No. 2003/47

IPOs Cycle and Investment in High-Tech Industries

Romain Bouis

Center for Financial Studies
an der Johann Wolfgang Goethe-Universität ▪ Taunusanlage 6 ▪ D-60329 Frankfurt am Main
Tel: (+49)069/242941-0 ▪ Fax: (+49)069/242941-77 ▪ E-Mail: ifk@ifk-cfs.de ▪ Internet: http://www.ifk-cfs.de

Center for Financial Studies

The *Center for Financial Studies* is a nonprofit research organization, supported by an association of more than 120 banks, insurance companies, industrial corporations and public institutions. Established in 1968 and closely affiliated with the University of Frankfurt, it provides a strong link between the financial community and academia.

The CFS Working Paper Series presents the result of scientific research on selected topics in the field of money, banking and finance. The authors were either participants in the Center´s Research Fellow Program or members of one of the Center´s Research Projects.

If you would like to know more about the *Center for Financial Studies*, please let us know of your interest.

Prof. Dr. Jan Pieter Krahnen

Prof. Volker Wieland, Ph.D.

Center for Financial Studies
an der Johann Wolfgang Goethe-Universität ▪ Taunusanlage 6 ▪ D-60329 Frankfurt am Main
Tel: (+49)069/242941-0 ▪ Fax: (+49)069/242941-77 ▪ E-Mail: ifk@ifk-cfs.de ▪ Internet: http://www.ifk-cfs.de

CFS Working Paper No. 2003/47

IPOs Cycle and Investment in High-Tech Industries*

Romain Bouis

November 2003

Abstract:
This paper analyses the effects of the Initial Public Offering (IPO) market on real investment decisions in emerging industries. We first propose a model of IPO timing based on divergence of opinion among investors and short-sale constraints. Using a real option approach, we show that firms are more likely to go public when the ratio of overvaluation over profits is high, that is after stock market run-ups. Because initial returns increase with the demand from optimistic investors at the time of the offer, the model provides an explanation for the observed positive causality between average initial returns and IPO volume. Second, we discuss the possibility of real overinvestment in high-tech industries. We claim that investing in the industry gives agents an option to sell the project on the stock market at an overvalued price enabling then the financing of positive NPV projects which would not be undertaken otherwise. It is shown that the IPO market can however also lead to overinvestment in new industries. Finally, we present some econometric results supporting the idea that funds committed to the financing of high-tech industries may respond positively to optimistic stock market valuations.

JEL classification: D92, G10, G24, G31

Keywords: IPO, divergence of opinion, real option, venture capitalism, stock market and high-tech investment

*This paper was presented at the Center for Financial Studies, Frankfurt/Main, Germany, "Workshop on Venture Capital and New Markets" and at the 20th Annual Meeting of the French Finance Association. Many thanks to Philippe Bernard, Antoine Biard, Christophe Boucher, Alain Butery, Patrick Herbst, Christophe Hurlin, Jean-François Jacques, Rafal Kierzenkowski, Pierre-Marie Larnac, Dima Leshchinskii, Mark Wahrenburg and Uwe Walz for helpful comments and suggestions. The usual disclaimer applies. Author's affiliation: CERPEM-CREFED, Paris Dauphine University, Place du Maréchal de Lattre de Tassigny 75775 Paris cedex 16, France. Tel:+33 (0)1 44 05 49 47.Fax:+33 (0)1 44 05 40 98.E-mail:romain.bouis@dauphine.fr.

1 Introduction

Investment in high technology industries, although representing a small part of GDP, plays a major role in the performance of the economy by promoting innovation. Now, many economists claim that having a market-based financial system is the best way of encouraging investment in emerging industries and several studies show that the presence of a vibrant stock market is a necessary condition to finance projects characterized by poor collateral value and highly uncertain returns. For example, Carpenter and Petersen (2002) for the US or Bottazzi and Da Rin (2002) for Europe find that high-tech firms going public are experiencing a substantial increase in capital expenditures and size in the immediate period following their IPO (Initial Public Offering). In addition, the stock market constitutes a very profitable exit way for the venture capitalism industry. As noted by Lerner (1994), venture capitalists generate the main part of their profits from firms sold on the stock market via an IPO.[1] Having an active IPO market is then critical to the existence of a well developed venture capitalism industry (see Black and Gilson, 1998) and so to the adoption of high-tech technologies (Michelacci and Suarez, 2003). In this vein, the set up of the "New Markets" in several European countries during the second half of the nineties was aimed at welcoming young firms in new industries and then at supporting entrepreneurship and innovation.[2]

Periods of strong activity on the IPO market are however usually associated with excessively optimistic market sentiment. The recent frenzy over Internet firms is not unique. It is well recognized that on average new industries IPOs underperform in the long-run (Ritter, 1991) whereas they initially exhibit high returns, known as initial returns or underpricing. Moreover, we know that periods of high IPO volume generally correspond with periods of high initial returns, a proxy for investors' sentiment. Such periods, called hot issue periods have been repeated in the US several times with varying degrees during the forty past years. Issuers would then take advantage of a window of opportunity by

[1]A Venture Economics study cited by Lerner finds that on average, an investment of $1 in a firm that is taken public provides a return to the venture capitalist of $1.95 beyond the initial investment with an average holding period of 4.2 years.

[2]For a description and an analysis of European new stock markets, see Bottazzi and Da Rin (2002).

selling stocks to overly optimistic investors, what seems confirmed by empirical studies which show that firms in a particular industry are more likely to go public when industry valuations are the highest.

The purpose of this paper is twofold. First, we develop a model of IPO timing in an overvaluation context. This allows us to derive the value of the firm to its owner when the issue market is hot and then to discuss in a second stage the role played by the IPO market in the decision to invest in new industries and the possibility of real overinvestment in such industries.

Few theoretical models have studied the dynamics of IPOs cycles in an overvaluation framework. Benveniste, Busaba and Wilhelm (2002) develop a model where the clustering of IPOs of a similar industry results from a decrease in the information production costs related to firms' industry prospects.[3] The approach used by these authors, by considering that secondary market prices reflect the true value of firms taken public, is nevertheless at odds with the well-documented long-run underperformance of IPOs. Here, we make the assumption that IPOs are temporarily overvalued because of heterogeneous beliefs among potential investors on the stock market and short-sale constraints. Before the IPO the firm is held by two agents: an entrepreneur and a venture capitalist. Going public enables the entrepreneur to finance the growth of the firm by issuing new shares whereas it allows the venture capitalist to sell his participations in the firm a few months after the IPO. With both profits of the project and a number of optimistic investors being stochastic, the optimal timing of the IPO is derived by considering the going public decision as a real option.[4] More precisely, it is shown that the IPO option is exercised after positive shocks on the number of optimists. Because in practice initial returns increase with the demand

[3]Underpricing is defined as the return of the stock between the offer price and the closing price of the first trading day – assumed in this model to reflect the true value of the firm. It is a compensation received by institutional investors for their production of information about the value of the stock and their truthful revelation of this value to the investment bank and the issuer (Benveniste and Spindt, 1989). As the number of IPOs increases, the production of information related to a common factor (namely, the industry factor) decreases and so underpricing, leading more firms to go public.

[4]Draho (2000) has first analysed IPO timing in a real option framework. In his model, investors on the stock market are supposed to be better diversified than the entrepreneur so that this latter discounts the revenues of the firm at a higher rate than do public investors. With profits evolving stochastically, the firm is taken public only when the market valuation is sufficiently larger than the entrepreneur's one, explaining why IPOs cluster around market peaks. This model is however enable to account for IPOs long run underperformance.

from optimistic investors, the model provides an explanation for the observed positive causality between average initial returns and IPO volume.

Since projects are sold on the stock market at an overvalued price, one can wonder about the efficiency of the stock market in allocating capital to profitable investments. The link between the stock market and real investment has been extensively studied in economics and empirical works have concluded that the stock market had poor incidence on real investment (see for e.g. Morck, Shleifer and Vishny, 1990; Blanchard, Rhee and Summers, 1993; Bond and Cummins, 2000; among others) so that there was no reason to worry about the consequences of stock market misvaluations on real economy. These studies however focus on investment behavior of firms that are generally listed on the stock market for a long time and which may not be financially constrained. Moreover, they do not consider the effects of overvaluation on the decision to undertake a project before going public. We argue in this paper that overvaluation, which is a characteristic feature of the IPO market, can have beneficial effects on investment in emerging industries up to a certain point. Indeed, when the IPO market is hot, investing in the industry gives agents the option of selling projects to public investors at an attractive price, enabling then the financing of positive NPV projects which would not be undertaken otherwise simply because of both uncertainty and irreversibility (see Dixit and Pindyck, 1994). However, when the hot market lasts too long, overinvestment occurs in the industry in vogue on the stock market whereas there is underinvestment in other promising industries not as much popular in the investors' community. Finally, we study the relation between the willingness of private investors to finance high-tech industries and optimistic investors demand on the IPO market by estimating an Error Correction Model (ECM) on quarterly data on the US venture capitalism industry for the period of 1990:1-2002:4. Results support the main idea of the paper, namely that funds committed to the financing of high-tech projects and so investments, are positively related in the long-run with the public market sentiment, what may lead to overinvestment in new industries.

The rest of the paper is organized as follows. Section 2 describes the structure of the model. Section 3 derives the optimal IPO timing. In section 4, we discuss the effects of the going public option on real investment decisions. Empirical analysis is presented in section 5. Section 6 concludes.

2 The model

We consider the emergence of a new industry in the economy. To be implemented, each project of this industry requires an investment cost I and generates a profit flow π_t with an initial profit level $\pi_0 > 0$. The fundamental value of the project is simply defined as the expected present discounted value of the profit flow and is denoted V_t. We suppose that entrepreneurs who are at the origin of the project's idea have no funds so that they must find an agent in the economy who accepts to provide financing in return for a participation in the fundamental value of the project. Let us call this agent a venture capitalist.[5] We denote Q_S the quantity of shares initially composing the capital of the firm. By paying I at date t, the venture capitalist receives θQ_S shares with $0 < \theta < 1$, that is an equity stake whose expected value is θV_t. Once the investment is undertaken, the project can be taken public on the stock market at any time with no delays to simplify. Going public enables the firm to issue a fixed quantity Q of new shares whereas it allows the venture capitalist to resell his θQ_S shares on the stock market a specified period of time after the IPO, called the lockup period.[6]

The proceeds of the issue are used by the entrepreneur to finance new investments or marketing expenditures in order to grab industry market shares. It is however assumed that these investments or expenditures have not a sufficiently large impact on the value of the firm to avoid a dilution of profits.

Assumption 1 *The initial public offering entails a dilution cost for pre-IPO owners due to an increase in the number of shares and a less proportional increase in the profits of the project.*

Consistent with this assumption, several studies (Jain and Kini, 1994; Bottazzi and Da Rin, 2002) document a drop in the profitability of firms going public, mainly because of

[5]The contribution of the venture capitalist to the project goes of course beyond the financial investment I as he will also use his business expertise to achieve the fundamental value V. This latter characteristic makes the venture capitalist financing a very appropriate one particularly in high-tech industries, in comparison with a common financing.

[6]In practice, insiders and other pre-IPO shareholders are generally prohibited from selling their own shares at the IPO date particularly when the firm is young and belongs to a new industry. Instead, they have to wait for a fixed period of time which typically lasts six months. Gompers and Lerner (1998) note that even after the expiration of the lockup, venture capitalists continue to hold their equity stakes for several months. Here, we assume to simplify that these stocks are distributed at the end of the lockup to the limited partners of the funds who in turn sell them on the stock market.

inefficient investments (*ceteris paribus*, post-IPO profits do not grow as much as assets). Without loss of generality, we will assume here that the fundamental value of the firm is not affected by the new investments financed by the issue of the Q primary shares. This will greatly simplify the exposition of the model. We further suppose that the venture capitalist anticipates this and so knows that the IPO entails a dilution cost. He always prefers selling his θQ_S shares on the secondary market at the lockup expiration date whereas the entrepreneur, more confident about the success of the firm strategy, keeps his stake in the firm for an undetermined period of time. Empirical studies show indeed that venture capitalists (or VC funds limited partners) do liquidate their participation around the lockup expiration date whereas entrepreneurs generally keep their shares (see Schultz and Zaman, 2001).

2.1 Industry description and fundamental valuation

Profits of the project, denoted π, are supposed to follow the geometric Brownian motion:

$$\frac{d\pi_t}{\pi_t} = \alpha_\pi dt + \sigma_\pi dz_\pi, \tag{1}$$

where $\alpha_\pi < 0$ and σ_π are constant parameters and dz_π is the increment of a standard Wiener process. The assumption relative to the drift's sign is commonly used to describe the evolution of profits in high technology industries. As noted by McDonald and Siegel (1986), when a new product is introduced by a firm, other firms introduce similar products and so, because of lagged entry in the industry, profits tend to disappear. This means there is enough competition in the industry, what seems quite realistic for high-tech and communication industries (see for instance Huisman, 2001). For a given level of profits π_t, the conditional expectation for profits at date s is

$$E\left[\pi_s \mid \pi_t\right] = \pi_t e^{\alpha_\pi (s-t)}. \tag{2}$$

Agents are risk averse. Discounting expected profits at the appropriate risk-adjusted rate $\rho > 0$, they value the project at date t, at

$$V_t = E\left[\int_t^\infty \pi_s e^{-\rho(s-t)} ds \mid \pi_t\right] = \int_t^\infty \pi_t e^{-(\rho-\alpha_\pi)(s-t)} ds = \frac{\pi_t}{\rho - \alpha_\pi}. \tag{3}$$

Let us define $\delta_\pi = \rho - \alpha_\pi > 0$ and rewrite (3) as:

$$V_t = \frac{\pi_t}{\delta_\pi}. \tag{4}$$

2.2 Stock market prices

Following Miller (1977), we consider that stock prices are prone to overvaluation due to both divergence of opinion and short-sale constraints. Indeed, firms going public are generally operating in new industries so that uncertainty about future profits is high. Because uncertainty and divergence of opinion are likely to be correlated[7], a high heterogeneity of beliefs concerning the return of firms taken public is observed. With short-sale constraints, the market price is determined by the most optimistic investors, leading to an overvaluation of the stock. Several papers have provided support for Miller's theory. For example, Boehme, Danielsen and Sorescu (2002) find that shares which are difficult to borrow and are prone to a high dispersion of investors opinion underperform in the long run.[8] Ofek and Richardson (2003) report that Internet stocks were abnormally costly to short whereas they were owned relatively more often by retail investors, a class of investors considered as the more likely to be optimistic.

Here we consider two types of investors. First, rational investors who estimate the project at the fundamental value V as do the venture capitalist. Next, optimistic investors[9] whose valuations are greater than V. Rational and optimistic investors use the same geometric Brownian motion (1) in their estimate of the value of the project but optimists anticipate that profits of a particular firm will experience an upward jump with a non-null probability at a future unknown date.[10] They behave as if they were investing in the next Microsoft. This has for consequence to increase the expected trend of the diffusion process of profits and so the valuation of the project. As each optimistic investor has different estimates of the probability of the positive Poisson event and/or of the size of the jump, we observe divergence of opinions even among this class of investors. For simplicity, we assume that each optimistic investor, generally associated to small, unsophisticated investors, can

[7] As Miller notes: "it is implausible to assume that although the future is very uncertain, and forecasts are very difficult to make, that somehow everyone makes identical estimates of the return and risk from every security".

[8] The authors find that there is overvaluation only when the stock is both difficult to sell short and is prone to divergence of opinion. Indeed, stocks with a great dispersion of investors opinion are not necessarily overpriced as soon as the cost of short selling is not prohibitive. Symmetrically, when short-sales are costly but there is little disagreement among investors about the value of the stock, there is no overvaluation.

[9] One could also consider the existence of pessimistic investors. However, because rational investors (typically associated to institutional investors) have sufficient resources to buy all the stocks at V, the presence of pessimistic investors will have no effect on the determination of market prices.

[10] Of course this positive event never occurs and that's why these investors are considered as optimistic.

buy only one share. Finally, since we are interested in hot issue periods, it is supposed that the number of optimistic investors is always greater than the number of stocks issued so that the marginal investor is always an optimist and the price is overvalued.[11]

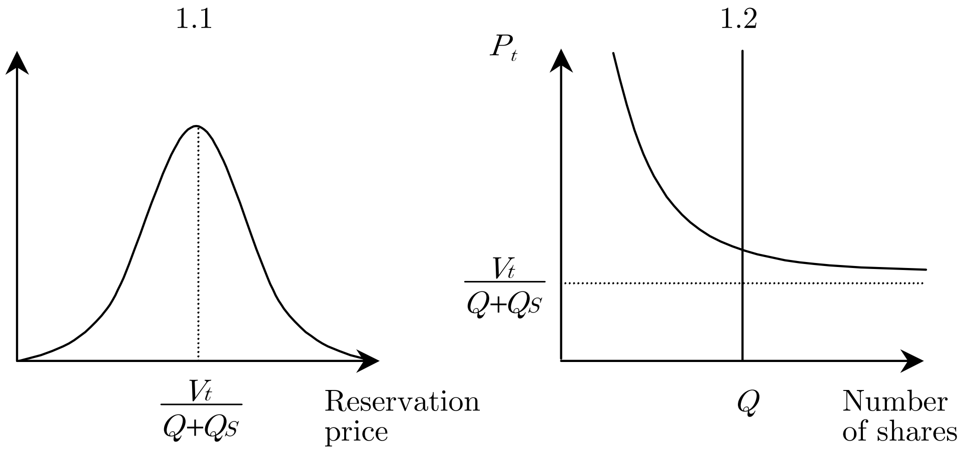
As a result of dispersion of opinion and short-sale constraints the demand curve slopes down. However, contrary to preceding models considering IPO stock pricing in an heterogeneous beliefs and short-sale constraints framework (see Ljungqvist, Nanda and Singh, 2001 or Aggarwal, Krigman and Womack, 2002), the absolute value of the slope of the demand curve is not supposed to be constant but decreasing with the number of shares. In other words, when the quantity of shares sold on the market increases, the price decreases but to a smaller and smaller extent. This is because as we get closer to the fundamental value, there are more and more potential investors willing to pay for the current price. This is a reasonable hypothesis as the distribution of the number of potential investors around the fundamental value may look like a shaped-bell curve rather than being uniform. Overall, the appropriate price curve is not a straight line but an hyperbola (see Figure 1). It is further assumed that as the number of optimistic investors increases, divergence of opinion gets higher.

Before the IPO, the total number of shares is Q_S, the quantity of secondary shares held by the entrepreneur and the venture capitalist. The initial public offering consists in an increase in the capital of the firm to $Q+Q_S$, where Q denotes the number of primary shares issued at the time of the offer. All profits are paid out as dividends to the shareholders, that is the initial owners of the firm (the entrepreneur and the venture capitalist) and the new shareholders from the IPO. The fundamental component of the stock at date t is then $\frac{V_t}{Q+Q_S}$. The overvalued part of the stock price is a convex decreasing function of the quantity of shares issued and increases with the number of optimistic investors. Let us suppose for simplicity that it is equal to $\frac{n_t}{Q}$, where n_t is the number of optimistic investors at date t. Overall, with an IPO occurring at t, the market price at the end of the first trading day is

$$P_t = \frac{V_t}{Q+Q_S} + \frac{n_t}{Q}. \tag{5}$$

[11] Is is common to observe during hot issue periods substantial oversubscription ratios for high-tech IPOs.

Figure 1. Distribution of the number of potential investors and corresponding price curve.



1.1 shows the distribution of the number of potential investors: the closer the reservation price to the fundamental value, the greater the observed number of potential investors. 1.2 plots the corresponding price curve sloping down in a convex manner. An increase in the number of optimistic investors will shift the curve outwards.

The number of optimistic investors, n_t is supposed to follow a mixed Poisson-Wiener process of the form:

$$\frac{dn_t}{n_t} = \alpha_n dt + \sigma_n dz_n - dq, \tag{6}$$

where $\alpha_n > 0$ and

$$dq = \begin{cases} 1 & \text{with probability } \lambda dt, \\ 0 & \text{with probability } 1 - \lambda dt. \end{cases}$$

The positive sign of the drift parameter comes from a contagion effect among unsophisticated investors.[12] The aim of the inclusion of the Poisson process is to take into account the possibility of a crash. Indeed, if the Poisson event occurs, the number of optimistic investors falls to zero where it remains forever, as zero is a natural absorbing barrier for geometric Brownian motions. Optimistic investors have definitively disappeared and this is the end of the hot market.

[12]Individual investors are considered as infrequent traders, explaining partly why they are unsophisticated in comparison with professional investors. At a given date, some of them may not participate on the IPO market but will only enter as time goes by due to a trend effect.

3 The timing of the IPO

Several empirical studies have stressed the ability of issuers to time their initial public offering in favorable market valuations conditions (see for instance, Lerner, 1994 or Pagano, Panetta and Zingales, 1998). Following Draho (2000), the IPO timing is here modelled as a real option. For this, we suppose that the IPO is irreversible. Besides, because as noted by Lerner (1994) venture capitalists can use control rights and board seats to insure that the IPO occurs at the time they consider as optimal, the optimal decision of when to go public is derived from the venture capitalist's utility.[13]

We assume to simplify that there is no underpricing. The offer price is then equal to the market price observed the day of the offer. The decision to go public will depend on the difference between the value of the shares to the venture capitalist when the firm is private (continuation payoff) and the value of these shares when the firm is taken public (termination payoff).

As long as the firm remains private, the venture capitalist gets at date t a fraction θ of the profits flow generated by the project. However if the firm is taken public, the profits flow must not only be shared with the entrepreneur but also with the new shareholders. Then, the going public decision entails an indirect cost for the original owners of the firm due to a dilution effect (see Assumption 1). On the other side, it enables the venture capitalist to sell the θQ_S shares at an overvalued price at the end of the lockup if the market is still bullish. With a lockup period of length T, the expected market price at the end of the lockup is

$$E[P_{t+T} \mid \pi_t, n_t] = \frac{E[V_{t+T} \mid \pi_t]}{Q + Q_S} + \frac{E[n_{t+T} \mid n_t]}{Q + \theta Q_S}. \tag{7}$$

Notice that the overvalued component of the market price is affected by the sale of the θQ_S secondary shares which appear in the denominator of the second term on the right-hand side of (7). This is corroborated by several empirical studies which show that stock prices decline around lockup expiration dates, particularly for venture-backed IPOs (see Field and Hanka, 2001; Bradley, Jordan, Roten and Yi, 2001; Ofek and Richardson, 2003).

[13] Pfirrmann, Wupperfeld and Lerner (1997) cite the case of the contract signed by the venture capitalist Apex Investment Partners and the firm AccessLine: "Apex proposed several contract provisions (...): punitive interest of dividend payments if the firm did not go public; the right for the venture capitalist to fire management if the firm did not go public by a certain date; the ability for the venture capitalist to require AccessLine to repurchase their shares (...)".

Overall, the termination payoff received by the venture capitalist by going public at t is

$$\Omega(\pi_t, n_t) = \frac{\theta Q_S}{Q + Q_S} \frac{\pi_t}{\delta_\pi} + \frac{\theta Q_S}{Q + \theta Q_S} n_t e^{-(\delta_n + \lambda)T}, \tag{8}$$

where $\delta_n = \rho - \alpha_n$ with $\rho > \alpha_n - \lambda$ (see appendix).

It is composed of two terms. The first one is what we call a fundamental component. It is the sum of the present values of the expected profits flow accruing to the venture capitalist between date t and $t + T$ and the expected fundamental part of the price at date $t + T$ when secondary shares are sold. The second term is the expected discounted overvalued component of the stock price at $t + T$ times the number θQ_S of secondary shares sold.

Let $F(\pi_t, n_t)$ denote the value to the venture capitalist from owning the θQ_S shares at date t. It is equal to the expected sum of the present value of the cumulated profits flow received until the unknown optimal IPO date $\tau(\pi^*, n^*)$ and the present value of the termination payoff $\Omega(\pi^*, n^*)$, that is:

$$F(\pi_t, n_t) = E\left[\int_t^{t+\tau(\pi^*,n^*)} \theta \pi_s e^{-\rho(s-t)} ds + e^{-\rho\tau(\pi^*,n^*)}\Omega(\pi^*, n^*) \mid \pi_t, n_t\right]. \tag{9}$$

The objective of the VC is to find the IPO date $\tau(\pi^*, n^*)$ that maximizes (9). However, with π and n evolving stochastically, $\tau(\pi^*, n^*)$ is a random variable and so cannot be determined *a priori*. Instead, the only way to resolve this optimal stopping problem is to derive the critical values π^* and n^* that trigger the IPO (we are more precisely looking for a threshold ratio $\frac{n^*}{\pi^*}$).

Over a small time interval dt, the state variables will have changed to $(\pi_t + d\pi_t)$ and $(n_t + dn_t)$. In the continuation region, the value of the shares can be expressed as the sum of the immediate profits flow and the discounted value of being private, that is:

$$F(\pi_t, n_t) = \theta \pi_t dt + \frac{1}{1 + \rho dt} E\left[F(\pi_t + d\pi_t, n_t + dn_t) \mid \pi_t, n_t\right]. \tag{10}$$

The Bellman equation for the optimal IPO timing strategy can then be written as:

$$F(\pi_t, n_t) = \max\left\{\Omega(\pi_t, n_t),\ \theta \pi_t dt + \frac{1}{1 + \rho dt} E\left[F\left(\pi_t + d\pi_t, n_t + dn_t\right) \mid \pi_t, n_t\right]\right\}. \tag{11}$$

Because time horizon is infinite and α_π, σ_π, α_n, σ_n and λ are constants, one can drop the t subscripts on π and n. In the continuation region, the second term on the right-hand side of (11) is the larger of the two. Let multiply it by $(1+\rho dt)$, omit terms that go faster than dt as $dt \to 0$ and rearrange, we get:

$$\rho F(\pi, n)dt = \theta\pi dt + E\left[dF\left(\pi, n\right) \mid \pi, n\right], \tag{12}$$

where

$$dF = F_\pi d\pi + F_n dn + \frac{1}{2}F_{\pi\pi}(d\pi)^2 + \frac{1}{2}F_{nn}(dn)^2 + F_{\pi n}(d\pi dn) + [F(\pi,0) - F(\pi,n)]dq \tag{13}$$

by application of Itô's Lemma, subscripts denoting derivatives.[14]

Note that if the Poisson event in (6) occurs, n goes to zero that is the market is cold forever and the firm is never taken public. Then, the value of the firm consists merely of the fundamental value $\frac{\pi}{\delta_\pi}$. This yields the following condition:

$$F(\pi, 0) = \theta\frac{\pi}{\delta_\pi}. \tag{14}$$

Finally, taking the expectation of (13) where $E\left[dz_\pi\right] = E\left[dz_n\right] = 0$, $E\left[dq\right] = \lambda dt$, $E\left[dz_\pi dq\right] = E\left[dz_n dq\right] = 0$ and $E\left[dz_\pi dz_n\right] = rdt$, rearranging and dividing by dt, equation (12) becomes the elliptic partial differential equation:

$$\frac{1}{2}(\sigma_\pi^2\pi^2F_{\pi\pi} + 2r\sigma_\pi\sigma_n\pi nF_{\pi n} + \sigma_n^2n^2F_{nn}) + (\rho - \delta_\pi)\pi F_\pi$$
$$+ (\rho - \delta_n)nF_n - (\rho+\lambda)F + \left(\frac{\delta_\pi + \lambda}{\delta_\pi}\right)\theta\pi = 0. \tag{15}$$

Besides (14) the solution to (15) must satisfy the standard value-matching and two smooth-pasting conditions, respectively:

$$F(\pi, n) = \frac{\theta Q_S}{Q+Q_S}\frac{\pi}{\delta_\pi} + \frac{\theta Q_S}{Q+\theta Q_S}ne^{-(\delta_n+\lambda)T}, \tag{16}$$

$$F_\pi(\pi, n) = \frac{\theta Q_S}{Q+Q_S}\frac{1}{\delta_\pi}, \tag{17}$$

$$F_n(\pi, n) = \frac{\theta Q_S}{Q+\theta Q_S}e^{-(\delta_n+\lambda)T}. \tag{18}$$

Solving this kind of problem generally requires the use of numerical methods. However, following McDonald and Siegel (1986) or Dixit and Pindyck (1994) we can reduce it to

[14] Equation (12) is the usual equilibrium relation which states that over the small time interval dt, the total expected return from holding the shares must be equal to the profits flow $\theta\pi dt$ plus the expected capital appreciation.

one dimension. Indeed, because $F(\pi, n)$ is homogeneous of degree one in (π, n) we can rewrite the value of the option as:

$$F(\pi, n) = \pi f\left(\frac{n}{\pi}\right) = \pi f(s). \tag{19}$$

The function f and the critical value of the ratio $s = \frac{n}{\pi}$ are then obtained using the standard optimal stopping problem method. Intuitively, the firm should go public when the dilution cost is relatively low, that is when π is low or when the number of optimistic investors is relatively high. Overall, IPO occurs when s is sufficiently high.

Proposition 1 *With profits of the project and a number of optimistic investors following respectively the stochastic processes (1) and (6), the firm is taken public when the ratio $s = \frac{n}{\pi}$ is greater than the threshold value*

$$\frac{n^*}{\pi^*} = s^* = \frac{\varepsilon_1}{\varepsilon_1 - 1} \frac{Q(Q + \theta Q_S)}{\delta_\pi Q_S(Q + Q_S)} e^{(\delta_n + \lambda)T} \tag{20}$$

where

$$\varepsilon_1 = \tfrac{1}{2} - \tfrac{\delta_\pi - \delta_n}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2} + \sqrt{\left[\tfrac{\delta_\pi - \delta_n}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2}\right]^2 + \tfrac{2(\delta_\pi + \lambda)}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2}} > 1. \tag{21}$$

The value of the firm to the venture capitalist is

$$F(\pi, n) = A_1 \frac{n^{\varepsilon_1}}{\pi^{\varepsilon_1 - 1}} + \theta \frac{\pi}{\delta_\pi}. \tag{22}$$

A_1 is given in appendix.

Proof: see appendix

The venture capitalist will then exercise the IPO option in particular after a positive shock on the number of optimistic investors n. This yields the following proposition:

Proposition 2 *Holding the profit level constant, firms should go public after positive shocks on the number of optimistic investors.*

Several papers have documented a positive relation between initial returns and the demand from retail investors. For example, Derrien (2002) finds from a sample of french IPOs, that the offer price as well as the initial return increase with the demand of individual investors.[15] Similarly for the US, using the TAQ database Zhang (2000) identifies the

[15] There exists in France an IPO procedure commonly used since 1999 which reserves a fraction of offered shares for individual investors. The demand from these investors is hence directly observable.

buying volume generated by small investors during the first trading day of the IPO and finds that underpricing is positively related to this volume. Finally, it is well recognized in the IPO literature that initial returns are positively and very significantly explained by stock market returns preceding the date of the offer (see Loughran and Ritter, 2002 or Derrien and Womack, 2003, among others). As evidenced by Derrien (2002), this is because market conditions have an impact on the demand of individual or optimistic investors, even in the few days before the IPO. Overall, high initial returns may be interpreted as a high level of optimists demand. Proposition 2 is then highly consistent with Lowry and Schwert's (2002) study which shows that past initial returns positively Granger cause the number of IPOs. More precisely, the Granger F-test rejects with a p-value below 1% the hypothesis that three lags of monthly average initial returns have no power to predict the number of IPOs. This means that firms are going public when average underpricing is high that is when the demand from optimistic investors is high. Since in practice the option of going public cannot be exercised instantaneously because of the offer registration period, a lag is observed between the increase in the number of optimistic investors and the rise in IPO volume.[16]

Notice that an increase in the probability of the Poisson event has two opposite effects on the IPO timing. First, a positive one. Indeed, the higher the probability λ of the negative event, the less valuable the option as $E[dn]$ decreases and so the firm should go public earlier. Second, a negative effect. Since the overvalued part of the proceeds from selling secondary shares is not received for T units of time, when λ increases, the venture capitalist will wait for a higher threshold ratio to take the firm public. It can also be noted that the value of the option is decreasing with the lockup duration T and that not surprisingly, as T goes to infinity $F(\pi, n)$ reduces to the fundamental value of the shares since A_1 in (22) goes to zero. The determination of the lockup period's length by stock market authorities may then have non negligible effects on the venture capitalism industry equilibrium.[17]

So far, we have considered the IPO timing decision by assuming that the firm faced

[16] Introducing a lag between the going public decision and the date of the IPO would not modify the results of the model. It would only raise the critical value s^* beyond which the issuer decides to go public.

[17] Venture capitalists rarely sell stocks on the stock market to then distribute cash to limited partners. Instead, they prefer distributing the shares to each limited partner who can decides when selling the stocks. Anyway, as long as the distribution of stocks occurs after the lockup period, the length of this period undeniably affects the venture capitalism industry equilibrium.

competition on the product market but enjoyed a monopolistic position on the IPO market. However, when the market is bullish, other firms in the same industry will be taken public and one might expect that the number of optimistic investors for each issuer gets down, leading to a decrease in initial returns and subsequent IPO volume. Econometric results does not however support this last assertion. As evidenced by Lowry and Schwert, the number of IPOs has no power to predict future initial returns. This could be because of bottlenecks on the offer side of the IPO market, as the investment bank industry cannot instantaneously adjust its size to a sudden increase in the demand for its services and the Security and Exchange Commission is unable to process the registration statements as quickly as in normal periods.[18] As a result, it may be that the number of optimistic investors present the first day of the offer (the variable n in the model) increases at a higher rate than do the number of IPOs and then, despite a larger quantity of stocks offered to investors, initial returns are still substantial.

4 IPO option and real investment

Shleifer (2000) points out that "when capital markets are not sufficiently developed to enable the financing of all privately profitable projects, bubbles play an extremely positive social role". Indeed, "overvaluation may enable firms to finance profitable projects that they could not finance otherwise because of imperfections in the capital markets". In this section, we show that the IPO market may be a good illustration of Shleifer's intuition.[19]

First, let us consider the investment decision of the venture capitalist when there is no IPO market. At date τ, the venture capitalist can pay I to get a payoff which is worth θV_τ where V_τ is the expected cumulated profits flow of the project, defined as in (3). Since profits and so, the project value, are expected to decrease over time, the optimal timing strategy clearly consists in investing immediately, provided that the current value V_τ lies above a given critical level noted V^*, that is that the investment option is deep in the money. V^* can be calculated by using the basic investment model under uncertainty.

[18] Lowry and Schwert report that high initial returns are associated with longer registration periods in following months. Without considering bottlenecks effects, this finding may seem quite paradoxical as potential issuers interpret high initial returns as a signal of a high level of optimistic demand and so should exercice their IPO option more quickly.

[19] Ljungqvist, Nanda and Singh (2001) also note concerning the IPO market that since "the possible expropriation of sentiment investors (...) subsidizes risk-taking by young firms, social welfare may be enhanced".

Let t denote a date when the investment option is out the money (that is $V_t < V^*$) and $\Psi(\pi_t)$ the termination payoff received by the VC when investing I at date t. We have:

$$\Psi(\pi_t) = \theta \frac{\pi_t}{\delta_\pi} - I. \tag{23}$$

The program of the venture capitalist can be stated as follows:

$$H(\pi_t) = \max \left\{ \Psi(\pi_t), \frac{1}{1+\rho dt} E \left[H \left(\pi_t + d\pi_t \right) \mid \pi_t \right] \right\}, \tag{24}$$

where $H(\pi_t)$ is the value of the investment opportunity without IPO market.

The only return from holding the investment opportunity is its expected appreciation. In the continuation region, the Bellman equation is then:

$$\rho H(\pi_t) dt = E[dH(\pi_t) \mid \pi_t]. \tag{25}$$

Once again, we can drop the t subscripts on π since the problem is time homogeneous. Expanding dH using Itô's Lemma, taking its expected value by noting that $E(dz_\pi) = 0$, $E(dz_\pi^2) = dt$ and dividing by dt, (25) becomes:

$$\frac{1}{2}\sigma_\pi^2 \pi^2 H''(\pi) + (\rho - \delta_\pi)\pi H'(\pi) - \rho H(\pi) = 0. \tag{26}$$

It must be stressed that with α_π negative, this relation can be used only for specific values of the drift and the variance parameters. Indeed, the value of waiting comes from the possibility for the VC not to undertake the project in case of a negative shock on profits. The larger the variance parameter of the profits flow, the higher this value. On the other hand, when the drift parameter is negative, waiting entails a cost not only because of the foregone profits flows but also because V is expected to decline over time. Overall, one must suppose that α_π is not too low in comparison with the variance σ_π^2 otherwise $E[dH(\pi) \mid \pi]$ would be negative and there would be no waiting region. This is summarized in the following assumption:

Assumption 2 *The amplitude of shocks over profits is sufficiently large in comparison with the drift so that there exists a waiting region. More precisely, α_π and σ_π^2 are such that the inequality:*

$$\frac{1}{2}\sigma_\pi^2 \pi^2 H''(\pi) + \alpha_\pi \pi H'(\pi) > 0$$

holds true, $H(\pi)$ being a continuous convex function at least twice differentiable in π.

Note that this hypothesis is more likely to be valid, *ceteris paribus*, in industries where profits are very volatile as this is the case in emerging industries. Resolving equation (26) under the standard boundary conditions (see Dixit and Pindyck, 1994) gives the critical value V^* of the project above which it is optimal to invest in the absence of the IPO market.

Proposition 3 *When profits are expected to decline over time, the critical value of V until which it is optimal to invest I is*

$$V^* = \frac{\xi_1}{\xi_1 - 1} \frac{I}{\theta} \tag{27}$$

with

$$\xi_1 = \tfrac{1}{2} - \tfrac{(\rho - \delta_\pi)}{\sigma_\pi^2} + \sqrt{\left[\tfrac{(\rho - \delta_\pi)}{\sigma_\pi^2} - \tfrac{1}{2}\right]^2 + \tfrac{2\rho}{\sigma_\pi^2}} > 1. \tag{28}$$

In the present case, the venture capitalist receives only a fraction θ of the value of the project. Then, he will invest I at date τ if θV_τ is greater than

$$\theta V^* = \frac{\xi_1}{\xi_1 - 1} I > I. \tag{29}$$

Suppose that V_0 is greater than V^*, then agents enter the industry until an unknown date t^* when $V_{t^*} = V^*$. Note however that at V^* there are still positive NPV projects in the industry which are not undertaken simply because of uncertainty over the evolution of profits.[20] This is more likely to occur when the variance of returns is high.

Proposition 4 *The higher the variance of the project's returns, the greater the critical value below which no investment will occur.*

Proof follows from derivation of ξ_1 with respect to σ_π^2.

From a fundamental value perspective, if V is initially greater than V^*, investment in an industry will occur until the critical value V^* is hit. However, one can imagine industries in the economy where V^* is so high that only a few project will be financed, despite the presence of other positive NPV projects. From proposition 4, this will happen in industries where the variance of returns is large, that is in emerging industries.

[20]The fact that venture capitalists abstain from undertaking these positive NPV projects cannot be viewed as suboptimal as it is the result of an optimal behavior once the opportunity cost of exercising the option to invest is taken into account. One can however consider that this situation is suboptimal for other agents in the economy as the implementation of these projects may increase their utility. I thank Mark Wahrenburg for having stressed this point.

Having the option to go public and so, the opportunity to sell the project at an overvalued price can now enable the financing of projects which would not be undertaken otherwise.[21] Indeed, in presence of optimistic investors, the value of the firm at date τ is given by (22). Then, the venture capitalist will invest in the industry if

$$I < F(\pi, n) = A_1 \frac{n^{\varepsilon_1}}{\pi^{\varepsilon_1 - 1}} + \theta \frac{\pi}{\delta_\pi}. \tag{30}$$

Overvaluation on the stock market will be beneficial to the economy if it enables the implementation of projects with positive net present values. In the absence of the IPO market, the region over which such projects are not financed is larger, the higher the variance of returns in the industry. But as the variance of returns increases, the evaluation of projects is prone to a greater divergence of opinion and so (30) may hold. As long as (30) holds, venture capitalists finance projects and sell them on the stock market.

If all positive NPV projects have been financed and the IPO market is still hot (that is the Poisson event in (6) has not yet occurred), venture capitalists may find optimal to undertake negative present value investments. In this case, overvaluation is harmful for two reasons. First, because it leads to overinvestment in the industry (too many similar projects are financed) and then wasting of capital. Gompers and Lerner (2003) report for example that in the early eighties, nineteen disk drive companies received venture capital financing and that two-thirds of these investments came in 1982 and 1983, a period when valuation of publicly traded computer hardware firms experienced a substantial increase. Whereas the rationality of the scale of investment in the industry was highly questionable, many of these companies went public, just before the market collapsed a few month later. A similar dynamic was observed in the biotechnology industry in the early nineties. The second reason why overvaluation is harmful is that positive NPV projects in other industries will be unfunded.[22] Indeed, the fundamental or real return of these projects, even if significant, may be lower than the financial return received from the sale of overvalued stocks if the number of optimistic investors n in (30) is very high, as it was the case for Internet companies in the late nineties.

[21] Draho (2000) draws a similar conclusion but by only considering the financing of projects whose NPV would be negative in the absence of the IPO market.

[22] Gompers and Lerner note that during the IPO cycle of 1998-2000, investments were concentrated in the sectors of Internet and telecommunication. Promising areas like energy technologies, micro manufacturing or advanced materials were not funded as venture capitalists preferred allocating funds to most popular investment areas.

5 Empirical analysis

The previous model suggests that venture capitalists or their limited partners may be more willing to finance projects in new industries when the IPO market for these industries is hot, that is when the demand from optimistic investors is high. Accordingly, we propose in this section to test for a relation between the decision to invest in high-tech industries and optimistic investors demand on the IPO market.

Funds invested by venture capitalists in private companies come essentially from external investors, mainly pension funds, through commitments in venture closed-end funds raised typically every two to five years. These funds are not immediately invested in the portfolio companies but are instead disbursed in stages over several years. An appropriate measure of the willingness of agents to invest in a given industry may then be the amount of commitments to venture funds targeted towards this industry rather than the amount of funds actually disbursed in companies.

Several papers have already studied the relation between IPO market activity and venture capital fundraising. Gompers and Lerner (1998) have found that the equity value of venture backed firms taken public in the previous year had a positive effect on current fundraising. Gompers (1996) has also showed that the number of firms taken public by a venture capitalist had a significant impact on the amount of capital this VC could raise in next funds, particularly when it is a young VC. Indeed, bringing companies public enables the VC to increase its reputation and hence to raise new funds more easily (grandstanding hypothesis). However, in Gompers' study the initial return of the IPO backed by the VC does not have a significant effect on future fundraising.

Here we follow a different approach from these papers by analyzing the impact on fundraising of average initial returns, which may represent a proxy for optimistic investors demand on the IPO market. We argue that when average initial returns for a given industry are high, rational investors expect that future IPOs of this industry will also exhibit high initial returns and so a good performance until the end of the lockup.[23] They are hence more willing to commit money for the financing of projects of this industry.

[23] Aggarwal, Krigman and Womack (2002) show that the buy-and-hold return from the IPO date to the lockup expiration date increases with the initial return of the stock considered via more recommendations from financial analysts.

5.1 Data and variable description

For the conduct of our econometric study we use US quarterly series of commitments and venture investments in high-tech industries over the period 1990:1-2002:4. Data are obtained from Venture Economics.[24] The analysis is restricted to investments by venture capitalists funds in private firms and firms which are in an IPO registration period (investments in public firms are not included). Moreover, buy-out as well as acquisition investments are excluded. Finally, funds of funds (venture funds that invest more than 50% of their capital in other venture funds) are also eliminated.

Concerning average initial returns, we rely on a sample of firm-commitment IPOs completed between 1990 and 2002 which are reported by the New Issues database of Securities Data Company (SDC). IPOs of the sample meet several criteria. Unit offerings, partnerships, American Depository Receipts (ADRs) or non-common shares and penny stocks (stocks with an offer price below $5) are eliminated. Moreover, only AMEX, NYSE and NASDAQ IPOs in high-tech industries are considered.[25] First-day trading prices are obtained from SDC or, if not reported by this database, from Datastream. If the closing price at the first-trading day is not available (concerns a total of 21 IPOs), we use the closing price at the second-trading day after the IPO or the close at the end of the first week of trading. We lost 9 IPOs for which we could not get market prices. The final sample is then composed of 1,602 IPOs.

As in Blondel, Hoang, Powell and Shi (2001), we compute for each quarter a proceeds-weighted measure of initial return instead of a simple arithmetic average measure. Indeed, firms which are raising smaller amounts of money generally exhibit higher initial returns *ceteris paribus.* Equal-weighted initial returns would then give a misleading measure of optimistic investors demand. Proceeds-weighted initial returns are given by the following

[24]This database defines high-technology investments as those in communications and media, Internet, computer hardware, computer other, semiconductors and other electronics industries.

[25]High-tech IPOs are here defined as those with SIC codes 3571, 3572, 3575, 3577, 3578 (computer hardware), 3661, 3663, 3669 (communications equipment), 3671, 3672, 3674, 3675, 3678, 3679 (electronics components and accessories), 3812, 3823, 3825, 3826, 3827 (search, detection, navigation, guidance), 3829 (measuring and controlling devices), 4812, 4813 (telephone equipment), 4899 (communications services), 7371, 7372, 7373, 7374, 7375, 7378, 7379 (software) and 7389 (Internet business services). We also considered IPOs with SIC codes 3559 (special industry machinery), 5045, 5065, 5199, 5261, 5311, 5734, 5735, 5941, 5945, 5961, 5991, 5999 (wholesale) when related to computers, software or Internet.

formula:

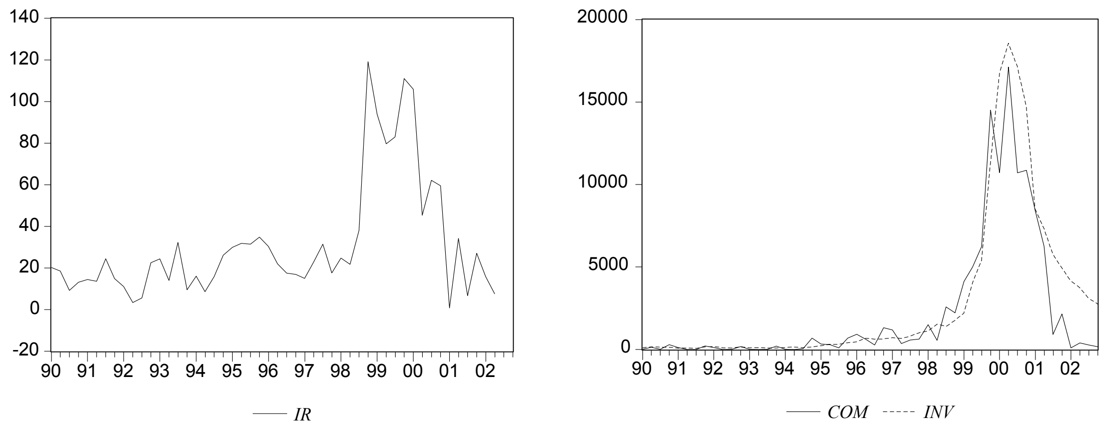
$$IR_t = \frac{\sum_{i=1}^{N}\{(\text{proceeds})_{i,t} \times IR_{i,t}\}}{\sum_{i=1}^{N}(\text{proceeds})_{i,t}} \times 100$$

where t = quarter $1, ..., 52$; i = IPO $1, ..., N$ where N denotes the number of IPOs in quarter t ; $(\text{proceeds})_{i,t}$ = (number of shares issued)$_{i,t}$ × (offer price)$_{i,t}$ and $IR_{i,t}$ = [(first-trading day closing price)$_{i,t}$ − (offer price)$_{i,t}$] / (offer price)$_{i,t}$.

The three series – IR for proceeds-weighted initial returns, COM for commitments and INV for investments – are plotted in Figure 2. As can be seen from this figure, the evolution of commitments seems to follow with a lag of six months the evolution of initial returns, particularly during the hot market of Internet IPOs. On the other hand, the series of investments is smoother, reflecting the fact that capital in venture funds is disbursed in stages. This leads to an hysteresis effect that may explain why despite the collapse of the bubble and the bearish market that prevails since then, venture investments remain relatively high. Overall, these observations reinforce our intuition that a modelling of commitments rather than investments is more appropriate to capture the effects of public market sentiment on private investors' decisions to fund high-tech projects.

Figure 2. Quarterly proceeds-weighted initial returns (in percent), commitments and investments (in millions of dollars) in high-tech industries for the period 1990:1-2002:4.

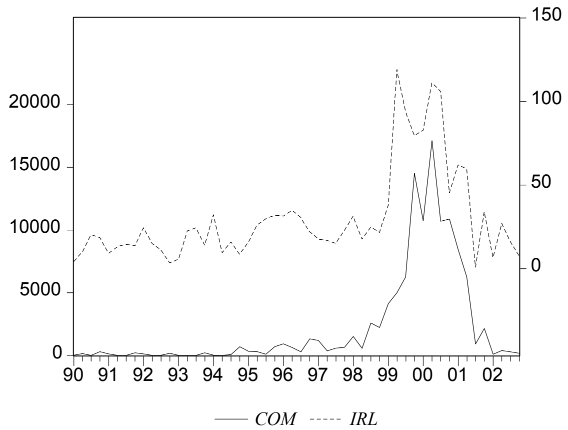
Note: there is no point for the series IR in 2002:3 since no IPO meeting our sample criteria occurred during this quarter.



Sources: Venture Economics and author's calculations based on the New Issues SDC database.

Finally, because of the stickiness of the supply of venture capital[26], the level of commitments may not adjust instantaneously to the IPO market sentiment. Instead of using the series IR, we then rely on its two quarters lagged measure, denoted IRL (see Figure 3).

Figure 3. Lagged quarterly proceeds-weighted initial returns (in percent) and commitments (in millions of dollars) in high-tech industries for the period 1990:1-2002:4.



Sources: Venture Economics and author's calculations based on the New Issues SDC database.

5.2 Unit root and cointegration tests

Unit root tests results for the series IRL and COM are presented in Table 1. The Augmented Dickey Fuller (ADF) as well as the Phillips-Perron (PP) tests indicate that the series IRL is a pure random walk (no time trend, no constant). For COM, the ADF test leads us to accept the non-stationarity hypotheses only at the 1% level. Indeed, the test suggests that the series is stationary around a trend at the 5% level. We however treat these series as integrated of order one as the Phillips-Perron test fails to reject the null hypothesis of non stationarity even at the 5% level (without any time trend or constant term).

Since the two series are $I(1)$, we test for the presence of a cointegrating relation using the two-step Engle-Granger (1987) procedure. Accordingly, we first estimate the following

[26]See Gompers and Lerner (2003) for the reasons of short-run rigidities in fundraising.

Table 1. Unit root tests for the period 1990:1-2002:4.

Variable	Null hypothesis	Alternative hypothesis	ADF[a]	PP[b]
IRL	$I(1)$	$I(0)$	-1.80	-1.55
	$I(2)$	$I(1)$	-9.37^{**}	-9.37^{**}
COM	$I(1)$	$I(0)$	-3.82^{*}	-1.73
	$I(2)$	$I(1)$	-3.46^{**}	-9.80^{**}

[a] Augmented Dickey Fuller test with a number of lags minimizing Akaike and Schwartz information criteria. [b] Phillips-Perron test with 3 truncation lags as suggested by the Newey-West criterion. ** and * denote rejection of the null hypothesis respectively at 1% and 5% significance levels, based on MacKinnon critical values.

cointegrating regression:

$$COM_t = a_0 + a_1\, IRL_t + z_t. \tag{31}$$

Then, we study the stochastic properties of the estimated residue $\hat{z}_t$. If COM and IRL are cointegrated, $\hat{z}$ should be stationary in level. OLS estimation of equation (31) yields the following results (t-statistics are in parentheses):

$$COM_t = \underset{(-2.97)}{-1354.45} + \underset{(10.62)}{117.7}\, IRL_t + \hat{z}_t \tag{32}$$

with sample size = 52, Adjusted $R^2 = 0.69$ and DW = 1.54.

This equation, referred to as the static relation indicates that in the long-run, the level of commitments is positively related to the level of lagged initial returns.

We however need to make sure that we are not in presence of a spurious regression. At first glance, the Durbin-Watson statistic shows that this is not the case. The value of this statistic is indeed significantly greater than the critical values tabulated by Engle and Yoo (1987).[27] A more reliable approach consists in testing for the non-stationarity of the residuals of the cointegrating relation using the ADF test without any trend or constant term. Results of the unit root test for $\hat{z}$ are presented in Table 2.

Table 2. Unit root test for the residuals of the static relation.

Variable	Null hypothesis	Alternative hypothesis	ADF[a]
$\hat{z}$	$I(1)$	$I(0)$	-5.61^{**}

[a] Augmented Dickey Fuller Test performed with zero lag according to the minimization of Akaike and Schwartz information criteria. ** denotes rejection of the null hypothesis at the 1% significance level, based on Engle and Yoo (1987) critical values.

[27] For a sample of 50 observations these values are 1.49, 1.03 and 0.83 at 1%, 5% and 10% significance levels respectively.

As can be seen from this table, we strongly reject the hypothesis of non-stationarity of the residuals, indicating that the series COM and IRL are cointegrated. This is confirmed by the Johansen (1988, 1991) tests[28] whose results are presented in Table 3.

Table 3. Johansen's cointegration tests.

Null hypothesis: cointegration rank $= r$	Max. eigenvalue test-statistic[a]	1% critical value	Trace test-statistic[a]	1% critical value
$r = 0$	31.65**	20.20	37.33**	24.60
$r \leq 1$	5.69	12.97	5.69	12.97

**denotes rejection of the null hypothesis at 1% significance level. [a] Tests performed by allowing for a constant in the cointegrating relation but not in the VAR.

5.3 Error correction model

In order to characterize the adjustments towards the equilibrium relation (32), we estimate an error correction model of the form[29]:

$$\Delta COM_t = c + \gamma \hat{z}_{t-1} + \sum_{i=1}^{l} \delta_{1,i} \Delta COM_{t-i} + \sum_{j=0}^{m} \delta_{2,j} \Delta IRL_{t-j} + \varepsilon_t \tag{33}$$

where Δ is the lag operator, $\hat{z}_{t-1}$ is the estimated error correction term from (32) and l and m are the optimal numbers of lags for the lagged dependent and independent variables. l and m are determined by proceeding in two stages. We first select the optimal number l that minimizes AIC and SIC in (33) by constraining all $\delta_{2,j}$ coefficients to zero. Then, using the optimal order of $\delta_{1,i}$, we determine the optimal order of $\delta_{2,j}$ once again according to the minimization of AIC and SIC.

Estimation results[30] are reported in Table 4. Notice that the coefficient of the error correction term is significantly negative, indicating that in case of a deviation from the long-run relation, the level of commitments is corrected back to this relation. As an example, a drop in the demand from optimistic investors, that is a fall in the variable IRL – as the one that occurred during the second half of 2000 – leads to an increase in the

[28]The variable COM is normalized to one in the cointegrating vector. The number of lags in the VAR in levels is determined by minimizing Akaike and Schwartz information criteria.

[29]We have chosen to model short run adjustments with a single equation (ECM) rather than with a vector form (VECM) as it would make no sense to explain past initial returns by current levels of commitments.

[30]A battery of tests was applied to the residuals of the model. We did not find any autocorrelations or ARCH effects. However, the White (1980) test indicates the presence of heteroskedasticity.

residue of the static relation that in turn implies a decrease in subsequent commitments. Note also that variations in commitments, ΔCOM positively depend on variations in initial returns that occur up to six quarters before (recall that the variable IRL indicates two quarters lagged initial returns). This tends to confirm previous results by Gompers and Lerner (1998) that the process of raising new funds in response to public market movements may be quite long.[31]

Overall, the econometric analysis reveals that agents do react to IPO market sentiment in their decision to provide funds for the financing of high-tech investments. A candidate explanation for this finding is that agents expect high VC returns when average initial returns are high as an important part of venture funds' returns depends on the proceeds from sales to public optimistic investors of portfolio companies' shares. Note that we could also have included in the analysis demand side factors like R&D expenditures or the number of patents, which are suspected to influence the level of VC fundraising. However, because these variables are trend stationary, they have no place in a cointegration approach.

Table 4. Error correction model estimates for the period 1990:1-2002:4.

	Dependent variable		
Regressors	ΔCOM_t	t-statistics[a]	p-values[a]
c	−45.13	−0.29	0.7728
$\hat{z}_{t-1}$	−0.48	−3.77	0.0005
ΔCOM_{t-1}	−0.31	−2.29	0.0268
ΔCOM_{t-2}	0.18	1.26	0.2143
ΔIRL_t	42.39	4.65	0.0000
ΔIRL_{t-1}	−13.85	−0.97	0.3391
ΔIRL_{t-2}	30.85	1.19	0.2411
ΔIRL_{t-3}	35.70	2.43	0.0196
ΔIRL_{t-4}	32.14	1.99	0.0534
Number of observations = 52, Adjusted $R^2 = 0.69$			

[a] Using White's (1980) heteroskedasticity-consistent standard errors.

It should be stressed that our explanation for the relation between IPO market activity and venture capital fundraising differs from the grandstanding hypothesis in that we argue that agents commit money more easily to VC funds when average initial returns

[31] Raising money and closing a new fund takes on average one year. However, the period of fundraising is shorter for more established venture capitalists and more generally during hot issue periods.

are high because they expect a more profitable exit from their investment[32] whereas the grandstanding hypothesis states that agents are more willing to provide funds to young venture capitalists when these latter have a sufficient record in terms of companies brought to the market. These two explanations are nevertheless not mutually exclusive.

Anyway, because of a disconnection between real and financial returns, overfunding in new industries may occur. It would be interesting to estimate empirically to what extend stock market overvaluation is welfare-enhancing in view of the financing of profitable projects. We leave this open for further research.

6 Conclusion

In this paper, we studied the effect of the IPO market on the decision to invest in new industries when investors on the stock market agree to disagree about the fundamental value of firms taken public and short sales are constrained. Following Draho (2000), we treated the IPO decision as a real option and showed that firms were more likely to go public when overvaluation was high relatively to profits, that is after price run-ups. Thanks to a substantial value of the IPO option, stock market bubbles may affect real investment decisions in high-technology industries. As revealed by the econometric analysis, funds allocated to the development of new industries may positively depend on exuberant beliefs reflected here by the degree of average initial returns on the IPO market. Bubbles can then be beneficial in the sense that they enable the financing of positive NPV projects which would not be undertaken otherwise because of great uncertainty over profits. On the other side, excessive and durable overvaluation certainly leads to overinvestment, that is investment in negative NPV projects in the industry in vogue on the stock market. The social benefits of having an active IPO market clearly depend on the magnitude and occurrence of these overvaluation events.

[32] This supposes that the length of time between funding projects and selling them on the stock market is not too long. This hypothesis seems justified, at least for the end of the nineties in view of the very young age of Internet IPOs.

Appendix

A.1 Derivation of the termination payoff $\Omega(\pi_t, n_t)$.

With a total number of shares equal to $Q + Q_S$, the discounted value of the expected flow of profits received by the venture capitalist between the IPO date t and the lockup expiration date $t + T$ is

$$\frac{\theta Q_S}{Q + Q_S} \frac{\pi_t}{\delta_\pi}(1 - e^{-\delta_\pi T}). \tag{A1}$$

The expected market price at $t + T$ is

$$E[P_{t+T} \mid \pi_t, n_t] = \frac{E[V_{t+T} \mid \pi_t]}{Q + Q_S} + \frac{n_t e^{(\alpha_n - \lambda)T}}{Q + \theta Q_S}, \tag{A2}$$

where

$$E[V_{t+T} \mid \pi_t] = E\left[E\left[\int_{t+T}^{\infty} \pi_s e^{-\rho(s-t-T)} ds \mid \pi_{t+T}\right] \mid \pi_t\right] = \frac{\pi_t}{\delta_\pi} e^{\alpha_\pi T}. \tag{A3}$$

Discounting (A2) at the rate ρ for length T, multiplying by the number of secondary shares θQ_S and adding to (A1) yields:

$$\Omega(\pi_t, n_t) = \frac{\theta Q_S}{Q + Q_S} \frac{\pi_t}{\delta_\pi} + \frac{\theta Q_S}{Q + \theta Q_S} n_t e^{-(\delta_n + \lambda)T}. \tag{A4}$$

A.2 Proof of Proposition 1

With $F(\pi, n) = \pi f\left(\frac{n}{\pi}\right) = \pi f(s)$, we have:

$$F_n(\pi, n) = f'(s), \quad F_\pi(\pi, n) = f(s) - s f'(s),$$

$$F_{nn}(\pi, n) = \frac{f''(s)}{\pi}, \quad F_{\pi\pi}(\pi, n) = \frac{s^2 f''(s)}{\pi} \text{ and } F_{\pi n}(\pi, n) = -\frac{s f''(s)}{\pi}.$$

Substituting these expressions in the partial differential equation (15), dividing by π and rearranging gives the ordinary differential equation for the function $f(s)$:

$$\frac{1}{2}(\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2)s^2 f''(s) + (\delta_\pi - \delta_n)s f'(s) - (\delta_\pi + \lambda)f(s) + \left(\frac{\delta_\pi + \lambda}{\delta_\pi}\right)\theta = 0. \tag{A5}$$

The general solution of the homogeneous part of (A5) have the form:

$$f(s) = A_1 s^{\varepsilon_1} + A_2 s^{\varepsilon_2}. \tag{A6}$$

Following Dixit and Pindyck (1994), it can be expressed as:

$$f(s) = As^{\varepsilon}. \tag{A7}$$

The particular integral to (A5) is $\dfrac{\theta}{\delta_\pi}$. Adding it to (A7) yields:

$$f(s) = As^{\varepsilon} + \frac{\theta}{\delta_\pi}. \tag{A8}$$

Substituting (A8) in (A5), we get the fundamental quadratic equation:

$$\frac{1}{2}(\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2)\varepsilon(\varepsilon - 1) + (\delta_\pi - \delta_n)\varepsilon - (\delta_\pi + \lambda) = 0, \tag{A9}$$

whose two roots are

$$\varepsilon_1 = \tfrac{1}{2} - \tfrac{\delta_\pi - \delta_n}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2} + \sqrt{\left[\tfrac{\delta_\pi - \delta_n}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2}\right]^2 + \tfrac{2(\delta_\pi + \lambda)}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2}} > 1$$

and

$$\varepsilon_2 = \tfrac{1}{2} - \tfrac{\delta_\pi - \delta_n}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2} - \sqrt{\left[\tfrac{\delta_\pi - \delta_n}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2}\right]^2 + \tfrac{2(\delta_\pi + \lambda)}{\sigma_\pi^2 - 2r\sigma_n\sigma_\pi + \sigma_n^2}} < 0.$$

Moreover, note that from $F(\pi, 0) = \theta\dfrac{\pi}{\delta_\pi}$, f must satisfy:

$$f(0) = \frac{\theta}{\delta_\pi}. \tag{A10}$$

Because $\varepsilon_2 < 0$, we must have $A_2 = 0$, otherwise as n went to zero, $f(s)$ would tend to infinity, which violates (A10). Finally, applying the value-matching and the smooth-pasting conditions to $f(s) = A_1 s^{\varepsilon_1} + \dfrac{\theta}{\delta_\pi}$ yields the system:

$$\begin{cases} A_1 s^{\varepsilon_1} + \dfrac{\theta}{\delta_\pi} = \dfrac{\theta Q_S}{Q + Q_S}\dfrac{1}{\delta_\pi} + \dfrac{\theta Q_S}{Q + \theta Q_S} s e^{-(\delta_n + \lambda)T} \\ A_1 s^{\varepsilon_1}\dfrac{\varepsilon_1}{s} = \dfrac{\theta Q_S}{Q + \theta Q_S} e^{-(\delta_n + \lambda)T}. \end{cases} \tag{A11}$$

Solving (A11) for s and A_1 gives:

$$s^* = \frac{\varepsilon_1}{\varepsilon_1 - 1}\frac{Q(Q + \theta Q_S)}{\delta_\pi Q_S(Q + Q_S)} e^{(\delta_n + \lambda)T} \tag{A12}$$

and

$$A_1 = \theta Q[\delta_\pi(\varepsilon_1 - 1)(Q + Q_S)]^{\varepsilon_1 - 1}\left(\frac{Q_S}{\varepsilon_1 Q(Q + \theta Q_S)}\right)^{\varepsilon_1} e^{-\varepsilon_1(\delta_n + \lambda)T}. \tag{A13}$$

References

Aggarwal, Rajesh K., Laurie Krigman and Kent L. Womack (2002), Strategic IPO Underpricing, Information Momentum, and Lockup Expiration Selling, *Journal of Financial Economics* 66, 105–137.

Benveniste, Lawrence M., Walid Y. Busaba and William J. Wilhelm (2002), Information Externalities and the Role of Underwriters in Primary Equity Markets, *Journal of Financial Intermediation* 11, 61–86.

Benveniste, Lawrence M. and Paul A. Spindt (1989), How Investment Bankers Determine the Offer Price and the Allocation of New Issues, *Journal of Financial Economics* 24, 343–361.

Black, Bernard S. and Ronald J. Gilson (1998), Venture Capital and the Structure of Capital Markets: Banks versus Stock Markets, *Journal of Financial Economics* 47, 243–277.

Blanchard, Olivier J., Changyong Rhee and Lawrence Summers (1993), The Stock Market, Profit, and Investment, *Quarterly Journal of Economics* 108, 115–136.

Blondel, David, Philip Hoang, John G. Powell and Jing Shi (2001), Detection of Financial Time Series Turning Points: A New CUSUM Approach Applied to IPO Cycles, Working Paper Australian National University.

Boehme, Rodney D., Bartley R. Danielsen and Sorin M. Sorescu (2002), Short-Sale Constraints and Overvaluation, *mimeo.*

Bond, Stephen R. and Jason G. Cummins (2000), The Stock Market and Investment in the New Economy: Some Tangible Facts and Intangible Fictions, *Brookings Papers on Economic Activity* 1, 61–108.

Bottazzi, Laura and Marco Da Rin (2002), Europe's 'New' Stock Markets, CEPR Discussion Paper 3521.

Bradley, Daniel J., Bradford D. Jordan, Ivan C. Roten and Ha–Chin Yi (2001), Venture Capital and IPO Lockup Expiration: An Empirical Analysis, *Journal of Financial Research* 24, 465–492.

Carpenter, Robert E. and Bruce Petersen (2002), Capital Market Imperfections, High-Tech Investment, and New Equity Financing, *Economic Journal* 112, 54–72.

Derrien, François (2002), Issuers, Underwriters and Institutional Investors: Why they All Like the Book-Building IPO Procedure, Working Paper, HEC.

Derrien, François and Kent L. Womack (2003), Auctions vs. Bookbuilding and the Control of Underpricing in Hot IPO Markets, *Review of Financial Studies* 16, 31–61.

Dixit, Avinash and Robert Pindyck (1994), *Investment under Uncertainty*, Princeton University Press, Princeton, New Jersey.

Draho, Jason (2000), The Timing of Initial Public Offerings: a Real Option Approach, *mimeo*, Yale University.

Engle, Robert F. and Clive W. J. Granger (1987), Co-integration and Error Correction: Representation, Estimation, and Testing, *Econometrica* 55, 251–276.

Engle, Robert F. and Byung S. Yoo (1987), Forecasting and Testing in Cointegrated Systems, *Journal of Econometrics* 35, 143–159.

Field, Laura C. and Gordon Hanka (2001), The Expiration of IPO Share Lockups, *Journal of Finance* 56, 471–500.

Gompers, Paul A. (1996), Grandstanding in the Venture Capital Industry, *Journal of Financial Economics* 42, 133–156.

Gompers, Paul A. and Joshua Lerner (1998), What Drives Venture Capital Fundraising?, *Brookings Papers on Economic Activity – Microeconomics*, 149–192.

Gompers, Paul A. and Joshua Lerner (2003), Short-Term America Revisited? Boom and Bust in the Venture Capital Industry and the Impact on Innovation, in *Innovation Policy and the Economy, Volume 3*, Adam B. Jaffe, Joshua Lerner and Scott Stern, editors, MIT Press, Cambridge, Massachusetts.

Huisman, Kuno J.M. (2001), *Technology Investment: a Game Theoretic Real Options Approach*, Kluwer Academic Publisher, Boston, Massachusetts.

Jain, Bharat A. and Omesh Kini (1994), The Post-Issue Operating Performance of IPO Firms, *Journal of Finance* 49, 1699–1726.

Johansen, Søren (1988), Statistical Analysis of Cointegrating Vectors, *Journal of Economic Dynamics and Control* 12, 231–254.

Johansen, Søren (1991), Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models, *Econometrica* 59, 1551–1580.

Lerner, Joshua (1994), Venture Capitalists and the Decision to Go Public, *Journal of Financial Economics* 35, 293–316.

Ljungqvist, Alexander P., Vikram Nanda, and Rajdeep Singh (2001), Hot Markets, Investor Sentiment and IPO Pricing, CEPR Discussion Paper 3053.

Loughran, Tim and Jay R. Ritter (2002), Why Don't Issuers Get Upset about Leaving Money on the Table?, *Review of Financial Studies* 15, 413–443.

Lowry, Michelle and William B. Schwert (2002), IPO Market Cycles: Bubbles or Sequential Learning?, *Journal of Finance* 57, 1171–1200.

McDonald, Robert and Daniel Siegel (1986), The Value of Waiting to Invest, *Quarterly Journal of Economics* 101, 707–728.

Michelacci, Claudio and Javier Suarez (2003), Business Creation and the Stock Market, *Review of Economic Studies*, forthcoming.

Miller, Edward M. (1977), Risk, Uncertainty and Divergence of Opinion, *Journal of Finance* 32, 1151–1168.

Morck, Randall, Andrei Shleifer and Robert W. Vishny (1990), The Stock Market and Investment: Is The Market a Sideshow?, *Brookings Papers on Economic Activity* 2, 157–215.

Ofek, Eli and Matthew Richardson (2003), Dotcom Mania: the Rise and Fall of Internet Stock Prices, *Journal of Finance* 58, 1113–1138.

Pagano, Marco, Fabio Panetta and Luigi Zingales (1998), Why Do Companies Go Public? An Empirical Analysis, *Journal of Finance* 53, 27–64.

Pfirrmann, Oliver, Udo Wupperfeld and Joshua Lerner (1997), *Venture Capital and New Technology Based Firms*, Physica-Verlag, Heidelberg.

Ritter, Jay R. (1991), The Long Run Performance of Initial Public Offerings, *Journal of Finance* 46, 3–27.

Schultz Paul and Mir Zaman (2001), Do the Individuals Closest to Internet Firms Believe they are Overvalued?, *Journal of Financial Economics* 59, 347–381.

Shleifer, Andrei (2000), *Inefficient Markets: an Introduction to Behavioral Finance*, Oxford University Press, New York.

White, Halbert (1980), A Heteroskedasticity-Consistent Covariance Matrix and a Direct Test for Heteroskedasticity, *Econometrica* 48, 817–838.

Zhang, Donghang (2000), Retail Demand and IPO Underpricing: a Model and Empirical Evidence, *mimeo*, University of Florida.

CFS Working Paper Series:

No.	Author(s)	Title
2003/38	**James Bullard** **In-Koo Cho**	Escapist Policy Rules
2003/39	**Seppo Honkapohja** **Kaushik Mitra**	Performance of Inflation Targeting Based On Constant Interest Rate Projections
2003/40	**Athanasios Orphanides** **John C. Williams**	Imperfect Knowledge, Inflation Expectations, and Monetary Policy
2003/41	**Sharon Kozicki** **P.A. Tinsley**	Permanent and Transitory Policy Shocks in an Empirical Macro Model with Asymmetric Information
2003/42	**Mordecai Kurz** **Hehui Jin** **Maurizio Motolese**	The Role of Expectations in Economic Fluctuations and the Efficacy of Monetary Policy
2003/43	**William A. Brock** **Steven N. Durlauf** **Kenneth D. West**	Policy Evaluation in Uncertain Economic Environments
2003/44	**Timothy Cogley** **Sergei Morozov** **Thomas J. Sargent**	Bayesian Fan Charts for U.K. Inflation: Forecasting and Sources of Uncertainty in an Evolving Monetary System
2003/45	**Guenter W. Beck**	Nominal Exchange Rate Regimes and Relative Price Dispersion: On the Importance of Nominal Exchange Rate Volatility for the Width of the Border
2003/46	**Michael Ehrmann** **Marcel Fratzscher**	Equal size, equal role? Interest rate interdependence between the euro area and the United States
2003/47	**Romain Bouis**	IPOs Cycle and Investment in High-Tech Industries
2003/48	**Martin D. Dietz**	Screening and Advising by a Venture Capitalist with a Time Constraint

Copies of working papers can be downloaded at http://www.ifk-cfs.de