QUANTIFYING THE CONCERNS OF DIMON AND BUFFETT WITH DATA AND COMPUTATION

Matthew Oldham
Department of Computational and Data Sciences
George Mason University:
4400 University Drive, Fairfax, Virginia 22030, USA
oldhamma@gmail.com

ABSTRACT

Agent-based artificial stock markets have been successful in producing insights into the mechanisms driving financial markets; however, the important step of considering an environment of multiple firms with endogenously determined earnings remains open. The need for such an approach arises because agent-based models can address the real-world concern that the management of publicly listed firms are becoming too concerned with the movement of their firm's share price, which is adversely influencing their resource allocation decisions. A related concern is that agents within financial markets are placing a disproportionate focus on short-term factors. These concerns imply that a positive feedback loop between firms and investors, is responsible for prejudicing the way management allocates their resources, with firm, and economic, growth adversely affected. While the determinants of firm growth and financial market volatility have not been definitively identified, sets of stylized facts – most notably power-law distributions – relating to firm size and market returns suggest both evolve as part of a complex system. To investigate the ramifications of the proposed feedback loop, on firm growth and market volatility, this paper implements a novel agent-based artificial stock market where management can consider the movements of their firms endogenously determined share price when allocating resources between sales and margin growth. The results highlight an inferior outcome regarding firm growth, and various other financial metrics, if management is overly concerned with share price movements. The growth of the firms (and market) is also affected by the mixture of the investor classes initiated due to the divergent levels of volatility they create. Additionally, the model presents insights into how and why the extent that agents consider past outcomes in their decision-making process becomes influential. Notably, the model is calibrated against an extensive set of global micro-level firm data.

Keywords: Agent-based modelling; market ecosystem; artificial stock markets; complex adaptive systems; efficient markets; agency theory; short-termism.

1 INTRODUCTION

> *"In our experience, quarterly earnings guidance often leads to an unhealthy focus on short-term profits at the expense of long-term strategy, growth and sustainability."* (Dimon & Buffett, 2018)

The statement from investment market heavyweights Jamie Dimon (Chairman and Chief Executive Officer (CEO) of J.P. Morgan) and Warren Buffett (Chairman and CEO of Berkshire Hathaway) implies that there are serious concerns relating to the operational efficiency of secondary equity markets. It is vital financial markets operate efficiently because they are an integral part of the modern economy, ensuring that firms can raise capital, and investors can diversify their risks widely (Stiglitz, 1989). While there are generally agreed principles as to how these markets should operate, at times they have performed in a manner that defies any ex-ante explanation, with short-termism on behalf of market participants one possible factor in the unexplained market behavior. The issues pertaining to short-termism relate to agents – both management and investors – in financial markets allocating a disproportionate weight to short-term factors over long-term factors (Haldane, 2011), with economic growth suffering because resource allocation is not efficient. The delayed recognition of short-termism is possibly due to the accepted propositions of the efficient market framework (EMF), where there is no place for short-termism. The EMF refers to not only Fama's (1970) efficient market hypothesis (EMH) but all theories that contribute to the ideal of efficient markets, including but not restricted to the random-walk (Samuelson, 1965), rational expectations (Muth, 1961), and the removal of irrational traders from financial markets (Friedman, 1953). The premise of the EMF is that investors only consider those strategies that affect the long-term growth prospects of the firm, which is meant to ensure the efficient allocation of resources by management. However, per Dimon & Buffett (2018), it is becoming apparent that short-termism is disrupting this process. This issue in turn raises the question of how it is affecting the growth and size of firms – a problem that forms the basis of this paper.

The genesis of the questionable behavior of firms is the separation between the owners and decision-makers of publicly listed firms. Smith ([1776] 1976), first identified the issue of management not acting in the best interest of shareholders at the onset of growth in limited liability companies (LLCs), with Jenson & Meckling (1976) eventually proposing a response to the issue through their theory on agency costs. Additionally, shareholders are not blameless, as a subset of investors trade in and out of stocks in search of short-term profits which, sends unreliable signals to management, which they in turn consider in their operations of the firm. This mechanism highlights how a positive feedback loop between management and investor behavior can result in inefficient behavior. (1776)

One approach that has been successful in explaining the behavior of financial markets and the growth of firms is a complex adaptive system (CAS) framework. Among other points (as detailed Section 2.4), this framework recognitions that feedback mechanisms between the agents in financial markets may affect their behavior (Sornette, 2014). This theme opens a broader question, one this paper addresses, being: is the excessive volatility observed in financial markets and firm growth a direct consequence of the positive feedback loop of management trying to meet the short-term earnings expectations of their investors? A consideration for any theory or model that proposes to explain the growth and size of firms is the need to rationalize the presence of the robust empirical facts discussed in Section 2.2. As such, the model implemented in this paper is informed by a set of global micro-level firm empirical facts (see Section 3).

The approach employed in this paper is to investigate, through a novel agent-based model (ABM), how management alters their strategy in response to price signals from an artificial stock market. The innovative step of the paper is having the model populated with a mixture (either fundamental and/or trend) of investors who invest across multiple firms – opposed to the standard agent-based artificial stock market approach of a single risky asset – with those firms' utilizing the price signals in their decision-making, which in turn affect the future earnings of the firms. Thereby, the earnings mechanism becomes endogenous. The focus of the model is to quantify (hence the title) how inefficient management decisions may result from them either: misinterpreting the price signals from the market, caused by the short-term-or noise investors; or, placing too much consideration in the behavior of the market at the expense of their judgment.

The results highlight an inferior outcome regarding firm growth, and various other financial metrics, if management is overly concerned with share price movements. The growth of the firms (and market) is also affected by the mixture of the investor classes initiated due to the divergent levels of volatility they create. Additionally, the model presents insights into how and why the extent that agents consider past outcomes in their decision-making process becomes influential. The remainder of this paper is laid out in the following manner: Section 2 expands upon the relevant concepts. Next, Section 3 explores the empirical facts used to inform the model. Contained in Section 4 are details of the implemented model, with its results presented in Section 5. Finally, Section 6 provides a summary and concluding comments

2 BACKGROUND

The justification for pursuing a greater understanding of the workings of secondary equity markets stems from the belief that the efficient pricing of assets is seen as a desirable outcome, as price efficiency guides real decisions (Bond, Edmans, & Goldstein, 2011). The direct relevance is seen in stock market returns being a significant leading indicator for investment (an example of a real decision) by publicly listed companies, with the effects flowing into the broader economy(Barro, 1990). The ramification of any phase where market prices deviate from their fundamental value for an extended period is that the economy will experience an over-or-under allocation of resources to investment, with economic growth affected.

2.1 The Behavior of Financial Markets and the Effects of Short-termism

Per the EMF, the returns of financial assets are assumed to follow a random–walk, with their dispersion matching a Gaussian distribution. However, the financial models informed by the EMF have been found to only provide a rough approximation of financial market returns and have failed to explain outlying events (Kirou, Ruszczycki, Walser, & Johnson, 2008). Rather the return characteristics of financial markets have been found to demonstrate a specific set of stylized facts. These facts, as summarized by Cont (2007) and Johnson et al. (2003), are excess volatility, heavy tails, and volume/volatility clustering. In an even greater violation of the assumed Gaussian distribution, asset returns have been found to match a power-law distribution (Botta, Moat, Stanley, & Preis, 2015).The existence of power-law returns provide the crucial insight that financial markets may operate as a CAS. Lux & Alfarano (2016) provide a detailed review of the empirical evidence supporting the existence of power-laws in financial markets.

The issue of short-termism has gained increased attention in the wake of the most recent financial crisis. In the USA, the issue has been raised by prominent investors and regulators (The Aspen Institute, 2009), while in the UK, the government commissioned a report regarding the issue (Kay, 2012). The mechanism by which short-termism – defined by Haldane (2011) as a situation where short-term factors are allocated a disproportionate weight at the cost of long-term factors – produces detrimental outcomes is that investors underestimate the value of medium to long-term cash flows, which in turn removes the incentive for management to invest in long-dated projects (Davies, Haldane, Nielsen, & Pezzini, 2014). The critical ramification for Kay (2012) is that short-termism may lead to hyperactivity by management, such as, frequent corporate restructures, mergers and acquisitions, and financial re-engineering. These activities in most cases do not generate a sufficient return on the investment associated with them (Jensen, 2005). Davies, Haldane, Nielsen, & Pezzini (2014) make the point that short-termism is one of the potential costs of modern capital markets, with the cost manifesting itself with both investors and management undertaking inefficient behavior that is detrimental to long-term wealth creation.

2.2 The Size of Firms and How They Grow

The determinants of firm growth and the connection to share price movements remains an elusive topic. Malkiel (1999) suggests that since Little (1962) proclaimed that it was useless to estimate future earnings from various past financial metrics, and those metrics should not influence the share price, the professional realm is no closer to understanding the growth profile of firms. While it has been generally accepted that the size-rank distribution of firms matches a Zipf-law (R. L. Axtell, 2001), firm growth rates match a Laplacian distribution, and the variance of growth rate scales with the size of the firm (Stanley et al., 1996), the implications for financial markets are yet to be formalized. These distributions rendered Gibrat's (1931) and many of the original theories of firm growth inaccurate because they assumed that any stochastic process involved in determining the growth of a firm was independent of firm size (Metzig & Gordon, 2014). At a minimum, investors need to be mindful that their growth expectations match these characteristics otherwise they will be overestimating growth.

In terms of alternative theories, the stylized facts suggest firms operate in a CAS (Simon & Bonini, 1958), thereby, implying the need to assess growth from a bottom-up perspective. While the CAS approach covers all firms, it is possible that the interaction of firms and investors, as subsystems, is at least partially responsible for the stylized facts. Of the possible frameworks that have been utilized to consider firm growth, the model described in Section 4 takes its cues from the model of Delli Gatti et al. (2005). The attractiveness of the framework is that it explores the link between the power-law distribution of firms' size and the Laplace distribution of firm growth in combination with business cycle fluctuations and the financial fragility.

2.3 Agency and Agency Costs

Publicly list firm take the form of LLC, where a firm's management is hired by debt and equity holders to run the company to achieve a mutually agreed-upon set of objectives. As discussed in Section 2.4 this relationship allows for a feedback loop between the two groups, which may result in inefficient behavior. The possibility of LLCs being operated inefficiently was first raised by Adam Smith ([1776] 1976), who suggested that it would be erroneous to expect the managers of LLCs to manage them with the same vigilance, as if they were the owners of the company. The concern raised by Smith was not fully incorporated into a theory related to the ownership structure of a firm until Jensen and Meckling (1976) recognized agency costs, which as discussed in Fox (2009), was the culmination of the ongoing debate regarding the behavior of firms, and whose interest the management of a firm is trying to maximize.

An insight from Jensen's and Meckling's (1976) work, is that market efficiency was meant to ensure that management would always act to maximize the value of the firm. However, with markets failing to maintain their "efficiency," and the short-termism of market participants, the efficient behavior of management is questionable. A negative side effect of owners trying to reduce agency costs by linking management remuneration to the share price performance of their firms is the increased preoccupation of management with their firm's share price. Management's concern with their firm's share price manifests itself in several ways, including: the value of any options issued for past performance; the achievement of current incentives; and reputational enhancement (Jensen & Meckling, 1976). The relevance of this issue is raised in Aghion & Stein (2008) and Stein (1989) when they present models that predict unfavorable behavior by management when they consider the share price of their firm. The paper of Aghion & Stein (2008) serves as a vital stimulus for the model implemented in Section 4.

2.4 Complex Adaptive Systems and Positive Feedback Loops in the Financial Markets

The use of a CAS framework has become increasingly popular and relevant to explain firm dynamics and financial market behavior (Farmer et al., 2012). The appeal of the CAS approach is that the dynamics and mechanisms behind endogenous changes are capable of being uncovered, and they are not constrained by equilibrium conditions nor the deductive top-down approach which requires a representative agent (Delli Gatti et al., 2005). If one is to accept that financial markets operate as a CAS, then one must accept that the behavior of the system is an emergent process based on the self-organized behavior of independently acting, self-motivated individuals (Farmer et al., 2012). Kirman (1992) presents a compelling argument against the utilization of a representative agent and the need to consider the economy as a CAS.

Within the CAS framework, a research stream of untapped potential is the consideration of financial markets as an ecosystem. Farmer (2002) first proposed the concept of a market ecosystem. The genesis of the theory comes from the notion, and subsequent recognition through empirical evidence (see for example, Bouchaud et al. (2009)), that investors of varying investment strategies, or classes, co-exist in the market. In turn, the interactions of the various investor classes are deemed responsible for the observed behavior of the financial markets. The recognition of the interaction of various investor classes invalidates the theory of the representative agents and supports the investigation of how these interactions may be affected by positive or negative feedback loops, and in turn how this influences the behavior of the market. A major component of this paper is to expand this ecosystem to include firms and investors.

Shiller (2005) highlights the relevance of positive feedback loops between investors by utilizing the concept to explain the various periods of irrational exuberance in financial markets. De Long et al. (1989) models the process by which positive feedback investors (later they became part of the noise trader literature) become responsible for excess market volatility. The primary aspect of the model was that positive feedback investors would buy an asset as the price rose and sell when the price fell – a behavior which contradicts economic theory. The presence of the positive feedback traders was reported as destabilizing because rational speculators would be aware of their presence, and would anticipate their decisions and trade ahead of them.

Another feedback mechanism affecting financial markets is the one that exists between firm management and investors. According to the EMF this loop is irrelevant because the behavior of management will not systematically fool investors; thus, a company's share price will solely reflect the long-term prospects of the firm (Stein, 1989). Jensen (1986) articulates the importance of this point by stating that the market, with its investors acting rationally, serves as a disciplinary device thus ensuring that management decisions were solely in the best long-term interest of shareholders. Further, Jensen (1986) states that short-term managerial behavior arises when management has too little regard for their share price. However, in the aftermath of the dot.com bubble and the Enron scandal, Jensen conceded that high valuations could lead to destructive behavior by management (Jensen, 2005). A critical point in Jensen's (2005) concession is that if a firm is overvalued, then is it only through chance that management will continue to meet the expectations of the markets. Another issue relates to the price signals provided by the market and whether management interprets the messages correctly. An example of this issue is provided by Dow & Gorton (1997), who specify a model where management, after deciding that the price of their stock is random and thereby following the EMF, ignore the behavior of their share price and do not invest for future growth, thus delivering inferior growth.

2.5 The Benefit of Agent-based Modeling

Assessing and gaining an understanding of the characteristics and dynamics of a CAS is problematic. However, agent-based modeling has proven to be viable solution because they are capable of addressing issues such as: heterogeneous expectations; out-of-equilibrium dynamics; the ramifications of a variable external environment (including shocks); and the adaptation and evolution of the agent population (Macal, 2016). In developing an ABM, a "bottom-up" perspective is taken, which allows for interaction between individual agents, with these agents acting and undertaking actions based on the context of their environment and basic rules (R. Axtell, 2000). A further justification for utilizing an alternate approach to understand financial markets comes from Tedeschi et al. (2012), who states that statistical analysis alone will not be sufficient to understand how the stylized facts of the financial markets arise.

Since the original agent-based artificial stock market (see Arthur et al. (1997)) an assorted and rich vein of research attempting to uncover the dynamics of financial markets through the of these models has developed. LeBaron (2000), Sornette (2014), and Dieci & Xue-Zhong (2018) provide extensive reviews of the research relating to ABM-based artificial stock markets. The research has the common theme of utilizing heterogeneous agents regarding both expectations and investment strategies with the intention of: studying how agents act and prices change; reproducing the stylized facts of the markets; and, most important, understanding the influence of the market's microstructure (Cont, 2007). This underlying philosophical approach has resulted in the various implementations reproducing the stylized facts of financial markets, and identifying the conditions under which the return characteristics match the EMF or models that utilize it. The model presented in Section 4 will extend this literature by having multiple firms – whose earnings are endogenously determined – traded on the artificial stock market

3 EMPIRICAL FACTS

Before proceeding to the details of the implemented ABM, various empirical facts are presented that explore the size and growth distributions and other financial metrics of all the publicly listed companies worldwide 2007 and 2017. In turn, these facts are used to inform the model. The Compustat – Capital IQ database (2018), retrieved from the Wharton Research Data Services (WRDS) website, was the source of the financial and price data for the companies used in this section. Support for the approach comes from Chaieb, Langlois & Scaillet (2018), who used the same database to investigate the variation in risk premiums across the globe. This approach varies from the likes of, Axtell (2001) – who explored all USA firms, or Stanley et al. (1996) – who used all publicly listed firms in the USA, or Williams et al. (2017) – who used a proprietary database with 13,342 global firms.

To assess the most relevant data, firms not classified as common or ordinary stocks were filtered out. Other data filtering steps include removing American Depositary Receipts (ADRs) and subsidiaries, and securities that only appeared in the data once in the 11 years. The last data processing step was to divide the stocks into sub-groups based on country of incorporation. The sub-groups are Northern America, Eastern Europe, the Middle East, Southern and Eastern Asia; thereby including both Japan and China, Africa, Latin America and the Caribbean, Oceania, and Western Europe. Given the volume of data collected, a select number of results are presented. The remainder of the results, along with their commentary, can be found in the appendix. The two figures provided best represent the intention of the ABM presented in Section 4. Figure 1 presents the inverse cumulative distribution functions (CDF) – (following a log transformation) of the market capitalization of the firms in the data set. Market capitalization is the best proxy for firm size as it captures the market's expectations regarding the future cash flows of the company, therefore the value of the firm.

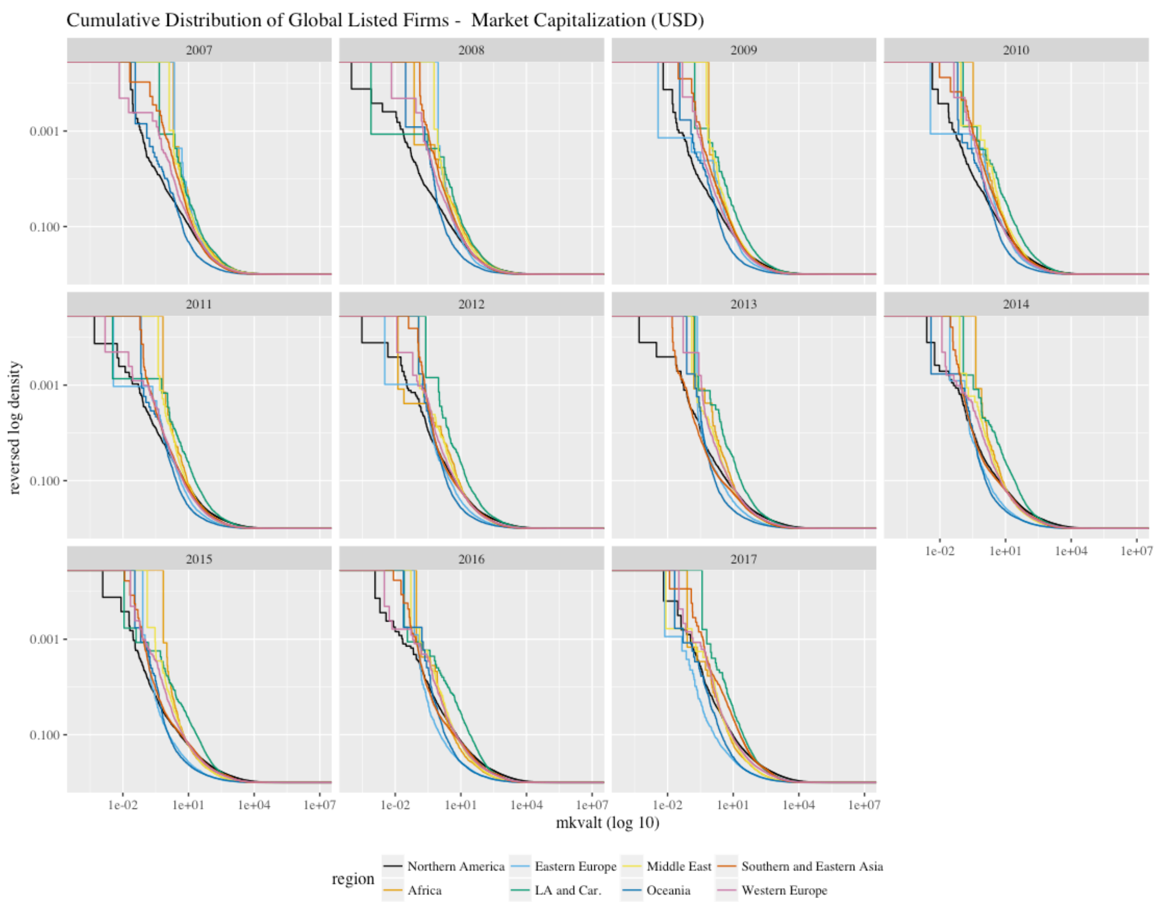

Figure 1: The distribution of the market capitalization of firms across regions and time. The distribution is represented by CDF, in log form. A "straight" line is indicative of a power-law distribution. Data source: Compustat – Capital IQ database (2018).

The impression from Figure 1 is that the market capitalization of firms consistently matches a power-law-like distribution across regions, with the justification being that the slopes appear linear in nature. Indeed, the slopes of the fitted functions range between 1.42 and 2.10 (Table 5 in the appendix). Concerning the variation between regions, the more developed markets – Northern American and Asia – exhibit flatter slopes, which is indicative of a broader spread in terms of firm size. A curious result was that Western Europe exhibited the steepest slope, which is indicative of a more limited range of firm size. This result is consistent the comments of Bancel & Mittoo (2009), who noted that numerous studies have reported that European companies tend to IPO later in the firm's life cycle compared to those in the USA. Figure 2 provides the growth in market capitalization of all globally listed firms.

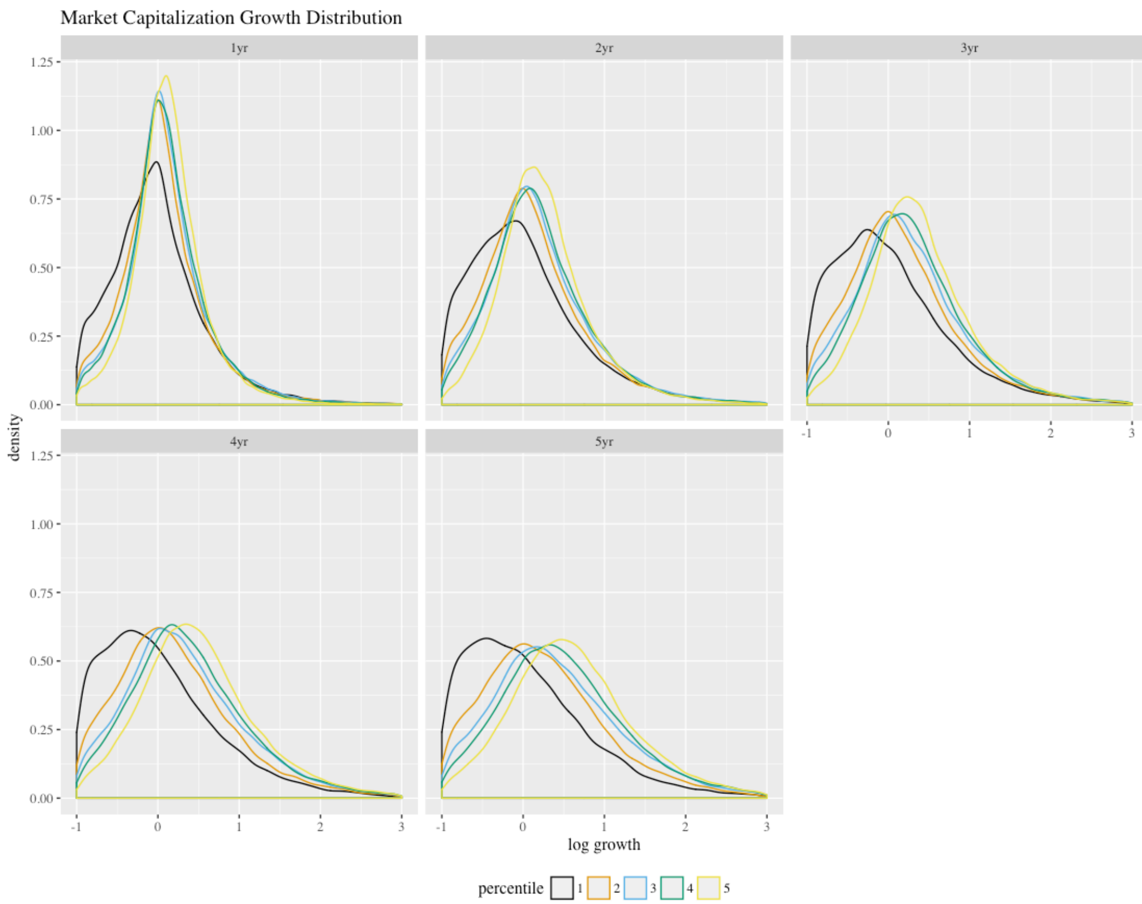

Figure 2: Growth in market capitalization of globally listed firms. Growth distributions are provided for 1,2,3,4, and 5 years of growth. A tent-shaped growth is representative of a Laplacian distribution. Data source: Compustat – Capital IQ database (2018).

Based on the previously detailed characteristics of firm growth and their Laplacian distribution, the shorter time frames should exhibit a tent-like shape, before the distributions become more bell-shaped over more extended periods. Also, the lower percentiles should present greater variability. The first observation of note is that the growth in market capitalization over the shorter periods matches the expectations; that is larger firms exhibit less variability than their smaller counterparts and the median growth is close to 0. The second major observation appears when growth is assessed over longer period. Here it is seen that the higher percentile stocks, on average, record higher growth. The justification for this comment is that the peaks of the distributions move rightward as the percentile moves higher. Before interpreting this result, a cautionary note is that there are 10,000 firms in the uppermost percentile – which is a much larger sample than previous studies have considered when deciding the benefits or otherwise in investing in small vs. large cap stocks. Despite this, the observation opens a potential avenue of research that would involve the farther dissection of the percentiles.

4 APPROACH AND MODEL DESIGN

4.1 Model Background

The implemented agent-based artificial stock market model fuses multiple frameworks with the intent to produce novel insights regarding the feedback mechanism between investors and the decision-making processes undertaken within each firms in the ecosystem. The first framework comes from the analytical model of Aghion & Stein (2008). Therefore, the challenge existed to "agentize" the model. Agentizing is defined by Guerrero and Axtell (2011) as the process of rendering neoclassical economic models into computational ones – a process which sees the contrived assumptions of neo-classical become more realistic. Axtell (2007) provides an extensive treatment of the benefits agentizing neoclassical models.

The intention of agentizing the model of Aghion & Stein (2008) is to see how firms and investors evolve, adapt, and behave in a dynamic environment, thus making the requirements of a CAS. Once this was achieved, the model was integrated into a market ecosystem – with the ecosystem's foundations coming from Delli Gatti et al. (2005) and Oldham (2017). The innovative aspect of the model is that there are multiple firms "listed" on the artificial stock market with investors trading those firms, with those firms in turn being potentially influenced by movement of their share price. This contrasts to the traditional agent-based artificial stock market literature, which has a large quantity of investors allocating their wealth between a cash proxy and a single risky asset, and where the earnings/dividend stream of the risky asset is a stochastic process that is unaffected by the market (Dieci & Xue-Zhong, 2018). Therefore, the model is internalizing the earnings process of the firms to better reflect real-world markets.

The essence, at least for the purpose of the implemented model of the Aghion & Stein (2008) model is that a representative firm's management possesses a utility function, with their behavior directed towards maximizing its value. Equation 1, illustrates that the management's utility (U), is a function of the profits of the firm in the current period (π_1), the price of the firm's stock (P_1), and management's concern for their share price (α). In their pursuit of their highest possible utility, management apply their pre-determined level of ability to generate output. In doing so they divide their effort between growing sales and realizing higher margins. This distinction is vital, because as explained later, the implemented model divides firms into sub-classes based on their primary intention to grow sales or margins.

Equation 1: Utiliy function for the management of firm from the Aghion & Stein (2008) model

$$U = \pi_1 + \alpha P_1 \quad \text{where } \pi_1 = s_1 + m_1$$

Regarding the effort employed by the representative firm, it is endowed with one unit of effort each period, with management allocating it between growing sales and margins as they attempt optimize profits. Equation 2 details how sales are determined in each period. By way of definitions: e is the effort applied by the firm into growing sales; q_1 is the size of the market; and ε^s is a normally distributed random variable – included to capture a sales shock. Noting that this is consistent with the need to include a stochastic process in the growth equation of a firm.

Equation 2: The sales function for the Aghion & Stein (2008) model

$$s_1 = aeq_1 + \varepsilon^s$$

Equation 3 details how margins are determined at each step. The management's ability is applied to the residual effort of the firm $(1 - e)$, with ε^m, a normally distributed random variable – again included to represent a stochastic shock to margins.

Equation 3: The margin function for the Aghion & Stein (2008) model

$$m_1 = a(1 - e) + \varepsilon^m$$

A key consideration in developing the implemented model was to replicate the stylized facts of firms' size and growth (see Section 2.2 and 3). The framework established by Delli Gatti et al. (2005) was able to re-produce these stylized facts, hence its selection as a building block for the implemented model. The functionality of the model has firms determine their output based on the conditions of the economy and their desire to grow profits. Equation 4 specifies how firm *i* produces Y_{it} at time *t*. In turn, firms can sell this output without question. By way of definitions for Equation 4, K_{it} is the capital stock of firm *i* at time *t*, ϕ is the capital productivity – which is assumed to be constant thru time and uniform across firms.

Equation 4: The Delli Gatti et al. (2005) production function

$$Y_{it} = \phi K_{it}$$

The price achieved by each firm is the result of an idiosyncratic shock (u_{it}) that each firm experiences and does not have a structural effect on the model. However, the process introduces a level of heterogeneity, as firms will not realize a persistent price across periods, nor will all firms receive an identical price within a period. Equation 5 is the profit (π_{it}) firm *i* generates at time *t*. The revenue for the firm is its output – Y_{it}, multiplied by the effective price (u_{it}) the firm received for its products in time *t*. The variable cost for the firm is given by $g * r_{it} * K_{it}$, which is proportional to the firm's financing cost. Within the variable cost term, the *g* variable is a constant which reflects the rate of global efficiency, r_{it} is the real interest rate, and K_{it} if the capital base of the firm.

Equation 5: The Delli Gatti et al. (2005) profit function

$$\pi_{it} = u_{it}Y_{it} - g * r_{it} * K_{it} = (u_{it}\phi - g * r_{it})K_{it}$$

4.2 Model specifics

This section provides a high-level overview of the implemented model. Interested readers can view a more detailed description of the model, and download the model from (**http://www.aussiecas.com/dissertation**). The basis of the model is that management is tasked with growing their firm by allocating their effort between growth sales or margins. This step is achieved by allocating the firms to sub-classes at initiation. Section 5 makes use of the two-classes in assessing the results of the model. In making this decision management assess their performance against internal expectations and may consider the market's reaction to their results. The relevant point from Aghion & Stein (2008) is that by trying to meet the expectations of the market, greater volatility in real variables, including sales and output, were found. These finding are linked to the concerns of Dimon and Buffett (2018) that firms are predisposed to matching the desire of the market at the expense of future growth. To assess the effects of short-termism, investors and firms utilize varying lengths of past performance in their decision-making process. The rationale is to evaluate where a short-term view creates more-or less volatility in the market and the growth of firms. The most significant change of the implemented model was to replace the debt markets of Delli Gatti et al. (2005), with an artificial stock market based on Oldham (2017), where there are multiple firms that the investors trade.

4.2.1 Agent Classes

4.2.1.1 Investors

The implemented model's investor population comprises a single representative agents from different investing classes. In this implementation of the model has five classes, with the user being able to activate any combination of the 5 possible investor classes. This mechanism contrasts to the traditional agent-based artificial stock markets, which have many heterogeneous investors. The investors classes either fundamental investors, who use either the price to earnings (PE) ratio, price to growth (PEG) ratio, or price to book (PB) ratio, or chartists, who utilize the trends in either a firm's earnings or prices to inform their decision. Investors also have the capability of considering varying amounts of history. The role of the investor is to maintain a portfolio of *n* firms, where the size of each holding will be a result of their investment decisions, as explained in Section 4.2.2.2. In assessing each firm, investors are aware of the sub-class of each firm, and judge them accordingly. Investors also retain a holding of a risk-free asset, which grows through dividend and sales, and shrinks after purchases. In making their investment decisions, investors maintain different benchmarks for sales growth and margin growth firms.

4.2.1.2 Firms

A firm's principal purpose is to generate sufficient growth in their primary metric allocated per their sub-class, that is to grow sales/revenue or margins. To achieve their goal management must decide how to allocate their effort between their primary and secondary objective. The relevance of this divide is that firms are endowed with 1 unit of effort and they must decide how to allocate that effort to meet their growth expectations knowing that a trade-off exists in that the aggressive pursuit of their primary objective will penalize their secondary objective, with capital growth adversely affected. For example, if a sales growth firm applies too much effort to growing sales, while they may achieve the required growth, they will have done so with very low (or possibly negative) profit margins. Alternatively, a margin growth firm may grow margins as required by will have achieved a less than optimal rate of sales growth. The specifications for the firm class is derived from utilizing specific variables from the previously mentioned models. Table 1 provides the details of the vital firm characteristics and variables.

Table 1: Firm characteristics and variables

Name	**Purpose**
Growth expectation	Firms hold a growth expectation which in turn guides the allocation of resources by the firm (Process 1 in Figure 3). Expectations are initially allocated and then firms adjust their expectations based on their performance against those expectations, as discussed in Section 4.2.2.4.
Additional effort level	Firms must decide how much effort they must allocate to achieving their primary goal. This variable represents the amount of additional effort the firm applies to achieve their growth objective.
Management ability	Firms are initiated with a constant fixed level of ability taken from a Gaussian distribution, thus providing an additional level of heterogeneity. A firm's ability is akin to the productivity of the firm.
Realized ability	Firms do not realize this ability with any certainty. They either under or overachieve in each period based on a deterministic stochastic process, with the variance of the stochastic factor increasing as the firm's growth expectations increase. The realized ability affects only the primary focus of the firms. The commentary for Process 1 and 2 of Figure 3, details this further.
Capital	Firms maintain and utilize a capital base to produce their output. The capital base is added to if the firm makes a profit, with the rate of capital accumulation affected by the reinvestment rate.
Pricing factor	Firms realize a different price for their output at each step, which has the potential to either dilute or compound the realization of a firm's productivity.
Margin realization	Firms realize a given level of efficiency at each time step. For firms focused on sales growth this variable is constant and equal to a global efficiency variable. For firms focused on margin growth their realization varies with in accordance of the realization of their ability.
Profit	Firms generate a profit or loss at each time step. The sales and variable cost components vary based on the realization of each firm's ability and price level.
Reinvestment rate	Firms must decide how much of their profits they will reinvest. The model assumes that sales growth firms will be lower margin, and less inclined to re-invest, and margin growth firms are assumed to be less concerned with growing their capital base; thereby, will have a higher pay-out.
Meet previous expectations	This variable (*met_p_e_y*) is updated to reflect whether the firm achieved its expectations in the prior period. It is used extensive in step 8 of the model as firms decide whether to adjust their expectations or effort.
Expectation performance	The over or underachievement of a firm's expectation is recorded through this variable (*pex_gap)*. The gap is used in the process of firms updating their expectations.
Miss count	A tally is recorded of how many consecutive periods miss their expectations through this variable. The variable is utilized by management to decide whether it is time for them to adjust expectations.

4.2.2 Model Dynamics

Figure 3 provides a flow diagram of the model. The diagram is color-coded to reflect the distinct nature of the different processes. Processes 1 and 2 cover the product market and how firms allocate their effort and the return they generate from that effort. Processes 3 and 4 relates to the decision-making process of the investors. Processes 5 through 7 involve the mechanics of determining share prices for each firm and updating investor portfolios. Processes 8 deals with how firms react to changes in their share price and achievement of their growth expectations. The final step relates to the firms updating their distributing any dividends.

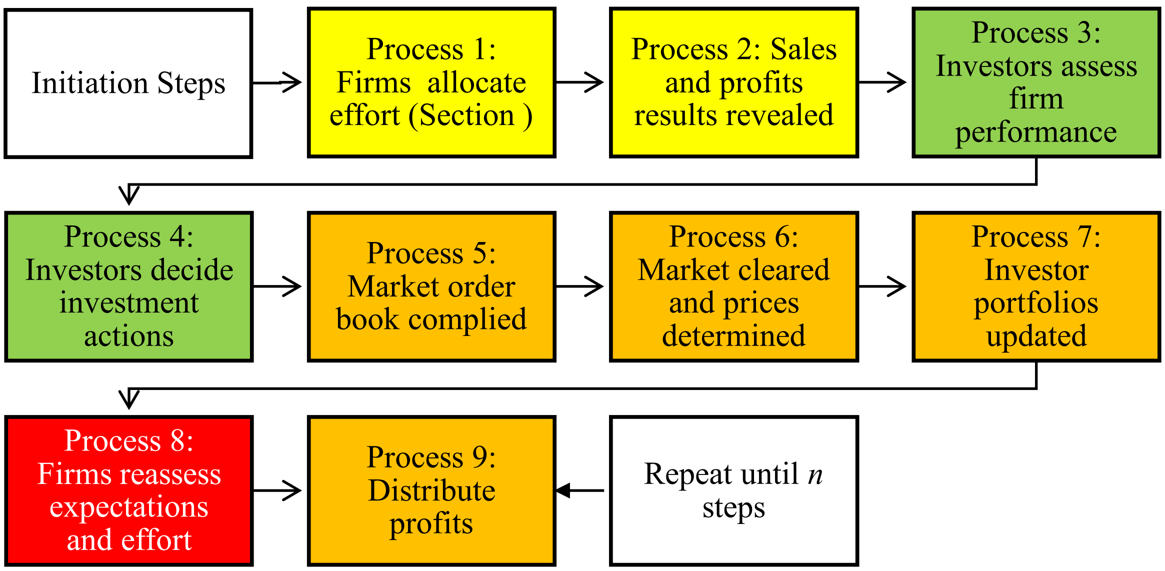

Figure 3: Representation of the model's processes completed during a step of the model.

4.2.2.1 Product Market

After initiation firms decide how much effort to apply into achieving their primary growth expectation. Firms apply a random search process to determine the optimal amount of effort to apply. The relevance of finding the optimal amount of additional effort is that a firm has a finite amount of effort to apply (1 unit), and a non-optimal allocation penalizes the firm. For a sales(margin) growth firm an over allocation of effort to their primary objective, while may mean greater sales it will come at a cost of reduced margins(sales). The opposite holds for an under allocation, with the additional issue that their primary expectation is unlikely to be met. Firms will adjust their effort and expectations over time in response to either the over(under) achievement of it, or in response to the market, per Process 8.

Next, firms realize their profit result for the period. This step contains several sub-steps, which are the realization of operating performance; price realization, the accounting steps to determine a firm's profit, and capital expenditure, and dividend payments for the period. Honoring both the principle of Aghion & Stein (2008) and the various models explaining firm growth, firms do not realize a constant return on their effort. However, in a significant deviation, the stochastic process is dependent on previous decisions of the firm, that is, it is an endogenous function.

Having realized their performance for a period, firms will update a host of variables relating to their performance. The variables of highest relevance are sales and margin growth. The firms then compare their growth to their expectation and update the *met_p_e_y* variable to reflect whether they achieved or otherwise their expectation. The *pex_gap* variable is updated to reflect the gap in performance and expectations. If the firm misses their expectation the *miss_count* variable is incremented by 1, or alternatively reset to 0 if the firm's growth expectation is met. The relevance of this will be seen in Process 8 of Figure 3.

If a firm generates a profit the firm will re-invest a certain proportion of those profits. Per Table 1 reinvestment is based on growth expectations and the firm's sub-class. This re-investment is a proxy for growth capital expenditure (capex); that is, capital employed to grow the business. Therefore, the reinvestment rate is an integral part of the mechanism that determines the growth of the firm. Growth capex differs to maintenance capex in this model – in a similar manner to Delli Gatti et al. (2005), in that maintenance capex is implicitly captured in the cost base of the business; thereby, covering the depreciation of the existing capital base. In the case of bankruptcy, a negative capital balance, the capital base of the firm is reset to 1.

4.2.2.2 Investor Decision-making

Investors implement a step decision-making process. The first process (Process 3 in Figure 3) has investors assess each firm's result metric against the investors allocated benchmark to determine an investment action. A vital component of calculating the result metric is that the metric will not be the most recent result realization; for example, the last periods earnings, instead the metric is an ensemble average of the relevant variable over previous periods. The rationale for this is to allow investors to consider trends in a firm's performance and to provide investors with the capability to vary the amount of information they utilize in the assessment process; thereby, allowing a comparison between short and long-term investors. Investors decide an investment action based on whether the result exceeded (a possible buy signal) or fell below their benchmark (a possible sell signal) – noting it is investors may simple hold their stock

After determining their preferred action, investors check they have the required resources to undertake the action and based on their conviction decide how much to trade. The need for the former comes from the model's assumption that investors cannot borrow or short-selling. If investors meet these requirements, they establish their conviction in the trade. Investor conviction is a function of the gap between the firm's actual result and the relevant investment threshold. The mechanism is such that a large(small) gap results in a higher (lower) conviction.

4.2.2.3 The Artificial Stock Market and Share Price Determination

The next two processes (Processes 5 and 6 of Figure 3) involves accumulating the trades of the investor(s) into an order book. The order book is then utilized to determine the new share prices of the firms following the clearing process. If orders for a given stock are positive (negative) this signals excess (insufficient) demand and the price of the stock will increase (decrease). There are a variety of ways to clear the market through an ABM. The method employed in this model is consistent with the market maker model as described by Farmer (2002).

An additional step in this model is the calculation of an index at the completion of each period. The index is a price-weighted index, like the Dow Jones Index (DJI), where the value of the index is the mean of the share prices of all firms in the market. The purpose of the index is to assess the volatility of the investors' behavior provide an overall indication of the level of investment activity.

4.2.2.4 Firms Updating Expectations

A defining feature of an ABM is the capability to have agents evolve and adapt as they react to other agents and their environment. Process 9 of Figure 3 involves the firms utilizing this capability to either adjust the level of effort applied to their primary goal or their growth expectations, noting these adjustments are both up and down. Figure 4 provides the decision tree that firms utilize in deciding their actions, with Table 2 summarizing the various alternatives.

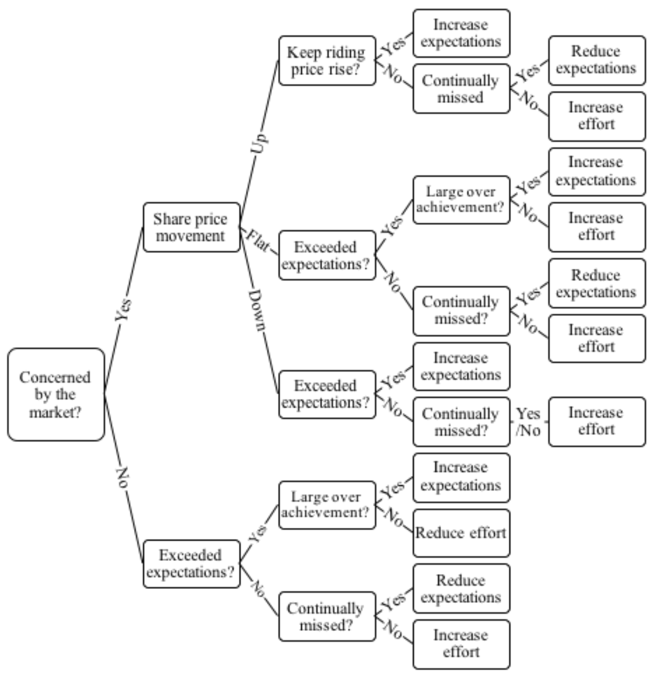

Figure 4: The decision tree that management considers.

4.2.2.4.1 Updating Expectations with no Consideration for the Stock Market

Per Figure 4 firms address whether they have exceeded their internal expectations. Firms that have met expectations will have their *met_p_e_y* variable set to "true" and their *pex_gap* variable will be a positive value. To decide whether to reduce effort or increase expectations, firms will assess the size of the overachievement, with the *pex_gap* variable providing this information. If the overachievement is large(minor) then the firm will increase(maintain) expectations. The rationale for this assumption is that the firm's management attributes significant overachievements to their abilities and feel they can achieve greater growth in their primary objective by maintaining the same levels of effort. Alternatively, a narrow overachievement signals to management that extra effort allocated to the secondary objective will still allow them to achieve their primary objective yet improve their secondary objective performance.

Table 2: Summary of the causes of changing expectations

Action	Scenarios
Increase in expectations	- No concern for the market and a large overachievement of expectations - Concern for the market, and achieved internal expectations, but share price fell materially - Concern for the market, and a large overachievement of expectations, but muted share price response
Reduction in expectations	- No concern for the market but continually miss expectations - Concern for the market, and continually miss expectations, but muted share price response - Concern for the market, share price materially increased, but decide not to ride the wave, and have continually missed expectations

The alternative scenario is that a firm has missed their growth expectation. In this instance the $met\_p\_e\_y$ variable is set to "false", the pex_gap variable will be a negative value, and the firm's $miss\_count$ variable will be greater than 0. Under this condition, the firm must decide how long they are prepared to tolerate the underachievement of their growth expectations. Unlike where firms over achieve, firms are less inclined to adjust their expectations. This assumption is based on the argument that having formed their expectations firms hold a strong belief that they can achieve their targets given time to find the optimal resource allocation.

The global memory variable (α) determines – via this formula $\frac{1}{|\ln(\alpha)|}$ – the number of consecutive periods that a firm will tolerate underachievement. The rationale for this approach is that if a firm has a long-term focus they will maintain a given target and adjust resources to meet that expectation. Alternatively, a short-term firm may prematurely reduce their expectation, thus forgoing future growth. In the instance that a firm has not breached their tolerance for missing expectations, they adjust their effort applied to their primary variable. This change results in subsequent changes to the effort levels for the secondary task and the reinvestment rate. If a firm does breach their tolerance for missing expectations, they will reduce expectations.

4.2.2.4.2 Updating Expectations with Consideration for the Stock Market

In this scenario firms assess their performance factoring in the response from the market, as assessed through the change in the firm's stock price. Figure 4 illustrates that there are three possibilities regarding how a firm views their share price movement: a material increase; an inconsequential change; or a material decrease. Each scenario elicits a different response from the firm. The most straightforward scenario is when there is an inconsequential price change. Under this condition, the firm assumes that the market is indifferent and they disregard the market and stick to their internal planning, per Section 4.2.2.4.1.

If the firm's share price has fallen materially – perceived as a sign of dissatisfaction – and the firm has achieved their internal expectation, the firm will increase their expectations. The rationale is that the downward price movement is read as a signed that the firm's growth expectations are too low. The expectation revision varies from Section 4.2.2.4.1, in that the expectation adjustment considers the share price change of the firm. The main implication is that a more (less) severe price movement coupled with a higher (lower) concern for the market's reaction results in a greater (lesser) change in the expectations. Alternatively, if the firm has not exceeded internal expectations and its share price has fallen materially, the firm will increase the level of effort allocated to the firm's primary objective. The rationale for this behavior is that the firm is in agreeance with the market about its to increase its performance.

If the firm's share price increases materially and the firm has exceeded internal expectations, the firm has an additional decision to make. The firm will perceive the positive price movement as a signal that the market is supportive of their performance and may look to capitalize on the positive sentiment, that is to follow the market's lead. The decision to follow the market is a random choice, with a 50:50 probability of selecting either option. If firms choose to capitalize on the positive sentiment, they will boost their current expectations.

An alternative option for firms is to ignore the temptation to ride the market higher after meeting expectations. In this situation firms reduce their internal expectations. The rationale for this action is that the firm perceives that it has over delivered and can therefore afford to reduce their expectations. Firms also face the possibility that their share price increased but they missed their internal expectations. Under this scenario the firm still undergoes the internal review because while they are pleased with the market's reaction, they are dissatisfied with continually missing expectations and will reduce them. If the firm has not continually missed their expectations, then the firm will increase the allocation of effort to the primary objective.

4.2.2.5 Dividend Distribution

Following the allocation of resources to capex, firms pay a fixed proportion of their excess capital out as a dividend to investors. The fixed proportion is 60%, with the remaining 40% assumed to be absorbed by other expenses that are not explicitly modelled. The process of paying out the dividend required several assumptions which stem from the market ecosystem experiencing an inflow of new funds via the dividend. Without this mechanism, the model will not work because the investors' wealth would be effectively consistent, while the firm's earnings/capital would grow causing the model to become unbalanced. This issue manifests itself in investors being unable to invest sufficient capital. Despite successfully infusing additional capital into the presented model, the opportunity remains to enhance this process

5 RESULTS AND FINDINGS

5.1 Experimental Settings and Results Summary

This section reports on the various experiments undertaken to test the validity of the model. The intention of the experiments was to uncover how a positive feedback mechanism between firms and the stock market could operate and whether its affects were analogous to what is seen in the real-world. With the novelty of the implemented ABM, it was necessary to establish reference behaviors and characteristics for the investor and firm classes before introducing multiple investor classes. Table 3 provides the details of the baseline setting utilized.

Table 3: Baseline settings

Variable	Settings
Steps per run	1,000
Runs per setting	60
Number of firms (J)	500
Proportion sales growth	50%
Market depth (λ)	0.15
Transaction ratio (tr)	0.15
Interest rate (ir)	0.05
Global efficiency variables	10
Memory Variable (α)	.80, .85, .90, .95
Market Concern	0, 1, 2

Table 4 provides an overview of the main components of the experiments and a summary of the findings. It should be noted that each model ran for 1,000 steps, with each experiment setting run 60 times. The rationale for this decision is that the time-period implied per step is a year. Therefore, the growth experienced in the real variables becomes excessively large, yet this issue had to be balanced with allowing sufficient time for any underlying dynamics to appear and stabilize. To report initial the characteristics of the model, charts divided into facet to distinguish the various experimental settings are utilized in Section 5.2. To aid readability, the horizontal facets have the prefixes a) through d), while the vertical facets are labelled 1) through 4); a given sub-plot will be referred to by its coordinates, such as facet a1. The time-series plots provide a temporal aspect concerning how the behavior of a given variable evolved across the runs of a given experimental setting. A LOESSS smoothing technique is used to enhance the value of the time-series plots by providing a stylized illustration of the behavior for each setting.

Table 4: Experimental design and result summary

Model setting	Key Components	Summary of Findings
Single investor classes	The following interval were utilized for the note variables: - Market concern [0,1,2] - Memory [.80, .85, .90, .95] - Investors [CE, PB, PE, PEG]	Where management disregarded the market's reaction it was found that the patience management showed, regarding achieving their expectations, affected capital growth. Once management considered the market, a more volatile market was more detrimental to capital growth. Once the market reduced in volatility, growth stabilized. Some agreeance with the stylized facts of firm size and growth were found.

5.2 Detailed Results

The first metric of interest is the rate and distribution of capital accumulation for the firms. Figure 5 provides the median capital level of the firms across time. The first observation is that when management becomes concerned with the market's reaction it has a detrimental effect on the rate of capital accumulation. The plots of capital accumulation where management has no concern for the market (the black lines) demonstrate this point. Once management becomes concerned with the market's reaction, a higher level of concern has an even more damaging effect on capital growth; that is, the orange lines sit above their blue counterparts. The various investor classes also appear to be influential on the level of capital growth, with higher levels achieved when management response to investors who utilize a PB methodology (value investors). An environment with PE investors also appears more conducive to growth over an environment with PEG and CE investors. The memory of both agent classes appears to influence the dynamics of capital accumulation.

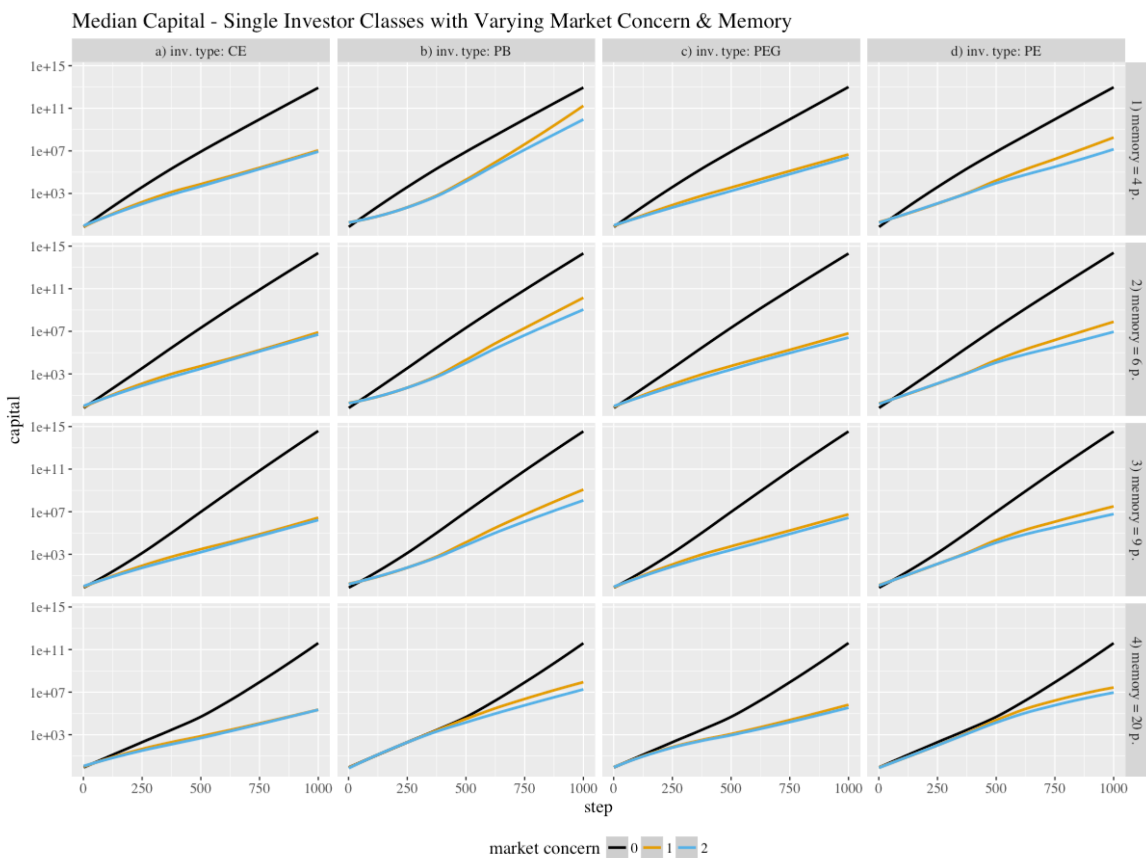

Figure 5: Temporal growth in the median capital levels of the firms. Facets differentiate the investors classes and the memory utilization of the investors. The lines represent the progression of the capital levels with management having different concern for the market, after utilizing LOESS smoothing

To develop an initial hypothesis as to how and why the different investor classes affect capital growth an analysis of the market return profiles is also required (see Figure 7). A second significant observation from Figure 5 is that the memory of management, even with no concern for the market, has a material effect. The results exhibit a “Goldilocks” outcome, where the optimal growth is achieved with the consideration of some history, but not too little or too much. This result is supported by facet rows 2 and 3 exhibiting the highest levels of accumulated capital. The initial hypothesis for this behavior, and one explored in depth later, is that the rate at which management update their expectations must have a meaningful effect on growth.

Having established that capital accumulation is influenced by management and investors, it is necessary to assess how that capital is distributed across firms. As discussed in Section 2.2 and confirmed in Section 3, the distribution of firm size should exhibit a power-law distribution. Figure 6 presents the capital distribution of firms for the various experimental settings in the same log (reversed) CDF as utilized in Section 3.

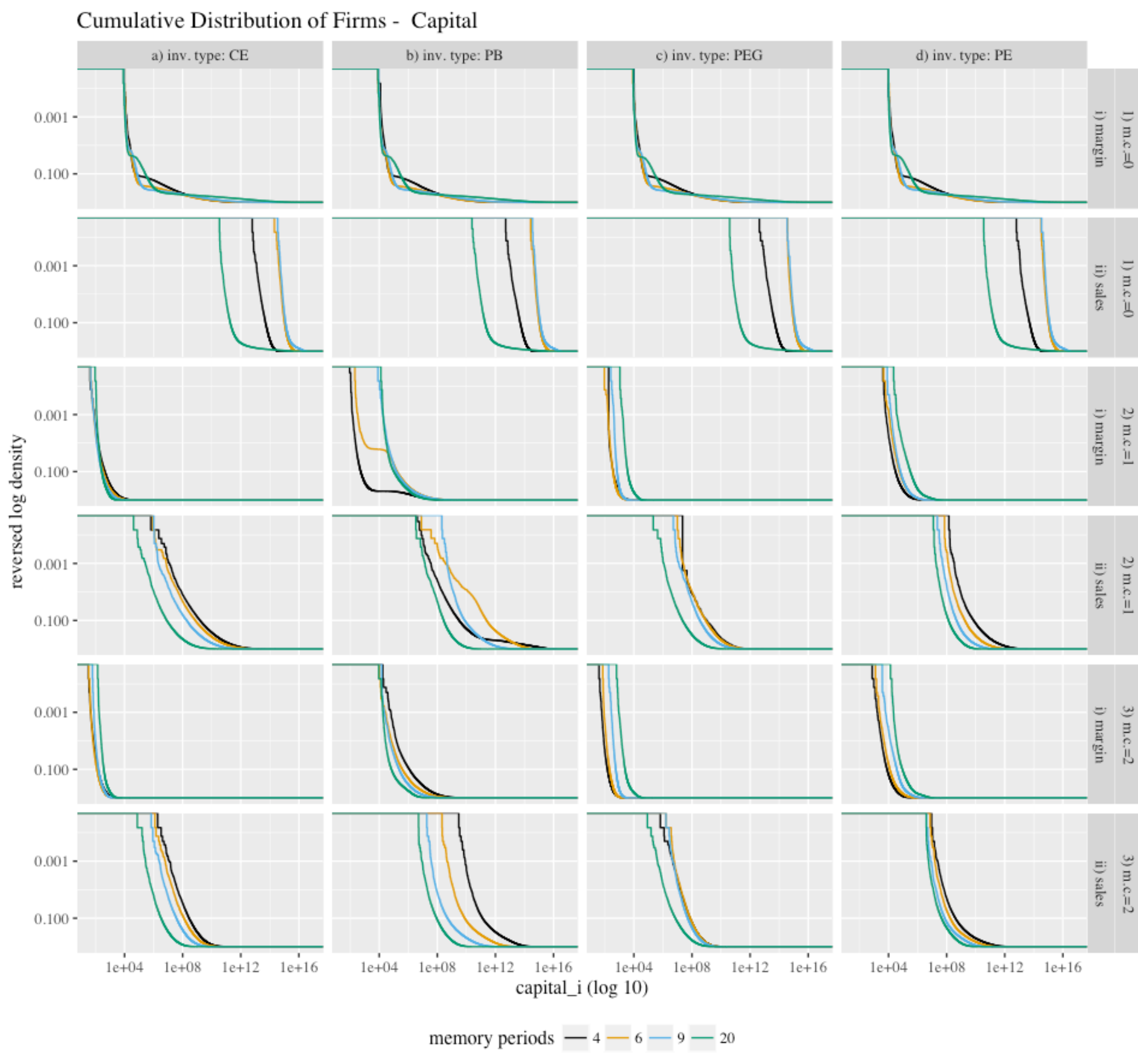

Figure 6: Firm size distribution at the completion of the simulation. Facets are differentiated further with the firm type recognized. The lines represent the CDF in log form and are separated by the memory utilized by the agents.

An additional facet is added to distinguish between the sales and margin growth firm classes to highlight the differential in capital levels between the two classes. It must be acknowledged that a factor in the division is the framework of the model; which had the margin growth firms tending to pay out a higher proportion of profits as a dividend. Regardless of this difference, Figure 6 highlights that the gap in capital between the two classes varies significantly, and margin growth firms are not precluded, under the right conditions, from growing to a size comparable with the sales growth firms. However, the shrinking of the gap is more a function of sales growth firms failing to grow.

In a result, consistent with that seen in Figure 5, Figure 6 shows that once management becomes concerned with the market's reaction, it has a material effect on the dynamics of the system. In a significant finding, which helps explain the dynamics of Figure 5, it is the sales growth firms that appear more responsible for the reduction in capital levels once management reacts to the market. This is supported by the distribution curves in facets row 1i being located farther to the right than what seen in rows 2i and 3i. In terms of the margin growth firms, they are also affected by management's concern for the market but not to same extent. In an environment where management does not consider the market (facet row 1), the Goldilocks effect is clearly seen for the sales growth firms, with margin growth firms appearing not as affected. The likely reason is that sales are more volatile than margins because sales growth, as explained in Section 4.2.2.1, is a function of past profits and stochastic processes for firm's realization of price and their ability, while margins are not reliant on past profits. Once management consider the market's reaction, interesting dynamics develop where the distribution of capital for the sales growth firms is less influenced by the memory variable. Alternatively, in general when compared to the base case, the capital distribution of margin growth firms is affected by memory length.

The foundation of an acceptable hypothesis as to how managements' reactions to their share price affects capital growth centers around the size and frequency of the share price movements. Namely, the more sizable the movement, the more immediate and larger the adjustment in expectations. Therefore, if a given investor class is responsible for a higher frequency of more significant price movements this will manifest itself in more frequent and larger changes in expectations – noting that no attempt is made at this stage to say whether the expectations are increased or decreased. The commentary regarding Figure 7 address the implications of this statement. Figure 7 presents the distribution of the percentage change in the index of the artificial stock market. Violin plots are employed to illustrate the behavior of the market because they have the advantage of showing both the distribution and density of the data. The immediate observation is that the CE and PEG investors are responsible for generating more extreme price movements, as witnessed by their respective plots; that is, they tend to be "taller," with higher density in the tails, with a bias towards larger downward movements. The upshot of this is that there is an asymmetrical relationship, which sees firms tend to experience extreme price moves, with a bias for larger downward price movements. This dynamic will be seen to be crucial to understanding the dynamics of the model as it sends confusing messages to management, with the rate of expectation adjustment and growth affected.

Alternatively, the remaining classes exhibit a more condensed distribution, with PB investors responsible for the least volatility. An important element of the PB return profile is the lack of large negative movements. The upshot of this is that management will not be needing to increase expectations to satisfy the investors' appetite for growth. A more general repercussion of the distribution is that if there are large extreme movements management become more active in their reactions. The direct effect of higher volatility was seen in Figure 5, where the more volatile markets deliver lower capital growth; hence, verifying the likely consequences of a positive feedback loop between management and investors; that is, reacting to a volatile market will lead to lower growth.

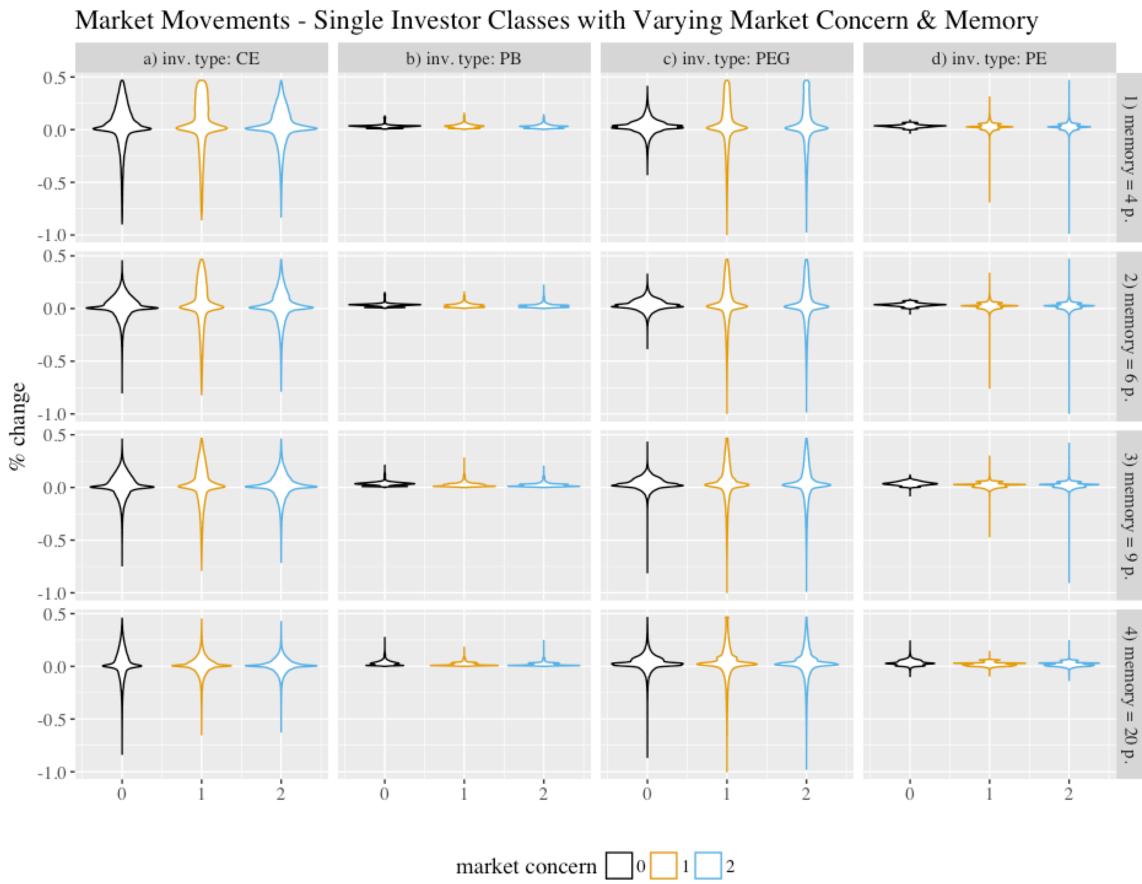

Figure 7: Distribution and density of the percentage change in the index. Facets differentiate the investors classes and the memory utilization of the investors. The violin plots represent the returns with management having different concern for the market.

Figure 8 presents the temporal evolution of the median growth rate for firms. The first observation, which is consistent with Figure 5, is that, for a given memory length, the growth is unaffected when management is not concerned with the market. The more relevant observation, which explains the Goldilocks result of Figure 5, is that the amount of history management considers, while still ignoring the market, affects the growth profile of the firms. An interim level of memory – facet rows 2 and 3, produces a prolonged period of elevated growth, which eventually tapers off. In contrast, less memory – facet row 1, sees growth decrease more rapidly, while extended patience – facet row 4, sees an overall lower level of growth. Regardless of the length of the memory used, it appears that the median growth rate can approach some degree of a steady state, which signifies that firms can self-organize and find some optimal level of expectations and resource allocation. Once management becomes concerned with the market the effect of the various investor classes is evident. An environment with more volatile investors –

columns a and c, exhibit lower growth, with growth declining from initiation, before eventually leveling out at an inferior level. A heightened concern for the market's reaction amplifies this behavior. Alternatively, the less volatile markets – columns b and d, sees growth initially trend up, before declining later in the cycle. This result is suggestive of a structural shift occurring in the market, which in turn is responsible for the transition in growth.

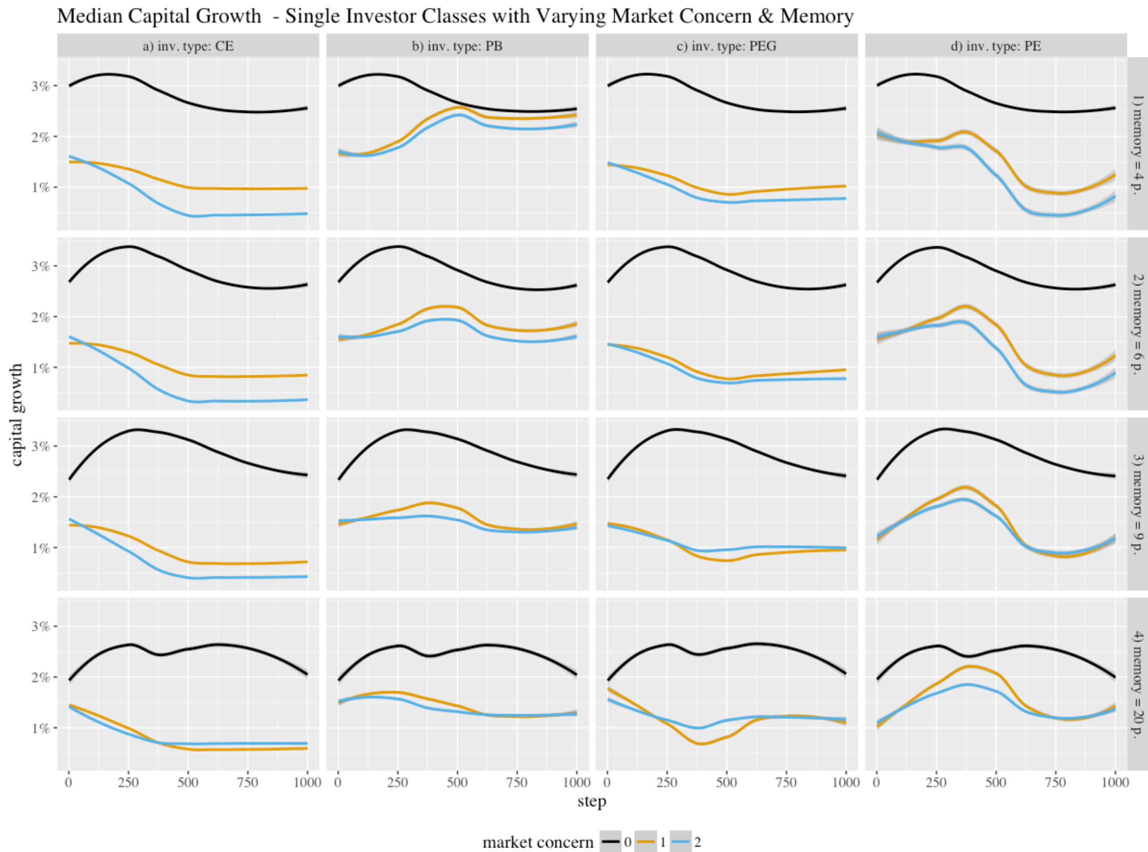

Figure 8: The temporal growth profile of the firms. Facets differentiate the investors classes and the memory utilization of the investors. The lines represent the progression of the median capital growth with management having different concern for the market, after utilizing LOESS smoothing.

Having established an overview of the growth dynamics of the firms, it is now essential to explore the growth dynamics within the population of firms, and more specifically to assess whether the growth rates exhibit Laplacian distributions over the short-term before becoming Gaussian over the longer-term. To explore the growth distribution separate charts are provided for each firm sub-class (sales growth (Figure 9) and margin growth firms (Figure 10)). The configuration of the figures differs from the previous charts. First the vertical facets reflect managements' concern for the market. Next, the horizontal facets reflect the per annum (pa) log growth of the firms for the following periods 50, 25, 10 and 5. There are multiple plots within each facet as firms were allocated to sub-groups based on the percentile rank of their capital levels. The distribution for the lower percentiles should exhibit a wider dispersion than the upper percentiles if the implemented model reflects the stylized facts of firm growth. The percentiles were allocated after sub-dividing the population data based on market concern and memory length. The final note is that Figure 9 and Figure 10 do not share the same x-axis scale, a fact that reflects the superior capital growth of sales growth firms.

Of note from Figure 9 is the absence of any bottom percentile firms; thus, confirming the superior capital growth of sales growth firms. Also, the characteristics of the distribution differs significantly when management does and does not consider the market. When the market is ignored, the plots exhibit a distribution, regardless of the percentile, tightly bunched around the mean. In a result counter to the expected dynamics, the distribution becomes less Gaussian as the analysis horizon expands. In terms of smaller firms exhibiting greater variance in growth, there is, at best, minor evidence of this in facet column a. Once sales growth firms start considering the market the dynamics, as expected, change. The first observation relates to the overall lower growth in the system – a point previously identified, with the distribution exhibiting a much wider dispersion. This dispersion of growth does reduce overtime, and in a result – more consistent with the empirical findings, the distribution does become more Gaussian.

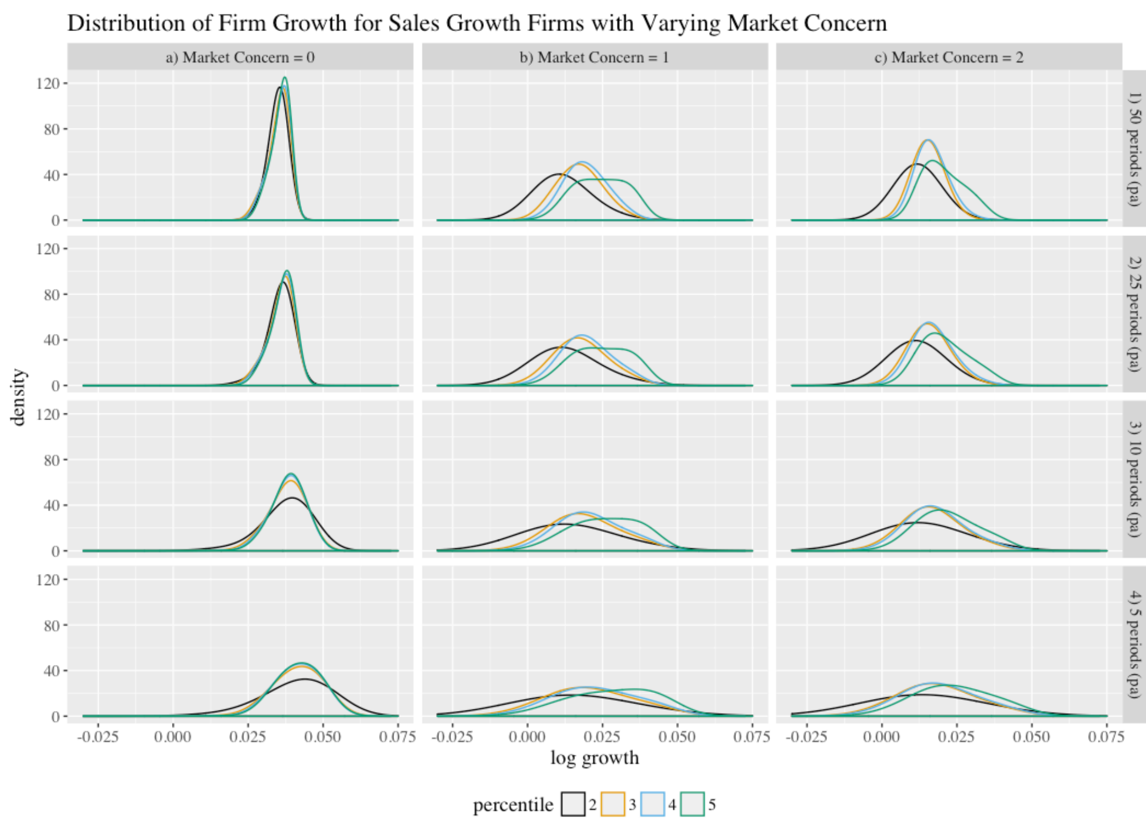

Figure 9: The capital growth distribution of sales growth firms. The vertical facets represent management concern for the market, with the horizontal facet denoting memory utilization. The distributions are split based on the percentile of the firm.

Figure 10 provides the growth distributions for the margin growth firms. Interestingly, the chart has plots for all five percentiles, indicating that under certain circumstances margin growth firms can achieve significant growth. However, this is very much the exception, so from this point forward the commentary will ignore the 5th percentile. The theme of Figure 10 supports the theory that once management becomes concerned with the market, outcomes change. When management does not consider the market, a contrasting result to the equivalent settings in Figure 9 appears. Namely, the distribution for the bottom two percentiles differs from the 3rd and 4th percentiles; that is, the lower two are tightly bunched, while the others are more dispersed. This result may occur due to a lack of data in the upper percentiles and contradicts the empirical result, which simply highlights the fact that validating a model of firm growth is not an easy task. The features of facet columns b and c in Figure 10; that is, firms respond to the market, are consistent with Figure 9. Specifically, larger firms tend to exhibit, on average, a higher propensity to grow. However, the distribution appears more consistent over time, with the only exception being that the lower percentile tends to exhibit a tighter band of lower growth – see facet c1.

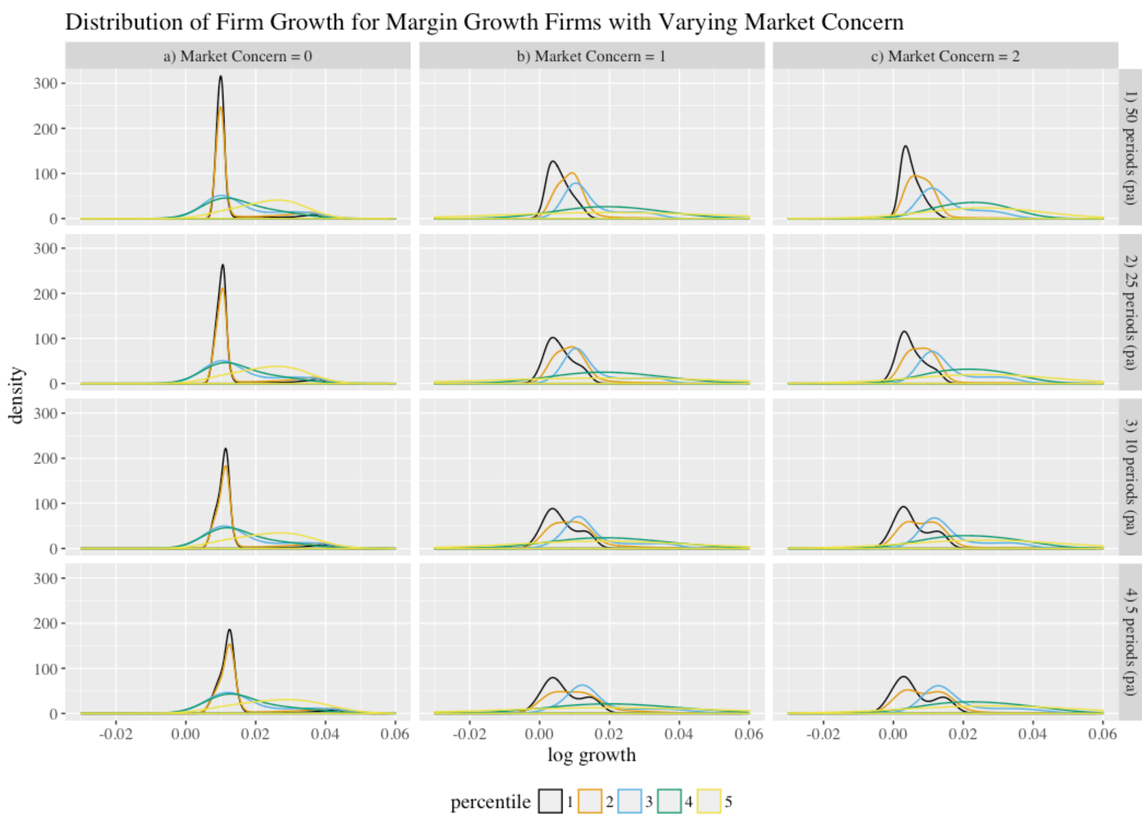

Figure 10: The capital growth distribution of margin growth firms. The vertical facets represent management concern for the market, with the horizontal facet denoting memory utilization. The distributions are split based on the percentile of the firm.

6 DISCUSSION AND CONCLUSION

While other models, such as Delli Gatti et al. (2005), have been successful in replicating the stylized facts of firm growth and size, with the increasing prevalence of short-termism among decision-makers in financial markets, it was deemed worthwhile to develop a framework capable of considering both issues. The initial findings are suggestive this research topic remains relevant and has considerable scope to expand. The first finding that supports ongoing research is how the speed at which management update their expectations affects capital growth. The relevance of this avenue is that traditional economic theory remains mute on how firms adjust their resource allocation in the face of a variety of inputs. This is because neo-classical economics assumes that firms will set production levels such that their marginal costs equal their marginal revenue, with the firms presumed to know their cost curve and the demand equation for their output.

Another insight from the model relates to how management interprets the price signals from the market. Though the recognition of these signals is not new, the model provided insight into how these signals may affect real economic variables, such as the capital accumulation of the firm. The finding of most significance is that if firms receive large signals, they overact, mainly by reducing expectations following a sizable upward price movement, and this has a detrimental effect on capital growth. In contrast, the model showed that if firms were left uninterrupted by the market, their ability to optimize their resource allocation improved. This result is meaningful and supports the hypothesis that by having to interact with the market continuously impairs firm performance, with the greater economy affected.

Coupled with this finding, is the result that certain investor classes were responsible for more extreme market behavior. It was also found that certain combinations created more divergent dynamics. These results are supportive of the need to address financial markets as an ecosystem and understand the dynamics between the growth and decline of certain investor classes. The ramification coming from this is that if management considers the market's reaction they need to be extremely mindful of who their investors are. This finding essentially fuses the decision-making process of firms with that of investors. The consequence of this relationship takes on greater meaning when one considers that the actions of management will influence the behavior of the investors; thereby, highlighting the dangers of allowing positive feedback loops to operate – a hazard that escalates if investors are more reactive.

Of course, the implications presented remain speculative unless supported by empirical evidence or make accurate predictions of how the market and firms will perform. The empirical facts of greatest relevance to this paper were the distributions relating to firm size and growth. An extensive dataset was analyzed with the results suggesting that certain discrepancies across regions exist, possibly due to structural issues of regional capital markets or the maturity of those markets. Additionally, widely recognized financial metrics (for example, PE and PB ratios), were also found to exhibit skewed distributions (see Figures 17 and 18) This finding provides another layer of validation requirement for future theories. As for the executed model, the level of validation was mixed, mainly due to an inability to decompose the empirical data to the same level of the model's data; that is, it is hard to establish what the primary objective of a real-world firm may be.

An ambitious research agenda was undertaken in this paper with a novel ABM implemented to address a vital concern relating to how secondary equity markets operate. An important, and novel, element of the research was to integrate the characteristics of empirical facts pertaining to investment market and firms, with all of them exhibiting the statistical imprint of a CAS. While many of these facts had been previously recognized, the novelty was to expand and combine the data. Ultimately, the research highlighted the benefits of agent-based modeling and the need to consider financial markets, and the economy in general, as a system of heterogeneous interacting agents interacting in complex system.

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Appendix

Table 5: Power-law Coefficients for Market Capitalization of Global Firms

Year	Region	Power-law comp.	X Min	p-value of the Kolmogorov-Smirnov test	Region	Power-law comp.	X Min	p-value of the Kolmogorov-Smirnov test
2007	Northern America	1.76	1,404.45	0.01	Middle East	1.64	238.93	0.02
2008	Northern America	1.83	1,348.70	0.28	Middle East	1.65	120.95	0.05
2009	Northern America	1.84	1,902.79	0.05	Middle East	1.71	205.53	0.06
2010	Northern America	1.83	1,746.02	0.02	Middle East	1.65	182.86	0.02
2011	Northern America	1.82	1,787.91	0.01	Middle East	1.72	170.60	0.19
2012	Northern America	1.80	1,703.62	0.01	Middle East	1.70	156.13	0.14
2013	Northern America	1.83	2,369.78	0.01	Middle East	1.71	209.80	0.14
2014	Northern America	1.83	2,731.00	0.00	Middle East	1.71	298.47	0.12
2015	Northern America	1.72	1,338.04	0.00	Middle East	1.64	119.13	0.01
2016	Northern America	1.77	2,159.35	0.00	Middle East	1.65	135.77	0.01
2017	Northern America	1.80	2,946.55	0.00	Middle East	1.65	135.49	0.01
2007	Africa	1.56	134.40	0.00	Oceania	1.79	208.32	0.07
2008	Africa	1.62	89.22	0.00	Oceania	1.71	61.50	0.64
2009	Africa	1.58	79.75	0.00	Oceania	1.50	11.25	0.00
2010	Africa	1.94	617.60	0.67	Oceania	1.53	24.29	0.00
2011	Africa	1.74	167.53	0.10	Oceania	1.73	128.17	0.12
2012	Africa	1.90	645.66	0.41	Oceania	1.59	55.92	0.01
2013	Africa	1.96	534.04	0.58	Oceania	1.58	50.55	0.01
2014	Africa	1.72	161.55	0.01	Oceania	1.59	61.44	0.01
2015	Africa	2.03	421.03	0.73	Oceania	1.42	7.80	0.00
2016	Africa	1.85	253.52	0.73	Oceania	1.49	17.05	0.00
2017	Africa	1.90	469.96	0.67	Oceania	1.44	10.61	0.00
2007	Eastern Europe	1.95	668.70	0.71	Southern and Eastern Asia	1.88	518.76	0.00
2008	Eastern Europe	1.57	19.27	0.08	Southern and Eastern Asia	1.85	209.21	0.00
2009	Eastern Europe	1.51	18.16	0.00	Southern and Eastern Asia	1.97	585.59	0.12
2010	Eastern Europe	1.52	37.82	0.00	Southern and Eastern Asia	1.99	753.43	0.02
2011	Eastern Europe	1.55	42.41	0.04	Southern and Eastern Asia	1.89	319.05	0.00
2012	Eastern Europe	1.59	71.12	0.11	Southern and Eastern Asia	1.88	361.87	0.00
2013	Eastern Europe	1.68	138.16	0.40	Southern and Eastern Asia	1.92	450.69	0.00
2014	Eastern Europe	1.74	155.06	0.65	Southern and Eastern Asia	2.03	835.18	0.01
2015	Eastern Europe	1.73	152.54	0.45	Southern and Eastern Asia	1.42	30.43	-
2016	Eastern Europe	1.67	106.47	0.15	Southern and Eastern Asia	1.42	30.99	-
2017	Eastern Europe	1.57	50.95	0.03	Southern and Eastern Asia	2.11	1,434.23	0.03
2007	Latin America and Car.	1.80	615.53	0.21	Western Europe	1.91	1,535.05	0.98
2008	Latin America and Car.	1.70	170.74	0.15	Western Europe	1.76	312.46	0.05
2009	Latin America and Car.	1.85	677.58	0.25	Western Europe	1.94	1,392.21	0.73
2010	Latin America and Car.	2.00	1,296.80	0.47	Western Europe	1.93	1,247.73	0.54
2011	Latin America and Car.	2.02	1,173.73	0.63	Western Europe	1.91	1,042.49	0.44
2012	Latin America and Car.	1.71	377.78	0.00	Western Europe	1.96	1,586.40	0.83
2013	Latin America and Car.	2.07	1,766.04	0.80	Western Europe	1.62	232.42	0.00
2014	Latin America and Car.	1.81	458.81	0.00	Western Europe	1.65	250.82	0.00
2015	Latin America and Car.	1.98	744.77	0.36	Western Europe	1.98	1,839.51	0.49
2016	Latin America and Car.	1.57	80.00	0.00	Western Europe	2.00	1,827.74	0.59
2017	Latin America and Car.	1.52	92.48	0.00	Western Europe	2.02	2,606.13	0.89

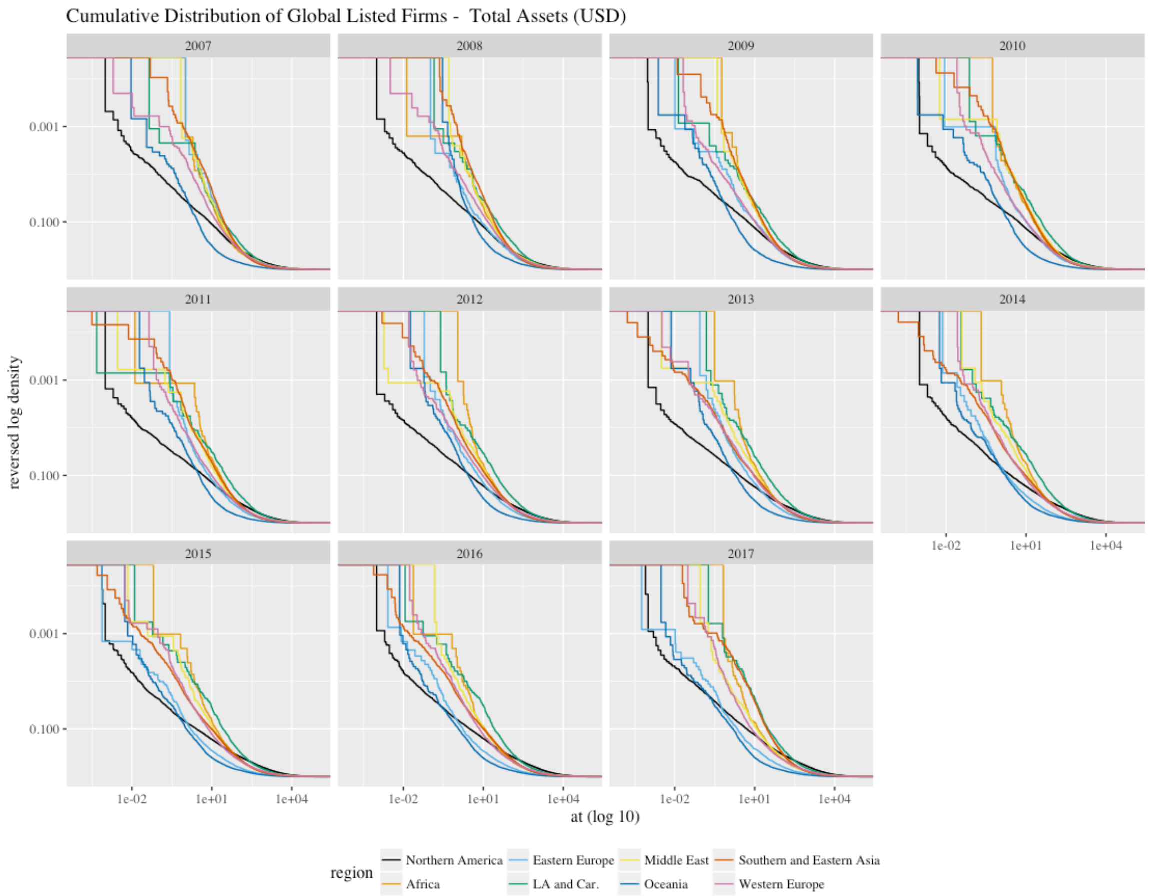

Figure 11: The distribution of the total assets of firms across regions and time. The distribution is represented by CDF, in log form. A "straight" line is indicative of a power-law distribution. Data source: Data source: Compustat – Capital IQ database (2018).

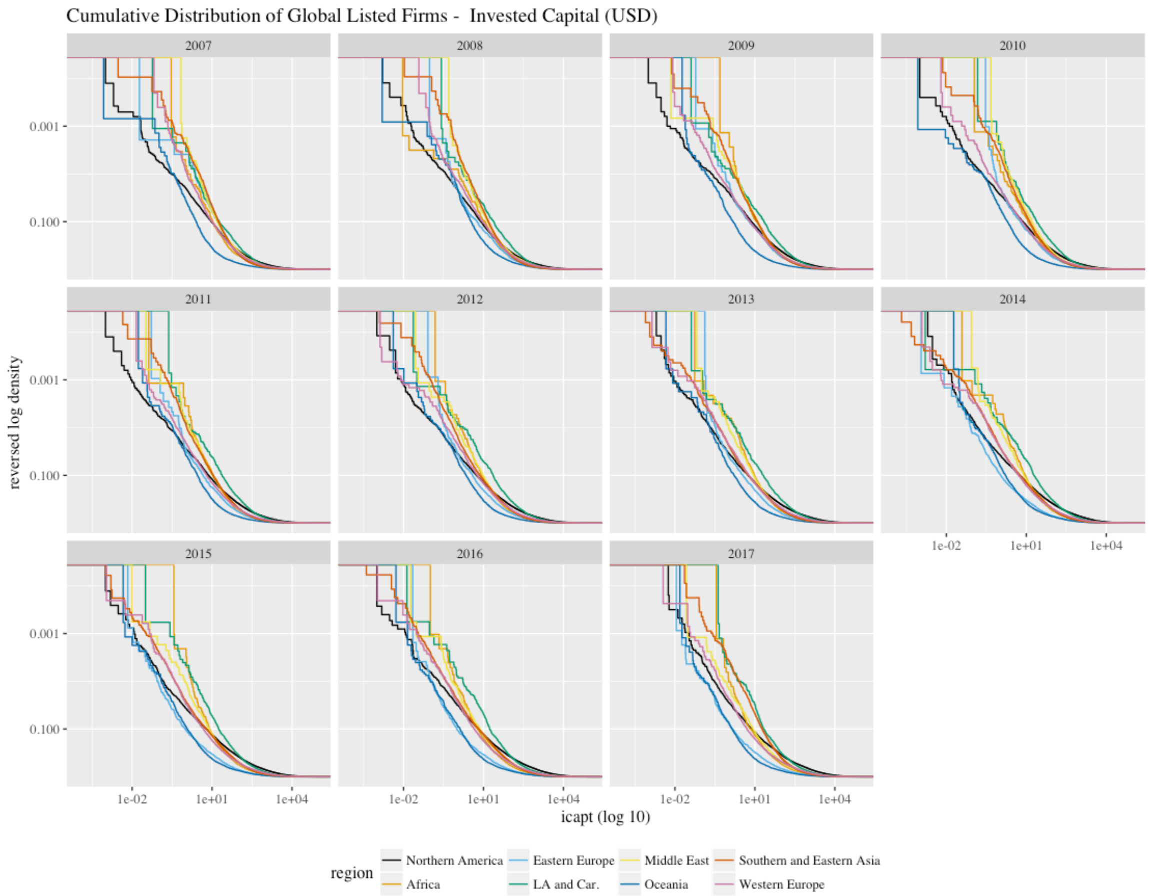

Figure 12: The distribution of the invested capital of firms across regions and time. The distribution is represented by CDF, in log form. A "straight" line is indicative of a power-law distribution. Data source: Compustat – Capital IQ database (2018).

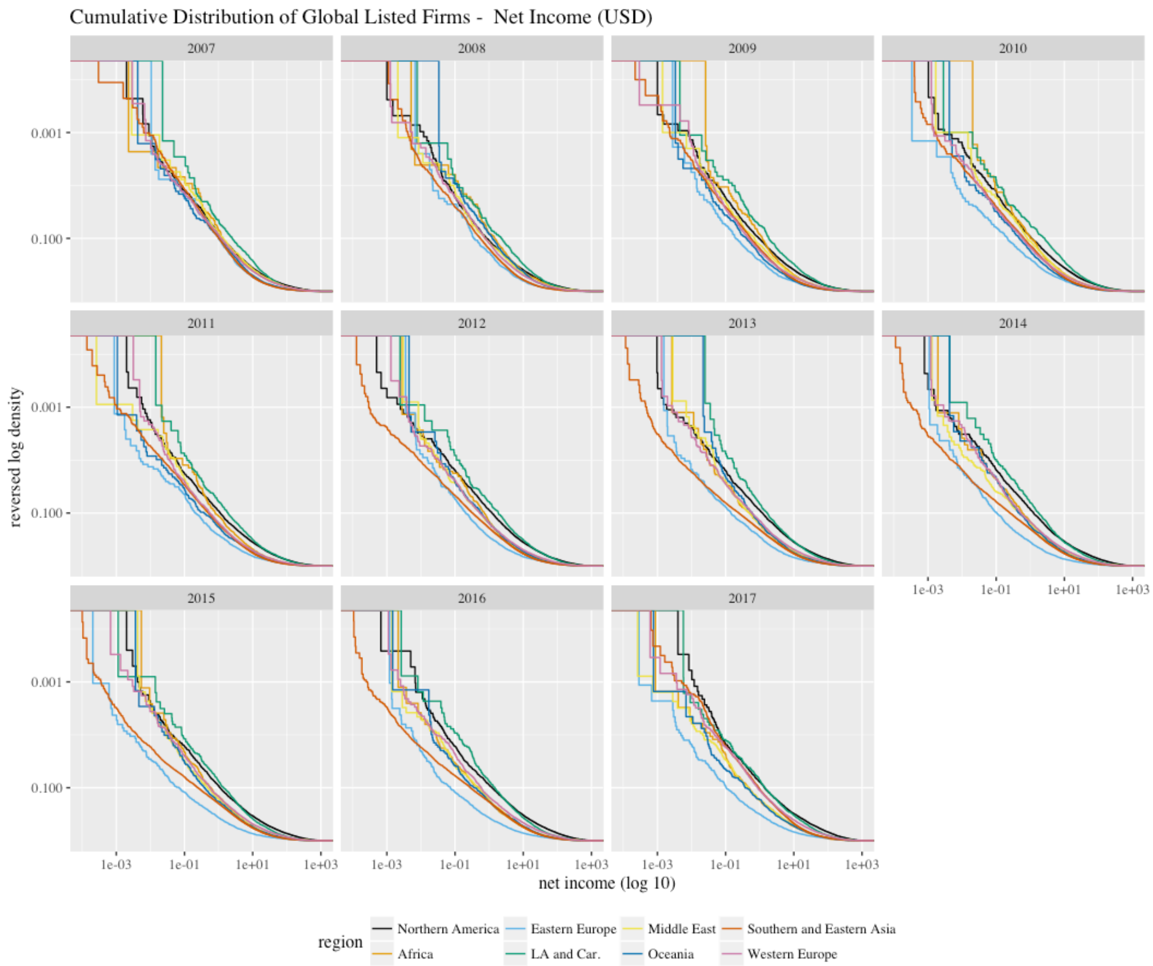

Figure 13: The distribution of the net income of firms across regions and time. The distribution is represented by CDF, in log form. A "straight" line is indicative of a power-law distribution. Data source: Compustat – Capital IQ database (2018).

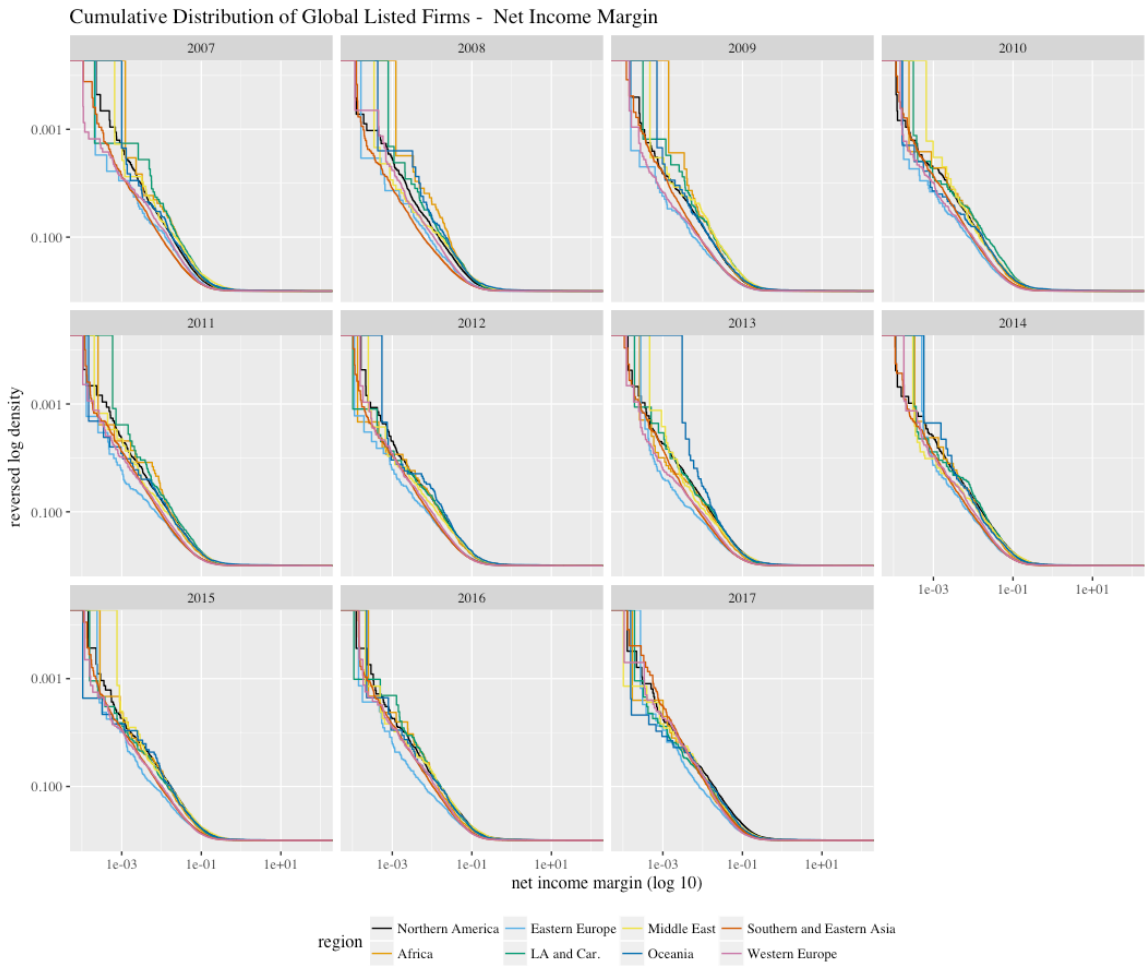

Figure 14: The distribution of net income margins of firms across regions and time. The distribution is represented by CDF, in log form. A "straight" line is indicative of a power-law distribution. Data source: Compustat – Capital IQ database (2018).

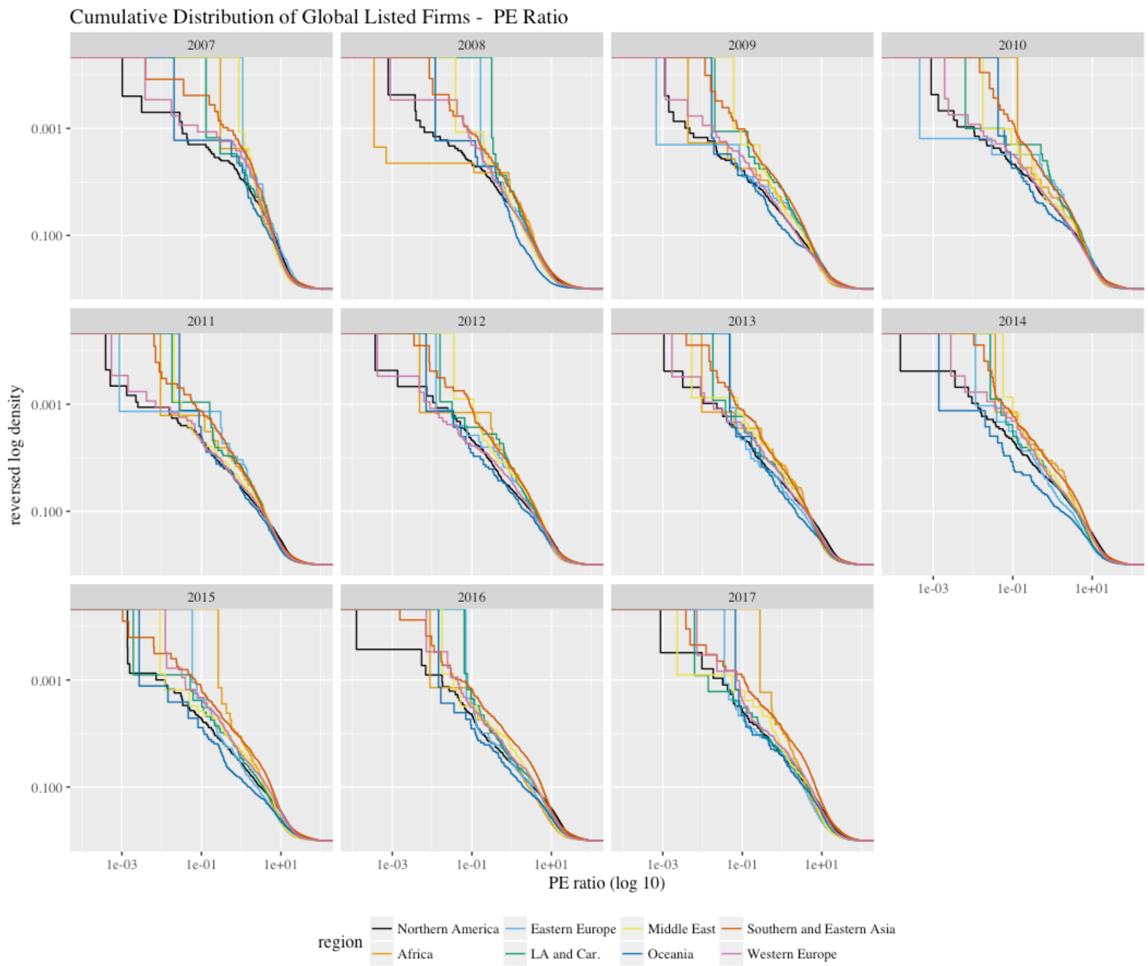

Figure 15: The distribution of the PE rations of firms across regions and time. The distribution is represented by CDF, in log form. A "straight" line is indicative of a power-law distribution. Data source: Compustat – Capital IQ database (2018).

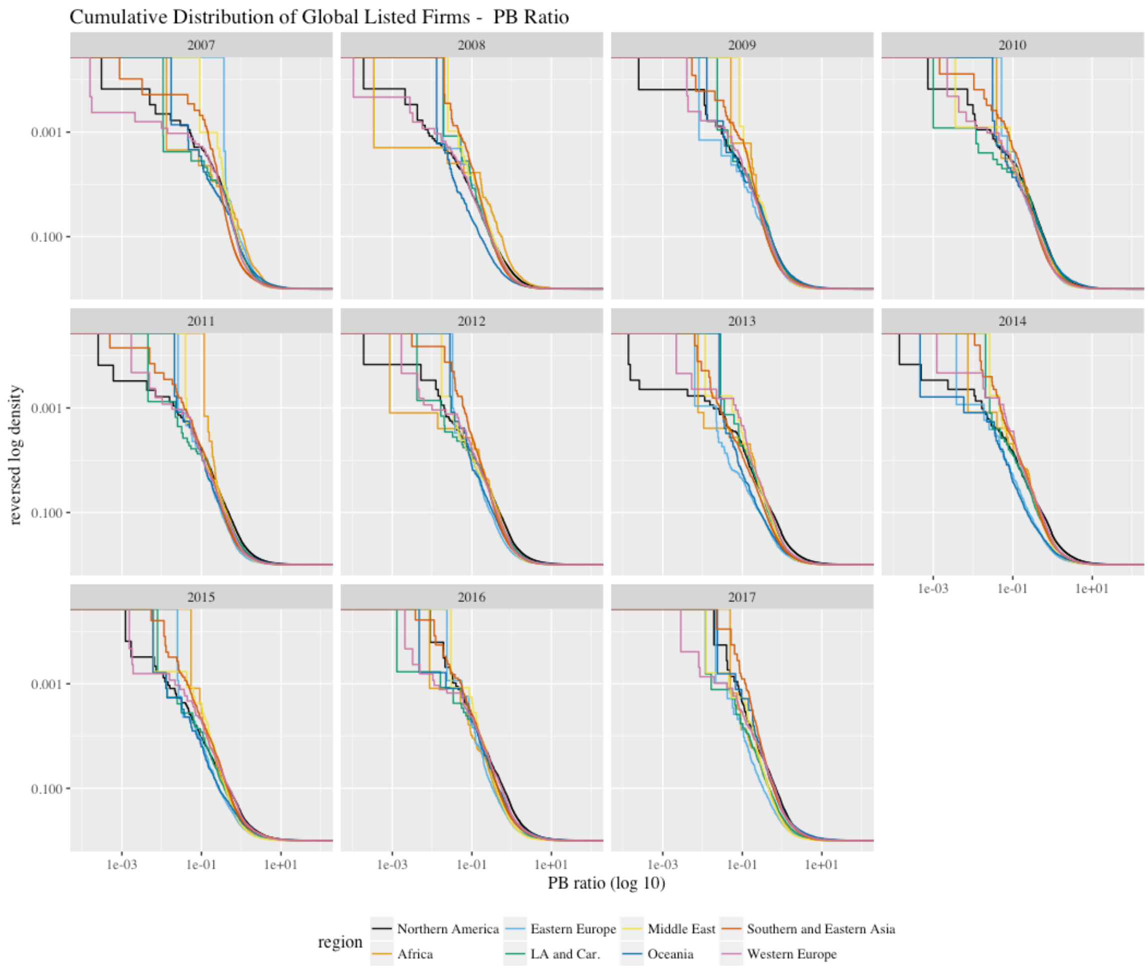

Figure 16: The distribution of the PB ratios of firms across regions and time. The distribution is represented by CDF, in log form. A "straight" line is indicative of a power-law distribution. Data source: Compustat – Capital IQ database (2018).