed for firm i in the fiscal quarter that is s quarters after the IPO. The dependent variable in our tests is $ROE_{i,s} - ROE_{i,0}$, the change in ROE over the first s quarters after firm i's IPO. ROE equals income before extraordinary items available for common stock plus deferred taxes, divided by book equity. We calculate earnings using quarterly Compustat data, and book value using both quarterly and annual Compustat data. Further details on the construction of $ROE_{i,s}$ are in the Appendix.

We estimate the volatility of ROE by the standard deviation of quarterly ROE over a five-year period after the IPO. Specifically, $VOL(i; s_0)$, or $VOL(s_0)$ for short, is the standard deviation of $ROE_{i,s}$ in quarters $s = s_0, ..., s_0 + 19$, assuming that at least 12 observations are available. We use two values of s_0. The natural choice is $s_0 = 0$ because $VOL(0)$ uses data as

[13] In the full sample of Loughran and Ritter (2004), the median firm age at the IPO is 7 years.

close to the IPO as possible. Under this choice, some of the earnings data used to compute $VOL(0)$ are also used to compute the dependent variable, $ROE_{i,s} - ROE_{i,0}$. Although there is no obvious bias, firms with large post-IPO increases or decreases in ROE are likely to have large values of $VOL(0)$. To address this concern, we also use $s_0 = s+1$. There is no overlap between the earnings data used to calculate $VOL(s+1)$ and $ROE_{i,s} - ROE_{i,0}$.

5.2. Separating Uncertainty from Volatility

To test the model's prediction regarding uncertainty, we need a proxy. Commonly used proxies for uncertainty such as firm age, size, return volatility, or analyst coverage are inadequate here because they proxy not only for uncertainty but also for the volatility of profitability, which has an opposite theoretical effect on the post-IPO drop in profitability. In general, firms with high uncertainty also tend to have high volatility, which presents an estimation challenge. However, we have found an empirical proxy whose value should be high when uncertainty is high and when volatility is low: the stock price reaction to post-IPO earnings announcements. In fact, we can link this proxy directly to our model.

Corollary 4: If the model's assumptions hold and, in addition, $\sigma_{\rho,1} = 0$, then

$$dR_t - E_t\left[dR_t\right] = M\left(\sigma_{\rho,2}, \widehat{\sigma}_0^2; \phi, t\right)\left(d\rho_t - E_t\left[d\rho_t\right]\right), \tag{34}$$

where

$$M\left(\sigma_{\rho,2}, \widehat{\sigma}_0^2; \phi, t\right) = Q_1\left(T-t\right) + Q_2\left(T-t\right)\phi\frac{\widehat{\sigma}_t^2}{\sigma_{\rho,2}^2}. \tag{35}$$

The quantity M represents the stock price reaction to earnings surprises. M is positive (i.e., earnings surprises and the associated abnormal returns have the same sign), increasing in uncertainty ($\widehat{\sigma}_t$), and decreasing in volatility ($\sigma_{\rho,2}$). The intuition is clear. Realized earnings are a noisy signal about average future profitability. Upon observing a given signal, investors update their beliefs about the firm value more when they are more uncertain and when the signal is less noisy (i.e., when earnings are less volatile).

Our model predicts that firms with higher values of M have smaller post-IPO drops in profitability, because such firms have higher uncertainty, lower volatility, or both (holding ϕ and t constant). Once we control for profit volatility, the regression of $ROE_{i,s} - ROE_{i,0}$ on M_i can be interpreted as a test of the model's prediction regarding uncertainty. The theoretical motivation for M is only approximate because Corollary 4 requires $\sigma_{\rho,1} = 0$. This assumption is unrealistic but its violation need not impair the usefulness of M by much because we estimate M in short periods around firm-level earnings announcements, during which firm-specific earnings news is likely to be the main driver of unexpected stock returns. While we are aware that M is not a perfect proxy, we find it satisfactory to use an empirical proxy that is directly motivated by the theoretical model being tested.

We estimate M_i for each IPO firm i based on earnings announcement data. On the left-hand side of equation (34), we interpret $dR_t - E_t[dR_t]$ as the abnormal return due to an earnings announcement. We measure this quantity by AR_{it}, the cumulative return of stock i in excess of stock i's industry's return starting one trading day before the firm's t-th post-IPO earnings announcement and ending one trading day after the same announcement. Quarterly earnings announcement dates are from IBES. Daily stock returns are from CRSP, and daily returns of 49 value-weighted industry portfolios are from Ken French's website. On the right-hand side of equation (34), we interpret $d\rho_t - E_t[d\rho_t]$ as unexpected quarterly profitability, which we compute as $(EPS_{it} - \mathrm{E}[EPS_{it}])/BE_{it}$. EPS_{it} denotes the quarterly earnings per share of firm i announced in its t-th post-IPO earnings announcement, from the IBES unadjusted actuals file. $\mathrm{E}[EPS_{it}]$ is the mean of all analyst forecasts of EPS_{it} using IBES's last pre-announcement set of forecasts for the given fiscal quarter. BE_{it} is book equity per share of firm i, using the most recent pre-announcement measurement.

To estimate M_i, we compute two measures, $ERC_1(i)$ and $ERC_2(i)$, which we refer to as the "earnings response" coefficients, or ERCs. First, we compute

$$RC_{it} = \frac{AR_{it}}{(EPS_{it} - \mathrm{E}[EPS_{it}])/BE_{it}}, \tag{36}$$

excluding observations where the denominator equals zero. From equation (34), RC_{it} is a proxy for M_i. Since RC_{it} is quite noisy (especially if the denominator is close to zero), we winsorize the highest 5% and lowest 5% of RC_{it} observations, and we also average the quarterly RC_{it}'s over the first three years after the IPO to increase precision:

$$ERC_1(i) = \frac{1}{13}\sum_{t=0}^{12} RC_{it}. \tag{37}$$

We compute $ERC_1(i)$ only if there are at least six valid observations of RC_{it}. To define $ERC_2(i)$, consider the following regression over the five-year period after the IPO:

$$(EPS_{it} - \mathrm{E}[EPS_{it}])/BE_{it} = \gamma_{i0} + \gamma_{i1} AR_{it} + \varepsilon_{it}, \qquad t = 0, 1, ..., 20. \tag{38}$$

According to equation (34), $\gamma_{i1} = 1/M_i$ but we do not measure M_i as $1/\hat{\gamma}_{i1}$ because $\hat{\gamma}_{i1}$ can be close to zero, producing outliers in $1/\hat{\gamma}_{i1}$. Instead, we define

$$ERC_2(i) = -\hat{\gamma}_{i1}, \tag{39}$$

with a minus sign so that large earnings responses are associated with large values of ERC_2. Unlike ERC_1, ERC_2 is not a direct estimate of M, but it preserves the same cross-sectional ranking. We make earnings surprises the dependent variable in equation (38) to mitigate the attenuation bias, since we believe there is more measurement error in earnings surprises than in abnormal returns. Since equation (34) indicates $\gamma_{i0} = 0$, we estimate the regressions in (38) without the intercept. We require at least 10 observations to estimate these regressions. Before running the regressions, we winsorize the highest and lowest 5% values of both AR_{it} and $(EPS_{it} - \mathrm{E}[EPS_{it}])/BE_{it}$ across all firms and quarters $t = 0, 1, ..., 32$. ERC_2 is similar to the earnings response coefficient of Easton and Zmijewski (1989) and others.

5.3. Summary Statistics

Table 4 reports some summary statistics. The three-year change in ROE, $ROE_{i,12} - ROE_{i,0}$, can be computed for 3,964 firms. The mean and median of $ROE_{i,12} - ROE_{i,0}$ are both negative, consistent with the model's prediction. In addition, $ROE_{i,12} - ROE_{i,0}$ is negatively correlated with the volatility of ROE and positively correlated with the ERCs. These correlations foreshadow our main empirical results.

Profitability in the quarter of the IPO, $ROE_{i,0}$, can be calculated for 5,795 of the 7,183 firms in our sample.[14] The median $ROE_{i,0}$ is 1.84% per quarter (or 7.4% per year), but the mean is only -0.79%, indicating a left-skewed distribution of ROE. This left skewness has been documented by Fama and French (2004) who attribute this pattern to small IPOs that are highly unprofitable. The low $ROE_{i,0}$ seems inconsistent with our model. In the model, the realized ROE typically exceeds expected long-run ROE at the IPO (this is why ROE declines after the IPO), so we would expect the ROE of IPOs to exceed the ROE of comparable non-IPO firms. Supporting evidence is provided by Jain and Kini (1994) who find that when firms go public, they are more profitable than the median firm in the same industry. To reconcile Jain and Kini's evidence with ours, note that their sample period is 1976–1988, which is roughly the first half of our sample (1975–2004). Fama and French (2004) show that IPO profitability declined in the 1990s. Indeed, in our sample, the medians of $ROE_{i,0}$ in three sub-periods, 1975–1984, 1985–1994, and 1995–2004, are 3.36%, 2.57%, and 0.40%, respectively (the corresponding means are 2.24%, 0.23%, and -2.83%). The low $ROE_{i,0}$ in Table 4 is thus driven by the most recent sub-period, which was unusual in many aspects. For example, in the late 1990s, firms went public at a younger age than ever before (Loughran and Ritter, 2004). It is not surprising that such young firms are less profitable than the more mature firms that went public in the earlier decades.

[14] In contrast, ROE for the quarter immediately preceding the IPO quarter can be computed for only 31 firms, so we cannot test the model's prediction that profitability increases shortly before the IPO.

Our model can be extended to accommodate the low $ROE_{i,0}$ in the 1990s. The model assumes that ROE mean-reverts around a constant mean $\overline{\rho}$, but in reality, this mean is likely to rise while the firm is very young. The start-up costs of a private firm often predictably exceed revenues, making ROE mean-revert around a negative mean $\overline{\rho}_t$ for t close to zero. Over time, $\overline{\rho}_t$ increases until it stabilizes as the firm matures. As long as the unknown value of $\overline{\rho}_t$ varies deterministically, our basic mechanism works also in this extended model. An IPO occurs if the perception of $\overline{\rho}_\tau$, $\widehat{\rho}_\tau$, is sufficiently high. To push $\widehat{\rho}_\tau$ up, realized profits must be higher than expected, which typically leads to $\rho_\tau > \widehat{\rho}_\tau$, which in turn induces a drop in ρ_t immediately after time τ. After the initial post-IPO decline, ρ_t either stabilizes or rises, depending on the extent to which $\overline{\rho}_t$ rises after time τ. When τ is low, $\widehat{\rho}_\tau$ is lower than in our model and it can even be negative. As a result, $\rho_\tau = ROE_{i,0}$ can also be negative, especially if τ (firm age at the IPO) is low, as it was in the late 1990s. To summarize, this realistic extension of our model, in which $\overline{\rho}_t$ increases while the private firm is very young, has the same basic implications while allowing $ROE_{i,0}$ to be low and even negative.

Back to Table 4, ERC_1 and ERC_2 can be computed for almost 40% of firms. (IBES coverage begins in 1982 and is poor for most of the 1980s.) The mean of ERC_1 shows that a 1% earnings surprise (scaled by book equity) is associated with a 3.13% abnormal stock return, on average. Theoretically, earnings surprises and stock returns should have the same sign, so ERC_1 should be positive and ERC_2 negative. However, ERC_1 is negative for 33% of firms, and ERC_2 is positive for 22% of firms. These unexpected signs are probably due to measurement error in expected earnings and non-earnings related news. The cross-sectional means of ERC_1 and ERC_2 do have the predicted signs and high statistical significance. Since ERC_1 and ERC_2 proxy for uncertainty divided by volatility, we expect them to be negatively correlated with the volatility of ROE, and they indeed are. However, ERC_1 and ERC_2 are almost uncorrelated with each other. This unexpected result is due to the observations of ERC_1 and ERC_2 that do not have the predicted signs (i.e., $ERC_1 < 0$ and $ERC_2 > 0$).[15] When these observations are excluded, the correlation increases. We define ERC_1^+ and ERC_2^- in the same way as ERC_1 and ERC_2, except we delete observations with $ERC_1 < 0$ and $ERC_2 > 0$, respectively. The correlation between ERC_1^+ and ERC_2^- is 0.3.

Figure 3 plots the change in ROE, $ROE_{i,s} - ROE_{i,0}$, in event time following the IPO. The top panel shows that average ROE drops steadily after the IPO, leveling off after about eight quarters. The median change in ROE, plotted in the middle panel, is also negative but

[15]Under the assumptions that deliver equation (34), ERC_1 and ERC_2 are approximate estimates of M and $-1/M$, respectively, so $ERC_2 \approx -1/ERC_1$. The function $f(x) = -1/x$ is monotonically increasing for $x > 0$ (which is the predicted sign of ERC_1), making x and $f(x)$ perfectly positively correlated, but the presence of negative values of x (i.e., values of ERC_1 with unpredicted signs) destroys this relation since we observe both branches of the hyperbola instead of just the branch with $x > 0$ and $f(x) < 0$.

smaller in magnitude than the mean change. The 75th percentile line shows that for more than a quarter of firms, ROE actually increases following the IPO. This is not inconsistent with the model, which makes predictions only about the average post-IPO change in ROE. The bottom panel shows the mean change in ROE in the sub-samples of firms that had IPOs in 1975–1984, 1985–1994, and 1995–2004. The patterns are remarkably similar across the three sub-samples, and they are also similar to the model-implied pattern in Figure 1.

Figure 4 compares the post-IPO average changes in ROE between firms with high and low values of volatility and the ERCs. We split all firms into two equally large sub-samples based on whether the firms' $VOL(0)$ is larger or smaller than the cross-sectional median of $VOL(0)$, and we do the same for ERC_1. (The results based on $VOL(13)$ and ERC_2 lead to the same conclusions.) We calculate each sub-sample's mean change in ROE at various horizons. We plot these changes in Panels A and B and we also plot their differences, along with 95% confidence intervals, in Panels C and D. Panels A and C show that mean profitability drops for both high- and low-$VOL(0)$ firms, the drop is significantly larger for firms with high $VOL(0)$, and the difference grows with the horizon. Similarly, Panels B and D show that mean profitability drops for both high- and low-ERC_1 firms, the drop is larger for low-ERC_1 firms, and the difference generally grows with the horizon. Both results are consistent with the model. However, since ERC_1 depends on both uncertainty and volatility, it is unclear which of the two variables drives the difference between the high- and low-ERC_1 firms. In the following section, we attempt to disentangle these effects by including both volatility and the ERCs in a multiple regression.

5.4. Regression Analysis

We estimate the following regression across all IPO firms with available data:

$$ROE_{i,s} - ROE_{i,0} = X_i \beta + \varepsilon_i, \tag{40}$$

where the vector X_i contains a constant and various combinations of our measures of ROE volatility and earnings response. We consider two horizons, $s = 4$ and $s = 12$ quarters. In each specification, we use as many observations as possible, so the sample is not necessarily the same across specifications. We estimate β by ordinary least squares and calculate its standard error by clustering the regression residuals in calendar time.[16]

Table 5 shows the results. First, we estimate the unconditional mean change in ROE over

[16] We allow non-zero correlations between the residuals of firms whose IPOs were $s/2$ or fewer quarters apart in calendar time. Specifically, we assume that $\mathrm{E}[\varepsilon_i \varepsilon_j]$ is equal to σ^2 for $i = j$ and to σ_t^2 for $i \neq j$, where t is the number of quarters between i and j's IPOs. For $t \leq s/2$, we estimate σ_t^2 from the relevant subset of the estimated OLS residuals; for $t > s/2$, we set $\sigma_t^2 = 0$.

the first 4 and 12 post-IPO quarters, respectively. The average value of $ROE_{i,4} - ROE_{i,0}$ is -2.68% per quarter ($t = -11.2$) and the average value of $ROE_{i,12} - ROE_{i,0}$ is -4.29% per quarter ($t = -16.2$). On average, firm profitability clearly drops after the IPO, consistent with the model and also with the earlier empirical studies.

Second, we test the model's prediction that ROE drops more for firms with more volatile ROE. Indeed, the slope coefficients on both $VOL(0)$ and $VOL(s+1)$ are negative and highly statistically significant, with t-statistics exceeding 7.4 in absolute value at both horizons. The relation is also economically significant: a one-standard-deviation cross-sectional increase in $VOL(0)$ is associated with a 1.74% per quarter larger four-quarter drop in ROE and a 5.01% per quarter larger twelve-quarter drop in ROE (not tabulated). The corresponding numbers for $VOL(s+1)$ are 1.48% and 1.88% per quarter, respectively.

Third, we test the prediction that ROE drops more for firms with smaller earnings response measures. Indeed, we observe positive slope coefficients on ERC_1 and ERC_2 in all four specifications (two horizons, two ERCs), and three of the four coefficients are statistically significant. A one-standard-deviation decrease in ERC_1 is associated with a 0.69% per quarter larger four-quarter drop in ROE and a 0.97% larger twelve-quarter drop in ROE. The corresponding numbers for ERC_2 are 0.20% and 0.58%, respectively.

Fourth, since firms with smaller ERC_1 and ERC_2 should have either lower uncertainty or higher volatility or both, we attempt to isolate the impact of uncertainty by including controls for volatility. In these multiple regressions, the slope coefficients on volatility remain negative and highly significant. The slope coefficients on ERC_1 and ERC_2 are positive in all eight specifications (two horizons, two ERCs, two volatility measures), but only three of these coefficients are statistically significant, and barely so. These results are consistent with the model's uncertainty prediction, but the evidence is not overwhelming.

The ERCs may contain substantial estimation error due to mismeasurement of investors' earnings expectations and to non-earnings-related news. This error is likely to affect especially the coefficient estimates that do not have the predicted signs (i.e., $ERC_1 < 0$ and $ERC_2 > 0$); in fact, this error is the most likely reason why these signs are opposite to what basic economics would predict. Therefore, we repeat the tests from Table 5 using ERC_1^+ and ERC_2^-, the ERCs that exclude observations that do not have the predicted signs.

Table 6 is an equivalent of Table 5 with ERC_1 and ERC_2 replaced by ERC_1^+ and ERC_2^-. First, consider the simple regressions of $ROE_{i,s} - ROE_{i,0}$ on either ERC_1^+ or ERC_2^-. The results show that ROE drops more for firms with smaller ERCs, and the evidence is even stronger than in Table 5: the slope coefficients on ERC_1^+ and ERC_2^- are significantly positive in all four univariate specifications, with t-statistics ranging from 2.30 to 6.68. Second, consider the same regressions but control for the volatility of ROE. The slope coefficients on ERC_1^+ and ERC_2^- are positive in all specifications, and five of the eight coefficients are statistically significant. These results are stronger than in Table 5; for example, the t-statistic for ERC_2 in the last specification increases from 1.97 in Table 5 to 4.77 in Table 6.[17] This increase in significance suggests that the decrease in precision resulting from a smaller number of observations is more than offset by the increase in precision resulting from using the ERCs that contain less measurement error. These results support the model's prediction that the post-IPO drop in ROE should be larger for firms with less uncertainty.

We conduct additional robustness tests. First, it makes little difference whether we use the median instead of the mean of analyst forecasts when estimating $\mathrm{E}\left[EPS_{it}\right]$, or whether we require at least two forecasts to compute the mean. Second, changing the number of post-IPO quarters over which ERC_1 and ERC_2 are computed leads to similar results. The tradeoff is that as we use more quarters, the ERCs become less noisy but we also lose more observations and we need to assume that observations several years after the IPO are equally informative about uncertainty and volatility at the time of the IPO. Third, changing the horizon over which we measure the post-IPO drop in ROE to two years or four years does not change any of our conclusions. Fourth, we obtain very similar results when we free up the intercept in the regression (38) used to estimate ERC_2, and also when we redefine ERC_2 as the slope in the reverse regression of abnormal returns on earnings surprises. Fifth, in the regression used to calculate ERC_2, we include an additional regressor, the cumulative stock return starting one day after IBES records the analyst forecasts and ending two trading days before the earnings announcement. The idea is to soak up some of the news that comes out before the earnings announcement but after analysts form their forecasts (about two weeks earlier, on average). The resulting modification of ERC_2 enters our regressions with the same sign but slightly lower statistical significance than the original ERC_2. However, the modified ERC_2 has the predicted sign less often than the original ERC_2, so including the additional regressor seems to reduce rather than increase precision. Sixth, controlling for firm-level sample estimates of the mean reversion coefficient ϕ leads to exactly the same conclusions. Overall, our empirical evidence seems reasonably robust.

[17] We obtain similar results when we winsorize the ERCs with unpredicted signs at zero instead of eliminating them. The slope coefficients on the ERCs are significantly positive in all four univariate specifications, and they are also positive in all eight specifications that control for the volatility of ROE, with four of the eight coefficients being statistically significant.

6. Conclusions

This paper develops a model of the optimal IPO decision, analyzes the model's novel predictions, and tests these predictions empirically. In the model, two types of agents, well-diversified investors and an under-diversified entrepreneur, both learn about the average profitability of a private firm by observing realized profits. There is no asymmetric information. The entrepreneur making the IPO decision faces a tradeoff between benefits of private control and diversification benefits of going public. It is optimal for the entrepreneur to take his firm public if the firm's market value exceeds the firm's private value. We show that an IPO takes place if the agents learn that the firm's average profitability is sufficiently high. The model predicts that firm profitability should decline after the IPO, on average, and that this decline should be larger for firms with more volatile profitability and firms with less uncertain average profitability. We test these predictions empirically and find significant support for them in the data. High volatility and high uncertainty tend to go together, but we separate them by estimating the stock price reaction to earnings announcements, which should be strong when uncertainty is high and when volatility is low.

In the model, IPO firms cannot return to private ownership, but the model's logic seems relevant for the going private decision (e.g., Zingales, 1995, Benninga et al, 2005, Bharath and Dittmar, 2006). Reversing our arguments for going public, a firm is taken private if the benefits of private control exceed the diversification benefits of public ownership, which happens when the agents learn that average profitability is sufficiently low. Such an extension of our model would predict that firms tend to experience declines in profitability before going private and increases in profitability after going private. Consistent with the first prediction, Halpern et al (1999) find that stock returns before leveraged buyouts are unusually low. We leave this model extension as well as its empirical testing for future research.

There is no role for venture capitalists (VCs) in our simple model. It would be interesting to add VCs to the model and analyze their effect on the IPO decision. Lerner (1994) is an early empirical study on the effect of VCs on the IPO timing. A simpler way to extend the model is to relax the assumption that the time of the IPO decision is given. This extension can be solved numerically in a way analogous to solving for the optimal time to exercise an American option. (Pástor and Veronesi (2005) follow this route in a related framework in their analysis of IPO waves.) The key implications of the model are preserved in that (more complex) framework. The entrepreneur chooses to go public immediately after expected profitability exceeds a cutoff, which happens after unexpected increases in profitability. Profitability is expected to decline after the IPO due to the same effects of learning and mean reversion that we describe here. This extension also generates IPO waves among firms in industries that recently became more profitable, as well as industry-wide post-wave declines in profitability. We do not pursue this extension formally because our focus is on learning whose implications come through also in the simpler model.

Our model assumes that the entrepreneur sells the entire private firm in an IPO. It would be interesting to extend the model to allow the entrepreneur to sell only a fraction of the firm. Such a model might allow one to solve for the optimal fraction to be sold in an IPO, and to relate this fraction to the firm's characteristics and to its post-IPO performance.

Although our model is designed for IPOs, it has some relevance for seasoned equity offerings (SEO) as well. If a shareholder owns a substantial fraction of a firm's shares, she faces a similar tradeoff as our entrepreneur: issuing equity makes the shareholder more diversified while reducing her control over the firm. Following the logic of the model, the shareholder may find it optimal to issue more equity after a sufficiently large improvement in profitability and, as a result, profitability should subsequently fall for the same reasons as in the model. Indeed, Loughran and Ritter (1997) find that firm profitability tends to increase before an SEO and decline thereafter, exactly as the model would imply. It would be interesting to test whether this pattern in profitability around SEOs is related to volatility, uncertainty, and to the fraction of equity held by the firm's largest shareholder.

Loughran and Ritter (1997) also argue that "The most salient feature concerning firms' equity issuance behavior is that most firms issue equity after large stock price increases." For example, Asquith and Mullins (1986) and Loughran and Ritter (1995) report that firms engaging in SEOs tend to exhibit high stock returns prior to the SEO. This empirical fact is also consistent with our model. In the model, an issue of equity is induced by recent unexpected increases in profitability, which should coincide with high stock returns. We cannot test this prediction on IPOs since pre-IPO stock returns are obviously unavailable, but the SEO evidence seems comforting. Also note that our model makes no unusual predictions regarding the post-issue stock returns, which are actively debated in the literature.[18] We have nothing to add to this debate. In our model, expected stock returns are not anomalous; they are determined by the covariances between returns and the stochastic discount factor. We analyze operating performance rather than stock performance.

[18]For example, Ritter (1991) and Loughran and Ritter (1995) show that stock returns of firms that recently went public are lower on average than returns of seasoned firms, while Brav and Gompers (1997) and Brav, Géczy, and Gompers (2000) argue that most IPOs are small growth stocks and such stocks have had low returns regardless of whether they recently went public. Degeorge and Zeckhauser (1993) find that after they go public, reverse LBOs actually have slightly higher stock returns than comparison firms.

Appendix.

Detailed Definitions of the Empirical Measures.

Profitability, ROE_{is}, equals $[I_{is} + DT_{is}]/BE_{is}$. The subscript s denotes the s-th fiscal quarter after the fiscal quarter of firm i's IPO. The fiscal quarter containing the IPO is quarter zero. I_{is} equals the income before extraordinary items available for common stock (Compustat quarterly item 25) for firm i in quarter s. DT_{is} equals deferred taxes from income account (Compustat quarterly item 35); we impute a zero value if this item is missing. BE_{is} is the book value of equity of firm i in quarter s. BE_{is} is calculated either from the previous fiscal quarter, previous fiscal year, current fiscal quarter, or current fiscal year, taken in that order depending on availability. Following Fama and French (1993), book value of equity equals stockholders' equity plus deferred taxes minus book value of preferred stock. If any of these three items is missing, then book value of equity is treated as missing. We treat negative or zero values of BE as missing. Stockholders' equity equals either "total stockholders' equity" (quarterly item 60, annual item 216), "total common equity" (quarterly item 59, annual item 60) + "carrying value of preferred stock" (quarterly item 55, annual item 130), "total assets" (quarterly item 44, annual item 6) - "total liabilities" (quarterly item 54, annual item 181), or missing, in that order depending on availability. Deferred taxes equals "deferred tax and investment tax credit" (quarterly item 52, annual item 35), or if that is missing, then zero. Annual book value of preferred stock equals either "redemption value of preferred stock" (annual item 56), "liquidating value of preferred stock" (annual item 10), "carrying value of preferred stock" (annual 130), or zero, in that order depending on availability. Quarterly book value of preferred stock equals "book value of preferred stock" (quarterly item 55), or zero if item 55 is missing. We eliminate firm-quarter observations where ROE_{is} is outside [-100%, +100%].

Abnormal stock return, AR_{it}, is the cumulative return of stock i in excess of stock i's industry, starting one day before the stock's t-th post-IPO earnings announcement and ending one day after the same announcement. Since the industry portfolios were constructed using Compustat SIC codes, we link firms to industries using the most recent annual Compustat SIC code (item 324), soonest future Compustat annual SIC code, most recent CRSP SIC code (SICCD), or soonest future CRSP SIC code, in that order depending on availability. Earnings announcement date is variable REPDATS from the IBES unadjusted actuals file.

Earnings per share, EPS_{it}, is the quarterly EPS of firm i announced in its t-th post-IPO earnings announcement (variable VALUE in the IBES unadjusted actuals file). $\mathrm{E}[EPS_{it}]$ is the mean of all analyst forecasts of EPS_{it} using IBES's last pre-announcement set of forecasts for the given fiscal quarter (variable MEANEST in the IBES unadjusted summary file). We eliminate observations for which the earnings announcement date is more than 60 days after the most recent set of earnings forecasts (roughly 1% of observations are eliminated).

Theoretical Results.

This appendix contains the formulas that we refer to in the text. The proofs of all propositions are contained in the Technical Appendix that is available on the authors' websites.

Market value: Let $\sigma_\pi = (\sigma_{\pi,1}, \sigma_{\pi,2})$ and $\sigma_\rho = (\sigma_{\rho,1}, \sigma_{\rho,2})$. In equation (20), we have

$$\begin{aligned} Q_0(s) &= -rs + \frac{\sigma_\rho \sigma_\rho'}{2\phi^2} Q_3(s) - \frac{\sigma_\pi \sigma_\rho'}{\phi} Q_2(s); \qquad Q_1(s) = \frac{1}{\phi}\left(1 - e^{-\phi s}\right) > 0; \\ Q_2(s) &= s - Q_1(s) > 0; \qquad Q_3(s) = s + \frac{1 - e^{-2\phi s}}{2\phi} - 2Q_1(s). \end{aligned}$$

Proposition 2: The utility from owning the firm from τ to T is given by (22), where

$$Z^O\left(\rho_t, \widehat{\rho}_t, \widehat{\sigma}_t^2; s\right) = e^{\overline{Q}_0(s) + (1-\gamma)Q_1(s)\rho_t + (1-\gamma)Q_2(s)\widehat{\rho}_t + \frac{1}{2}(1-\gamma)^2 Q_2(s)^2 \widehat{\sigma}_t^2} \tag{41}$$

in which $Q_i(.)$ are given above and $\overline{Q}_0(s) = -\beta s + (1-\gamma)^2 \frac{\sigma_\rho \sigma_\rho'}{2\phi^2} Q_3(s)$.

Proposition 3: An IPO takes place if and only if condition (25) is satisfied, where

$$f(T-\tau, \widehat{\sigma}_\tau, \sigma_\rho) = e^{(1-\gamma)\left(-\left(r - \frac{\beta}{1-\gamma}\right)(T-\tau) + \gamma \frac{\sigma_\rho \sigma_\rho'}{2\phi^2} Q_3(T-\tau) - \frac{\sigma_\pi \sigma_\rho'}{\phi} Q_2(T-\tau)\right) + \frac{1}{2}\gamma(1-\gamma) Q_2(T-\tau)^2 \widehat{\sigma}_\tau^2} g(T-\tau) - \eta$$

$$\widehat{Z}(\rho_\tau, \widehat{\rho}_\tau, \widehat{\sigma}_\tau; u-\tau; T) = e^{\widehat{Q}_0(u-\tau;T) + (1-\gamma)\widehat{Q}_1(u-\tau;T)\rho_\tau + (1-\gamma)\widehat{Q}_2(u-\tau;T)\widehat{\rho}_\tau + \frac{1}{2}(1-\gamma)^2 \widehat{Q}_3(u-\tau;T)\widehat{\sigma}_\tau^2}$$

Above,

$$g(T-t) = \left(\frac{\left(1 + \eta^{\frac{1}{\gamma}} \frac{1-\gamma}{\gamma}\left(r - \frac{\beta}{1-\gamma} + \frac{1}{2}\frac{1}{\gamma}\sigma_{\pi,1}^2\right)\right) e^{\frac{1-\gamma}{\gamma}\left(r - \frac{\beta}{1-\gamma} + \frac{1}{2}\frac{1}{\gamma}\sigma_{\pi,1}^2\right)(T-t)} - 1}{\frac{1-\gamma}{\gamma}\left(r - \frac{\beta}{1-\gamma} + \frac{1}{2}\frac{1}{\gamma}\sigma_{\pi,1}^2\right)} \right)^\gamma$$

and

$$\begin{aligned} \widehat{Q}_0(u-\tau;T) &= \overline{Q}_0(u-\tau) - \overline{Q}_0(T-\tau) \\ \widehat{Q}_1(u-\tau;T) &= Q_1(u-\tau) - Q_1(T-\tau) < 0 \\ \widehat{Q}_2(u-\tau;T) &= Q_2(u-\tau) - Q_2(T-\tau) < 0 \\ \widehat{Q}_3(u-\tau;T) &= Q_2(u-\tau)^2 - Q_2(T-\tau)^2 < 0 \end{aligned}$$

IPO decision: An IPO takes place if and only if condition (26) holds, where

$$\overline{Z}(x_\tau, \widehat{\rho}_\tau, \widehat{\sigma}_\tau, u-\tau, T) = e^{\widehat{Q}_0(u-\tau,T) + (1-\gamma)\left(\widehat{Q}_1(u-\tau,T)x_\tau + (u-T)\widehat{\rho}_\tau\right) + \frac{1}{2}(1-\gamma)^2 \widehat{Q}_3(u-\tau,T)\widehat{\sigma}_\tau^2}$$

Proposition 4: The expected drop in profitability is given in equation (33), where

$$k\left(x_\tau, \tau; t, x_t, \widehat{\rho}_t, \widehat{\sigma}_t^2\right) = \frac{\underline{\rho}(x_\tau) - \widehat{\rho}_t - a\left(t, \tau; \widehat{\sigma}_t^2\right)\left(x_\tau - e^{-\phi(\tau - t)} x_t\right)}{\sqrt{\left(\widehat{\sigma}_t^2 - \widehat{\sigma}_\tau^2\right)\left(1 - b\left(t, \tau; \widehat{\sigma}_t^2\right)^2\right)}} \tag{42}$$

$$\mu_x = e^{-\phi(\tau-t)}x_t; \qquad \sigma_x^2 = \frac{1-e^{2\phi(\tau-t)}}{2\phi}\left(\sigma_{\rho,1}^2+\sigma_{\rho,2}^2\right)+\left(e^{-2\phi(\tau-t)}\widehat{\sigma}_t^2-\widehat{\sigma}_\tau^2\right) \tag{43}$$

and $a\left(t,\tau;\widehat{\sigma}_t^2\right)$ and $b\left(t,\tau;\widehat{\sigma}_t^2\right)$ are given by

$$\begin{aligned}
a\left(t,\tau;\widehat{\sigma}_t^2\right) &= \frac{\widehat{\sigma}_\tau^2-e^{-\phi(\tau-t)}\widehat{\sigma}_t^2}{\frac{1-e^{2\phi(\tau-t)}}{2\phi}\left(\sigma_{\rho,1}^2+\sigma_{\rho,2}^2\right)+\left(e^{-2\phi(\tau-t)}\widehat{\sigma}_t^2-\widehat{\sigma}_\tau^2\right)}\\
b\left(t,\tau;\widehat{\sigma}_t^2\right) &= \frac{\widehat{\sigma}_\tau^2-e^{-\phi(\tau-t)}\widehat{\sigma}_t^2}{\sqrt{\frac{1-e^{2\phi(\tau-t)}}{2\phi}\left(\sigma_{\rho,1}^2+\sigma_{\rho,2}^2\right)+\left(e^{-2\phi(\tau-t)}\widehat{\sigma}_t^2-\widehat{\sigma}_\tau^2\right)}\sqrt{\widehat{\sigma}_t^2-\widehat{\sigma}_\tau^2}}
\end{aligned}$$

Proposition 5: The value function at time 0 is given in equation (28), where

$$\begin{aligned}
V_0^O\left(B_0,0\right) &= \frac{B_0^{1-\gamma}}{1-\gamma}\times\left\{\alpha^{1-\gamma}\int_0^\tau Z^O\left(\rho_0,\widehat{\rho}_0,\widehat{\sigma}_\tau^2;u\right)du\right.\\
&\quad +e^{-\beta\tau}\left[g\left(T-\tau\right)e^{G_0(\tau,T)+G_1(\tau,T)x_0+G_2(\tau,T)\widehat{\rho}_0}H^y\left(x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2,\tau,T\right)\right.\\
&\quad +\int_\tau^T \alpha^{1-\gamma}e^{\overline{G}_0(\tau,u)+G_1(\tau,u)x_0+G_2(\tau,u)\widehat{\rho}_0}H^n\left(x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2,\tau,u\right)du\\
&\quad \left.\left.+\eta e^{\overline{G}_0(\tau,T)+G_1(\tau,T)x_0+G_2(\tau,T)\widehat{\rho}_0}H^n\left(x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2,\tau,T\right)\right]\right\}
\end{aligned}$$

where

$$\begin{aligned}
H^y\left(x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2,\tau,u\right) &= \int e^{G_3(\tau,u)x_\tau}\left(1-\mathcal{N}\left(k_2\left(x_\tau,\tau,u;0,x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2\right)\right)\right)\Phi\left(x_\tau;\mu_x\left(x\right),\sigma_x^2\left(t,\tau\right)\right)dx\\
H^n\left(x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2,\tau,u\right) &= \int e^{G_3(\tau,u)x_\tau}\mathcal{N}\left(k_2\left(x_\tau,\tau,u;0,x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2\right)\right)\Phi\left(x_\tau;\mu_x\left(x\right),\sigma_x^2\left(t,\tau\right)\right)dx_\tau
\end{aligned}$$

$$k_2\left(x_\tau,\tau,u;x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2\right)=k\left(x_\tau,\tau;0,x_0,\widehat{\rho}_0,\widehat{\sigma}_0^2\right)-(1-\gamma)\,a_2\left(\tau,u\right)\sqrt{\left(\widehat{\sigma}_0^2-\widehat{\sigma}_\tau^2\right)\left(1-b\left(0,\tau;\widehat{\sigma}_0^2\right)^2\right)}$$

and $G_i(\tau,u)$, $i=0,..,3$, $\overline{G}_0(\tau,u)$, and $a_2(\tau,u)$ are given in the Technical Appendix.

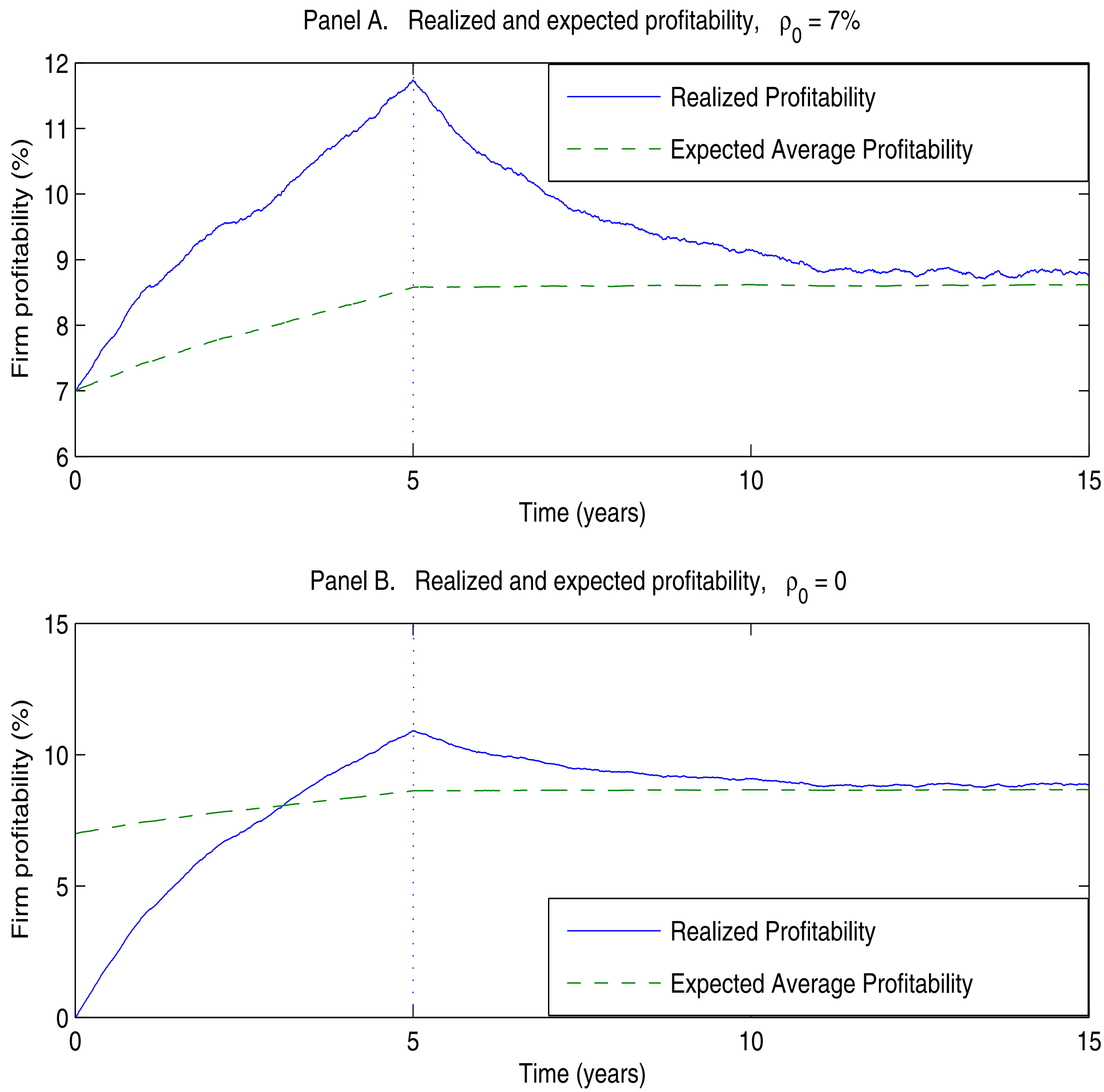

Figure 1. Model-Implied Expected and Realized Profitability Around an IPO. This figure plots the average paths of realized profitability (ρ_t; solid line) and expected average profitability ($\widehat{\rho}_t$; dashed line), in percent per year, where the paths are averaged across 10,000 simulations of our model in which an IPO takes place at time $\tau = 5$. Given the large number of simulations, these average paths represent expected patterns in ρ_t and $\widehat{\rho}_t$ conditional on an IPO. In Panel A, the initial profitability $\rho_0 = \widehat{\rho}_0 = 7\%$; in Panel B, $\rho_0 = 0$. The remaining model parameters are from Table 1.

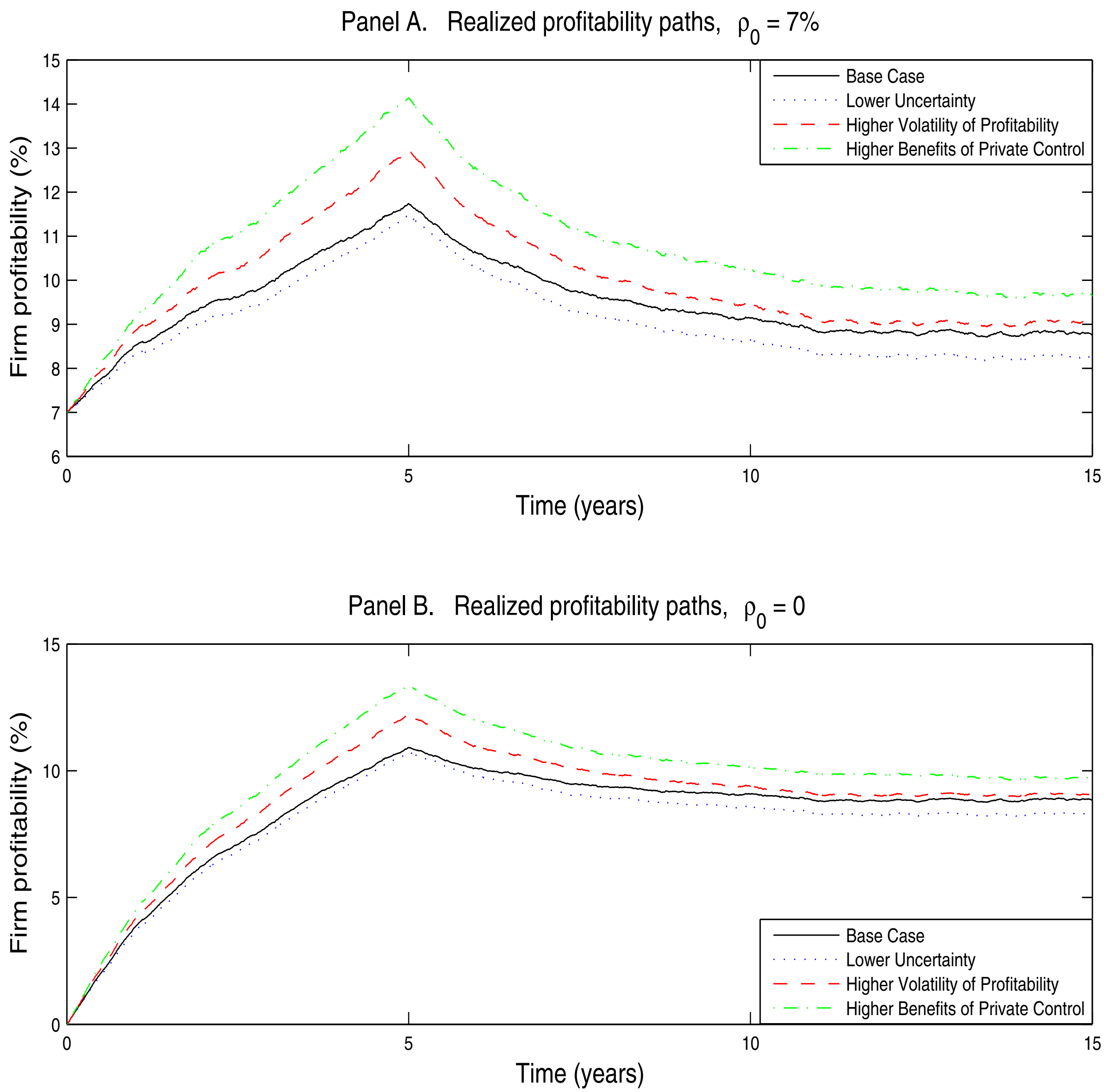

Figure 2. Model-Implied Realized Profitability Around an IPO. This figure plots the average paths of realized profitability, ρ_t, in percent per year, where the average is computed across 10,000 simulations of our model in which an IPO takes place at time $\tau = 5$. Given the large number of simulations, these average paths represent expected patterns in ρ_t conditional on an IPO. In Panel A, the initial profitability $\rho_0 = \widehat{\rho}_0 = 7\%$; in Panel B, $\rho_0 = 0$. The solid line corresponds to the baseline case, in which the model parameters are from Table 1. The other lines correspond to one-parameter deviations from Table 1: private benefits are increased to $\alpha = 0.11$ (dashed-dot line), uncertainty is reduced to $\widehat{\sigma}_0 = 0.04$ (dotted line), and volatility of profitability is increased to $\sigma_{\rho,1} = \sigma_{\rho,2} = 0.065$ (dashed line).

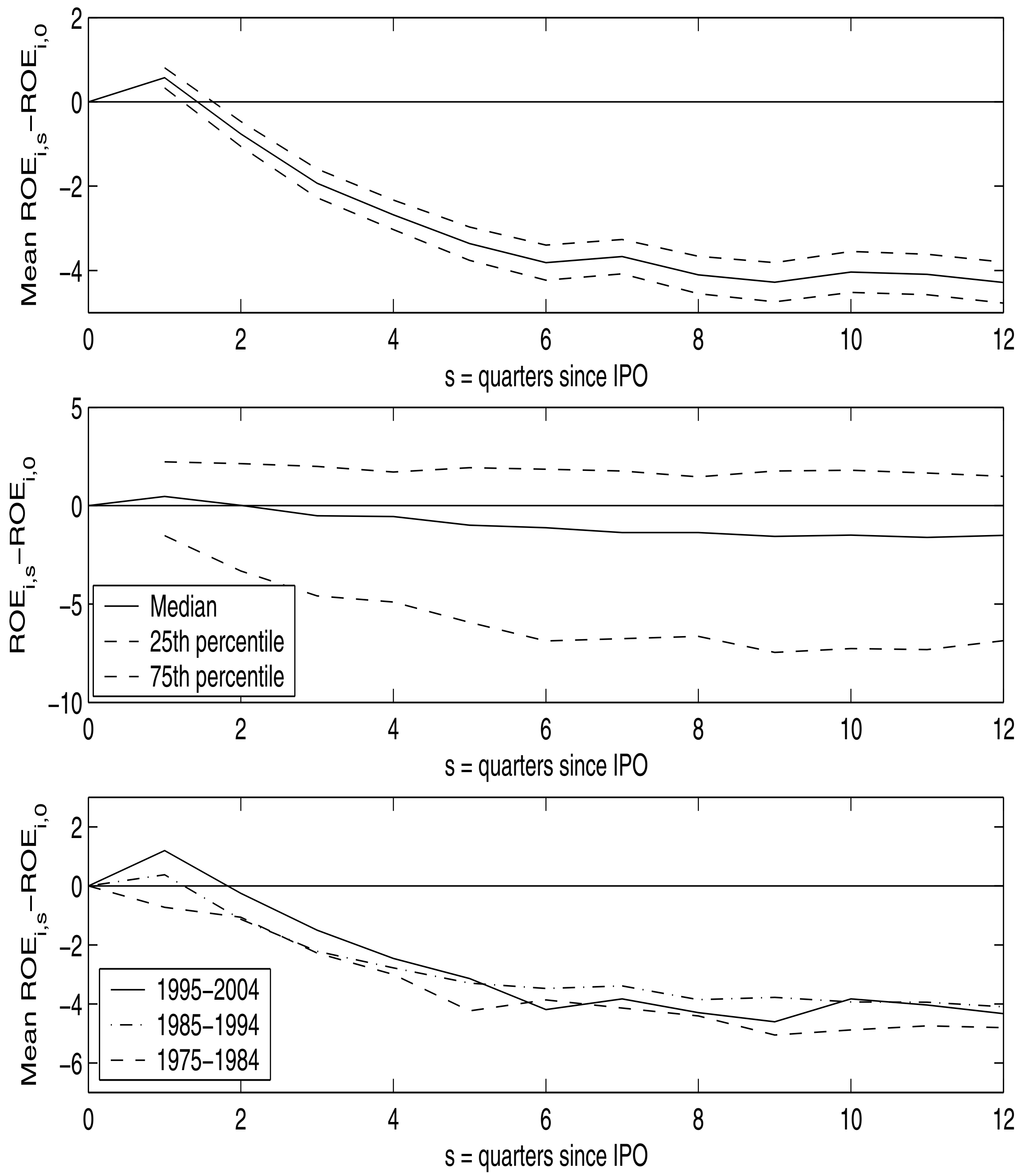

Figure 3. Post-IPO Changes in Profitability. This figure plots the post-IPO changes in firm profitability, measured as return on equity (ROE), for our sample of 7,183 IPOs in the U.S. from 1975–2004. Time 0 is the quarter of the IPO. $ROE_{i,s}$ is firm i's profitability s quarters after its IPO, in percent per quarter. The top panel plots the equal-weighted average of $ROE_{i,s} - ROE_{i,0}$ across all firms for which both $ROE_{i,s}$ and $ROE_{i,0}$ can be computed (solid line), as well as the 95% confidence interval for the mean (dashed lines). The middle panel plots the median value of $ROE_{i,s} - ROE_{i,0}$ (solid line), as well as the 25th and 75th percentiles (dashed lines). The bottom panel plots the equal-weighted average of $ROE_{i,s} - ROE_{i,0}$ across IPOs in three sub-samples: 1975–1984, 1985–1994, and 1995–2004.

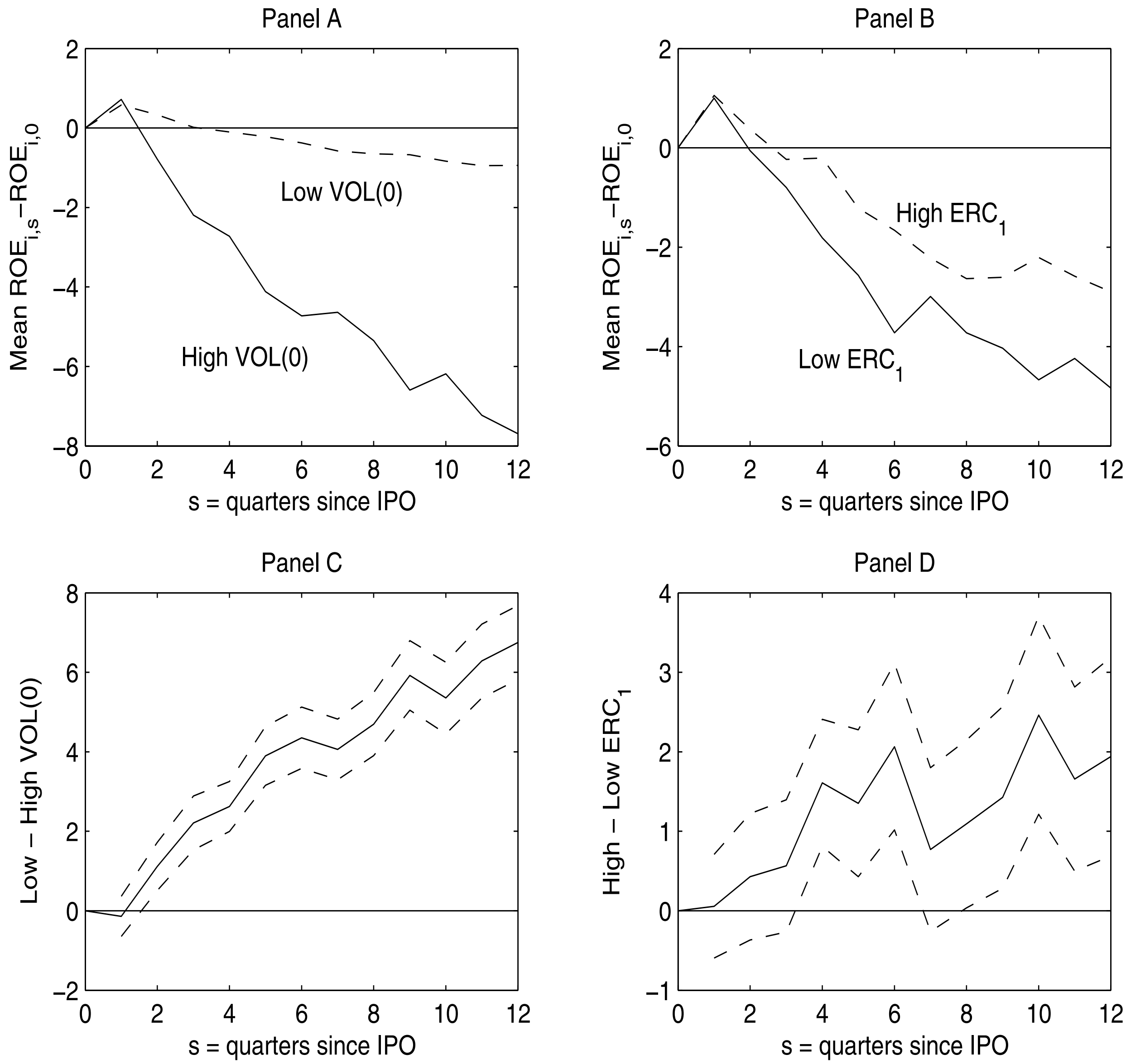

Figure 4. Post-IPO Changes in Profitability: Volatility vs. Uncertainty. We split our sample of 7,183 IPOs in 1975–2004 into high-volatility IPOs and low-volatility IPOs, and also into high-ERC_1 IPOs and low-ERC_1 IPOs. The left-hand panels split the sample using the median of $VOL(0)$, 5.28% per quarter. The right-hand panels split the sample using the median of ERC_1, 2.19. ERC_1 measures firm i's average stock price reaction to earnings surprises; $ROE_{i,s}$ is firm i's profitability s quarters after its IPO, in percent per quarter; and $VOL(0)$ is the standard deviation of $ROE_{i,s}$ for $s = 0, ..., 19$ quarters. Time 0 is the quarter of the IPO. Panels A and B plot the means of $ROE_{i,s} - ROE_{i,0}$ across the firms in the respective sub-samples split by volatility (Panel A) and ERC_1 (Panel B). Panel C plots the low volatility sub-sample's mean $ROE_{i,s} - ROE_{i,0}$ minus the high volatility sub-sample's mean $ROE_{i,s} - ROE_{i,0}$. Panel D plots the high ERC_1 sub-sample's mean $ROE_{i,s} - ROE_{i,0}$ minus the low ERC_1 sub-sample's mean $ROE_{i,s} - ROE_{i,0}$. The dashed lines denote the 95% confidence interval for this difference in differences.

Table 1
Parameter Values used in Simulations

This table contains the baseline parameter values used in simulations from the model. T is the time until the patent expiration, τ is the time until the IPO decision, r is the risk-free rate, σ_π determines the volatility of the stochastic discount factor, $\sigma_{\rho,1}$ is systematic volatility of profitability, $\sigma_{\rho,2}$ is idiosyncratic volatility of profitability, ϕ is the mean reversion coefficient for profitability, $\widehat{\rho}_0$ is the prior mean of $\overline{\rho}$, $\widehat{\sigma}_0$ is the prior standard deviation of $\overline{\rho}$, α captures the entrepreneur's consumption due to private control, γ denotes risk aversion, η determines the relative importance of terminal wealth in the entrepreneur's utility function, and β is the entrepreneur's subjective discount rate. All values are expressed in annual terms.

T	τ	r	σ_π	$\sigma_{\rho,1}$	$\sigma_{\rho,2}$	ϕ	$\widehat{\rho}_0$	$\widehat{\sigma}_0$	α	γ	η	β
15	5	0.03	0.60	0.0584	0.0596	0.3968	0.07	0.05	0.10	2	1	0.03

Table 2
The Average Expected Post-IPO Drop in Profitability ($\tau = 5$)

Panel A shows the average expected post-IPO drop in profitability, computed at time 0 conditional on an IPO at time $\tau = 5$. Panel B shows the average volatility of the firm's stock returns, and Panel C reports the average expected excess return on the firm's stock. For any given combination of prior uncertainty, $\widehat{\sigma}_0$, and the volatility of profitability, $\sigma_{\rho,1} = \sigma_{\rho,2}$, all three averages are computed across all admissible values of benefits of private control, α, and the prior mean, $\widehat{\rho}_0$. The admissible values of α and $\widehat{\rho}_0$ are subsets of the intervals $[5\%, 15\%]$ and $[-20\%, 40\%]$, respectively, that include only the sets of parameters for which the condition (29) is satisfied. The initial profitability is $\rho_0 = 0$ and all remaining parameters are in Table 1.

		$\sigma_{\rho,1} = \sigma_{\rho,2}$ (% per year)									
		1	2	3	4	5	6	7	8	9	10
		Panel A: Average Expected Drop in Profitability (% per year).									
	0	0.28	0.64	2.78	4.82	6.26	7.97	10.44	16.20	17.46	21.78
	1	-0.01	1.87	3.89	4.87	6.83	8.02	12.50	16.77	19.77	22.02
	2	-0.22	1.13	3.58	6.78	10.88	11.53	15.92	19.29	22.73	23.49
	3	-0.55	1.13	3.44	5.10	8.45	10.58	15.24	16.37	21.68	20.55
$\widehat{\sigma}_0$	4	-0.78	0.30	2.15	3.34	5.97	8.94	12.19	15.19	19.05	21.25
	5	-0.99	-0.12	1.17	2.78	4.61	7.12	9.67	13.86	14.29	18.94
(% p.a.)	6	-	-0.63	0.52	2.14	4.13	6.44	8.43	10.57	12.23	13.34
	7	-	-0.92	0.11	1.70	3.89	5.18	7.17	9.15	11.99	10.74
	8	-	-	-0.24	1.12	3.00	5.37	8.59	9.29	8.95	10.42
	9	-	-	-	-	2.27	4.12	6.76	-	-	-
	10	-	-	-	-	-	-	-	-	-	-
		Panel B: Average Stock Return Volatility (% per year).									
	0	3.50	6.99	10.49	13.99	17.48	20.98	24.48	27.97	31.47	34.97
	1	4.83	7.92	11.16	14.50	17.90	21.33	24.78	28.24	31.70	35.18
	2	5.90	9.65	12.75	15.85	19.04	22.31	25.64	29.00	32.39	35.79
	3	6.30	10.97	14.48	17.59	20.66	23.77	26.95	30.19	33.47	36.78
	4	6.48	11.79	15.89	19.30	22.43	25.50	28.58	31.70	34.87	38.09
$\widehat{\sigma}_0$	5	6.57	12.29	16.94	20.77	24.13	27.27	30.34	33.40	36.50	39.62
	6	-	12.61	17.69	21.95	25.62	28.95	32.10	35.18	38.24	41.32
(% p.a.)	7	-	12.81	18.22	22.87	26.88	30.47	33.78	36.94	40.02	43.09
	8	-	-	18.62	23.58	27.93	31.79	35.31	38.60	41.77	44.86
	9	-	-	-	-	28.78	32.92	36.67	-	-	-
	10	-	-	-	-	-	-	-	-	-	-
		Panel C: Average Expected Excess Stock Return (% per year).									
Any $\widehat{\sigma}_0$		1.48	2.97	4.45	5.93	7.42	8.90	10.38	11.87	13.35	14.84

Table 3
The Average Expected Post-IPO Drop in Profitability ($\tau = 7$)

Panel A shows the average expected post-IPO drop in profitability, computed at time 0 conditional on an IPO at time $\tau = 7$. Panel B shows the average volatility of the firm's stock returns, and Panel C reports the average expected excess return on the firm's stock. For any given combination of prior uncertainty, $\widehat{\sigma}_0$, and the volatility of profitability, $\sigma_{\rho,1} = \sigma_{\rho,2}$, all three averages are computed across all admissible values of benefits of private control, α, and the prior mean, $\widehat{\rho}_0$. The admissible values of α and $\widehat{\rho}_0$ are subsets of the intervals $[5\%, 15\%]$ and $[-20\%, 40\%]$, respectively, that include only the sets of parameters for which the condition (29) is satisfied. The initial profitability is $\rho_0 = 0$ and all remaining parameters are in Table 1.

		$\sigma_{\rho,1} = \sigma_{\rho,2}$ (% per year)									
		1	2	3	4	5	6	7	8	9	10
		Panel A: Average Expected Drop in Profitability (% per year).									
	0	0.09	1.14	2.94	5.15	6.87	9.24	10.78	13.25	13.69	12.92
	1	-0.15	0.62	2.34	4.61	6.39	8.72	10.42	12.82	14.77	12.78
	2	-0.01	1.42	2.57	3.96	6.01	7.39	9.26	11.74	13.81	13.40
	3	-0.14	0.85	2.03	4.17	4.83	6.32	9.16	9.94	13.59	12.27
$\widehat{\sigma}_0$	4	-0.22	0.46	1.73	2.27	4.04	5.91	8.03	9.16	12.87	14.71
	5	-0.28	0.30	1.13	2.27	3.57	5.25	6.95	10.05	10.37	14.09
(% p.a.)	6	-	0.00	0.80	1.95	3.61	5.33	6.82	8.30	9.51	10.38
	7	-	-0.10	0.63	1.87	3.60	4.76	7.04	7.95	10.29	9.04
	8	-	-	0.52	1.57	3.12	5.09	7.93	8.61	8.47	10.50
	9	-	-	-	-	2.70	4.20	6.57	-	-	-
	10	-	-	-	-	-	-	-	-	-	-
		Panel B: Average Stock Return Volatility (% per year).									
	0	3.42	6.83	10.25	13.66	17.08	20.49	23.91	27.32	30.74	34.15
	1	4.23	7.47	10.72	14.03	17.38	20.75	24.12	27.51	30.91	34.31
	2	4.72	8.45	11.73	14.94	18.17	21.44	24.74	28.06	31.40	34.76
	3	4.88	9.09	12.68	15.99	19.20	22.41	25.64	28.89	32.16	35.46
	4	4.95	9.44	13.37	16.91	20.23	23.46	26.67	29.88	33.10	36.34
$\widehat{\sigma}_0$	5	4.98	9.64	13.84	17.63	21.13	24.47	27.72	30.93	34.14	37.35
	6	-	9.76	14.16	18.17	21.88	25.36	28.71	31.97	35.19	38.40
(% p.a.)	7	-	9.84	14.37	18.57	22.47	26.12	29.59	32.94	36.22	39.45
	8	-	-	14.53	18.87	22.93	26.74	30.35	33.81	37.17	40.46
	9	-	-	-	-	23.30	27.26	31.00	-	-	-
	10	-	-	-	-	-	-	-	-	-	-
		Panel C: Average Expected Excess Stock Return (% per year).									
Any $\widehat{\sigma}_0$		1.45	2.90	4.35	5.80	7.24	8.69	10.14	11.59	13.04	14.49

Table 4
Summary Statistics for the IPO Sample

Panel A contains summary statistics (means, standard deviations, percentiles) for the 7,183 firms in our sample of IPOs from 1975-2004. N is the number of firms for which the given variable can be calculated. t-stat is the t-statistic testing the hypothesis that the mean of the given variable is equal to zero. $ROE_{i,s}$ is the return on equity of firm i computed s quarters after the firm's IPO, in percent per quarter. $VOL(s_0)$ is the standard deviation of $ROE_{i,s}$ for $s = s_0, \ldots, s_0 + 19$. ERC_1 is the average of the first 12 post-IPO stock price reactions to earnings surprises. ERC_1^+ is equal to ERC_1 when $ERC_1 > 0$ and missing otherwise. ERC_2 is the negative of the regression slope of earnings surprises on abnormal stock returns using firm i's first 20 post-IPO quarters of earnings surprises. ERC_2^- is equal to ERC_2 when $ERC_2 < 0$ and missing otherwise. Panel B shows pairwise correlations computed across firms.

Panel A. Summary Statistics.

					Percentiles		
Variable	N	Mean	Std. dev.	t-stat	25th	50th	75th
$ROE_{i,0}$	5,795	-0.79	12.57	-4.8	-3.81	1.84	4.62
$ROE_{i,12} - ROE_{i,0}$	3,964	-4.29	15.56	-17.4	-6.85	-1.51	1.48
$VOL(0)$	4,546	8.03	7.45	72.7	2.52	5.28	11.11
$VOL(13)$	2,606	7.65	7.74	50.5	2.30	4.61	10.35
ERC_1	2,773	3.13	6.86	24.1	-1.06	2.19	6.79
ERC_2	2,588	-0.035	0.067	-26.7	-0.064	-0.026	-0.002
ERC_1^+	1,855	6.46	5.59	49.8	2.16	5.17	9.00
ERC_2^-	2,007	-0.056	0.056	-44.7	-0.078	-0.040	-0.018

Panel B. Cross-Sectional Correlations.

	$ROE_{i,12}$ $-ROE_{i,0}$	$VOL(0)$	$VOL(13)$	ERC_1	ERC_2	ERC_1^+	ERC_2^-
$ROE_{i,12} - ROE_{i,0}$	1.00						
$VOL(0)$	-0.33	1.00					
$VOL(13)$	-0.15	0.65	1.00				
ERC_1	0.07	-0.16	-0.11	1.00			
ERC_2	0.04	-0.14	-0.06	-0.05	1.00		
ERC_1^+	0.08	-0.25	-0.14	1.00	0.14	1.00	
ERC_2^-	0.16	-0.31	-0.18	0.16	1.00	0.30	1.00

Table 5
Cross-Sectional Regressions

This table reports OLS estimates of β from the model $ROE_{i,s} - ROE_{i,0} = \beta X_i + \epsilon_i$. The sample contains 7,183 IPO firms from 1975-2004 less any firms for which at least one variable is missing, for a total of N firms. $ROE_{i,s}$ is the return on equity of firm i computed s quarters after the firm's IPO, in percent per quarter. X_i contains combinations of the following variables: a constant, $VOL(s_0)$ (the standard deviation of $ROE_{i,s}$ for $s = s_0, \ldots, s_0 + 19$), ERC_1 (the average of firm i's first 12 post-IPO stock price reactions to earnings surprises), and ERC_2 (minus the regression slope of firm i's earnings surprises on firm i's abnormal stock returns around earnings announcements). The t-statistics, shown in parentheses, are computed by clustering the error terms in calendar time.

Panel A. One-Year Horizon. (Regressand: $ROE_{i,4} - ROE_{i,0}$)

Constant	-2.68	0.48	0.35	-1.33	-0.44	0.38	0.54	0.51	0.58
	(-11.2)	(1.65)	(1.31)	(-4.08)	(-1.49)	(0.97)	(1.52)	(1.34)	(1.74)
$VOL(0)$		-0.238				-0.186	-0.163		
		(-10.8)				(-5.93)	(-5.00)		
$VOL(5)$			-0.198					-0.177	-0.123
			(-9.04)					(-5.64)	(-3.89)
ERC_1				0.100		0.063		0.028	
				(3.35)		(2.08)		(0.88)	
ERC_2					3.05		1.30		6.58
					(1.04)		(0.44)		(2.10)
R^2	0.000	0.028	0.024	0.004	0.000	0.021	0.012	0.019	0.011
N	5,340	4,124	3,353	2,526	2,373	2,211	2,301	1,816	1,978

Panel B. Three-Year Horizon. (Regressand: $ROE_{i,12} - ROE_{i,0}$)

Constant	-4.29	1.20	-0.70	-4.32	-2.76	1.71	1.20	-0.99	-0.41
	(-16.2)	(3.86)	(-2.01)	(-9.66)	(-7.36)	(2.97)	(2.63)	(-2.09)	(-0.83)
$VOL(0)$		-0.708				-0.820	-0.659		
		(-21.8)				(-17.8)	(-14.8)		
$VOL(13)$			-0.248					-0.268	-0.230
			(-7.48)					(-6.11)	(-5.31)
ERC_1				0.144		0.020		0.060	
				(3.05)		(0.46)		(1.32)	
ERC_2					8.71		1.57		8.67
					(2.04)		(0.38)		(1.97)
R^2	0.000	0.108	0.024	0.004	0.002	0.140	0.092	0.033	0.024
N	3,964	3,940	2,312	2,121	2,239	2,118	2,238	1,224	1,379

Table 6
Cross-Sectional Regressions, Excluding ERCs with Unpredicted Signs

This table reports OLS estimates of β from the model $ROE_{i,s} - ROE_{i,0} = \beta_s X_i + \epsilon_i$. The sample contains 7,183 IPO firms from 1975-2004 less any firms for which at least one variable is missing, for a total of N firms. $ROE_{i,s}$ is the return on equity of firm i computed s quarters after the firm's IPO, in percent per quarter. X_i contains combinations of the following variables: a constant, $VOL(s_0)$ (the standard deviation of $ROE_{i,s}$ for $s = s_0, \ldots, s_0 + 19$), ERC_1^+ (the average of firm i's first 12 post-IPO stock price reactions to earnings surprises, excluding negative values), and ERC_2^- (minus the regression slope of firm i's earnings surprises on firm i's abnormal stock returns around earnings announcements, excluding positive values). The t-statistics, shown in parentheses, are computed by clustering the error terms in calendar time.

Panel A. One-Year Horizon. (Regressand: $ROE_{i,4} - ROE_{i,0}$)

Constant	-2.68	0.48	0.35	-1.76	-0.07	-0.55	0.68	-0.43	0.66
	(-11.2)	(1.65)	(1.31)	(-4.87)	(-0.18)	(-1.08)	(1.62)	(-0.86)	(1.65)
$VOL(0)$		-0.238				-0.092	-0.167		
		(-10.8)				(-2.46)	(-4.23)		
$VOL(5)$			-0.198					-0.118	-0.098
			(-9.04)					(-3.26)	(-2.64)
ERC_1^+				0.164		0.111		0.101	
				(3.87)		(2.51)		(2.24)	
ERC_2^-					9.09		3.97		11.34
					(2.30)		(0.93)		(2.69)
R^2	0.000	0.028	0.024	0.009	0.003	0.011	0.014	0.016	0.013
N	5,340	4,124	3,353	1,692	1,847	1,484	1,789	1,230	1,554

Panel B. Three-Year Horizon. (Regressand: $ROE_{i,12} - ROE_{i,0}$)

Constant	-4.29	1.20	-0.70	-4.60	-0.83	1.26	1.51	-0.86	0.19
	(-16.2)	(3.86)	(-2.01)	(-8.51)	(-1.78)	(1.58)	(3.21)	(-1.54)	(0.38)
$VOL(0)$		-0.708				-0.688	-0.545		
		(-21.8)				(-12.4)	(-10.6)		
$VOL(13)$			-0.248					-0.230	-0.157
			(-7.48)					(-5.01)	(-3.41)
ERC_1^+				0.203		0.001		0.045	
				(3.08)		(0.01)		(0.78)	
ERC_2^-					36.48		18.55		25.52
					(6.68)		(3.34)		(4.77)
R^2	0.000	0.108	0.024	0.007	0.025	0.106	0.083	0.031	0.036
N	3,964	3,940	2,312	1,425	1,747	1,424	1,747	832	1,094

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