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Information manipulation and rational investment booms and busts

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ABSTRACT

A model of endogenous investment booms and busts with rational agents is presented where outside investors are uncertain about both industry (aggregate) and firm-specific capital productivity, and insiders manipulate information through strategic productivity disclosures. For intermediate and high levels of agency conflict, there are aggregate investment distortions along the equilibrium path, investment dynamics are history-dependent, and depict patterns of persistent investment booms or investment busts even though investors design optimal incentive contracts based on Bayes-rational beliefs. Moreover, the aggregate uncertainty may not be resolved in the limit, as the number of firms and disclosures gets arbitrarily large.

1. Introduction

Investment in growth opportunities generated by innovations and development of new economic opportunities is central to the evolution of industries and economic growth (Schumpeter, 1942; Romer, 1990). However, investment often pours into the new industries, especially in their incipient stages, leading to overinvestment or overcapacity relative to the efficient capital allocation levels *ex post*. Two prominent recent examples are the investment booms in the telecommunications industry during 1996–2000 (driven by the internet innovation) and in the housing sector in the U.S. during 2002–2006 (driven by financial innovations in the derivatives markets); the former left a glut of fiber-optic capacity, while the latter resulted in over-building of housing stock. Indeed, there is a litany of such examples historically speaking (Kindleberger, 1978; Garber, 2001).[1] But capital investment in new industries can also be fragile, sometimes falling sharply. These investment booms and busts are often attributed to investor irrationality — driven by "spontaneous optimism" and "animal spirits" (Keynes, 1936), "irrational exuberance" (Greenspan, 1996), or over-reactions to innovations (Shiller, 2005).

However, a historical analysis highlights the crucial role of manipulation of outside investors' beliefs by informed insiders through overly optimistic representations of financial performance and economic prospects. For example, Sidak (2003, p. 207) argues that "WorldCom's false internet traffic reports and accounting fraud encouraged overinvestment in long-distance capacity and internet backbone capacity [and]… has destroyed billions of dollars of shareholder value in other telecommunications firms."[2] Similarly, there is a wide-spread perception that mortgage lenders, investment banks, and the

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[1] For example, the South Sea Trading Company in the 18th century; the development of the railroad industries in Britain and the U.S. in the 1830s and the 1860s, respectively; and the growth of power Utilities in the U.S. in the 1920s.

[2] Strategic information manipulation was rampant among the emerging internet-based firms in the late 1990s, often abetted by the filing of erroneous financial statements From January 1997 through June 2002, about 10% of all listed companies announced at least one earnings restatement (Kedia and Philippon, 2009), which on an average resulted in a 10% drop in their stock price.

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credit rating agencies strategically misled investors regarding the risk of the newly designed structured finance securities (Coffee, 2011). In essence, economic uncertainty regarding innovations often resolves only in the long term, and during the incipient stages of their development outside investors neither have access to reliable economic performance related data nor do they have well-developed business models to interpret such data (e.g., Gort and Klepper, 1982). Instead, investors depend largely on disclosures by informed insiders to assess the economic prospects of innovations.[3]

This paper characterizes the dynamic aggregation of information regarding unknown industry (or aggregate) productivity and the attendant effects on the efficiency of aggregate capital investment when managers of entering firms are privately informed of their idiosyncratic (firm-specific) productivities that are correlated with the unknown aggregate productivity. If outside investors are dependent on insiders' reports, then for a wide range of parameters, the aggregate uncertainty may not be resolved and aggregate investment distortions may persist *in the limit* — when the number of such disclosures gets arbitrarily large — even though outside investors design optimal incentive contracts to induce information based on Bayes-rational beliefs. In these situations there is aggregate overinvestment — relative to the benchmark where the industry productivity is known — when the true productivity is low and aggregate under-investment when the true productivity is high. But even if outside investors can learn in the limit by observing firms' outputs, there are distortions in aggregate investment along the equilibrium path. Moreover, the equilibrium investment dynamics depict patterns of persistent investment booms or investment busts.

Of course, economists have long studied the role of asymmetric information in distorting the allocation of capital to firms. But these papers generally consider only asymmetric information and investment efficiency with respect to *project-specific* productivity and not the uncertainty regarding the underlying aggregate or industry-wide productivity that is faced by investors in new industries (built on innovations).[4] Unlike relative mature industries — where markets have acquired sufficient information to essentially resolve the aggregate uncertainty — outside investors in emerging industries confront incomplete information with respect to both the idiosyncratic project *and* aggregate productivity; disclosures by informed insiders on the former can influence outside investors' beliefs on the latter. However, the process of learning from a large number of project-based disclosures by strategic informed agents and its implications for aggregate investment is unexplored in the literature.

In our model, there is an agency conflict between outside investors and managers because the latter enjoy private benefits from controlling larger investments or assets. But outside investors can provide incentives for informative disclosures through optimal wage contracts and renegotiation-proof investment plans (see Bolton and Dewatripont, 2005) and can learn from the previous disclosures by other managers.[5] However, investment policies that are inefficient *ex post* are not renegotiation-proof and the revelation principle (e.g., Myerson, 1979) does not apply because investors cannot credibly precommit to inefficient investment policies. Inducing truthful information from insiders with low productivity prospects can then be incentive inefficient; the optimal renegotiation-proof contract, therefore, allows low productivity managers to report inflated prospects with a positive probability or potentially even *pool* with the high productivity managers. Hence, learning can be incomplete (cf. Aghion et al., 1991) in the limit even as the number of firms and disclosures gets arbitrarily large and, consequently, capital investment distortions (at the firm and industry levels) persist. And, allowing alternative sources of information (such as, firms' outputs) does not eliminate investment distortions.

The novel aspect of our analysis is to highlight the dynamic interdependency that exists between early disclosures and aggregate investment efficiency in the limit. While productivity expectations are formed on *past* disclosures, they also determine the information content of *future* disclosures through their influence on the design of optimal incentive contracts.[6] Because of this information externality, manipulation of information by individual firms can have long term learning and aggregate investment implications. In particular, the capital allocation distortions introduced by uncertain industry productivity and asymmetric information at the level of the firm can be amplified (rather than diluted) by communications and disclosures from informed insiders.

The model also has the economically appealing result that the equilibrium information manipulation (or content) of disclosures by managers is positively related to the level of agency conflict between the outside investors and the managers. Intuitively, factors that make it costlier for investors' to induce true productivity disclosures, such as high growth potential and private benefits of control and abundant availability of investment capital, raise the level of agency conflict. In the extreme case of a very high level of agency conflict, informative disclosures are too costly and there is no information

[3] It is often observed that investors in the incipient stages of a new industry — e.g., railroads, internet, telecommunications, financial innovations — rely less on hard performance measures, such as earnings or sales, and more on their beliefs regarding the economic prospects of the industry (Gort and Klepper, 1982). In the internet/telecom boom of the late 1990s, most start-up firms that received funding had no earnings or guaranteed sales (Sidak, 2003); and, during the housing boom, investors (including large financial institutions) that purchased *novel* mortgage-based derivatives did not have access to return performance data.

[4] De Meza and Webb (1987) and Martin (2009) show that private information on project productivity results in over-investment in the industry. In contrast, others either predict under-investment because of adverse selection in equity markets (Myers and Majluf, 1984; Greenwald et al., 1984), or capital rationing by debt markets (Stiglitz and Weiss, 1983), or irrelevance of strategic disclosures (Stein, 1989). The incentive contracting literature also typically considers private information on project-specific productivity (Harris and Raviv, 1996; Kumar and Langberg, 2009).

[5] Our model departs from the literature on dynamic renegotiation-proof contracting with hidden information (Dewatripont, 1988; Laffont and Tirole, 1990; Battaglini, 2007) by examining an infinite sequence of agents with randomly varying but correlated types.

[6] As in models of social learning (Bannerjee, 1992; Bikhchandani et al., 1992), individuals in our model face common payoff uncertainty, receive private signals, and sequentially make decisions after observing previous decisions by other informed individuals. But in contrast to these models, our framework allows communication of private information that is governed through renegotiation-proof bilateral contracts whose design depends on the observed history of contracts and their outcomes.

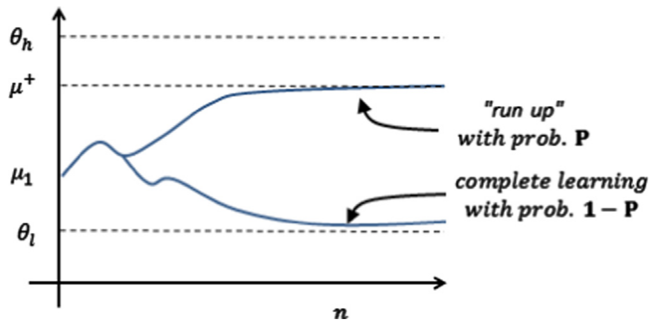

Fig. 1. Two possible learning paths in equilibrium as more firms (n) enter the industry when the true industry or aggregate productivity is low. With positive probability (P) there is a run up in investors' expectations regarding the actual aggregate productivity, while with the remaining probability ($1-P$) investors asymptotically learn the true productivity.

revelation at any stage; incomplete learning and both firm- and industry-level investment distortions are, therefore, assured in the limit. Conversely, inducing truthful reports is incentive efficient when the conflict level is very low and there is efficient information aggregation (complete learning) in the limit.

However, endogenous (or history-dependent) investment booms or busts can arise when the agency conflicts are in the intermediate range because the information content of disclosures depends on beliefs and, in particular, investors' aggregate productivity expectations are positively (negatively) related to equilibrium information manipulation when the agency conflict is relatively high (low). Thus, if the agency conflict is high, then with positive probability there is a Bayes-rational "run up" in investors' aggregate productivity expectations based on inflated project productivity disclosures by the first movers in the industry. But such overly optimistic beliefs endogenously lower the equilibrium information content of subsequent disclosures, leaving investors "stuck" at their "rationally exuberant" levels of expectations even in the limit.[7] To fix ideas, suppose that the unknown aggregate productivity θ can be low (θ_ℓ) or high (θ_h), with prior expectation μ_1. Fig. 1 shows the possible equilibrium learning paths when $\theta=\theta_\ell$, where μ^+ (the threshold level of posterior expectations) and the probability P are determined in equilibrium. Meanwhile, if the agency conflict is relatively low, then a fall in investors' productivity expectations leads to less informative subsequent managerial disclosures. Hence, unexpected low productivity reports can cause sharp and permanent declines in investor expectations and investments.

Our analysis is also related to a literature that examines the effects of Bayesian learning on dynamic investment with symmetric uncertainty on capital productivity. However, these models, such as Rob (1991), Zeira (1999) and Barbarino and Jovanovic (2007) predict either *under-investment* (relative to the efficient levels) or a gradual buildup of investment in which any overcapacity occurs only in the last period. Beaudry and Portier (2004) provide a model of Pigouvian cycles where excess investment can occur because agents randomly receive an incorrect positive signal on productivity growth and respond positively to it (because these signals are usually precise). But there is no structural explanation of what generates such "incorrect" signals and why investors would not learn to discount them over time.

It is noteworthy that overinvestment models based on irrational optimism or rational behavior based on incorrect signals imply that agents should be enthusiastic and optimistic during the investment buildup and there should be no systematic evidence of malfeasance by informed agents. Yet, historically, during investment buildups there has been considerable *contemporaneous* skepticism expressed of the profit projections by insiders and the wisdom of observed high investment flows (Kindleberger, 1978; Shiller, 2005) along with systematic evidence *ex post* of strategic manipulation of market's beliefs. Our model, based on structural uncertainty in emerging industries and the possibility of misreporting by informed insiders, fills this gap and helps explain the historically observed confluence of innovations, misleading disclosures, and industry-wide overcapacity, even though the opportunity to induce information through disclosures appears available to capital markets.

The paper is organized as follows. Section 2 specifies the basic model and Section 3 characterizes equilibrium information manipulation. Section 4 analyzes equilibrium learning and investment dynamics; Section 5 examines asymptotic learning and aggregate investment; Section 6 considers endogenous investment booms and busts; and, Section 7 concludes.[8]

2. The model

Consider an emerging industry built on some technological or financial innovation, where firms enter the industry sequentially and make investments based on their firm-specific (or idiosyncratic) productivity. The production technology, information structure, and contracting assumptions in this industry are specified next.

[7] In this parametric range, investors' dynamically consistent investment response to favorable managerial productivity reports increases with their expectations, which tightens the truth-telling incentive constraints and makes inducing information costlier. Hence, the equilibrium information manipulation by low-productivity managers is positively related to their expectations.

[8] In supplementary materials that are available online, we provide an extension of the basic model and proofs of the results given below.

2.1. Technology and information structure

The firm-specific productivities depend on the underlying but unobservable *industry productivity* that influences the long run economic returns from the innovation. The firm-specific productivities are positively correlated with the industry productivity because firms' economic performance depends on both firm-specific factors (such as, managerial efficiency) and aggregate or industry-level factors (such as, the technical performance of and demand intensity for the innovation).

For parsimony, the industry productivity θ can be either high (θ_h) or low (θ_ℓ) with prior probabilities β_1 and $(1-\beta_1)$, respectively.[9] Firms then enter sequentially at stages $n = 1, 2, \ldots$, and draw their idiosyncratic firm-specific productivity s_n, which can be either high (s_h) or low (s_ℓ) with the probabilities θ and $1-\theta$, respectively. The firms then choose their capital investment levels k_n that stochastically determine the output y_n, which is positively associated with the idiosyncratic productivity and investment. For simplicity, y_n can take the high value of 1 with probability $2s_n\sqrt{k_n}$ and the low value of 0 with the remaining probability.[10] Thus, a higher industry productivity (i.e., θ_h) makes it more likely that the firms' idiosyncratic productivities are also high and conversely when the industry productivity is low.

Firms are characterized by a separation of ownership and control (Berle and Means, 1932). One can imagine each firm being "incorporated" upon entry with its shares traded in a frictionless stock market with risk-neutral investors, but being controlled by a self-interested manager. To focus on the main ideas, it is assumed that firms have no internal capital and managers, therefore, depend on outside investors for financing their desired investment levels. All investors have identical information sets and a common opportunity cost of investment given by the gross return $R > 1$.

There is an agency conflict between managers and outside investors because managers have private information on the firm-specific productivity and because they derive non-pecuniary benefits from controlling larger assets. The managers can communicate with the outside investors regarding their privately observed productivity (i.e., each manager makes a report $r_n \in \{s_\ell, s_h\}$). But because of the said agency conflict managers have an incentive to misreport or inflate the firm's idiosyncratic productivity to induce higher investments from the outside investors; these investors, however, can give incentives for more accurate communications by making their investments contingent on the reports and any other relevant available information.

Based on the motivations given above, and for notational parsimony, it will be mostly assumed that investors do not have access to reliable or informative performance indicators at the time of their financing decision. Specifically, for any firm n (i.e., firm that entered at stage n) the observable history for outside investors at $n \geq 2$ is the profile $\phi_n^c = (c_1, \ldots c_{n-1})$ where $c_n = (r_n, k_n)$ (and ϕ_1 is an empty set). And, without loss of generality, it is assumed that firms enter the industry sequentially between $t=0$ and $t=1$ and the outputs for all the firms are realized and observed simultaneously at $t=1$; firms are liquidated thereafter. However, the main results regarding the distortions in investment efficiency along the equilibrium path derived below will hold even if investors can observe the outputs of previously entered firms (see Section 6).

2.2. Contracting

All managers are risk-averse with identical attitudes toward risk that are represented by the (CRRA) expected utility function $u(w) = w^{1/\gamma}, \gamma > 1$, and the monetary value of the private benefits of control is given by $b(k_n) = \psi\sqrt{k_n}, \psi > 0$.[11] For notational ease, we suppress the manager's subjective rate of discount for future consumption; therefore, the expected utility of manager n is $U(w_n, k_n) = \mathbb{E}(w_n^{1/\gamma}) + \psi\sqrt{k_n}$. Managers have no initial wealth and enjoy limited liability (hence, wages must be non-negative), and their reservation utilities are normalized to zero, without loss of generality.[12] Since all investors are risk-neutral with identical information sets, it is convenient to designate a representative owner for entering firms (say, X_n for firm n) who designs incentive contracts to induce information (on the firm's idiosyncratic productivity) from the manager (M_n).

In general, a contract $\mathbf{C}_n = (\pi_n, \mathbf{w}_n, \mathbf{k}_n)$ specifies (i) a possibly noisy or randomized reporting policy π_n for the manager, contingent on its productivity (or "type"); (ii) a wage policy $\mathbf{w}_n$ that determines the manager's compensation as a function of the report (r_n) and the output (y_n); and, (iii) an investment policy $\mathbf{k}_n$ that determines the level of investment contingent on the manager's reported productivity. The owner's residual payoffs at the time of liquidation, given an investment k_n, output y_n, and wage w_n are

$$v(w_n, k_n, y_n) = y_n - w_n - Rk_n \tag{1}$$

π_n^{jr} denotes the probability that M_n reports $r_n = r$ when the firm's actual type is j, for $j, r = \ell, h$. And conditional on the report r, k_n^r is the owner's investment response, while $w_n^{r,+}$ (or $w_n^{r,0}$) is the manager's wage compensation when output y_n is positive (or zero).

[9] Our main results are most easily exposited by assuming that θ can take only two values. However, the results will qualitatively hold for more general distributions of θ and these details are available upon request.

[10] To ensure that the probability of high output remains bounded above by 1, it is assumed that $1 > s_h > s_\ell$, and the maximal investment is set at $k^{\max} = (2s_h)^{-1}$.

[11] Such benefit functions have a special relevance in the financial services industry, where managers' compensation typically includes a component that is proportional to the (asset) size of the fund. While this parameterization of $b(k)$ is useful for tractability, our results will apply for any benefits function $b(\cdot)$ that is increasing in the asset size of the firm.

[12] Our results do not rely on each manager having a zero reservation utility, but require that the managers earn information-based rents in equilibrium. It is assumed that managers do not trade in the equity market.

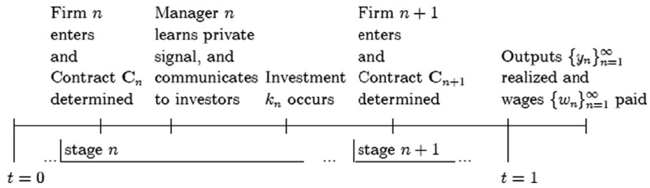

Fig. 2. The sequence of events in the model.

2.3. The market for control and renegotiation

In practice, there is often an asymmetry in shareholders' ability to commit to managerial compensation versus committing to arbitrary investment policies. From an institutional perspective, shareholders delegate the responsibility of wage contracting (with management) to the board of directors. These employment contracts are enforceable in the sense that managers can move the courts to enforce prior wage contracts even though the ownership of the firm changes.[13] In contrast, credible pre-commitment to investment policies is limited by the possibility of a change in control of the firm ex post through a takeover. Because investment at any given time is legally the domain of the *current* capital owners, the new owners can choose any desirable (and feasible) investment level. In particular, investment levels that are inefficient ex post are not viable in the presence of a frictionless market for corporate control (Kumar and Langberg, 2009).

Therefore, investment policies will be required to be *renegotiation-proof* (see Bolton and Dewatripont, 2005): A contract is renegotiation-proof if and only if an outside investor cannot benefit from gaining control of the firm and changing investment. That is, any admissible investment policies must be such that for each firm n, conditional on the public information (ϕ_n^c, c_n), there is no profitable opportunity in revising the investment k_n by effecting a change of ownership.

It is noteworthy that relaxing the assumption of commitment on wages will only reinforce our results regarding pooling and incomplete learning. This is because commitment facilitates truth-telling. In particular, if there is commitment on wages, then low-productivity managers can be induced to reveal their true state in equilibrium by promising them wages that give them the same expected utility as they would obtain from pooling with high productivity managers (and drawing in a larger investment). However, if managers doubt *ex ante* the investors' commitment to such incentive wages, then the equilibrium information manipulation will tend to be higher.[14] The timing conventions of the model are summarized in Fig. 2.

2.4. Equilibrium

Our set-up confronts a contracting problem with adverse selection but when the principal has limited commitment (with respect to the investment response). It is well-known that the revelation principle fails to hold in such a setting and one cannot restrict attention in general to truth-telling contracts (see e.g., Bester and Strausz, 2007). The Perfect Bayesian Equilibrium (PBE) solution concept (e.g., Fudenberg and Tirole, 1991) will, therefore, be used to characterize the sequence of managerial communications and investment decisions. A PBE will require that contracts and managerial reporting strategies are sequentially rational, and that players use Bayes rule whenever possible to update their beliefs on θ based on the equilibrium reporting strategies of managers.[15]

Notice that while firm owners incur the costs of eliciting reports, they cannot extract any rents from the future firms from this information. Thus, given any history ϕ_n, when the posterior expectations of θ are $\mu_n = \mu_n(\phi_n)$, the sequentially rational contract is the optimal *stage contract* that maximizes the expected net output $v(w_n, k_n, y_n)$ (cf. (1))

$$\max_{\mathbf{C}_n = (\pi_n, \mathbf{w}_n, \mathbf{k}_n)} \mathbb{E}(y_n - w_n - Rk_n | \mu_n) \tag{2}$$

subject to the constraints that (1) the investment k_n^r is *ex post* efficient given the posterior beliefs of the owners based on the manager's report (r_n):

$$k_n^r \in \arg\max_k \mathbb{E}(y_n - w_n - Rk | \mu_n, r_n = r, k_n = k) \quad \text{for } r = \ell, h \tag{3}$$

[13] Indeed, there is much evidence that, in the event of job termination from change of control, executives are able to successfully enforce their wage contracts, including the payment of deferred bonuses and severance payments (Murray, 2006; Lublin and Thurm, 2006). In fact, executives are often able to enforce their bonus compensation contracts even when their firms are in financial distress; this became a major issue in the case of CitiBank and AIG during the recent financial crisis, for example.

[14] More generally, note that any allocation that is achievable with dynamically consistent wage policies can be replicated with wage commitment by following the same policies. Indeed, the revelation principle requires complete precommitment from the contract designer regarding the agent's payoffs from truthful reports (Myerson, 1979; Laffont and Tirole, 1988, 1990) and renegotiation-proofness constraints typically reduce the set of feasible allocations (Bolton and Dewatripont, 2005).

[15] As will be seen below in Section 4, there is a dynamic informational externality along the equilibrium path because informational manipulation at any stage influences the information content of disclosures in the future.

(2) the manager's reporting strategy π_n^{jh} is incentive compatible for, $j=\ell,h$:

$$\pi_n^{jh} \in \arg\max_{\pi\in[0,1]} \{\pi\mathbb{E}(U(w_n,k_n)|\mu_n,s_n=s_j,r_n=h)+(1-\pi)\mathbb{E}(U(w_n,k_n)|\mu_n,s_n=s_j,r_n=\ell)\} \tag{4}$$

and (3) managerial compensation is non-negative. It will be convenient to write the optimal contract in stage n as $\mathbf{C}_n(\mu_n)$.

2.5. Information manipulation and the agency conflict

Intuition suggests that the information manipulation tolerated in equilibrium will be positively related to the *intensity* of the agency conflict between managers and outside investors: More intense agency conflicts tighten the incentive constraints and hence increase the expected wage costs of inducing truthful reporting, and the optimal contract responds by tolerating greater noise in the reports. It is, therefore, useful to formulate the intensity of the agency conflict in terms of the costs and benefits to investors of eliciting the true firm-specific productivity; understanding the main determinants of these costs and benefits which will facilitate intuition for our analysis below.

Clearly, the information elicitation costs will be increasing with the manager's private benefits of control (ψ), and they will be increasing with the productivity gap (s_h-s_ℓ), which raises the incentives for inflating productivity reports. Meanwhile, the benefit of eliciting productivity information increases with the investment *inefficiency* from information manipulation, which is positively related to the productivity gap (s_h-s_ℓ), but is decreasing in the cost of capital (R) because ceteris paribus investment levels are negatively related to the discount rate. In sum, while the effects of ψ and R on the intensity of the agency conflict are unambiguous, the effects of the productivity gap are ambiguous.

3. Information manipulation in the stage contract

The bench-mark case where investors can perfectly pre-commit to investment policies is analyzed first. This analysis sharpens intuition on the effects of the commitment constraints on investment.

3.1. Perfect commitment benchmark

When owners can credibly pre-commit to both wage and investment policies, the revelation principle applies and one can restrict attention to direct mechanisms where the truth-telling is optimal. While the perfect commitment case has been analyzed by Harris and Raviv (1996) and Kumar and Langberg (2009), their main insights are summarized below in Proposition 1.

Let us denote the optimal stage contracts with complete information and with incomplete information but perfect commitment by $\mathbf{C}_n^*$ and $\hat{C}_n$, respectively. The complete information optimal investment levels are $k_j^*=s_j/R^2$, $j=\ell,h$, and the managers receive zero wages. But these investment levels are not incentive compatible at zero wages when managers are privately informed of their firm-specific productivity. To induce truthful reporting, the low productivity managers have to be provided incentive wages. The incentive-efficient stage contract, therefore, reduces the investment gap ($\hat{k}_h-\hat{k}_\ell$) to lower the incentive wage costs for the low-productivity managers. And, to relax the incentive compatibility constraints for the low-productivity managers, the optimal contract sets zero wages for high-productivity reports.

Proposition 1. *If owners can perfectly precommit to wage and investment policies, then the optimal stage contract for firm n,* $\hat{C}_n=\{\hat{w}_n^{r,+},\hat{w}_n^{r,0},\hat{k}_n^r\}_{r=\ell}^h$ *satisfies*

$$\hat{w}_n^{h,+}=\hat{w}_n^{h,0}=0 \quad \text{and} \quad \hat{w}_n^{\ell,+}=\hat{w}_n^{\ell,0}=\psi\left(\sqrt{\hat{k}_n^h}-\sqrt{\hat{k}_n^\ell}\right).$$

Moreover, relative to the complete information efficient investment levels, there is over- (under-)investment in the low (high) productivity firms, i.e., $k_\ell^*<\hat{k}_\ell<\hat{k}_h<k_h^*$.

Note that in this benchmark case, where there are no commitment restrictions, because of managerial risk aversion, the incentive efficient wage contract for both productivity type managers is not contingent on output.

3.2. Renegotiation-proof investment policies

For expositional ease, it is convenient to focus on *over-reporting* optimal contracts where wages are not output contingent, i.e., $w_n^{r,+}=w_n^{r,0}=w_n^r$, $\{\ell,h\}$[16]; the low-type managers may over-report their firm's productivity, i.e., $0\le\pi_n^{\ell h}\le 1$; and

[16] It is shown in the online supplementary material that more general wage contracts do not eliminate the possibility of pooling equilibria and incomplete learning in the limit. Alternatively, one could assume that investors could not commit to anything expect the spot wage, e.g., since wages are paid at the time of the report whereas investment takes time.

the high-type managers always report truthfully, i.e., $\pi_n^{h\ell}=0$.[17] Three outcomes are feasible in such over-reporting contracts: *truth-telling* when $\pi_n^{\ell h}=0$; *pooling* when $\pi_n^{\ell h}=1$; and *noisy revelation* (or over-reporting) when $0<\pi_n^{\ell h}<1$. The low-productivity managers' over-reporting probability $\pi_n^{\ell h}$ therefore represents the (extent of) information manipulation in our model.

In our model a single variable, which is a function of the primitive parameters of the model, can summarize the various channels for the intensity of the agency conflict discussed in Section 2.5

$$\upsilon \equiv \frac{\psi^{\gamma}(s_h - s_\ell)^{\gamma-2}}{R^{\gamma-1}}. \tag{5}$$

Note that υ is increasing with the managers' private benefits of control ψ but decreasing with the cost of capital R (since $\gamma>1$). However, consistent with the foregoing discussion, the relation of υ to the productivity gap (s_h-s_ℓ) is ambiguous. But (5) clarifies that the resolution of the conflicting effects of the productivity gap on the agency conflict depends on the risk aversion parameter (γ).[18] If $\gamma>2$, then υ increases in (s_h-s_ℓ), but it decreases in the productivity gap if $1<\gamma<2$. Intuitively, when managers are more risk averse (i.e., γ is relatively high), then the expected wage costs of inducing more informative reports rise faster with the productivity gap compared with the investment efficiency gains.

The next proposition clarifies the monotone relation between υ and the equilibrium information manipulation in the optimal stage contracts. In particular, inducing truth-telling from the low-type manager is optimal when υ is sufficiently low; pooling is optimal when υ is sufficiently high; and, noisy revelation is optimal when υ is in an intermediate range. Let $\underline{\upsilon}(\mu_n)\equiv\mu_n/(\mu_n+\gamma(1-\mu_n))<\overline{\upsilon}(\mu_n)\equiv\mu_n^{2-\gamma}$. Then,

Proposition 2. *Pooling is optimal if the agency conflict is sufficiently severe, i.e.,* $\upsilon>\overline{\upsilon}(\mu_n)$, *while truth-telling is optimal if this conflict is sufficiently low, i.e.,* $\upsilon<\underline{\upsilon}(\mu_n)$. *For intermediate levels of* υ, *i.e.,* $\underline{\upsilon}(\mu_n)\le\upsilon\le\overline{\upsilon}(\mu_n)$, *over-reporting with positive probability is optimal and the information manipulation* $(\pi_n^{\ell h})$ *is increasing in* υ.

Proposition 2 indicates that the equilibrium information manipulation at any stage depends generally on both the intrinsic agency conflict (υ) and the (history-dependent) industry productivity expectations of outside investors (μ_n). However, if the agency conflict is sufficiently extreme, then the optimal contract induces pooling or truth-telling *independent* of investors' beliefs. To see this, define the extreme agency conflict thresholds $\upsilon_P\equiv\max(\theta_h^{2-\gamma},\theta_\ell^{2-\gamma})$ and $\upsilon_T\equiv\theta_\ell/(\theta_\ell+\gamma(1-\theta_\ell))$. Because investors' expectations μ_n must lie between the low and high (productivity) values, i.e., $\theta_\ell\le\mu_n\le\theta_h$, $\overline{\upsilon}(\mu_n)$ is bounded from above by υ_P and $\underline{\upsilon}(\mu_n)$ is bounded from below by υ_T. Thus, if $\upsilon>\upsilon_P$, then pooling is optimal regardless of μ_n; and, similarly, truth-telling is always optimal if $\upsilon<\upsilon_T$. Finally, there is an intermediate agency conflict threshold $\upsilon_N\equiv\min(\theta_h^{2-\gamma},\theta_\ell^{2-\gamma})$ such that reports are at least partially informative (i.e., $\pi_n^{\ell h}<1$) for all μ_n if $\upsilon\le\upsilon_N$.

Fig. 3 graphically depicts the regions in which the optimal stage n contract induces truth-telling (or perfect revelation), noisy revelation, and pooling, as a function of expectations μ_n, the severity of the agency conflict υ, and managerial risk aversion γ.

4. Learning and investment dynamics

The information content of managerial disclosures determines the learning process of outside investors regarding the unknown aggregate productivity. In the extreme case, if there is pooling everywhere along the equilibrium path (i.e., $\pi_n^{\ell h}=1$), then there is no learning and expectations in the limit are just the prior expectations (μ_1) because investors never receive a low productivity report from any firm. More generally, starting with the prior expectation $\mu_1=\beta_1(\theta_h-\theta_\ell)+\theta_\ell$, the evolution of the posterior expectation μ_n can be recursively computed using Bayes' rule. Given μ_n and the report r_n, investors' updated productivity expectation $\mu_{n+1}=\mathbb{E}(\theta|\mu_n,r_n)$ is

$$\mu_{n+1}=\begin{cases}\dfrac{\sigma_n(1-\pi_n^{\ell h})+\mu_n\pi_n^{\ell h}}{\mu_n(1-\pi_n^{\ell h})+\pi_n^{\ell h}} & \text{for } r_n=h\\[2ex] \dfrac{\mu_n-\sigma_n}{1-\mu_n} & \text{for } r_n=\ell\end{cases} \tag{6}$$

where $\sigma_n\equiv\mathbb{E}(\theta^2|\phi_n)=(\mu_n-\theta_\ell)\theta_h+\mu_n\theta_\ell$. (Note that, by the definition of σ_n and μ_n, $\mathrm{Var}_n(\theta|\phi_n)=(\sigma_n-\mu_n^2.)$[19]

In turn, investors' beliefs have a direct effect on their investment in firms because the equilibrium investments $k_j(\mu_n)$, conditional on the belief μ_n and the report $r_n=j, j=h,\ell$, are (see Eq. (3))

$$k_h(\mu_n)=\left(\frac{\mu_n s_h+(1-\mu_n)\pi_{\ell h}(\mu_n)s_\ell}{R(\mu_n+(1-\mu_n)\pi_{\ell h}(\mu_n))}\right)^2>\left(\frac{s_\ell}{R}\right)^2=k_\ell(\mu_n). \tag{7}$$

[17] Kumar and Langberg (2009) provide sufficient conditions for the optimality of this approach in a one-shot version of the model—see also Laffont and Tirole (1990) and Bester and Strausz (2007) for a similar result.

[18] Note that the coefficient of relative risk aversion is $(\gamma-1)/\gamma$, which is increasing in γ.

[19] Note that, $\Pr(\theta=\theta_h|\mu_n,r_n=i)=\Pr(\theta=\theta_h,r_n=i|\mu_n)/\Pr(r_n=i|\mu_n)$, for $i=\ell,h$, $\Pr(\theta=\theta_h,r_n=h|\mu_n)=((\mu_n-\theta_\ell)/(\theta_h-\theta_\ell))(\theta_h+(1-\theta_h)\pi_n^{\ell h})$, and $\Pr(\theta=\theta_h,r_n=\ell|\mu_n)=((\mu_n-\theta_\ell)/(\theta_h-\theta_\ell))(1-\theta_h)(1-\pi_n^{\ell h})$.

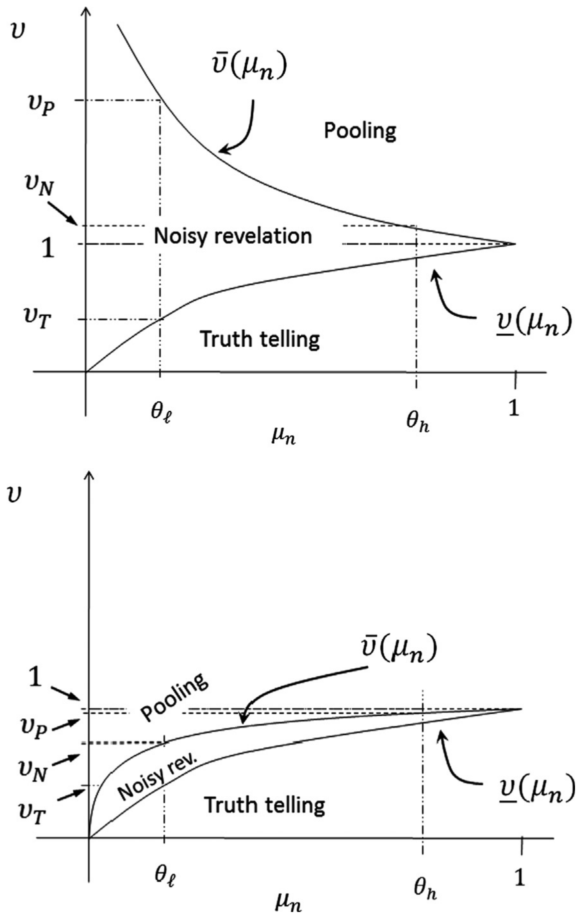

Fig. 3. Graphical depiction of the regions in which the optimal stage n contract induces truth-telling (or perfect revelation), noisy revelation, and pooling, as a function of expectations μ_n, the severity of the agency conflict $υ$, and managerial risk aversion γ. (Top) For the case $\gamma > 2$ and (Bottom) For the case $\gamma \in (1, 2)$.

Note that the expected investment of the firm at stage n, say $k(\mu_n)$, is increasing in beliefs μ_n.[20] Information manipulation at any stage, therefore, has *intertemporal* implications because *ceteris paribus* it raises investors' productivity expectations in the future and influences the low-type manager's equilibrium reporting strategy.

Meanwhile, the *aggregate* investment at stage n is the sum of the investment levels of all entering firms: conditional on the sequence of equilibrium reports $(r_{1,\ldots,}r_n)$ and corresponding expectations $(\mu_{1,\ldots,}\mu_n)$, the *aggregate* investment at stage n is $K_n^A \equiv \sum_{i=1}^n k_{r_i}(\mu_i)$. Thus, inflated reporting by managers with low idiosyncratic productivity not only induces over-investment in their firms but also induces aggregate investment distortions in the future because of the dynamic informational externality. However, these intertemporal effects of firm-specific disclosures arise only because of structural uncertainty regarding the aggregate productivity (θ). If θ is common knowledge, then the optimal contracts are not history dependent and the equilibrium reporting strategies and the investment levels are $\pi_{\ell h}(\theta)$ and $k_j(\theta)$, $j=h$, ℓ. Hence, for analyzing aggregate investment distortions, the proper benchmark is the case where the aggregate productivity is common knowledge but managers are still privately informed of their idiosyncratic (or firm-specific) productivity — the situation typically considered by the literature on asymmetric information and investment.

More precisely, the aggregate investment in the benchmark at stage n is $K_n^{A-BM} \equiv \sum_{i=1}^n k_{r_i}(\theta)$. A comparison of K_n^A with K_n^{A-BM} thus contrasts aggregate investment distortions in the incipient phases of a new industry with structural uncertainty regarding the underlying industry (or aggregate) productivity with investment paths in more mature industries, where the aggregate structural uncertainty has been essentially resolved, and outside investors are uncertain only about the idiosyncratic project-specific productivities.[21] However, because industry capacity with an arbitrarily large number of firms is infinite, the natural comparison is between the levels of aggregate investments with and without structural uncertainty.

[20] Formally, $k(\mu_n) \equiv [\mu_n + (1-\mu_n)\pi_{\ell h}(\mu_n)]k_h(\mu_n) + (1-\mu_n)(1-\pi_{\ell h}(\mu_n))k_\ell(\mu_n)$.

[21] Note that there will still be investment distortion in the benchmark case relative to the *complete information* efficient investment levels.

That is, conditional on $\theta \in \{\theta_\ell, \theta_h\}$, the *aggregate investment distortion* at stage n is the ratio $d_n(\theta) \equiv K_n^A / K_n^{A-BM}$, and there is *aggregate over* (*under*)-*investment* at stage n if $d_n(\theta) > 1$ ($d_n(\theta) < 1$).

5. Asymptotic learning and aggregate investment

There is an intuition that if there is "sufficient" information content in each manager's communication, then investors will eventually learn the true industry productivity despite the strategic noise in managerial reports because of the Law of Large Numbers. But if there are some equilibrium paths where the optimal contract induces pooling so that managers' reports are completely uninformative, then investors may never learn the true industry productivity. This intuition is made precise in the following result, building on the fact that conditional beliefs obeying Bayes' law are martingales, and applying the Martingale Convergence Theorem (e.g., Billingsley, 1979).

Theorem 3. *There exist random variables $\overline{\mu}$ and $\overline{\sigma}$ such that, with probability 1, $\mu_n \to \overline{\mu}$ and $\sigma_n \to \overline{\sigma}$ along any equilibrium path. Moreover,*

$$[\overline{\sigma} - \overline{\mu}^2][1 - \pi_{\ell h}(\overline{\mu})] = 0 \quad a.s. \tag{8}$$

where, $\pi_{\ell h}(\overline{\mu}) = \lim_{n \to \infty} \pi_n^{\ell h}(\mu_n)$.

Since $\mathrm{Var}_n(\theta | \phi_n) = \sigma_n - \mu_n^2$, Theorem 3 indicates that in the limit the aggregate uncertainty converges to $(\overline{\sigma} - \overline{\mu}^2)$. And (8) implies that if managers' communications are informative in the limit ($\pi_{\ell h}(\overline{\mu}) < 1$), then investors' productivity expectations are asymptotically consistent, i.e., $\mathrm{Var}_n(\theta | \phi_n) \to 0$, and there is *complete* learning (a là Aghion et al., 1991). But *if* pooling is approached in the limit ($\pi_{\ell h}(\overline{\mu}) = 1$), then learning is *incomplete*, and aggregate uncertainty is not resolved even when an infinite number of reports from informed insiders are transmitted to the capital markets because $\mathrm{Var}_n(\theta | \phi_n) \to (\theta_h - \overline{\mu})(\overline{\mu} - \theta_\ell) > 0$.

Consider, next, the properties of the aggregate investment distortion in the limit. There is aggregate over (under)-investment at the limit if $d(\theta) > 1$ ($d(\theta) < 1$) where $d(\theta) \equiv \lim_{n \to \infty} d_n(\theta)$ (cf. Section 4). In the limit, as the number of entering firms gets large, investors' beliefs on the industry productivity converge (cf. Theorem 1) and consequently the expected firm-level investment also converges to $\lim_{n \to \infty} k(\mu_n) \equiv k(\overline{\mu})$.[22] It follows that, for a given $\theta \in \{\theta_\ell, \theta_h\}$, the *average* firm-level investments also converge, namely, $\lim_{n \to \infty} (1/n) K_n^A = k(\overline{\mu})$ and $\lim_{n \to \infty} (1/n) K_n^{A-BM} = k(\theta)$.[23] The learning and aggregate investment distortions in the limit are directly linked: there is an aggregate investment distortion in the limit with incomplete learning because aggregate investment with unknown aggregate productivity can only converge to the benchmark if investors learn the true state in the limit.

Theorem 4. *The aggregate investment distortion at the limit is $d(\theta) = k(\overline{\mu}) / k(\theta)$ for $\theta \in \{\theta_\ell, \theta_h\}$. Hence, if there is incomplete learning, then there is also an aggregate investment distortion at the limit (because $d(\theta) \neq 1$).*

5.1. *Aggregate investment distortions with extreme levels of agency conflict*

In general, the relationship between the equilibrium information content of reports and υ is *history-dependent*, i.e., depends on the posterior beliefs of the outside investors μ_n (cf. Proposition 2). A key issue is whether pooling can become optimal along the equilibrium path. Recall that reports are completely uninformative, independent of the history of beliefs, when the agency conflict is sufficiently high ($\upsilon > \upsilon_P$), but reports are at least marginally informative when the agency conflict is sufficiently low ($\upsilon \leq \upsilon_N$). Note that if reports are uninformative at any n, then there is no further information received, i.e., $\mu_{n+i} = \mu_n$, $i \geq 1$, by forward induction.

Proposition 5. *The relation between the extreme levels of agency conflict and the aggregate investment distortion at the limit is as follows*:

1. *For $\upsilon \leq \upsilon_N$, there is complete learning and hence no aggregate investment distortion at the limit (i.e., $\overline{\mu} = \theta$ and $d(\theta) = k(\overline{\mu}) / k(\theta) = 1$).*
2. *But for $\upsilon > \upsilon_P$, there is incomplete learning and aggregate investment distortion at the limit (i.e., $\overline{\mu} = \mu_1$ and $d(\theta) = k(\mu_1) / k(\theta) \neq 1$). In particular, there is aggregate over-investment in low productivity state (i.e., $d(\theta_\ell) = k(\mu_1) / k(\theta_\ell) > 1$) but aggregate under-investment in the high productivity state (i.e., $d(\theta_h) = k(\mu_1) / k(\theta_h) < 1$).*

Fig. 4 presents simulated learning paths when the actual industry productivity is low ($\theta = \theta_\ell$) and truth telling is optimal ($\upsilon = 0.13 < \upsilon_T$; corresponding to case 1 in Proposition 5). When beliefs converge to the true state, the process β_n (the posterior beliefs that the true productivity is high) approaches zero. Because reports are truthful here, aggregate uncertainty is alleviated rapidly. In Path 1, beliefs seem to converge to the true state after 10 firms enter the industry, while in Path 2

[22] Given the continuity of the expected investment function $k(\mu_n)$, it follows that $\lim_{n \to \infty} k(\mu_n) = k(\lim_{n \to \infty} \mu_n) \equiv k(\overline{\mu})$. The continuity of $k(\mu_n)$ follows from (7) and the continuity of the reporting strategy $\pi_{\ell h}(\mu_n)$ (cf. Proposition 2).

[23] Note that if θ is known, then in any given period the expected firm-level investment is $k(\theta)$ by definition.

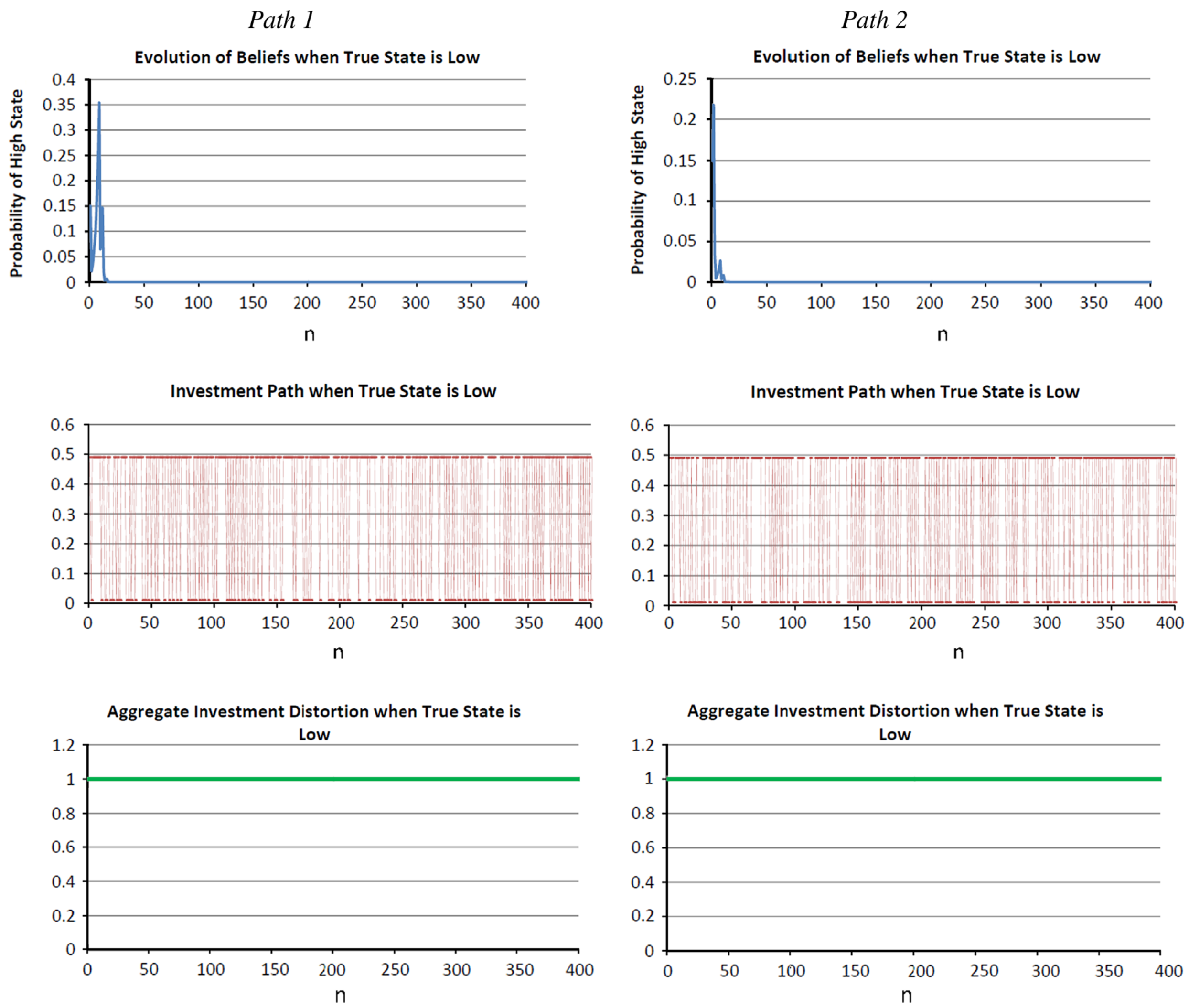

Fig. 4. Simulation of two random paths when the true aggregate productivity is low. The top graphs depict the evolution of beliefs; the middle graphs depict the firm-level investments; and the bottom graphs depict the ratio of aggregate investment with unknown and known θ. The parameters are ($\theta_l = 0.6$, $\theta_h = 0.95$, $s_l = 0.1$, $sh = 0.7$, $\Psi = 0.6$, $R = 1$, $\gamma = 3$), where $\upsilon = 0.13$, and the probability of a run up in expectation is 0%.

they do so after 15 firms have entered.[24] Consequently, firm-level investment $k_{r_n}(\mu_n)$ is efficient and there is no aggregate investment distortion. Fig. 5 presents two simulated paths for somewhat higher levels of agency conflict i.e., $\upsilon = 0.8 \in (\upsilon_T, \upsilon_N)$, while keeping the true industry productivity low. Because there is noisy revelation here, learning appears to be delayed (relative to Fig. 4). The investment processes here highlight the effects of structural uncertainty on *aggregate* productivity for *firm-level* investments: note that spikes in investors' beliefs regarding high industry productivity — following high managerial reports — positively influence firm-level investment. Consequently, there are aggregate investment distortions in the initial stages. However, after investors learn the true state the aggregate investment comparison ratio settles at 1.

Proposition 5 does not provide much insight on how investment booms and busts can endogenously emerge in equilibrium as firms enter the industry. This is considered in the next section where the asymptotic learning and aggregate investment outcomes are history-dependent and stochastic.

6. Endogenous investment booms and busts

Consider now the equilibrium information manipulation for intermediate levels of agency conflict ($\upsilon_N < \upsilon < \upsilon_P$). Recall that pooling is optimal if $\upsilon > \overline{\upsilon}(\mu_n) \equiv \mu_n^{2-\gamma}$ (see Proposition 2) or if $\upsilon \mu_n^{\gamma-2} > 1$. Intuitively, raising μ_n has two conflicting effects on the

[24] The simulated benchmark model is based on the same realizations of firm specific productivities $(s_1, \ldots, s_{400})$ as the model with structural uncertainty. The reporting strategies in both models are generated via a sequence $(x_1 \ldots, x_{400})$ where x_i is i.i.d distributed $U[0,1]$: at any stage n there is over reporting if $s_n = s_\ell$ and $x_n < \pi_{\ell h}(\mu_n)$ or in the benchmark case if $x_n < \pi_{\ell h}(\theta_\ell)$.

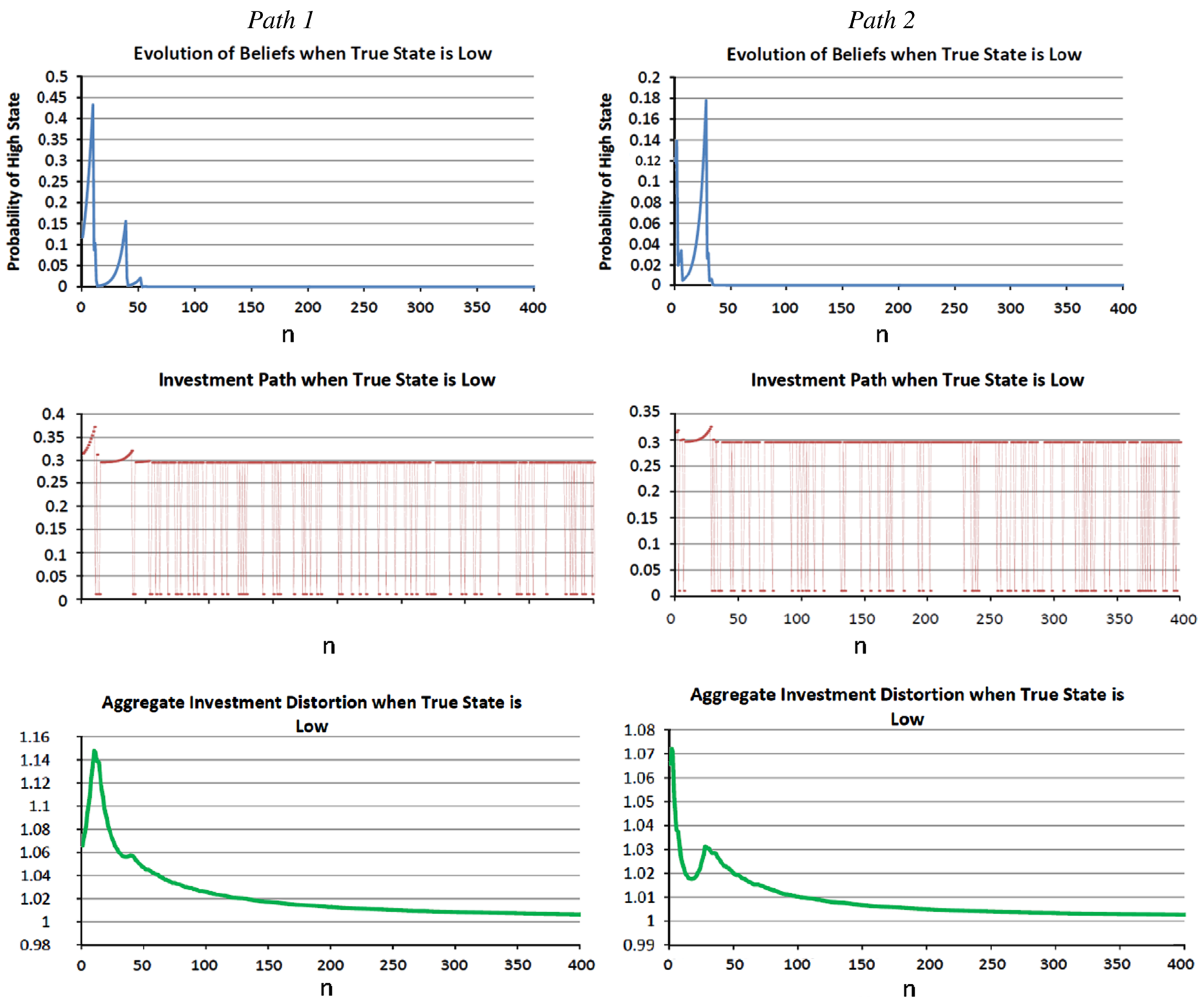

Fig. 5. Simulation of two random paths when the true aggregate productivity is low. The top graphs depict the evolution of beliefs; the middle graphs depict the firm-level investments; and the bottom graphs depict the ratio of aggregate investment with unknown and known θ. The parameters are ($\theta_l = 0.6$, $\theta_h = 0.95$, $s_l = 0.1$, $sh = 0.7$, $\Psi = 1.1$, $R = 1$, $\gamma = 3$), where $\upsilon = 0.8$, and the probability of a run up in expectation is 0%.

optimal information manipulation. More optimistic beliefs raise the investment response to favorable productivity reports, tighten the truth-telling incentive constraints, and raise the costs of eliciting information. But raising μ_n also increases the likelihood that the aggregate productivity is high, thereby reducing the expected wage costs. The former effect is more important when the information manipulation is high. Meanwhile, the information costs are also higher ceteris paribus for more risk tolerant managers. Therefore, for high levels of agency conflict ($\upsilon > 1$) pooling is always optimal for low managerial risk aversion ($1 < \gamma < 2$) and equilibrium information manipulation is increasing with μ_n otherwise ($\gamma > 2$). Conversely, for low levels of agency conflict ($\upsilon < 1$), pooling becomes optimal only when beliefs are sufficiently pessimistic and managers have low risk aversion.

It is thus useful to explore the cases of high agency conflict ($\upsilon > 1$) and low agency conflict ($\upsilon < 1$) separately. It will turn out that in both cases pooling can emerge endogenously leading to persistent aggregate investment distortions even at the limit. In particular, there can be an endogenous run-up in expectations leading to aggregate over-investment or an endogenous fall in productivity expectations leading to aggregate under-investment.

6.1. High levels of agency conflict

Consider first the case where the agency conflict is intermediate but relatively high, i.e., $1 < \upsilon_N < \upsilon < \upsilon_P$. The critical level of expectations where $\upsilon \mu_n^{\gamma-2} = 1$, namely, $\mu^+ \equiv \upsilon^{(1/2-\gamma)}$ will play an important role in the analysis.[25] In this case, pooling is optimal when beliefs are sufficiently optimistic, i.e., $\mu_n \geq \mu^+$. But investors' *pessimism* at the outset (i.e., $\mu_1 < \mu^+$)

[25] Note that in the interval of interest $\upsilon_N < \upsilon < \upsilon_P$ the critical value μ^+ is feasible in equilibrium (i.e., $\mu^+ \in (\theta_\ell, \theta_h)$).

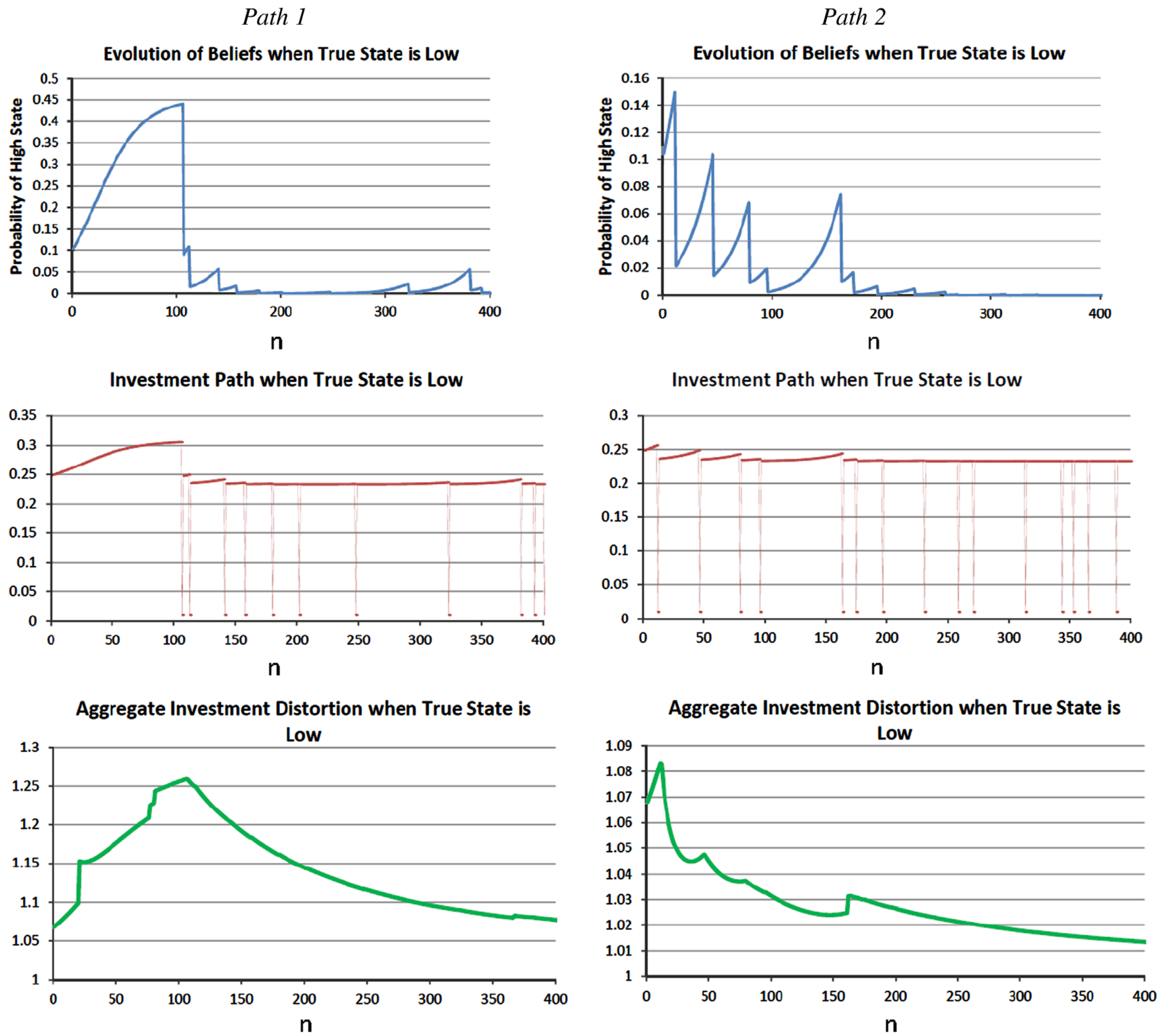

Fig. 6. Simulation of two random paths when the true aggregate productivity is low. The top graphs depict the evolution of beliefs; the middle graphs depict the firm-level investments; and the bottom graphs depict the ratio of aggregate investment with unknown and known θ. The parameters are ($\theta_l = 0.6$, $\theta_h = 0.95$, $s_l = 0.1$, $sh = 0.7$, $\Psi = 1.3$, $R = 1$, $\gamma = 3$), where $\upsilon = 1.33$, and the probability of a run up in expectation is 13.4%.

does not guarantee complete learning because they may *become* sufficiently optimistic following a sequence of favorable productivity reports. Intuitively, when $\theta = \theta_h$, there is a greater likelihood of high productivity realizations at the firm level. But as beliefs become more optimistic following a sequence of high productivity reports, the equilibrium information content of subsequent reports progressively weakens.[26] Therefore, learning will be incomplete when the industry productivity is high because expectations will eventually rise to the upper bound $\overline{\mu} = \mu^+$ and not proceed further to the true state.

Now suppose that the true industry productivity is low (i.e., $\theta = \theta_\ell$). In this case, the limiting learning outcomes are much richer and stochastic: Beliefs can either converge to the true state ($\overline{\mu} = \theta_\ell$), or diverge to the upper bound $\overline{\mu} = \mu^+$; i.e., there is a *run-up* in expectations with a probability that depends on the prior expectations μ_1.

Theorem 6. *Suppose that the agency conflict is intermediate but relatively high* (*i.e.*, $1 < \upsilon_N < \upsilon < \upsilon_P$) *and investors' prior beliefs are* $\mu_1 < \mu^+$:

1. *If the industry productivity is high,* $\theta = \theta_h$, *then there is incomplete learning and aggregate under-investment in the limit, i.e.,* $\mu_n \to \mu^+$ *and* $d(\theta_h) = k(\mu^+)/k(\theta_h) < 1$.

[26] Intuitively, along the equilibrium path the posterior expectations are monotonic in their priors: at any stage n, for any report r_n, the posterior expectation μ_{n+1} is increasing in the prior expectation μ_n. Since, managerial reports are completely uninformative at the cutoff level μ^+, it serves also as an upper bound to beliefs when priors satisfy $\mu_1 < \mu^+$.

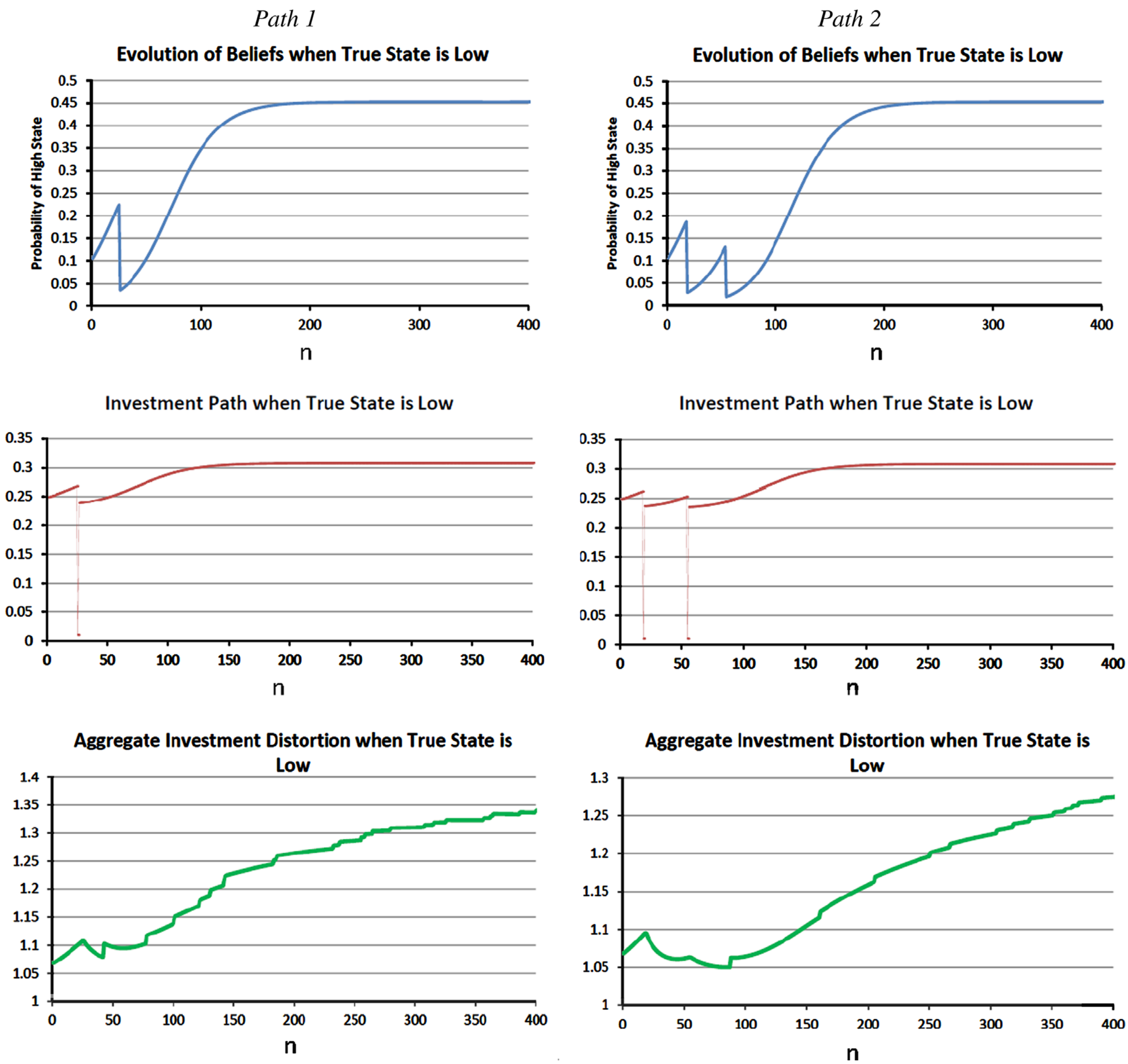

Fig. 7. Simulation of two random paths when the true aggregate productivity is low. The top graphs depict the evolution of beliefs; the middle graphs depict the firm-level investments; and the bottom graphs depict the ratio of aggregate investment with unknown and known θ. The parameters are ($\theta_l = 0.6$, $\theta_h = 0.95$, $s_l = 0.1$, $sh = 0.7$, $\Psi = 1.3$, $R = 1$, $\gamma = 3$), where $\upsilon = 1.33$, and the probability of a run up in expectation is 13.4%.

2. *If the industry productivity is low, $\theta = \theta_\ell$, then there is a run-up in investors' productivity expectations and aggregate over-investment, i.e., $\mu_n \to \mu^+$ and $d(\theta_\ell) = k(\mu^+)/k(\theta_\ell) > 1$, with probability $p(\theta_\ell, \mu_1)$; but there is complete learning and no aggregate investment distortion at the limit, i.e., $\mu_n \to \theta_\ell$ and $d(\theta_\ell) = 1$, with probability $1 - p(\theta_\ell, \mu_1)$, where*

$$p(\theta_\ell, \mu_1) = \left(\frac{\theta_h - \mu^+}{\mu^+ - \theta_\ell}\right)\left(\frac{\mu_1 - \theta_\ell}{\theta_h - \mu_1}\right) \quad \text{for } \mu_1 \in (\theta_\ell, \theta_h). \tag{9}$$

Fig. 6 presents simulated paths of investors' beliefs satisfying the parametric restriction of Theorem 6 when $\theta = \theta_\ell$ and $\upsilon = 1.33$. The probability of a run-up in expectations in this case is 13.4%. The simulated posterior beliefs that $\theta = \theta_h$, i.e., β_n, is depicted in the top graphs in Figs. 6 and 7. In the two paths simulated in Fig. 6, the more severe agency conflict substantially delays learning about the true productivity state. Fig. 7 (using same parameters as in Fig. 6) depicts the run-up in productivity expectations. In contrast to Figs. 4 and 5, Figs. 6 and 7 indicate the stochastic or history-dependent outcomes of investors' learning process in the limit, in particular the possibility of incomplete learning. Notice that the learning distortions are not mitigated even as more firms enter the industry; on the contrary, as firms continue to enter beliefs diverge further.

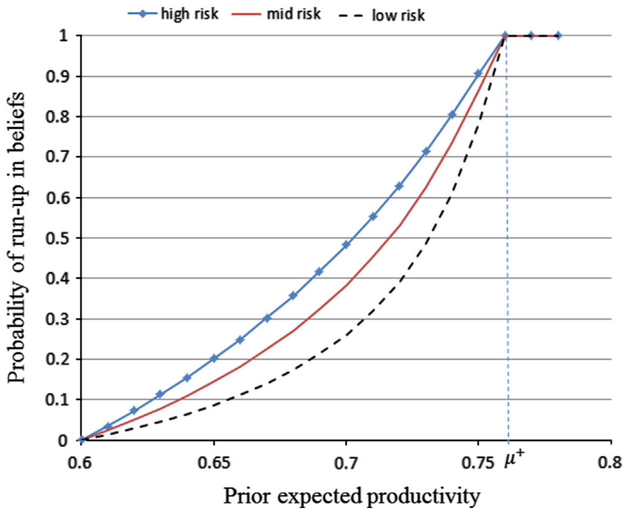

Fig. 8. Plots of the a priori probability of a run up in investors' expectations regarding the true aggregate productivity in the low productivity state (i.e., $(p(\theta_\ell, \mu_1))$, as a function of the a priori expected state of productivity for three levels of risk. The graph is plotted for parameters $\gamma = 3$, $\upsilon = 1.31$, and $\theta_h - \theta_\ell = 0.35, 0.25, 0.20$.

Next, from the closed form solution in (9) one can calculate the expected distortions in investors' beliefs at the limit

$$\mathbb{E}(\overline{\mu}|\theta_\ell) - \theta_\ell = (\theta_h - \mu^+)\left(\frac{\mu_1 - \theta_\ell}{\theta_h - \mu_1}\right), \quad \mathbb{E}(\overline{\mu}|\theta_h) - \theta_h = -(\theta_h - \mu^+) \tag{10}$$

Therefore, the higher is the agency conflict υ; the lower is the critical level of optimistic expectations μ^+; the higher is the probability of a potential run up in expectations; and the higher is the absolute value of the distortion in investors' beliefs at the limit.

The closed form solution in (9) also facilitates comparative dynamics analysis: $p(\theta_\ell, \mu_1)$ is increasing in the prior expectation μ_1, but decreasing in the intensity of agency conflict (υ). Moreover, there is a link between investors' *ex ante uncertainty* on θ, namely, $\Delta \equiv (\theta_h - \theta_\ell)$ and $p(\theta_\ell, \mu_1)$ because one can write

$$p(\theta_\ell, \mu_1) = \left(\frac{\mu_1 - \mu^+ + (1-\beta_1)\Delta}{\mu^+ - \mu_1 + \beta_1 \Delta}\right)\left(\frac{\beta_1}{1-\beta_1}\right) \tag{11}$$

$p(\theta_\ell, \mu_1)$ is strictly increasing in Δ. Similarly, β_1 (the *ex ante* probability of a high θ) is negatively related to the riskiness of the innovation. Consistent with this, $p(\theta_\ell, \mu_1)$ is negatively related to β_1 (cf. (11)) *ceteris paribus*. Fig. 8 depicts the *ex ante* likelihood of converging to beliefs μ^+ when the true productivity is low. This probability can be seen to be increasing in μ_1 and the *ex ante* uncertainty regarding θ.

6.2. *Low levels of agency conflict*

If the agency conflict is intermediate but relatively low ($\upsilon_N < \upsilon < \upsilon_P < 1$), then pooling is optimal when beliefs are sufficiently *pessimistic*, i.e., $\mu_n \le \mu^+$ and learning occurs as long as $\mu_n \in (\mu^+, \theta_h)$. Thus, while investors may initially learn from disclosures when $\mu_1 \in (\mu^+, \theta_h)$, a sequence of low productivity reports can sufficiently reduce their expectations below the critical level μ^+, and reports become uninformative thereafter. Therefore, low productivity expectations need not be corrected, leading to aggregate under-investment at the limit when the true industry productivity is high. However, there is always aggregate over-investment at the limit when the true industry productivity is low because it is impossible for investors to learn the true state as managerial disclosures become progressively less informative with falling expectations.

Interestingly, investment distortions can be triggered rather quickly when $\upsilon < 1$. This is because in any period n, with beliefs μ_n, investors' posterior expectations following a low report drop to the level $\mu_{n+1} = (\mu_n - \sigma_n)/(1-\mu_n)$. Consequently, with a positive probability, the learning process can be permanently distorted by even a *single* low productivity report.[27] In contrast, in the high agency conflict case, a run up in expectations and aggregate investment distortion in the low state is caused by a sequence of high productivity reports.

Figs. 9 and 10 present simulated paths when $\upsilon = 0.8 \in (\upsilon_N, \upsilon_P)$ and when $\theta = \theta_h$. Unlike the earlier simulations, here the risk aversion is taken to be $\gamma = 1.5$ (because $\gamma \in (1, 2]$ when $\upsilon < 1$ and $\upsilon \in (\upsilon_N, \upsilon_P)$, as noted above). The top two graphs in Fig. 9 indicate that investors have essentially learnt the true state (θ_h) after about twenty firms enter the industry (in both cases). And it is apparent from the middle graphs that during the learning phase firms experience under-investment, but this is

[27] More precisely, this is true for $\mu_n \in (\mu^+, \breve{\mu})$ where $\breve{\mu} = (\mu^+ - \theta_\ell \theta_h)/(1 + \mu^+ - \theta_\ell - \theta_h)$.

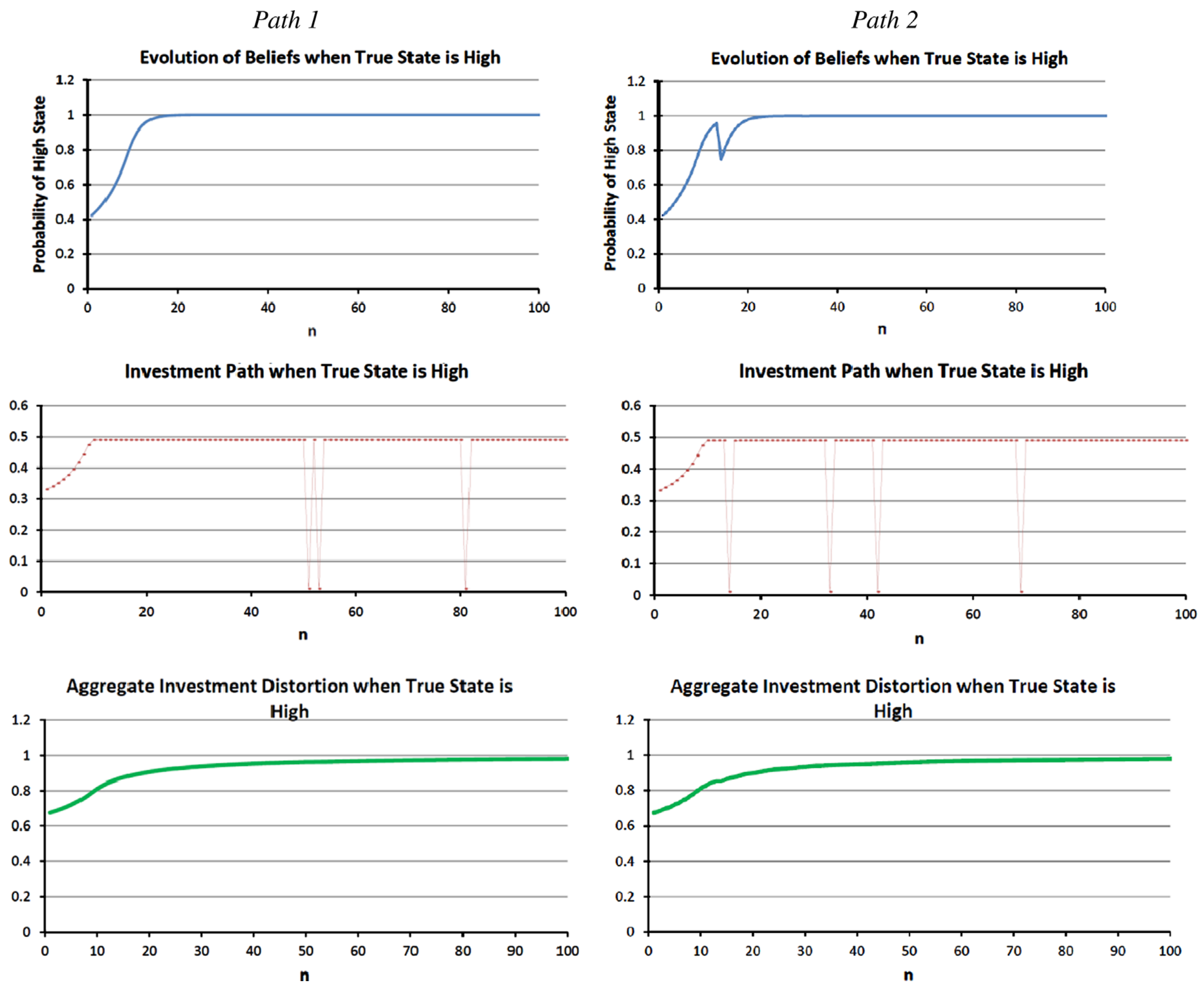

Fig. 9. Simulation of two random paths when the true aggregate productivity is high. The top graphs depict the evolution of beliefs; the middle graphs depict the firm-level investments; and the bottom graphs depict the ratio of aggregate investment with unknown and known θ. The parameters are ($\theta_l = 0.6$, $\theta_h = 0.95$, $s_l = 0.1$, sh=0.7, $\Psi = 0.7$, R=1, $\gamma = 1.5$), where $\upsilon = 0.80$.

mitigated as more firms enter into the industry. Consequently, as the bottom graphs show, the aggregate investment approaches the benchmark level. However, aggregate investment distortion can also occur at the limit, as seen in Fig. 10, where a sequence of low productivity reports pushes down productivity expectations permanently.

Now, as noted above, for new and emerging industries in their incipient stages outside investors typically have little basis for interpreting any preliminary "performance" data released by the first movers.[28] Therefore, our somewhat extreme assumption thus far that managerial disclosures are the only reliable signals on firms' idiosyncratic productivities is substantially realistic in our context. This assumption has led to some striking results, such as the possibility of incomplete learning and aggregate investment distortions in the limit. However, the next section shows that relaxing this informational assumption and allowing investors to learn from observing outputs do not eliminate aggregate investment distortions along the equilibrium path.

6.3. *Learning from output observations*

Suppose now that for some pre-specified natural number $\lambda \geq 2$, the observable history of outputs is the profile $\phi_n^y = (y_1, \ldots y_{n-\lambda})$ for $n > \lambda$ (and $\phi_1^y, \ldots, \phi_\lambda^y$ are empty sets). Clearly, investors' updating depends only on disclosures for $n \leq \lambda$. However, beyond stage $n = \lambda + 1$, investors use the information set $\Phi_n = (\phi_n^c, \phi_n^y)$. But because low productivity reports are

[28] For example, during the internet boom of the late 1990s, the actual economic performance of internet-related firms was considered to be irrelevant; the traditional valuation principles appeared to be ignored by financial analysts and investors, and replaced by models or valuation-drivers (such as the "number of eyeballs per day") that disregarded the (negative) contemporaneous earnings of these "new economy" firms.

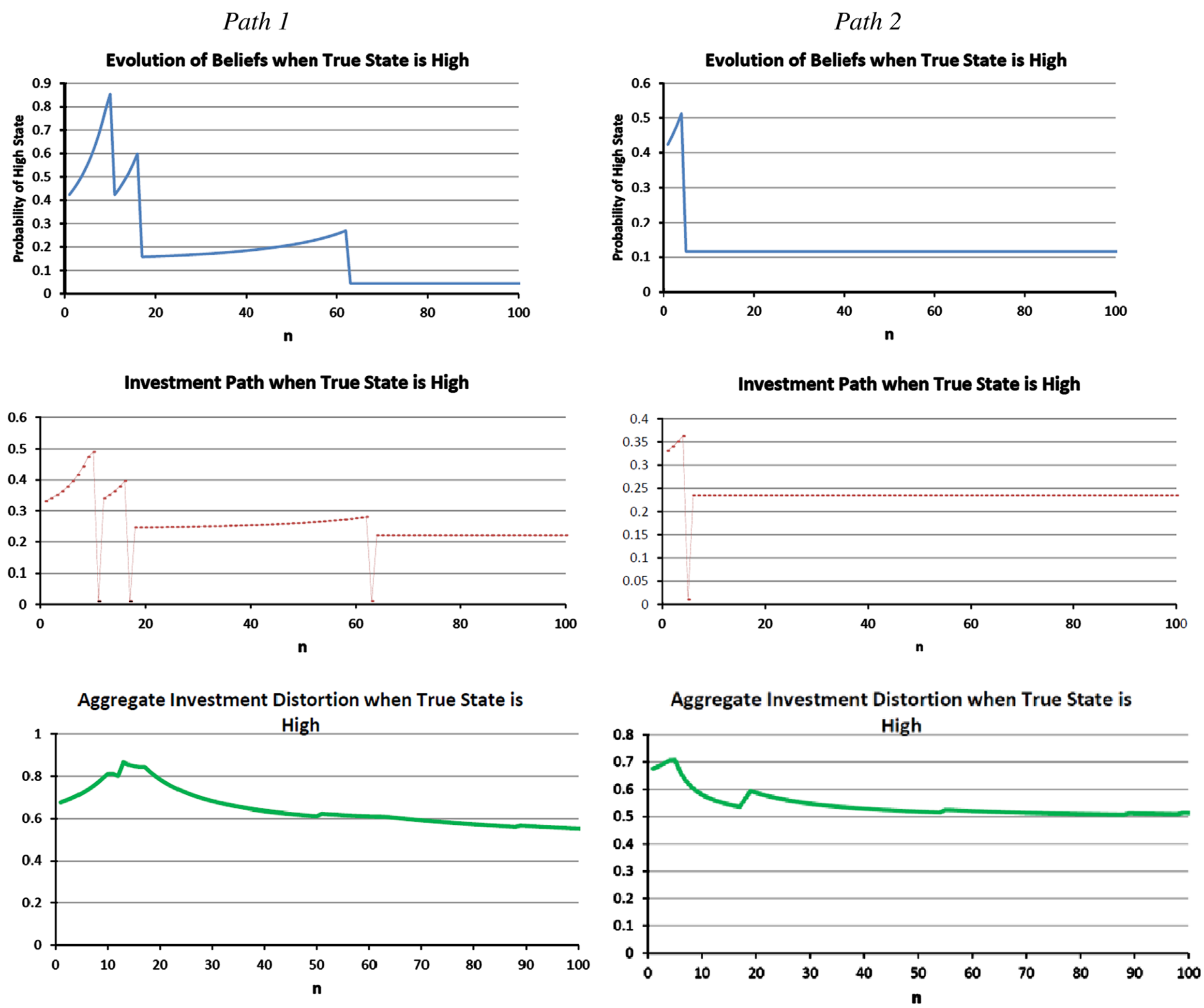

Fig. 10. Simulation of two random paths when the true aggregate productivity is high. The top graphs depict the evolution of beliefs; the middle graphs depict the firm-level investments; and the bottom graphs depict the ratio of aggregate investment with unknown and known θ. The parameters are ($\theta_l = 0.6$, $\theta_h = 0.95$, $s_l = 0.1$, $sh = 0.7$, $\Psi = 0.7$, $R = 1$, $\gamma = 1.5$), where $\upsilon = 0.80$.

perfectly revealing in the noisy revelation equilibrium only output realizations of firms whose managers reported high productivity will lead to a downward revision in beliefs. And while it follows from the Law of Large Numbers that there will be complete learning in the limit with timely informative output observations, the important implication of our analysis is that this is also *required* (for the resolution of productive uncertainty) when the level of agency conflict is sufficiently high.

Proposition 7. *The availability of past output observations leads to complete learning in the limit, but aggregate investment is nonetheless distorted with positive probability for any finite stage n if the agency conflict is sufficiently severe* (*i.e.*, $\upsilon > \upsilon_T$).

Note that, even if there is complete learning in the limit, there will be aggregate investment distortions along the equilibrium path. To illustrate, suppose that $\upsilon > \upsilon_P$ and managerial reports are therefore completely uninformative (cf. Proposition 5). If, however, output becomes observable and learning occurs with lag of λ, then investors will eventually learn the true productivity and hence there will be no aggregate investment distortion at the limit. However, aggregate investment distortions will still persist for any finite "sample" of entering firms while managers withhold their private information.

7. Summary and conclusions

Growth opportunities generated by innovations often engender persistent investment booms and sharp investment busts. While often ascribed to investor irrationality, a historical analysis highlights the crucial role of manipulation of investors' beliefs by self-interested and informed insiders through overly optimistic representations of financial performance and economic prospects. Because the economic uncertainty regarding innovations typically resolves only in the long term, investors are highly dependent on communications and disclosures by informed insiders in the incipient stages of the industry. Our analysis finds that investor' structural uncertainty regarding the industry-wide productivity in new industries may not be resolved in the presence of asymmetric information and strategic communications by informed insiders in the limit as the number of informed disclosures gets arbitrarily large, and even though outside investors design optimal incentive contracts based on Bayes-rational beliefs. There can be an endogenous run-up in expectations leading to persistent aggregate over-investment or an endogenous fall in productivity expectations leading to a persistent aggregate under-investment. And even if investors can learn from observing outputs, these aggregate investment distortions persist along the equilibrium path. Thus, the capital allocation distortions introduced by adverse selection can be amplified (rather than diluted) by the communications and disclosures from informed insiders with resultant systematic aggregate investment distortions. Thus, for new and emerging industries market "exuberance" or "pessimism" that leads to persistent investment booms or investment busts can be consistent with Bayes-rationality and common priors, and can occur even when incentive mechanisms are optimally designed to elicit information.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at http://dx.doi.org.10.1016/j.jmoneco.2013.03.001.

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