INNOVATION-FUELLED, SUSTAINABLE, INCLUSIVE GROWTH

Working Paper

Manager Remuneration, Share Buybacks and Firm Performance

Herbert Dawid
Department of Business Administration and Economics
and Center for Mathematical Economics, Bielefeld University

Philipp Harting
Department of Business Administration and Economics,
Bielefeld University

Sander van der Hoog
Department of Business Administration and Economics,
Bielefeld University

2/2018 January

This project has received funding from the European Union Horizon 2020 Research and Innovation action under grant agreement No 649186

Manager Remuneration, Share Buybacks and Firm Performance ⋆

Herbert Dawid[a] Philipp Harting[b] Sander van der Hoog[b]

January 2018

Abstract

Using a dynamic heterogeneous agent industry model we examine the impact of manager remuneration schemes on firms investment decisions and on the evolution of their competitiveness and share values. Whereas an increase in the share-based manager remuneration component is always beneficial to the manager, it is beneficial for shareholders only if such a change in the remuneration scheme is adopted by all firms in the industry. In that case productivity growth is slowed down and workers real wages are reduced.

1 Introduction

The last decades have seen an increasing financialization of large parts of the manufacturing industry worldwide. Key aspects of this development are that firms spend an increasing fraction of their net income on the purchasing of (own) shares as well as an increased orientation of manager remuneration on share based components. Sakinc (2017) shows, based on data from 298 S&P Europe 350 companies, that expenditures for share repurchases have more than tripled between 2000-2007 and, after the breakdown during the financial crisis, have again more than doubled between 2009 and 2015. Qualitatively similar evidence is reported in Lazonick (2014) for 251 S&P 500 companies. With respect to managerial compensation, Edmans et al. (2017) report that the average share-based component (stock plus stock-options) of CEO remuneration in S&P 500 companies has increased from 36% in 1992 to 60% in 2014.

Although the evidence with respect to the size of the impact of share repurchases on stock prices is somewhat mixed (see e.g. Peyer and Vermaelen

⋆This research has been supported by the European Unions Horizon 2020 grant No. 649186 - Project ISIGrowth.

[a]Department of Business Administration and Economics and Center for Mathematical Economics, Bielefeld University, E-mail: hdawid@wiwi.uni-bielefeld.de.

[b]Department of Business Administration and Economics, Bielefeld University, E-mail: {pharting,svdhoog}@wiwi.uni-bielefeld.de.

(2009), Fu and Huang (2016)) and also seems to depend on domestic institutional specificities (Andriosopoulos and Lasfer, 2015), it has been argued that the changes in the remuneration schemes for managers might play an important role for the increase in share buybacks and that this might induce a crowding out of investment in physical capital and R&D activities (see Lazonick (2014), Kotnik et al. (2017)). This line of reasoning is supported by empirical studies (see e.g. Bens et al. (2002) or Bhargava (2013)). In particular, Bhargava (2013) shows that for a sample of 700 U.S. firms share repurchases of the firm's own shares are positively associated with the amount of stock options granted by the firms as part of their executive compensation schemes. Furthermore, share repurchases and stock options are negatively associated with expenditures on research and development as well as with long-term investments of these firms.

In spite of this empirical work linking manager remuneration schemes to share buybacks and real investments, a theoretical analysis examining the impact of different manager remuneration schemes on investment decisions as well as the evolution of firms' competitiveness and share value is missing. In this paper we provide such an analysis relying on a dynamic heterogeneous agent industry model, which combines approaches from the evolutionary literature on Schumpeterian competition (see Nelson and Winter (1982), Dosi et al. (1995)) with the literature on dynamic models of financial markets with heterogeneous expectations (see Hommes (2006), Dieci and He (2018)).

In particular, we consider an industry in which firms that are each run by a single manager compete by offering horizontally differentiated goods. Managers are driven by the incentives generated by their remuneration schemes, which include share-based and profit-based components, make decisions about R&D investment and the investment in share buybacks. R&D investments influence the (long term) competitiveness of the firm, affecting the profits and dividend payout to shareholders. The size of dividend payments influence the expectations of financial market participants about future dividends of a firm. The (net) demand of a financial trader for shares of a firm depends on the dividend expectations as well as on the expectations about the future share price. In case the firm engages in share buybacks financial traders adjust their expectation about the future share price upwards or downwards depending on their type (optimist/pessimist). The share price is determined by market clearing on the financial market and the realization of the share price feeds back into the manager's income, as the manager sells the shares she receives as part of her remuneration package.

This model captures the trade-off between the (anticipated) short-term financial gains for managers potentially arising from share buybacks and the long-term effects on a firm's competitiveness, which then feeds back into the long-run levels of the firms share price. This therefore allows us to examine how a change in the manager remuneration scheme of a single firm in the industry, or alternatively, a simultaneous adjustment of the remuneration schemes by all firms in the industry, influences the dynamics of firm profits, manager incomes as well as the firms' productivity. Furthermore, since in our model setup the expectations of financial market participants about the impact of share buybacks on share prices are explicitly represented by optimistic and pessimistic expectations, we can also examine to what extent the sentiment on the financial market influences the dynamics of the industry. In particular, we address the following main questions:

- How does the fraction of stock-based compensation influence a manager's share buyback decision?
- Does an increase in stock-based compensation crowd out R&D investments? How does the intensity of the crowding out evolve over time?
- How are long-term competitiveness and share prices affected if a firm increases the fraction of stock-based manager compensation?
- How closely is the manager's (long term) income related to the (long term) performance of the firm?
- How do the expectations of financial market participants about the effects of buybacks on share prices influence the manager's investment decisions as well as the dynamics of firm productivities and share prices?

Although the focus of our analysis is the effect of an increase of share-based manager remuneration, we also explore how the expected duration of the managers' tenure at a firm influences her decision how to allocate expenditures between R&D and share repurchases as well as the dynamics of her expected income and the firm's share price. There are two main reasons for considering this issue. First, it has been argued in the literature that an increase of share based manager remuneration leads to 'short-termism' of managers who focus too much on short term performance of the firm. Hence, we like to understand whether the implications of such a change in the remuneration scheme are indeed equivalent to a reduction of the manager's planning horizon, which is in a natural way induced by increasing the job separation rate for the manager. Second, empirical evidence seems to suggest that contract durations of CEOs have decreased over time (see Cziraki and Xu (2014)) and whereas contributions like Barker III and Mueller (2002) have studied the effect of CEO characteristics, like CEO tenure[1], on R&D investment, a systematic analysis of expected duration in the firm on the allocation between R&D and buybacks is so far missing.

Following the rich literature on agent-based analyses of industry- and market-level dynamics[2] we address these questions by carrying out computational experiments in which key parameters, in particular the amount of shares the manager receives as part of her remuneration, the manager job separation rate and the expectations of financial market participants, are systematically varied. We then check whether and to what extent such variations result in a significant change of (the distribution of) the dynamics of key economic variables. This analysis is carried out for a parameterization of the model which has been empirically calibrated to reproduce several empirical stylized facts about the firms' investment patterns, manager remuneration and productivity growth using OECD data.

[1]It should be noted that tenure in this context refers to the time the CEO has already spent in the firm, whereas we refer to the expected future duration in the firm.

[2]See Dawid (2006) for a survey of this literature starting with Nelson and Winter (1982) and e.g. Malerba et al. (2008); Dawid and Reimann (2011) and Chang (2015) for more recent contributions.

A key insight from our analysis is that, whereas an increase in the share-based manager remuneration component is always beneficial for the manager, it is beneficial for shareholders only if such a change in the remuneration scheme is adopted by all firms in the industry. If this change in the remuneration scheme is adopted only by a single firm, it has detrimental effects on that firm's long run competitiveness and share price. The underlying mechanism is that the change in remuneration scheme induces a re-balancing of the firm's expenditures towards share buybacks and the resulting decrease in R&D investment induces a lower growth rate of the firm's productivity, which, due to market competition, induces lower profits and dividends. The negative impact of the reduction in dividends then outweighs the positive direct effects of buybacks on share prices. If all competitors also change their remuneration schemes in a similar way, the competition effect disappears and the increased buybacks induce higher share prices in the long run. However, also in this scenario productivity growth is slowed down by the stronger orientation of manager compensation on share based components, which has negative implications for the purchasing power in real terms of the wages-earners in the industry. An increase in the manager's job separation rate in many respects has similar implications as an increase in the share based remuneration. However, the manager's per period income is positively affected only if all firms increase the separation rate. If such a change occurs only at a single firm this has negative implications for the expected per period income of the manager of that firm. Finally, our analysis shows that managers and shareholders profit if the average expectations of financial market participants about the impact of buybacks on share prices becomes more optimistic.

Apart from addressing the stated economic questions the paper also makes a methodological contribution by providing a modeling framework of a financial market with heterogeneous traders in which the dividend streams of the different traded assets is endogenously determined based on profits derived from an explicit representation of the dynamic competition between the different firms on the market. This distinguishes our setup both from existing industry dynamic models, in which an explicit representation of the associated dynamics on the financial market determining the firms' share prices is typically missing, as well as the large literature on dynamic financial market models, in which dividends are typically modeled as exogenously given dynamic stochastic processes.

The paper is organized as follows. In Section 2 we present our model, and in Section 3 we present the baseline scenario and discuss the reproduction of several empirical stylized facts. The core of the paper is Section 4 in which we present and discuss the findings of our simulation analysis. A discussion of some implications of our results and of possible extensions is provided in the concluding Section 5. In the Appendix we present the details of the parametrization of our model, provide evidence for the statistical significance of the reported results and show that the findings obtained in Section 4 stay intact if we extend the model by introducing a endogenous adjustment dynamics for the expectation types of the financial market participants.

2 The Model

2.1 Overview over the model structure

We consider a dynamic model of an oligopolistic industry in which each of n firms is run by a decision maker (denoted as 'manager' here), who every period decides on the level of real investments and on the amount dedicated to buybacks of shares of the firm. We model long-term investments in a simple reduced form, and assume in the tradition of Nelson and Winter (1982) that such investment with some probability increases the firm's productivity and thereby reduces its production costs. In this sense the long-term investment here covers both investments in R&D and the building up of human capital.

In order to capture the interplay of the effects of share buybacks of firms and the evolution of firm profits on the dynamics of share prices we link the oligopoly model to a simple financial market model based on a setup similar to the one introduced in Brock and Hommes (1998). Traders' (excess) demand for shares is determined by their expectations about the future dividend paid by the firm and the future value of the share price. Dividends are determined by the firm's liquidity in the current period. There are two types of traders on the financial market, who differ with respect to their belief whether current share buybacks have positive ('optimists') or negative ('pessimists') effects on the future share price. This is motivated by empirical work (e.g. Pettit (2001); Andriosopoulos and Lasfer (2015)) demonstrating that even if on average buybacks are associated with increases in the share price, the responses are mixed and there is also a significant positive probability for a negative impact. A trader's expectation about the change in share value is determined by her type as well as the amount that is invested in buybacks by the firm. To keep this part of the model as simple as possible it is assumed that the shares of each firm are traded in isolation on a separate financial market, such that the firms compete only on the product market, but not on the financial market. This avoids having to deal with a multi-asset market with heterogeneous expectations, which would be very challenging from a technical perspective.[3]

The remuneration of the firm's manager consists of three parts: a fixed remuneration, a payment depending on current firm profits and a part depending on the current price of a share of the firm's stock on the financial market. The model captures also the expectations of the manager about the duration of her job tenure.

2.2 Sequence of events

Before describing in more detail the different decision problems and interactions arising in the model we give a broad overview by listing the timeline of events in each period t. The variables in brackets refer to the more detailed description provided below:

1. Firms compete on the product market and realize market profits ($\Pi^*_{i,t}$).

[3]It would involve solving a multi-dimensional portfolio optimization problem for each trader, and a general equilibrium market clearing solution.

2. Managers determine long-term investments ($I^*_{i,t}$) and the amount to spend on share buybacks ($B^*_{i,t}$).
3. Firms' operating profits are determined ($\Pi^o_{i,t}$).
4. Firms determine the dividend payout ($D_{i,t}$).
5. Financial market participants determine their net demand for shares ($z_{h,i,t}$).
6. The market clearing prices for all firm shares ($V_{i,t}$) are determined and the financial market participants' portfolios are updated. Managers sell all the shares they received as remuneration in the previous period.
7. Dividends per share ($d_{i,t}$) are determined and paid out; dividend expectations are adjusted.
8. The managers receive their remuneration including β units of shares (β can be fractional).
9. Productivity of firms ($A_{i,t}$) is updated.

2.3 Market Competition and Productivity Dynamics

We consider a market where n firms engage in price competition producing horizontally differentiated goods. The demand function reads

$$Q^D_{i,t} = \left[1 - a^d P_{i,t} + \frac{b^d}{n-1}\sum_{j\neq i} P_{j,t}\right]. \tag{1}$$

The parameter $a^d > 0$ captures the price sensitivity of consumers and $b^d \in [0, a^d]$ the degree of horizontal differentiation between products.[4] Firms produce with labor ($L_{i,t}$) as a single input according to the production function

$$Q_{i,t} = A_{i,t} L_{i,t},$$

where $A_{i,t}$ denotes the productivity of firm i at time t. It is assumed that the wage is uniform across firms and grows proportionally to the average productivity in the industry. Formally we have

$$\frac{w_t}{w_0} = \frac{\sum_{i=1}^n Q_{i,t-1} A_{i,t-1}}{\sum_{i=1}^n Q_{i,0} A_{i,0}}.$$

The marginal production costs of firm i are given by

$$C_{i,t} = w_t / A_{i,t}.$$

Firms choose prices according to the Bertrand equilibrium solution, which is given by

$$P^*_{i,t} = \frac{(2a^d(n-1) + b^d)(1 + a^d C_{i,t}) + a^d b^d (\Sigma_{C,t} - n C_{i,t})}{(2a^d(n-1) + b^d)(2a^d - b^d)}. \tag{2}$$

[4] This demand structure can be derived from the utility maximization of consumers with a quadratic utility function.

Here $\Sigma_{C,t} = \sum_{j=1}^{n} C_{j,t} = w \sum_{j=1}^{n} \frac{1}{A_{j,t}}$ denotes the sum of the marginal costs of all competitors. This yields the equilibrium quantities

$$Q^*_{i,t} = \frac{a\left[(2a^d(n-1)+b^d) - (a^d(2a^d(n-1)+b) - b^d(a^d(n-2)+b^d))C_{i,t} + a^d b^d \Sigma_{C,t}\right]}{(2a^d(n-1)+b^d)(2a^d-b^d)} \tag{3}$$

and the market profit for firm i is given by

$$\Pi^*_{i,t}(C_{i,t}, \Sigma_{C,t}) = Q^*_{i,t}\left(P^*_{i,t} - w/A_{i,t}\right) = \frac{(Q^*_{i,t})^2}{a^d}. \tag{4}$$

Due to cost heterogeneity across firms, in principle, expression (3) can become negative for certain firms. In this case, the quantity of the firm with highest costs is set to zero and equilibrium prices (2) and quantities (3) of the remaining firms are recalculated, where the term $\Sigma_{C,t}$ no longer includes the costs of the firm that has been dropped. This procedure is repeated till all remaining firms produce positive quantities. An inactive firm producing zero output in a certain period might become active again in the next period if its productivity has increased due to a successful innovation.

Firms can increase their productivity due to long-term real investments. Such investments can be focused on R&D or on training of the labor force (human capital accumulation). We do not distinguish between these types of investment and denote by $I_{i,t}$ the amount of long-term real investment of firm i at t. Such investment triggers with positive probability an increase of the firm's productivity. More precisely, we assume that the arrival rate of the innovation is a concave function of the real investment. Formally, we have

$$A_{i,t+1} = \begin{cases} \mu A_{i,t} & \text{with Prob. } \alpha(1 - e^{-\lambda_i \sqrt{I_{i,t}}}) \\ A_{i,t} & \text{with Prob. } (1-\alpha) + \alpha e^{-\lambda_i \sqrt{I_{i,t}}} \end{cases} \tag{5}$$

The parameter $\alpha > 0$ denotes the maximal innovation probability per period, whereas $\lambda_i > 0$ captures the effectiveness of firm i with respect to long term investment.

2.4 Manager Remuneration

In each period the manager determines the optimal amount of long-term investment, $I^*_{i,t}$, and the optimal amount $B^*_{i,t}$ to invest in share buybacks. The manager receives a remuneration consisting of a fixed amount W^f, a performance-related payment proportional to the firm's operating profit (if positive) and an amount of β_i units of firm stock, which the manager immediately sells on the stock market in the following period. The simplifying assumptions that the manager is paid in stock rather than stock options, and that she sells them immediately, are made in order to avoid having to deal with the complex issue of determining the optimal selling time by the manager or the problem of stock option pricing.[5] The main effect we intend to capture is the positive impact

[5] Also, empirical evidence points towards a recent shift in using units of stock rather than stock options in the variable part of manager's remuneration scheme. So called restricted

of an increase of the firm's stock market value on the manager's (current and future) income, which is satisfied in our formulation since the manager expects to receive additional shares in the future. Summarizing, the manager income in period t is given by

$$W^m_{i,t} = \beta_i V_{i,t} + \gamma \max[0, \Pi^o_{i,t}] + W^f, \tag{6}$$

where

$$\Pi^o_{i,t} = \Pi^*_{i,t} - I_{i,t} - W^f + rS_{i,t}$$

denotes the operating profit of the firm.[6] Furthermore, $V_{i,t}$ is the share price of firm i in period t and $S_{i,t}$ are the firm's savings. The interest rate $0 \leq r < 1$ is assumed to be constant and exogenously given. The share-based remuneration parameter $\beta_i \geq 0$ will play a key role in our analysis and we will consider scenarios in which this parameter is heterogeneous across firms. The other remuneration parameters will always be assumed to be homogeneous in the industry.

2.5 Dividend Policy and Dynamics of Firm Savings

Dividends play an important role for the dynamics of the share price, since traders on the financial market take (expected) dividend payments into account when determining their demand for firm stocks. It is assumed that each firm has a simple and fixed dividend policy such that a constant fraction of current firm liquidity (after market profits and manager remuneration) is paid out as dividends (if positive). In particular, the total dividend payout is given by[7]

$$D_{i,t} = \mathbf{D}(I_{i,t}) := \delta_i \max\left\{0, (1+r)S_{i,t} + \Pi^*_{i,t} - W^f - \gamma \max[0, \Pi^o_{i,t}(I_{i,t})]\right\}. \tag{7}$$

The parameter $\delta_i > 0$ is denoted as the dividend payout ratio. The dividend is paid out at the end of each period t and the dividend per share $d_{i,t}$ depends on the number of shares publicly held at the end of the period. The updating of the number of shares over time is explained in the next subsection.

Taking into account the dividend payments as well as the firm's expenses for share buybacks the dynamics of the firm's savings is given by

$$S_{i,t+1} = S_{i,t} + \Pi^o_{i,t} - (\gamma \max[0, \Pi^o_{i,t}] + W^f) - D_{i,t} - B_{i,t}. \tag{8}$$

In order to capture financial constraints the firm is facing we assume for simplicity that the firm cannot go into debt, implying that the investment decisions $I_{i,t}$ and $B_{i,t}$ have to satisfy the additional condition $S_{i,t+1} \geq 0$.

stock units (or RSUs) are used due to fair value accounting considerations that led to changes in GAAP, and because it may yield a tax benefit for the manager's income tax when the stock price at time of vesting of the stock grant differs from the price at the time of selling the stock.

[6] It should be noted that whereas real investments are treated as costs (e.g. labor costs for R&D employees or training costs), the expenses for buybacks (accounting-wise) do not reduce the firm profits.

[7] This formulation assumes that the amount of dividends paid out is determined such that it is not directly affected by the amounts the firm spends on long-term investments and buybacks. This assumption is made to avoid a direct trade-off between investment and dividend payouts. Such a connection would introduce a complex channel through which investments affect future share prices and hence future manager incomes.

2.6 Financial Market Interaction

We denote by $N_{i,t}$ the total number of shares of firm i that are held by investors/traders on the financial market, including the manager, at the beginning of period t. Shares for each firm are traded on separate financial markets.

Before going into the details of the financial market interaction that determines the share price $V_{i,t}$, note that the dividend per share is given by

$$d_{i,t} = \frac{D_{i,t}}{N_{i,t} - \frac{B_{i,t}}{V_{i,t}}}. \tag{9}$$

Here, $\frac{B_{i,t}}{V_{i,t}}$ is the reduction in the number of publicly held shares due to share buybacks by firm i in period t.[8] To determine the number of shares at the beginning of period $t+1$ it also has to be taken into account that the manager receives β_i shares at the end of period t. Therefore, the evolution of the number of shares is given by

$$N_{i,t+1} = N_{i,t} - B_{i,t}/V_{i,t} + \beta_i \qquad \text{with} \qquad N_{i,t} \in \mathbb{R}. \tag{10}$$

Note that the dividend per share $d_{i,t}$ is determined after the firm has repurchased $\frac{B_{i,t}}{V_{i,t}}$ shares, but before the manager has received the new β_i shares.

We assume there are M traders on the financial market, who have standard CARA utility functions and maximizing expected current utility. Well-known results (see e.g. Brock and Hommes (1998)) show that the demand for shares of firm i by trader type h is given by

$$z_{h,i,t} = \frac{\mathbb{E}_{h,t}[V_{i,t+1} + d_{i,t+1} - (1+r)V_{i,t}]}{\tilde{a}\hat{\sigma}^2_{i,t}} \tag{11}$$

where $\tilde{a}$ denotes the rate of relative risk aversion and $\hat{\sigma}_{i,t}$ is the agents' expectation regarding the standard deviation of dividends plus share price in period t. It is assumed that the expected standard deviation is proportional to the last observed dividend per share, i.e.

$$\hat{\sigma}_{i,t} = \mathbb{E}_{i,t}[\sigma_t] = f(d_{i,t-1}) = \tilde{\sigma} d_{i,t-1} \qquad \text{for some} \qquad \tilde{\sigma} > 0,$$

where $\tilde{\sigma}$ is a scaling parameter.

Let $\iota_{h,i,t}$ denote the quantity of shares a trader of type h holds at the end of period t. The net demand for shares of each trader of type h is given by $z_{h,i,t} - \iota_{h,i,t-1}$.

A trader's type is determined by his expectation about the market impact of the share buyback $B_{i,t}$ on the stock price $V_{i,t}$. Two types of traders are considered, depending on whether they have optimistic (o) or pessimistic (p) expectations about the market price impact. Formally, the expectation about the share price plus dividend in the following period is given by

$$\mathbb{E}_{h,t}[V_{i,t+1} + d_{i,t+1}] = V_{i,t-1}\left(1 + \kappa_h \frac{B_{i,t}}{V_{i,t}N_{i,t}}\right) + \mathbb{E}_t[d_{i,t+1}], \tag{12}$$

[8] We assume the firm can repurchase any volume, hence the number of shares repurchased is allowed to be any positive real number.

where $h \in \{o, p\}$ denotes the type of agent h. Note that the expectations about dividends $\mathbb{E}_t[d_{i,t+1}]$ are assumed the same for both types, so they are independent of h. The parameter κ_h captures the expectations of type h about the impact of the share buyback on the stock market price $V_{i,t+1}$, where $\frac{B_{i,t}}{V_{i,t}N_{i,t}}$ denotes the fraction of all shares repurchased by firm i in period t. We further assume that $\kappa_o > 0$ and $\kappa_p < 0$.

In our baseline model we assume that the fraction of traders with optimistic expectations, denoted by θ_t, stays constant over time. This assumption is made for simplicity and also allows us to study how the market sentiment, i.e. the fraction of optimistic traders, influences the behavior of managers and thereby the incentives of firms to provide managers strongly stock-based remuneration schemes. In a robustness check we relax this assumption and assume that the fraction of optimistic traders θ_t adjusts over time based on the past relative prediction performance of the two types. Details of this adjustment dynamics are provided in Appendix C.

Concerning expectations about the dividends per share, we assume that these are adjusted adaptively according to

$$\mathbb{E}_t[d_{i,t+1}] = \hat{d}_{i,t+1} := (1 - \phi) \cdot \mathbb{E}_{t-2}[d_{i,t-1}] + \phi \cdot d_{i,t-1}.$$

Again, note that this formulation is independent of the type h, so optimists and pessimists are assumed to have the same expectations about the dividends per share. Further note that information about $d_{i,t}$ is available only at the end of period t and therefore cannot be used for the expectation updating at this point. In an extension of the model it will also be interesting to consider markets where long-term investments of a firm have (positive impact) on the dividend expectations.

Apart from the financial market traders also the manager acts on the financial market, because in each period she sells β_i units of the stock she received at $t - 1$ as part of her remuneration. The manager does not trade on the stock market for other purposes, which means that the demand and supply of stock by the manager is given by $z_{m,i,t} = 0$ and $\iota_{m,i,t} = \beta_i$. Taking into account that the firms' demand for its own shares is given by $\frac{B_{i,t}}{V_{i,t}}$, the market clearing condition reads

$$\begin{aligned}
&M \left[\theta_t \frac{\hat{d}_{i,t+1} + V_{i,t-1}\left(1 + \kappa_o \frac{B_{i,t}}{V_{i,t}N_{i,t}}\right) - (1+r)V_{i,t}}{\tilde{a}\hat{\sigma}^2_{i,t}} - \theta_{t-1}\iota_{o,i,t-1} \right] + \\
&M \left[(1-\theta_t) \frac{\hat{d}_{i,t+1} + V_{i,t-1}\left(1 + \kappa_p \frac{B_{i,t}}{V_{i,t}N_{i,t}}\right) - (1+r)V_{i,t}}{\tilde{a}\hat{\sigma}^2_{i,t}} - (1-\theta_{t-1})\iota_{p,i,t-1} \right] \\
&-\iota_{m,i,t-1} + \frac{B_{i,t}}{V_{i,t}} = 0. \qquad (13)
\end{aligned}$$

The total number of shares held at the beginning of period t is $M\theta_{t-1}\iota_{o,i,t-1} + M(1-\theta_{t-1})\iota_{p,i,t-1} + \iota_{m,i,t-1}$ and therefore this expression is equal to $N_{i,t}$. Taking this into account and rescaling the constant risk aversion coefficient by the number of traders $a = \tilde{a}/M$, the market clearing condition can be rewritten as

$$\frac{\hat{d}_{i,t+1} + V_{i,t-1}\left(1 + [\theta_t\kappa_o + (1-\theta_t)\kappa_p]\frac{B_{i,t}}{V_{i,t}N_{i,t}}\right) - (1+r)V_{i,t}}{a\hat{\sigma}^2_{i,t}} = N_{i,t} - \frac{B_{i,t}}{V_{i,t}}. \tag{14}$$

The left hand side gives the demand for shares by all market participants, whereas the right hand side equals the number of shares on the market after the firm's share repurchase.

Solving (14) for $V_{i,t}$ shows that the equilibrium share price at time t is given by the positive root of the quadratic equation:

$$(1+r)V^2_{i,t} - \left(\hat{d}_{i,t+1} + V_{i,t-1} - a\hat{\sigma}^2_{i,t}N_{i,t}\right)V_{i,t} - B_{i,t}\left(\frac{[\theta_t\kappa_o + (1-\theta_t)\kappa_p]V_{i,t-1}}{N_{i,t}} + a\sigma^2\right) = 0.$$

Using the notation

$$X_{1,i,t} = \hat{d}_{i,t+1} + V_{i,t-1} - a\hat{\sigma}^2_{i,t}N_{i,t}, \tag{15}$$

$$X_{2,i,t} = \frac{[\theta_t\kappa_o + (1-\theta_t)\kappa_p]V_{i,t-1}}{N_{i,t}} + a\hat{\sigma}^2_{i,t}, \tag{16}$$

this yields a market clearing equilibrium share price given by

$$V_{i,t} = \frac{X_{1,i,t} + \sqrt{X^2_{1,i,t} + 4(1+r)X_{2,i,t}B_{i,t}}}{2(1+r)}. \tag{17}$$

In what follows we will only consider scenarios in which the share price is positive even if no buybacks are carried out, which corresponds to the assumption that $X_{1,i,t} > 0$. Only parameter settings where this condition is fulfilled will be considered.[9]

2.7 Managers' Decision Problem

When making their decisions managers take into account that they might have to leave their position in the future. In particular, we assume that the manager behaves based on an estimated job separation rate $\omega_i > 0$ and that she maximizes the expected remuneration over her remaining tenure at the firm.[10] Hence, the manager chooses $I_{i,t}$ and $B_{i,t}$ to maximize the objective function

$$J_i = \mathbb{E}\sum_{t=0}^{\infty} e^{-(\rho+\omega_i)t}W^m_{i,t}, \tag{18}$$

[9] A sufficient condition for $X_{1,i,t} > 0$ is that $a\hat{\sigma}^2_{i,t}$ is sufficiently small. Let N_0 be the initial number of outstanding shares for each firm, and let $\bar{d} > 0$ be a minimum dividend per share that is bounded away from zero. Then if $a\hat{\sigma}^2_{i,t} < \bar{d}/(N_0 + T\beta_i)$, the condition $X_{1,i,t} > 0$ is satisfied. Here $N_0 + T\beta_i$ represents an upper bound on the number of shares outstanding for each firm after T periods if there are no share buybacks.

[10] It should be noted that the expected job separation rate for managers might be heterogeneous across firms due to different designs of work contracts, ownership structures or firm cultures.

where $\rho > 0$ is the discount rate. Furthermore, the condition that firm savings always have to be non-negative induces the constraint

$$I_{i,t} + B_{i,t} + \mathbf{D}(I_{i,t}) \leq (1+r)S_{i,t} + \Pi^*_{i,t} - W^f. \tag{19}$$

It should be noted that due to the dependence of the manager remuneration on the operating profit, the dividend $D_{i,t} = \mathbf{D}(I_{i,t})$ (see (7)) is a function of the real investment in t. In order to determine the optimal level of real investments and buybacks, $I_{i,t}$ and $B_{i,t}$, in each firm the manager calculates the estimated expected marginal effect of both types of investments on her objective function (18).

As a first step in estimating the marginal return of current real investment the manager determines how her future income stream is affected by a marginal change in the operating profit of the current period. Such a change does not only affect the manager's current remuneration (through the profit based part of $W^m_{i,t}$) but also future remunerations. An increase in the firm's operating profit increases the firm's savings and therefore the interest the firm receives/pays in future periods. This affects future operating profits of the firm and thereby future remunerations of the manager. Denoting by η the estimated marginal effect of a change in the current operating profit on the manager's objective function J_i we obtain

$$\begin{aligned}
\eta &= \gamma \left(1 + r \sum_{s=1}^{\infty} e^{-(\rho+\omega_i)s} \frac{\partial S_{i,t+s}}{\partial \Pi^o_{i,t}} \right) \\
&= \gamma \left(1 + r(1-\gamma) e^{-(\rho+\omega_i)} \sum_{s=0}^{\infty} e^{-(\rho+\omega_i)s} (1 + r(1-\gamma))^s \right) \\
&= \gamma \left(1 + \frac{r(1-\gamma)e^{-(\rho+\omega_i)}}{1 - e^{-(\rho+\omega_i)}(1 + r(1-\gamma))} \right). \qquad (20)
\end{aligned}$$

It can be seen that the estimated size of the marginal effect is actually constant across periods. As a second step the manager needs to obtain an estimate of the increase in the future stream of firm profits that is induced by a successful innovation in the current period. The manager estimates this under the assumption that the additional profit generated by an increase of the own productivity by the factor μ is constant across periods. This clearly is a simplification since the actual increase in future period profits triggered by the current innovation might change if additional innovations of the firm or its competitors follow later on. Based on these assumptions such an increase in the profit can be estimated by

$$\Delta\Pi_{i,t} = \Pi^*_{i,t}\left(\frac{w}{\mu A_{i,t}}, \Sigma_{C,t} + \frac{w}{\mu A_{i,t}} - \frac{w}{A_{i,t}} \right) - \Pi^*_{i,t}\left(\frac{w}{A_{i,t}}, \Sigma_{C,t} \right).$$

where $\Pi^*_{i,t}(.)$ is given by (4). The expected marginal change of the managers objective J_i with respect to an increase of real investment is then calculated under the assumption that all future operating profits and dividends are positive.

Taking into account the arrival rate of productivity enhancing innovations given by (5), this yields

$$\begin{aligned} MV^I_{i,t}(I_{i,t}) &= \eta \left(\frac{\partial\ \alpha\left(1-e^{-\lambda_i\sqrt{I_{i,t}}}\right)}{\partial I_{i,t}} \sum_{s=1}^{\infty} e^{-(\rho+\omega_i)s}\Delta\Pi_{i,t} - 1 \right) \\ &= \eta \left(\frac{\alpha\lambda_i e^{-(\rho+\omega_i)}}{2(1-e^{-(\rho+\omega_i)})\sqrt{I_{i,t}}} \Delta\Pi_{i,t} e^{-\lambda_i\sqrt{I_{i,t}}} - 1 \right). \end{aligned} \tag{21}$$

Considering the expected marginal change of the managers objective J_i with respect to share buybacks B_{it}, the manager estimates the impact of a buyback on the financial market for the current period[11], but simultaneously assumes that $B_{i,t}$ has no impact on any future stock values $V_{i,t+s}$, for all $s > 0$. Since share buybacks do not reduce the firm's operating profit in period t, there are no negative implications of a buyback for the manager's remuneration in that period, which is an important difference to the case of real investment discussed above. Nevertheless, buybacks do reduce the firm's savings in future periods, which affects the profit-based remuneration of the manager through the interest channel. The expected marginal value of the share buyback for the manager is therefore given by

$$\begin{aligned} MV^B_{i,t}(B_{i,t}) &= \beta_i \tfrac{\partial V_{i,t}}{\partial B_{i,t}} - (\eta-\gamma). \\ &= \beta_i \tfrac{X_{2,i,t}}{\sqrt{X^2_{1,i,t}+4(1+r)X_{2,i,t}B_{i,t}}} - (\eta-\gamma). \end{aligned} \tag{22}$$

Since $\lim_{I\to 0} MV^I_{i,t}(I) = \infty$, it follows that real investment is always positive. Furthermore, if under the managers optimal choice both types of investments are positive, we must have $MV^I_{i,t}(I^*_{i,t}) = MV^B_{i,t}(B^*_{i,t})$ and, if the marginal values are positive under this optimal choice, it follows that budget constraint (19) is binding. Furthermore, both marginal values decrease with an increasing investment level. Denoting by $B^{max}(I)$ the value of $B_{i,t}$ such that for $I_{i,t} = I$ the budget constraint (19) holds as equality, then it follows from these arguments that the optimal real investment is determined by the equation

$$MV^I(I^*_{i,t}) = \max[0, MV^B(B^{max}(I^*_{i,t}))].$$

If $MV^B(B^{max}(I^*_{i,t})) \geq 0$, then $B^*_{i,t} = B^{max}(I^*_{i,t})$, otherwise $B^*_{i,t} = \inf\{B \geq 0 : MV^B(B) < 0\}$, which might also be zero.

The chosen real investment $I^*_{i,t}$ then determines the actual operating profit in period $\Pi^o_{i,t}$ and the probability of an increase of the firm's productivity at the end of the period (see the timeline in Section 2.2). The expenditure for buybacks $B^*_{i,t}$ is observed by the financial market participants and influences their expectations about the future stock prices (see (12)). It also affects the demand for shares on the financial market (see (13)).

[11] It should be noted that $B_{i,t}$ is determined before the financial market in period t clears.

3 Baseline Scenario and Empirical Validation

As a basis for the following economic analysis we first develop a baseline scenario which generates output that matches empirical regularities observed in the literature.[12] Following the usual procedure for empirical calibration of an agent-based model, we set parameters for the baseline scenario such that a relevant set of empirical stylized facts can be reproduced.[13] Given the focus of our analysis on the relationship between managerial compensation and real versus financial investment decisions we use targets with respect to these issues that have been recently established by empirical work using European firms. In particular, Kotnik et al. (2017) analyze data from 227 large publicly traded companies listed in the S&P Europe 350. They find that on average the share-based pay accounts for 51% of total CEO compensation. Furthermore, Sakinc (2017) examines the relative size of investments in R&D and share buybacks of 298 European firms in 2015 and finds that the total expenditures for R&D were approximately 136 Billion € compared to approximately 60 Billion € spent in total for purchasing common stock. Both amounts were substantially less than the approximately 268 Billion € that was paid out as dividends.[14] Since real investments in our model translate to increases in firm productivity we compare the growth rate of the productivity parameter $A_{i,t}$ in our model with the average growth rate of labor productivity in the manufacturing industry. Relying on OECD data for the growth rate of value added per hour worked in the manufacturing industry in the time interval between 1995 - 2016 we find 2.7% as the average across all 28 (current) EU Member States.

In the framework of our model we assume that investment decisions and dividend payouts are determined on a quarterly basis, which means that one time period in our model corresponds to one quarter. Based on this assumption, the job separation rate has been determined as $\omega_i = 0.025,\ i = 1, .., 10$ implying that the manager assigns a 10% probability to be fired in a given year. Empirical evidence with respect to these expectations and also about the average total length of CEO tenures at a company are hard to find in the literature. Data reported in Cziraki and Xu (2014) implies that in the U.S. the average duration of a CEO contract is about 3.25 years, but that a substantial percentage of CEOs get renewals on their contracts. Given this observation and the anecdotal evidence that CEO turnover tends to be higher in the U.S. than in European companies our choice of an average tenure of 10 years for a CEO seems reasonable. In our analysis we will also consider scenarios with larger job separation rates. The interest (and the discount) rate is fixed at 1.2% corresponding to low interest scenarios as has been experienced in recent years. Following the insights from the majority of the empirical literature that ceteris paribus buybacks tend to

[12] The model has been implemented in the simulation framework FLAME to generate the simulation data presented in the following sections (see `www.flame.ac.uk`). The simulation data has been processed and analyzed using the statistical software package R, see R Core Team (2017).

[13] Developing methods for rigorously estimating the parameters in agent-based models is currently an active field of research, see e.g. Grazzini et al. (2017); Guerini and Moneta (2017) orBarde and van der Hoog (2017).

[14] All figures are taken from Figure 1 in Sakinc (2017).

be associated with a positive change in the share price we set $\theta_t = 0.75,\ \forall t$ and thereby assume that the majority of stock market participants are optimists.

In all simulation runs we initialize the industry with 10 firms with homogeneous productivity. Over time the firms typically evolve to be heterogeneous and, as discussed in Section 2.3, some firms might become inactive and stop producing if their productivity lags too much behind that of their competitors. Since we do not model firm entry, in the very long run this might lead to a strong concentration of the industry, but in our analyses we will only consider time horizons during which a large majority of firms stays active in the market. The homogeneous initialization of all firm productivities is crucial in order to be able to isolate the effect of differences in firms' remuneration schemes and manager separation rates on the firms' investment behavior and (long run) performance. We always consider ensembles of 100 simulation runs for a given scenario and parameter setting in order to capture the stochastic nature of the emerging dynamics.

The baseline parameterization of the model is given in Table 2 in Appendix A. In addition to the parameters also the initialization of the different variables has to be considered. The initial values for wages and productivities are both normalized to 1, which implicitly determines the units of measurement for prices and quantities. The beliefs of financial market participants about the stock value of each firm has an important impact on the dynamics of the model. More precisely, in order to determine traders' expectations in $t = 1$ according to (12) an initial value of $V_{i,0}$ has to be determined. In Figure 1 we show the dynamics of the mean of the distribution of firm stock values for three initializations of traders' expectations about the firms' share prices.[15] As can be clearly seen only for an initialization of $V_{i,0} = 0.005$ the average share price does not exhibit a trend but stays approximately constant. Hence, the initial beliefs of traders in this scenario correspond well to the actual share prices that emerge as a result of the profits and dividends realized over time in the market. Hence, in what follows we will use $V_{i,0} = 0.005, i = 1, .., 10$ as the initialization for all simulation runs.

In Figure 2 we show the evolution of firm productivity, average investments in R&D, and average investments in share buybacks for the baseline scenario. In addition to the population means of these variables we also depict the corresponding standard deviation of the population distribution at each point in time (dotted lines). Due to the homogeneous initialization of the firms this measure of heterogeneity is zero at the beginning of each run. However, due to the different success of firms in obtaining productivity increasing innovations firms quickly become more heterogeneous not only with respect to productivity but also with respect to the amount they invest in R&D and share buybacks. This heterogeneity emerges despite the fact that in the baseline scenario all firms use the same remuneration schemes and hence there are no systematic differences in manager incentives. Turning to the reproduction of stylized facts, from panel (a) of Figure 2 we obtain that average productivity after 200 periods (which corresponds to 50 years) is approximately 3.9. Hence the average growth rate

[15] In all figures with time series we show the median across 100 batch runs of the depicted variables.

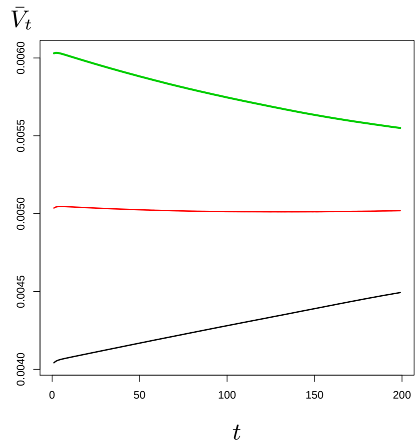


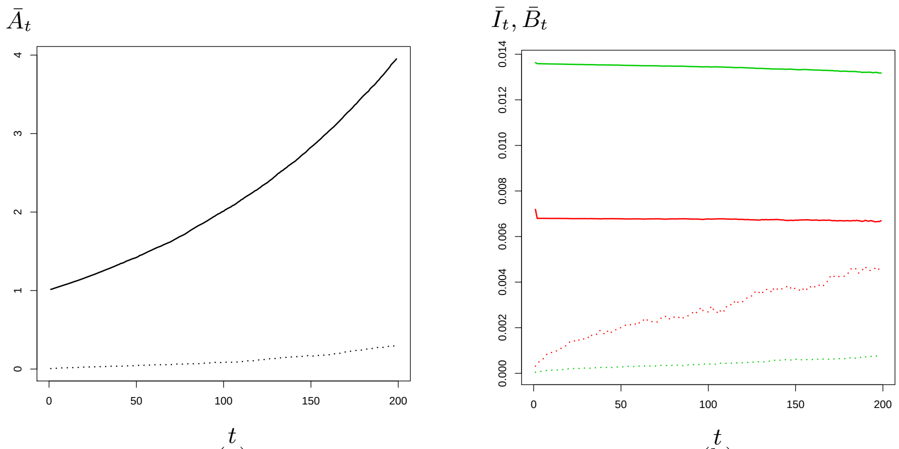
Figure 1: Dynamics of the average share price for the baseline parameterization for different initial expectations about the share price: $V_{i,0} = 0.004$ (black), $V_{i,0} = 0.005$ (red) and $V_{i,0} = 0.006$ (green).

Indicator	Simulation Output (%)	Empirical Target (%)	Source
Productivity Growth Rate	2.76 (0.0383)	2.7	OECD Data
Fraction of share based component of total manager compensation	0.48 (0.0007)	0.51	Kotnik et al. (2017)
Ratio of industry-wide R&D investment to total expenditures for share buybacks	1.95 (0.0501)	2.26	Sakinc (2017)
Ratio of total expenditures for share buybacks to total dividend payouts	0.16 (0.0027)	0.22	Sakinc (2017)

Table 1: Comparison of baseline simulation results with empirical stylized facts.

of productivity is 2.76%, which is very close to the target of 2.7% obtained from OECD data. Similarly, from panel (b) it can be clearly seen that the average R&D expenditures are about twice as high as expenditures for share buybacks, which matches the empirical target described above.

In Table 1 we compare the average values for different indicators obtained in period $t = 200$ in our baseline scenario with the empirical target values. For the simulation results we provide for each indicator the mean as well as, in brackets, the standard deviation across the batch runs. This table shows that our model qualitatively reproduces all the empirical observations and for several indicators even provides a close quantitative fit despite the fact that no systematic rigorous calibration or estimation was carried out. The intention of our following analysis is to provide qualitative insights into the implications of changes in the remuneration schemes and the expected manager tenure, rather than providing quantiative predictions. Based on the results of this brief empirical validation of the model, it seems well suited to provide meaningful insights into the dynamic mechanisms that emerge from such changes in the manager incentives.



(a) (b)

Figure 2: Dynamics of the (a) average firm productivity and (b) the average investments in R&D (green) and share buybacks (red). The dotted lines always indicate the standard deviation of the population distribution of these variables.

4 Economic Analysis

Having established a baseline scenario, we now address our main research questions. In particular, we first analyze the impact of changes of the remuneration scheme (β_i) and of the expected duration of manager tenure (ω_i) in a single firm on the performance of this firm, on the income of that firm's manager, as well as on the industry dynamics. In these experiments the corresponding parameters will be varied only for a single firm, which in our case is always labeled as firm 1. Afterwards, we consider scenarios in which the corresponding changes are implemented by all firms in the industry and explore how this affects the industry dynamics and the income of all managers. Finally, we examine the implications of changes in the expectations on the financial market (about the impact of share buybacks on the future share price) for firm behavior and industry dynamics.

4.1 Increasing the share based manager remuneration component in a single firm

To study the implications of an increase in the share-based manager compensation we now compare different scenarios in which the number of shares granted to the manager of firm 1 in each period is varied. Below we refer to this firm as the *target firm*. More precisely, we compare runs for the baseline setting $\beta_1 = 0.3$ with runs for $\beta_1 = 0.6$ and $\beta_1 = 0.9$. In line with empirical observations that the increase in the share-based compensation has been associated with an increase in total manager compensation we assume that the increase in β_1 is not compensated by a decrease in the other components of the remuneration scheme. This increase in share-based compensation does not come with

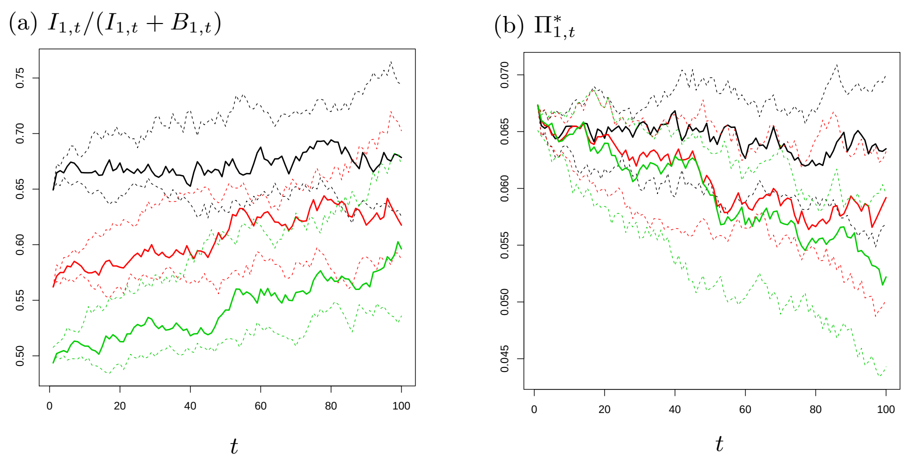


Figure 3: Time series of the ratio of R&D investments to total investments (panel (a)) and profit (panel (b)) of firm 1 for $\beta_1 = 0.3$ (black), $\beta_1 = 0.6$ (red) and $\beta_1 = 0.9$ (green). The dotted lines indicate the 25th and 75th percentiles of the distribution across batch runs.

any direct costs to the firm (in terms of the operating profit), but of course it might in principle lead to an increase in the number of shares on the market and thereby to a dilution of the share price. As we will see below, due to changed manager behavior this effect however does not occur in our model. Associating the increase of β_1 with a decrease in the fixed manager salary would not affect the qualitative results presented below.

In Figure 3 we show the dynamics over 100 periods (i.e. 25 years) of the ratio of R&D investment to total investment (i.e. R&D investment plus expenditures fo buybacks) of firm 1 as well as the evolution of the target firm's profit for the three considered values of β_1. Considering the 25% and 75% quantiles around the batch run medians highlights that there is substantial heterogeneity across runs. Since we are considering a single firm, the performance of which is strongly driven by the (stochastic) success of its innovation projects, such high variance has to be expected. Nevertheless, a clear pattern can be observed. An increase of the values of β_1 on average leads to a reduction of R&D investments relative to expenditures for share buybacks. As a result of this, the market profit of firm 1 under a large share-based remuneration component ($\beta_1 = 0.9$) decreases over time and develops substantially worse than under the baseline scenario, in which firm 1 chooses the same value of $\beta_1 = 0.3$ as its competitors. As can be clearly seen the negative effect of a large value of β_1 on the firm profit becomes more pronounced over time, whereas the difference between the three scenarios with respect to the ratios of R&D investment to total investment decrease over time. The fact that an increase of β_1 initially increases the manager's incentive to invest in buybacks follows directly from (22).[16] However, the emerging dynamics

[16] This holds true only if the coefficient of β_i in (22) is positive, i.e. if the expected impact of a buyback on the share price is positive and sufficiently large. However, this is the only relevant case for us, since otherwise we are in the case of zero buybacks.

of the investment ratio and the implications for the evolution of share prices and manager income are less clear.

To obtain a clearer understanding of the significance of the observed effects and of the underlying mechanisms, we show in Figure 4 several boxplots with the distributions of several key indicators at $t = 100$ across the batch runs.[17] Panels (a) and (b) indicate that the effect of an increase of β_1 on the R&D investment share and the profit of the target firm is clearly significant. Panel (c) highlights that the smaller (relative) R&D investments of the firm under larger values of β_1 leads to a slower increase of productivity of the target firm. In particular, this implies that the productivity of the target firm on average grows slower than that of its competitors (which all use $\beta_i = 0.3$) and since the wage grows at the same rate as the average productivity in the industry, this induces increasing unit costs and decreasing competitiveness for the target firm. This explains the negative effect of a large value of β_1 on the profit of firm 1 and also why this effect increases over time.

The lower profit under a higher share-based remuneration component negatively affects the share price through the dividend channel (see Figure 4(d)) even though the increased incentive for the manager to invest in buybacks under a large value of β_1 indeed implies that in such a scenario fewer shares are traded on the market (see panel (e)). Whereas this generates an upward pressure on the firm's share price, it is dominated by the effect that the lower profits induce reduced expectations with respect to dividends by the financial market participants. Figure 4(e) also shows that in our model emitting more shares in order to remunerate the manager does not lead to an increase of the total number of shares on the market, since this share emission is over-compensated by larger buybacks carried out by the firm. Hence, there is no dilution of the share price, however the shareholders are nevertheless negatively affected by such a change in the remuneration scheme since the shift in investment incentives has detrimental long-term implications for the profit earned and the dividend paid out to shareholders. It should be stressed that this effect emerges only after some time. When comparing the share price at early stages of runs (e.g. after 5 periods, not shown here), the mean values for $\beta_1 = 0.6, 0.9$ are above that for the baseline of $\beta_1 = 0.3$.

The observation that under higher values of β_1 the share price of the target firm over time decreases relative to the level it would have under the baseline also explains the observation in Figure 3(a) that the ratio of R&D investment to total investment over time seems to converge between the three scenarios: a lower share price reduces the incentives for managers to invest in share buybacks (see (22) and (15,16)) and shifts the ratio towards a higher R&D investment share. Simulation results not shown here suggest that in the very long run (after 200 periods) this effect becomes so strong that the ratio of R&D investment to total investment is larger under $\beta_1 = 0.9$ than under $\beta_1 = 0.3$.

Finally, as is highlighted in panel (f) of Figure 4, the implication of an

[17] In Appendix B we report p-values from Wilcoxon tests, which indicate that with one exception all the differences between the distributions for different values of β_1, which we discuss here, are highly significant. Only the equality between the distributions of share prices for $\beta_1 = 0.6$ and $\beta_1 = 0.9$ (see panel (d)) cannot be rejected at a 5% level.

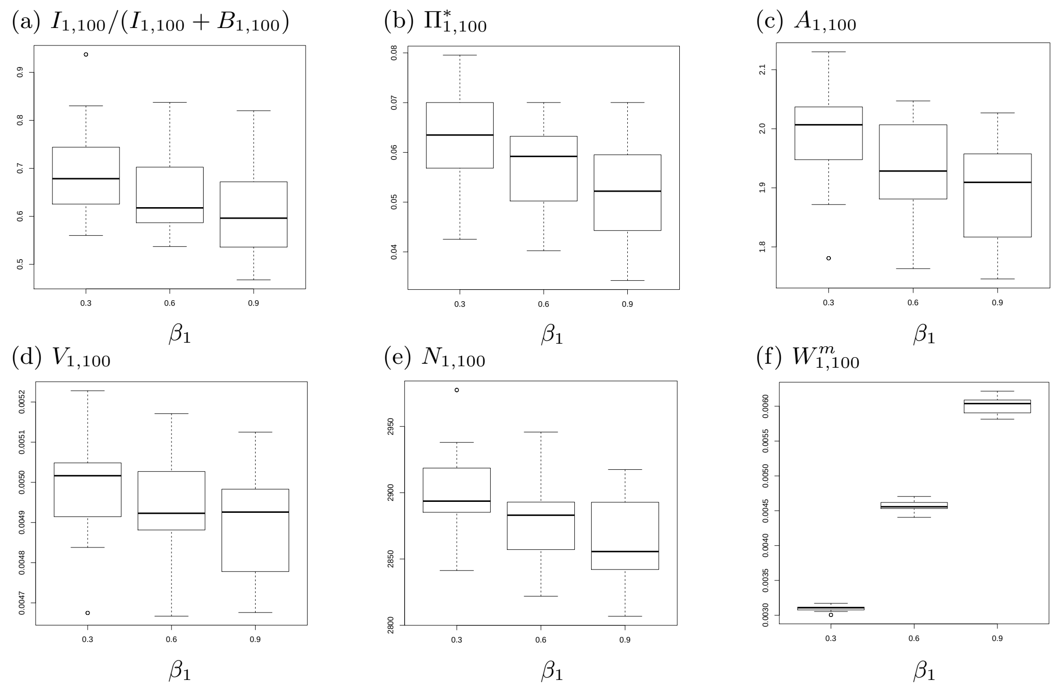


Figure 4: Comparison of key indicators of the target firm 1 at $t = 100$ for different values of β_1: (a) ratio of R&D investment to total investment; (b) profit; (c) productivity; (d) share price; (e) number of shares on the market; (f) manager income. The boxplots show the variation across different batch runs.

(a) $\Pi^*_{-1,100}$ (b) $V_{-1,100}$ (c) $W^m_{-1,100}$

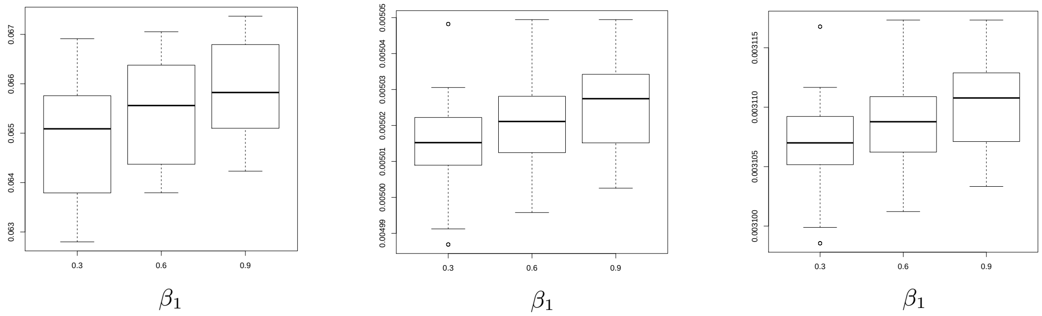


Figure 5: Comparison of the average of key indicators of the competitors of firm 1 at $t = 100$ for different values of β_1: (a) profit; (b) share price; (c) manager income.

increase of β_1 on the income of the manager is clearly positive also after 100 periods. The positive direct effect of being able to sell a larger amount of shares on the market outweighs the negative impact of the adjusted investment strategy on the share price.

Having examined the implications of an increase of β_1 for the target firm, let us now briefly turn to the effect on the competitors. As discussed above, under a larger share-based remuneration component the target firm over time tends to loose competitiveness and intuitively this should have positive implications for the other firms on the market. Figure 5 confirms this intuition. As can be seen in panel (a) of the figure, the reduced competitiveness of the target firm 1 for large values of β_1 implies a significant increase in the profits of the competitors after 100 periods. These higher profits imply that the competitors pay higher dividends, but also lead to an increase in the amount these firms spend on share buybacks.[18] Both effects generate an upward pressure on the share price, and as can be seen in Figure 5(b) the share price of the competitors indeed is positively affected by an increase in the share-based remuneration component of firm 1. Due to their profit-based and share-based components of their remuneration schemes the managers of the competitors indirectly benefit from an increase of β_1 although their own contract is not affected (see panel (c)).

4.2 Decreasing the expected tenure of the manager in a single firm

The results discussed in the previous section show that an increase in the share-based remuneration component of the manager induces a shift of firm investment towards share buybacks, which although pushing the share price upwards in the short run, has detrimental implications for the firm's profits as well as for its share price in the medium and long run. In this section we analyze to

[18]The boxplot comparing the average number of shares of firms $i = 2, .., 10$ on the market at $t = 100$, which is not shown here, indicates that for higher values of β_1 fewer shares of these competitors remain on the market.

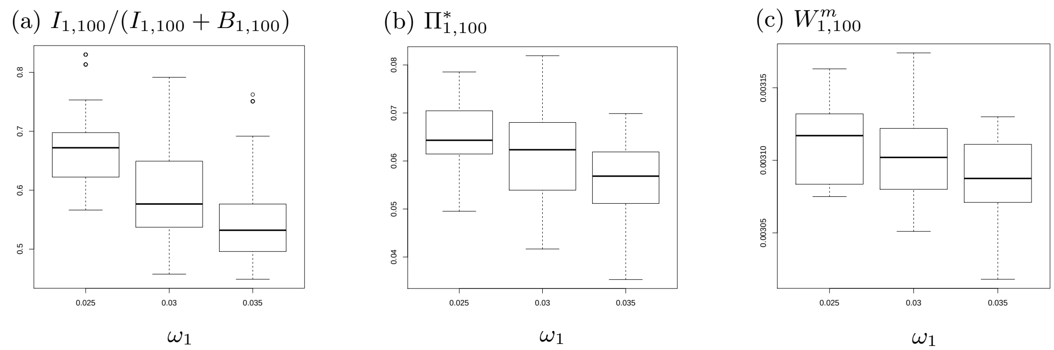


Figure 6: Comparison of key indicators of firm 1 at $t = 100$ for different values of ω_1: (a) ratio of R&D investment to total investment; (b) profit; (c) manager income.

what extent similar effects can arise even without changes in the remuneration scheme, if a reduced expected duration of the manager's tenure shifts her attention more towards the short term performance of the firm. Taking again our baseline scenario as the benchmark, we now compare it with scenarios in which the manager's job separation rate at firm 1 is larger than the baseline value. Considering (21) and (22) shows that such a change ceteris paribus decreases the expected marginal value of R&D investment for the manager, whereas the expected marginal value of a buyback is only affected in the sense that the manager now values firms savings less, and is therefore increased. Hence, one should expect a shift in investments from R&D towards buybacks. As can be seen in Figure 6(a) this effect is persistent over 100 periods and a firm with a faster (expected) turnover of managers is characterized by a smaller share of R&D investment. Through similar mechanisms to those discussed in the previous section, this shift in investment leads to smaller profits (panel (b)) and eventually also to smaller share prices for the target firm. Since the remuneration scheme of the manager of the target firm is the same across all three considered scenarios, it follows directly that the average manager remuneration is smaller after 100 periods, compared to the baseline, if the expected manager separation rate is larger. This is confirmed in Figure 6(c). Hence, in our setting an increase in the manager turnover has negative implications both for the shareholders of the target firm and for the expected manager income.

4.3 Effects of industry-wide changes in remuneration schemes and in the expected tenure of managers

The analysis in Section 4.1 has clearly shown that a single firm which increases the stock-based remuneration component of its manager to a higher level than that used by its competitors faces detrimental long-run effects in terms of competitiveness, firm profits and also its share price. Nevertheless, such a change is very attractive from the manager's perspective, whose income increases. Taking into account potential competition effects for the best managers, which is not explicitly captured in our model, or the orientation on short-term goals might nevertheless induce firms to adopt such remuneration schemes with a higher share-based component, in particular if such changes are also carried out by the firm's competitors. Indeed, as discussed in the Introduction, in many industries a general trend towards a more strongly share-based manager remuneration has been observed. This gives rise to the question to what extent the implications of an increase of the share-based component change if such a measure is not carried out by one firm in isolation, but rather in a synchronized way by all firms in the industry.

To address this question we now consider scenarios in which all firms share a common value β of their parameter $\beta_i, i = 1, .., n$. In particular, we compare the baseline $\beta = 0.3$ with the scenarios $\beta = 0.6$ and $\beta = 0.9$, in which all firms move to a more strongly share-based remuneration of managers. Again, we consider the implications of such a change after 100 periods. Figure 7 shows the distribution of median values of all firms in the market across the batch runs for the three scenarios. As expected, a larger value of β implies a shift of the firms' investment from R&D towards share buybacks (panel (a)). This leads to a significant decrease in the average industry productivity (panel (b)). However, since this decrease of the growth rate (on average) is uniform across firms and also induces lower wage growth rates, unit costs, competitiveness and profits of the individual firms are not negatively affected.[19] Hence, there is also no negative impact of this investment shift on share prices through the dividend channel and therefore the increased incentives for share buybacks now induce an *increase* in the average share price in the long run (panel (c)). The combination of an increase in the number of shares each manager receives and the increased share price induces a substantially larger income for the managers for larger values of β.

This analysis shows that there is a crucial difference between scenarios in which a single firm increases its own level of β_i and scenarios in which this is done by all firms in the industry. In the former case the shareholders are negatively affected by the change in the long run, whereas in the latter case not only the managers but also the shareholders profit in the long run from such a change in remuneration schemes. However, the industry-wide increase of the β parameter negatively affects the average productivity growth rate. This implies also a lower growth rate of wages and since average market prices in our setting are the same across the three scenarios,[20] this means that the purchasing power of workers is lower for larger β values. Although we did not carry out a systematic welfare analysis, this observation makes clear that an increase of the β positively affects the manager and shareholder incomes, but can be associated to a negative effect of the wage-earners' purchasing power.

Similar to the exploration of the effect of an industry-wide increase of the parameter β we have also analyzed scenarios in which the job separation rate of managers increases uniformly for all firms in the industry, i.e. we have compared

[19] The boxplot for firm profits, not shown here does not exhibit any significant differences between the three scenarios.

[20] Due to the assumption that wages grow at the same rate as average productivity, average unit costs and therefore also average prices are independent from the productivity growth rate.

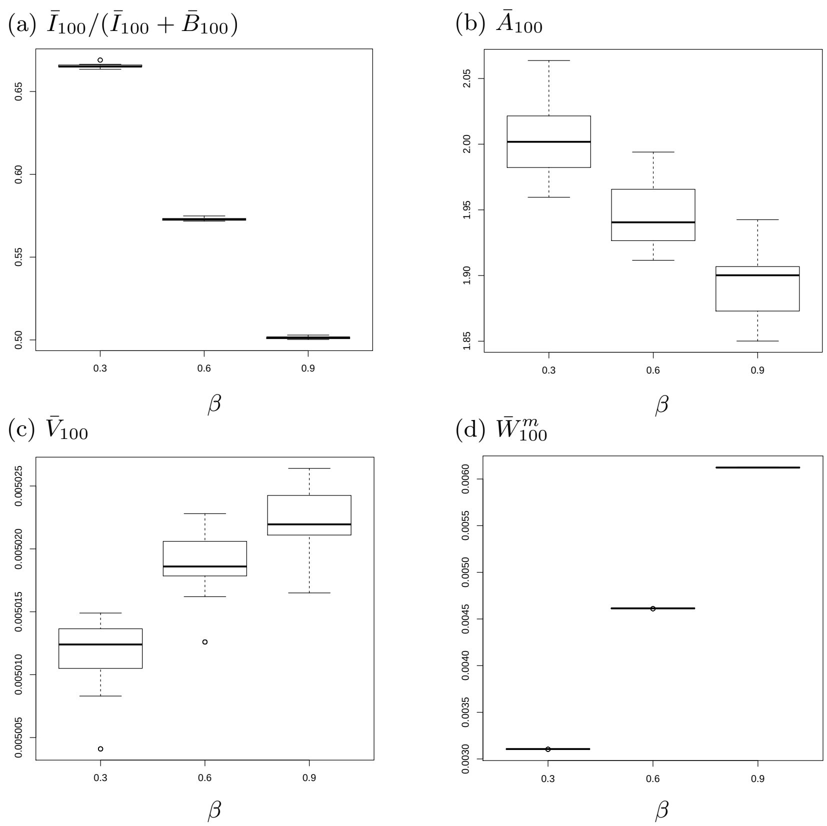


Figure 7: Comparison of the average of key indicators in the industry at $t = 100$ for different values of β: (a) ratio of industry-wide R&D investment to industry-wide total investment; (b) productivity; (c) share price; (d) manager income.

the baseline to scenarios with $\omega = 0.03$ and $\omega = 0.035$, where $\omega_i = \omega \; \forall i = 1,..,n$. The effect of such industry-wide increases of ω_i qualitatively matches those observed for an increase in β. In particular, we observe that a higher value of ω induces a lower share of R&D investment, lower average productivity, higher average share prices and higher average manager income at $t = 100$. We refrain from showing the corresponding boxplots since qualitatively they are very similar to those shown in Figure 7. Overall these findings show that an increase in the (expected) manager turnover (higher ω) at all firms in the industry has positive implications for shareholders and the managers' average income, but is detrimental for the firms' innovative activities. Following the arguments discussed above this should also have negative implications for purchasing power of consumers.

4.4 How do market expectations about the effects of share buybacks affect the industry dynamics?

The incentive of a manager to invest in share buybacks does not only depend on her remuneration scheme and her expected remaining job tenure, but also on the expectations of the traders on the financial market with respect to the impact a buyback has on the future share price.[21] Formally this can be seen by observing from (22) that the expected marginal value of a buyback for the manager depends positively on $X_{2,i,t}$, which is an increasing function of the average market sentiment $\theta_t \kappa_o + (1 - \theta_t)\kappa_p$ (see (16)). Hence, the amount of buybacks and R&D investments, and thereby the dynamics of the industry and of key market variables, is influenced by the fraction of optimists (i.e. traders who expect that buybacks lead to higher share prices) respectively pessimists on the financial market.

In our baseline scenario we have assumed that optimists outweigh pessimists ($\theta = 0.75$). In simulation runs not reported here we have verified that under a 'neutral' market sentiment ($\theta = 0.5$) managers would not engage in any share buybacks if the other model parameters are chosen according to the baseline setting of the model.[22] To explore the impact of the expectations on the financial market we compare the baseline with scenarios in which the number of optimists is further increased, which means that on average market participants anticipate a stronger positive effect of buybacks on future share prices. Figure 8 shows that such a change in expectations indeed has a significant effects on the investment pattern of the firms as well as the long term income of shareholders and managers. In particular, if financial market participants are more optimistic about the effect of buybacks on share prices, then this has a very similar effect as an industry-wide change of a firm parameter that positively affects the managers' incentives to invest in share buybacks. In particular, the growth rate of firm productivity is reduced, whereas the (medium and long-run) levels of

[21] Note that we assume that the manager is able to correctly estimate what the average trader's expectations are, and takes this into account when deciding hom much to spend on real versus financial investments.

[22] It should be noted that this observation is not self-evident, because even under a neutral market sentiment a buyback has a direct positive effect on the share price by reducing the number of shares traded on the market.

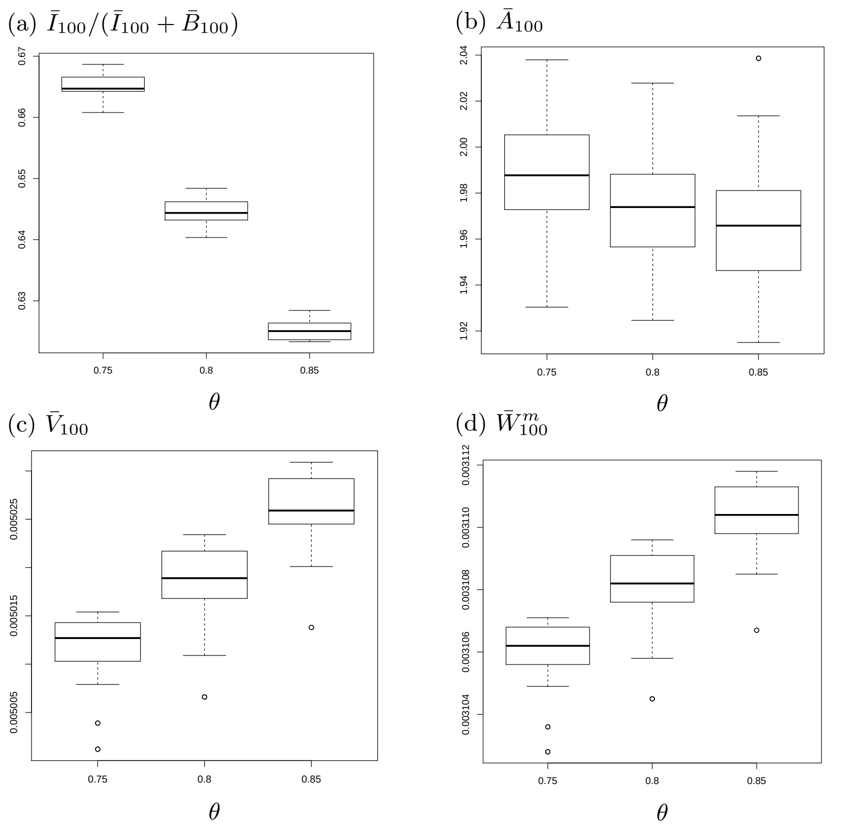


Figure 8: Comparison of the average of key indicators in the industry at $t = 100$ for different values of the fraction of optimists on the financial market (θ): (a) ratio of industry-wide R&D investment to industry-wide total investment; (b) productivity; (c) share price; (d) manager income.

manager income and share price are positively affected. We like to stress that the effect of the financial market expectations on the share price dynamics is based on a feedback between the financial and the real market. The behavior of the firms on the real market changes in response to different expectations of financial market participants and this in turn influences the number of shares traded and the share price.

The insight that the fraction of optimists on the financial market has significant effects on the industry dynamics might raise concerns that our assumption that θ_t stays constant over time is overly restrictive and that endogenizing this fraction could change the qualitative insights discussed so far. To address this issue we present in Appendix C an extension of our model in which the fraction of optimists adjusts over time based on the relative prediction error of pessimists versus optimists in the current period. As demonstrated in that Appendix it turns out that the fraction of optimists stays close to our baseline level in such an extension and the qualitative findings about the effect of changes of key parameters for an individual firm and for all firms all stay intact.[23]

5 Conclusions

In this paper we have employed a heterogeneous agent model, which captures key properties of the feedback between firms investment decision, the industry dynamics and the associated dynamics on the financial market, to study the implications of changes in the share based remuneration component of the firm manager as well as the expected duration of the manager's tenure. We have shown that if a single firm increases the share based remuneration of the manager, without its competitors following suit, this has negative implications for the medium and long run competitiveness of the firm and also for its share price, whereas the manager income increases. In case such a change in the remuneration scheme is adopted by all firms in the industry, both share prices and manager income increase, however the growth rate of the average productivity in the industry is lower, and the wage rate of workers is negatively affected. Very similar conclusions arise if a reduction in the expected tenure of the manager is considered, with the only exception that if such a change occurs only at a single firm this is actually detrimental for the expected per-period manager income. Furthermore, we have shown that a change in the expectations of financial market trader, which makes them more optimistic about the impact of share buybacks on future share prices, also induces higher share prices and manager income, but lower productivity growth rates.

Our results highlight mechanisms by which manager remuneration schemes and financial market sentiments influence the speed of technological change and the growth of (real) wage rates. The fact that an industry wide adoption of a stronger orientation towards share based remuneration is beneficial for

[23] We have checked the robustness of our qualitative findings also with respect to other variations of the model, e.g. a version in which expenses for buybacks are subtracted when calculating the operating profit, and alternative parameter constellations. These experiments indicate that our findings are very robust with respect to such variations of the model setup and parametrization.

share holders, whereas similar measures taken by a single firm has negative implications for long term share prices, suggests that there is potential merit of collusion between owners (and managers) of competing firms in an industry to adjust their remuneration schemes in a coordinated way. Our results however also highlight that such a move is not in the interest of fostering the speed of technological change and economic growth, and comes at the expense of wage-earners' purchasing power. This hints at a possible linkage of our results to the more broader discussion on the deterioration of the labour share in many industrialized countries.

Whereas the model developed in this paper breaks new ground by linking a financial market model with heterogeneous traders to an industry model – such that dividend payouts to shareholders are endogenously determined by the interaction on the real market – it is based on a number of simplifying assumptions. The model does not include any taxes, which means that incentives for share buybacks which are generated by a different tax treatment of income from wages and dividends compared to capital gains from share ownership cannot be addressed in this modelling framework. Also, from a more technical perspective, in this model it has been assumed that when managers estimate the effect of R&D investments on their own expected future income, they do not take into account how changes in the firm's competitiveness might influence future share prices through the dividend channel. Designing a more sophisticated model of the manager's expectations formation taking such aspects into account is certainly challenging, but would be a valuable extension of the present framework.

Appendix A: Baseline Parametrization

Symbol	Name	Value
β_i	Amount of shares for manager per period	0.3
ω_i	Manager's job separation rate	0.025
δ	Dividend ratio	0.68
ϕ	Dividend expectation smoothing parameter	0.5
ρ	Discount rate	0.003
r	Interest rate	0.003
γ	Share operating profit	0.00005
θ	Fraction optimists	0.75
W^F	Manager salary	0.0016
a^d	Demand sensitivity wrt own price	0.8
b^d	Demand sensitivity wrt competitors' prices	0.2
μ	Productivity growth factor	1.01
α	Max. innovation probability	1
λ	R&D effectiveness	10
κ_o	Impact factor optimists	0.2
κ_p	Impact factor pessimists	-0.2
$\tilde{a}$	Coefficient CARA	0.1
$\tilde{\sigma}$	Coefficient expected standard deviation	0.5
M	Number of financial market participants	10000
n	Number of firms	10

Initialization

Symbol	Name	Value
$A_{i,0}$	Initial firm productivity	1
w_0	Initial wage	1
$N_{i,0}$	Initial number of shares	3000
$V_{i,0}$	Initial share price	0.005

Table 2: Parametrization of the model.

Appendix B: Statistical Tests

In this Appendix we show the significance of the effects of changes of β_1 for key variables of the target firm 1 and of all competitors. In particular, we test the significance of the differences in the distributions for $\beta_1 = 0.3, 0.6, 0.9$ shown in Figure 4 (Table 3) and Figure 5 (Table 4). A Wilcoxon signed rank test is used, which is a pairwise nonparametric test for testing the null hypothesis that two samples stem from the same distribution. We refrain from presenting the Wilcoxon test results for all the other figures in the paper, but the boxplots indicate a similar high level of significance as for the effects of changes of β_1.

Variable	Values	p- Value
$I_{1,100}/(I_{1,100}+B_{1,100})$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 0.00324^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.001315^{***}$
$\Pi^*_{1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 5.995e-07^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.003059^{***}$
$A_{1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 2.586e-07^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.001844^{***}$
$V_{1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 0.0006956^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.1824$
$N_{1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 1.482e-06^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.0001381^{***}$
$W^m_{1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p < 2.2e-16^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p < 2.2e-16^{***}$

Significance levels:
$*$ 0.1, $**$ 0.05, $***$ 0.01

Table 3: P-values of Wilcoxon tests applied to the data underlying the boxplots shown in Figure 4.

Variable	Values	p- Value
$\Pi^*_{-1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 8.737e-06^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.0126^{**}$
$V_{-1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 1.225e-05^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.01498^{**}$
$W^m_{1,100}$	$\beta_1 = 0.3$ and $\beta_1 = 0.6$	$p = 1.722e-05^{***}$
	$\beta_1 = 0.6$ and $\beta_1 = 0.9$	$p = 0.0254^{**}$

Significance levels:
$*$ 0.1, $**$ 0.05, $***$ 0.01

Table 4: P-values of Wilcoxon tests applied to the data underlying the boxplots shown in Figure 5.

Appendix C: Model extension with endogenous fraction of optimistic traders

In the extension we consider a simple adjustment dynamics of the form

$$\theta_{t+1} = \theta_t + \zeta \Delta_t, \qquad \theta \in [0,1]. \tag{23}$$

Here Δ_t denotes the current period's relative prediction error of pessimists versus optimists and $\zeta \geq 0$ is the adjustment speed of the fraction of optimist agents.

The relative prediction error is calculated according to

$$\begin{aligned}\Delta_t &= \tfrac{1}{K}\textstyle\sum_{i=1}^n \left[(V_{i,t} - \mathbb{E}_{p,t-1}[V_{i,t}])^2 - (V_{i,t} - \mathbb{E}_{o,t-1}[V_{i,t}])^2\right] \\ &= \tfrac{1}{K}\textstyle\sum_{i=1}^n \left[\left(V_{i,t} - V_{i,t-2}\left(1 + \kappa_p \frac{B_{i,t-1}}{V_{i,t-1}N_{i,t-1}}\right)\right)^2\right. \\ &\qquad\qquad \left. - \left(V_{i,t} - V_{i,t-2}\left(1 + \kappa_o \frac{B_{i,t-1}}{V_{i,t-1}N_{i,t-1}}\right)\right)^2\right],\end{aligned}$$

with

$$K = \sum_{i=1}^{n} \max\left[(V_{i,t} - \mathbb{E}_{p,t-1}[V_{i,t}])^2, (V_{i,t} - \mathbb{E}_{o,t-1}[V_{i,t}])^2\right]$$

as a normalization constant.

To check the robustness of our qualitative findings in the main text, below we show the results of experiments where, analogous to our analyses in Sections 4.1 and 4.3, the β parameter of a single firm and that of all firms is varied, respectively. No changes to the baseline parametrization have been made and the adjustment speed of θ_t has been set to $\zeta = 10^7$ in order to allow a reasonable speed of change.[24] Alternative values of this parameter have been tested with

[24] This high value is needed because the relative prediction error of pessimists versus optimists as rather small, which is due to the fact that the share prices $V_{i,t}$ are on the order of 10^{-3}. To make θ_t vary between $[0,1]$ we therefore need to scale up the errors.

(a) θ_t (b) θ_t

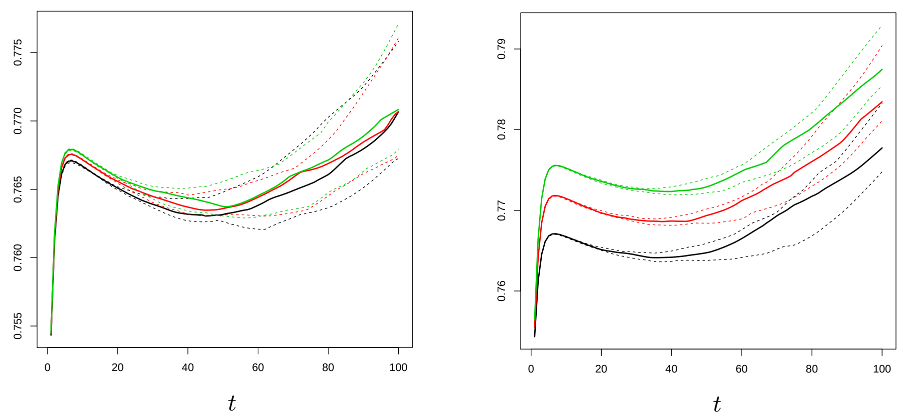


Figure 9: Time series of the fraction of optimists for a variation of the values of the parameter β only for firm 1 (panel (a)) and for all firms in the industry (panel (b)): $\beta = 0.3$ (black), $\beta = 0.6$ (red) and $\beta = 0.9$ (green). The dotted lines indicate the 25% and 75% quantile in the set of batch runs.

similar qualitative results. The initial fraction of optimists is set to the baseline level $\theta_0 = 0.75$.

In Figure 9 the evolution of the fraction of optimists is shown under the variation of only β_1 and of the industry wide level of β. It can be seen that after a rather small initial adjustment the fraction shows a U-shaped pattern, without large fluctuations or deviations from the time-average. Not surprisingly the effect of a change in the β parameter on the dynamics of θ_t is more pronounced if the parameter variation occurs at all firms rather than only at a single firm.

In order to check the robustness of our qualitative findings with respect to this model extension we first consider the variation of only β_1. In Figure 10 we show the analogous boxplots of key variables of the target firms to those provided in Figure 4 under the assumption of a constant fraction of optimists. It can be seen that all boxplots are very similar between these two figures and all qualitative insights which we have obtained are robust with respect to the extension with a dynamic adjustment of θ_t. Similar conclusions arise from comparing Figures 11 and 7 for the variation of the industry wide level of β. In a similar vein, we have also checked the robustness of our results of the implications of changing ω_1 versus the industry wide level of ω. Also these results remain robust when we allow for the endogenous variation of the fraction of optimists θ_t.

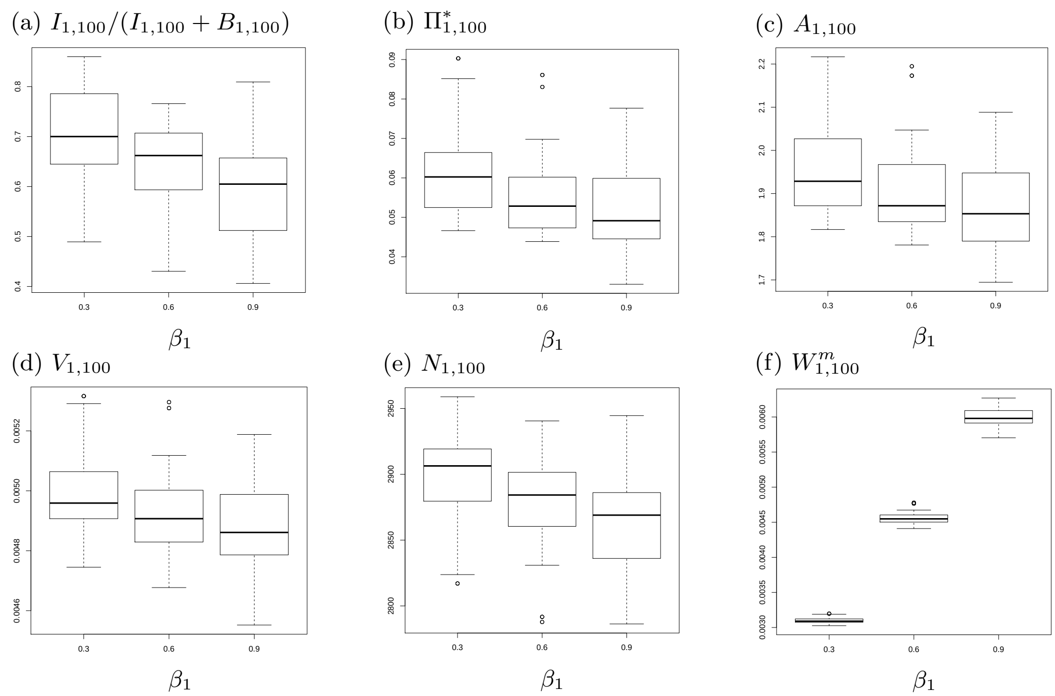


Figure 10: Comparison of key indicators of the target firm 1 at $t = 100$ for different values of β_1, with dynamic adjustment of the fraction of optimists on the financial market: (a) ratio of R&D investment to total investment; (b) profit; (c) productivity; (d) share price; (e) number of shares on the market; (f) manager income. The boxplots show the variation across different batch runs.

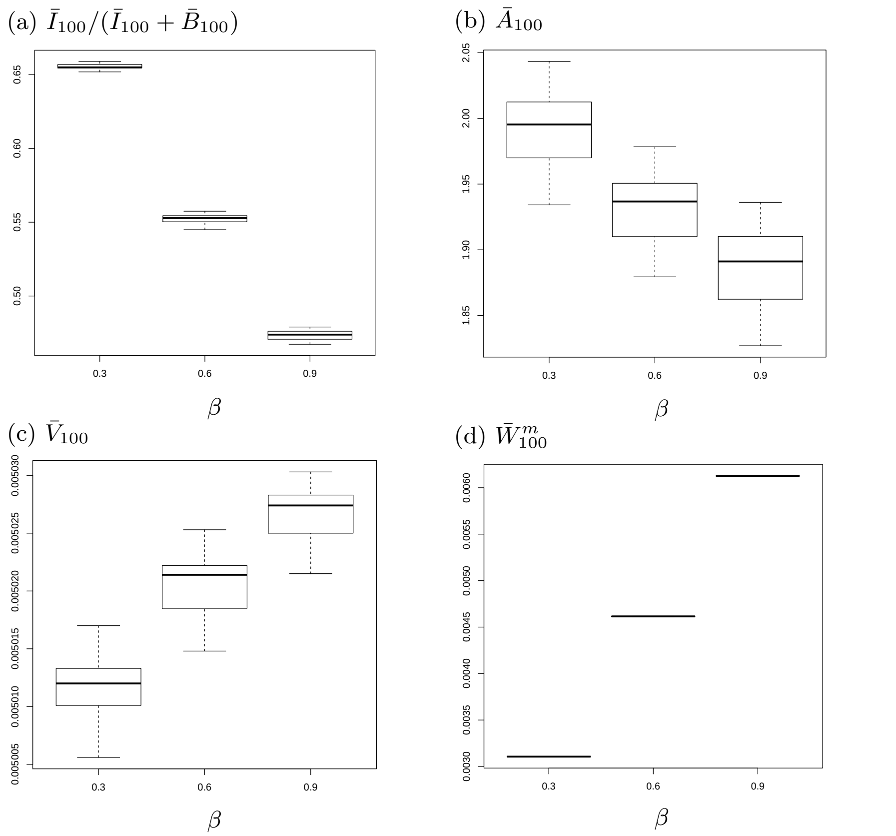


Figure 11: Comparison of the average of key indicators in the industry at $t = 100$ for different values of β, with dynamic adjustment of the fraction of optimists on the financial market: (a) ratio of industry-wide R&D investment to industry-wide total investment; (b) productivity; (c) share price; (d) manager income.

Supplementary Information

The data for reproducing the plots in this paper is available as a Data Publication Dawid et al. (2018) from the Bielefeld University Publication Server: `https://pub.uni-bielefeld.de/data/2916796`

References

Andriosopoulos, D. and M. Lasfer (2015): "The market valuation of share repurchases in Europe," *Journal of Banking and Finance*, 55, 327–339.

Barde, S. and S. van der Hoog (2017): "An empirical validation protocol for large-scale agent-based models," *Bielefeld Working Papers in Economics and Management No. 04-2017*.

Barker III, V. and G. Mueller (2002): "CEO Characteristics and Firm R&D Spending," *Management Science*, 48, 782–801.

Bens, D., V. Nagar, and M. Wong (2002): "Real investment implications of employee stock option exercises," *Journal of Accounting Research*, 40, 359–393.

Bhargava, A. (2013): "Executive compensation, share repurchases and investment expenditures: econometric evidence from US firms," *Review of Quantitative Finance and Accounting*, 40, 403–422.

Brock, W. and C. Hommes (1998): "Heterogeneous beliefs and routes to chaos in a simple asset pricing model," *Journal of Economic Dynamics and Control*, 22, 1235–1274.

Chang, M.-H. (2015): *A Computational Model of Industry Dynamics*, New York: Routledge.

Cziraki, P. and M. Xu (2014): "CEO Job Security and Risk-Taking," *Financial Markets Group Discussion Paper No. 729*.

Dawid, H. (2006): "Agent-based models of innovation and technological change," in *The Handbook of Computational Economics, Volume 2*, ed. by L. Tesfatsion and K. Judd., North-Holland, 1235–1272.

Dawid, H., P. Harting, and S. van der Hoog (2018): "Data for the Paper: Manager Remuneration, Share Buybacks and Firm Performance," Bielefeld University, doi:10.4119/unibi/2916796.

Dawid, H. and M. Reimann (2011): "Diversification: A Road A Road to Inefficiency in Product Innovations?" *Journal of Evolutionary Economics*, 21, 191–229.

Dieci, R. and X.-Z. He (2018): "Heterogeneous Agent Models in Finance," in *The Handbook of Computational Economics, Volume 4 (forthcoming)*, ed. by C. Hommes and B. LeBaron, Amsterdam: Elsevier North-Holland.

Dosi, G., O. Marsili, L. Orsenigo, and R. Salvatore (1995): "Learning, market selection and the evolution of industrial structures," *Small Business Economics*, 7, 411–436.

Edmans, A., X. Gabaix, and D. Jenter (2017): "Executive Compensation: A Survey of Theory and Evidence," in *The Handbook of the Economics of Corporate Governance, Volume 1*, ed. by B. Hermalin and M. Weisbach, North-Holland, 383–539.

Fu, F. and S. Huang (2016): "The Persistence of Long-Run Abnormal Returns Following Stock Repurchases and Offerings," *Management Science*, 62, 964–984.

Grazzini, J., M.G.Richiardi, and M. Tsionas (2017): "Bayesian estimation of agent-based models," *Journal of Economic Dynamics and Control*, 77, 26–47.

Guerini, M. and A. Moneta (2017): "A method for agent-based models validation," *Journal of Economic Dynamics and Control*, 82, 125–141.

Hommes, C. (2006): "Heterogeneous Agent Models in Economics and Finance," in *The Handbook of Computational Economics, Volume 2*, ed. by L. Tesfatsion and K. Judd., Amsterdam: Elsevier, North-Holland, 1109–1186.

Kotnik, P., M. Sakinc, A. Slavec, and D. Guduras (2017): "Executive compensation in Europe: Realized gains from stock-based pay," *ISIGrowth Working Paper No. 07-2017*.

Lazonick, W. (2014): "Profits Without Prosperity," *Harvard Business Review*, 92, 46–55.

Malerba, F., R. Nelson, L. Orsenigo, and S. Winter (2008): "Public policies and changing boundaries of firms in a history-friendly model of the co-evolution of the computer and semiconductor industries," *Journal of Economic Behavior and Organization*, 67, 355–380.

Nelson, R. and S. Winter (1982): *An Evolutionary Theory of Economic Change*, Belknap, Cambridge, MA.

Pettit, J. (2001): "Is a share buyback right for your company?" *Harvard Business Review*, 79, 141–147.

Peyer, U. and T. Vermaelen (2009): "The nature and persistence of buyback anomalies," *Review of Financial Studies*, 22, 1693–1745.

R Core Team (2017): *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria.

Sakinc, M. (2017): "Share Repurchases in Europe: A Value Extraction Analysis," *ISIGrowth Working Paper No. 16-2017*.