Optimal design and consequences of financial disclosure regulation: a real options approach

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ABSTRACT

This paper examines the optimal design and consequences of financial disclosure regulation. Our model represents the regulation as creating a real option for an investor to delay investment until information is disclosed. We find conditions on investment opportunities that ensure that regulation raises or lowers investor profits. We also find that investment typically falls immediately after regulation, and that the long-term effects on investment and profits are distinct and depend on market characteristics. For parameters calibrated to the time around the Sarbanes-Oxley Act, we calculate the extent and period of disclosure to maximise individual investor profits. We calculate the optimal parameters for a two company market, show that company-specific regulation is profit maximising, and calculate the investor profit loss from having market-wide rather than company-specific regulations.

Keywords:

Financial disclosure

Regulation

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[2] The author thanks Joe Tanega for suggesting the importance of learning and uncertainty for explaining responses to disclosure regulation.

1. Introduction

Following the Enron bankruptcy and other financial scandals (Coates, 2007), the US Government enacted the Sarbanes-Oxley Act (Sarbanes-Oxley, 2002) in 2002. The Act aims to protect investors by improving the quality of information disclosed by companies publicly quoted in the US. It set up a body to oversee the auditing of public companies, it increased restrictions on the activities of auditors, company insiders, and analysts, it increased penalties for malfeasance, and it expanded disclosure requirements.

The Sarbanes-Oxley disclosure requirements, as implemented by the Securities and Exchange Commission (SEC), initially proposed that large companies would have to implement the disclosure rules by 2004 and small companies by 2005 (Gao et al, 2009). Following concerns about the burden placed on companies and lack of transparency in the regulation (Hartman, 2007), there followed a series of extensions of the implementation dates (Gao et al, 2009), particularly for small companies, who ultimately were granted an exemption from an expensive disclosure requirement (Dodd-Frank, 2010, section 989G).

This paper examines the optimal design of disclosure regulation such as the Sarbanes-Oxley Act, and the consequences of its implementation. The questions we address are: how much information should be disclosed? How quickly should it be disclosed? What happens to investment during the disclosure period? Our model recognises that disclosure regulation allows companies to wait until information is revealed in order to make better informed choices. The formulation is similar to that used for American options, applied to real investment decisions. For parameters calibrated to the period around the Sarbanes-Oxley Act, we investigate the properties of the model by numerical methods.

We determine when investors benefit or lose from disclosure regulation, and so show when regulation can increase profits that can be derived from a market. We present expected investment patterns before and after regulation is introduced, and show that declines in investment after the introduction are to be expected, irrespective of the persistent effect of the legislation. We also show that declines in long term investment do not necessarily indicate that the legislation is reducing investor profits.

We calculate the extent of disclosure and time period of disclosure which maximise the profits to individual investors. We show how the optimal parameters vary with the profits derivable from an investment project, and the cost of disclosure. We calculate the optimal parameters for a two company market, show that company-specific regulation is optimal, and calculate the investor profit loss from having identical disclosure requirements applied to all companies rather than tailored for each company.

Section two presents our model, and section three describes its solution and parameterisation. Section four gives the consequences and optimal design of the regulation when there is a single company, and section five does the same for multiple companies. Section six concludes.

2. Model

Our model formulates the disclosure regulation as creating a real option for the investor based on disclosure of information over a finite period. The investor then faces a set of investment decisions similar to those confronted by an owner of an American option. There are a few papers in the literature which have examined how real options arise in disclosure (Acharya et al, 2010; Delaney and Thijssen, 2011; Dempster, 2006; Wysocki, 1998). However, these papers present companies or managers holding the options, rather than the investors as in our paper. Technically, our closest precursor is Dempster (2006), who uses a Black-Scholes formulation to calculate indirectly the value of disclosure.

An investment opportunity is available in a market. The income earned depends on managerial quality, which consists of n separate components. Each component can be low or high quality. If a component is high quality, income increases by a value H, and if a component is low quality, income does not change. If all components are low quality, income is zero. We also considered alternative forms for management quality, including those measured by continuous variables, and discuss their modelling in the conclusion.

Income only starts being generated by the investment when an investor provides funds, and the size and timing of subsequent income relative to the investment date are independent of that date. The investment has a price of 100 units, and investment is irreversible so that once the investment is purchased an investor has no opportunities for resale.

A potential investor is risk neutral and maximises their expected profits. They are unaware of the managerial quality prior to investment in the investment opportunity, and have a belief that the probability of each individual component being high quality is p. Thus, the investor expects that the income from the investment will be npH. The investor discounts future income at a rate r per year.

We assume that the company does not disclose the information voluntarily. The unravelling argument (Grossman and Hart, 1980; Grossman, 1981) indicates that companies will voluntarily disclose all information. However, the assumptions of the unravelling result have been challenged (Beyer et al, 2010). It is clear that not all relevant information was disclosed prior to the financial scandals in the US in the early 2000s, leading investors to overvalue some companies by very large amounts, while the use of disclosure regulation indicates that government does not accept that disclosure happens to an efficient level.

A government seeks to maximise expected income to investors, taking their behaviour as given. It introduces disclosure regulation which reveals truthfully the quality of the investment management. It discloses a proportion s of the total number of quality components, with $0 \leq s \leq 1$ and sn an integer, and the disclosure happens at a level rate over T years. The disclosure regulation thus results in progressive reduction in uncertainty about the income from investment opportunities, consistent with the risk dynamic observed by Akhigbe and Martin (2008) following the Sarbanes-Oxley Act.

Disclosure is costly, and is paid for from the investment income. The cost is proportional to the expected value of the investment, as the extent of managerial operations and so the extent of disclosure should rise with the expected value. It is also proportional to the share of disclosure s and inversely proportional to the time T taken for disclosure. If regulation demands that companies disclose their information quickly, companies are likely to face strain on their managerial resources, resulting in overtime work, exceptional hiring, and inflationary pressures on resource costs.

Alternative functional forms linking costs with the disclosure share and disclosure period may alter the exact optimal values of these parameters and derived quantities. The basic relations deduced between the parameters and optimal values will not be affected however, if we continue to assume the plausible positive relations between disclosure quantity and cost, and disclosure speed and cost. As our model is calibrated rather than estimated, we do not differentiate between the statistical performances of the possible functional forms.

The model does not allow for any uncertainty about costs. Following the introduction of actual regulation the level of uncertainty about costs can be high, as shown in the survey of executives and directors described in Hartman (2007) following the Sarbanes-Oxley Act. Hartman (2007) also describes how uncertainty about costs declined over time after the Act. In the conclusion, we discuss the inclusion of cost uncertainty in the model.

The investor faces the problem of choosing when to invest, if ever. The profit of immediate investment is $D_t + E(U_t) - CnpHs/T - 100$, where D_t is the value of the disclosed managerial quality at time *t*, U_t is the value of the undisclosed managerial quality at time *t*, and *C* is a constant. They will invest at time *t* when the profit of immediate investment exceeds the value of waiting. We denote the value of the option to invest at time *t* by V_t. Then immediate investment occurs when

$$Max(D_t + E(U_t) - CnpHs/T - 100,0) > (1+rdt)^{-1} E(V(D_{t+dt}, U_{t+dt}, t+dt)$$

where *dt* is a small time period. The value V_t satisfies the Bellman equation

$$\begin{aligned} &V(D_t, U_t, t) \\ &= \max(\max(D_t + E(U_t) - CnpHs/T - 100,0), (1+rdt)^{-1} E(V(D_{t+dt}, U_{t+dt}, t+dt))) \\ &\qquad\qquad\qquad\qquad\qquad\qquad \text{if } t < T \end{aligned}$$

and

$$V(D_t, U_t, t) = \max(D_T + E(U_T) - CnpHs/T - 100, 0) \qquad \text{if } t \geq T$$

D_t satisfies the dynamic stochastic equation

$$D_{t+dt} = D_t + (neHs/T)dt \qquad \text{if } t < T$$

and

$$D_{t+dt} = D_t \qquad \text{if } t \geq T ,$$

where $D_t = 0$ and *e* is a Bernoulli random variable with parameter *p*.

U_t satisfies the dynamic equation

$$U_t = npH - npHst/T \qquad \text{if } t < T$$

and

$$U_t = (1-s)npH \qquad \text{if } t \geq T .$$

The government's problem is to choose the amount *s* of information disclosed and the period *T* over which disclosure occurs in order to maximise the expected profit to the investor. They maximise the expression

$$\sum_S (1+r)^{-t} P(D_t, U_t, t)(D_t + E(U_t) - CnpHs/T - 100)$$

where the domain S is defined by the set of knowledge states at time *t*, (D_t, U_t, t), satisfying

$$\{D_t, U_t, t : Max(D_t + E(U_t) - CnpHs/T - 100, 0) > (1 + rdt)^{-1} E(V(D_{t+dt}, U_{t+dt}, t + dt)\}$$

and $P(D_t, U_t, t)$ is the probability of reaching the triple (D_t, U_t, t) without having previously invested.

3. Solution

3.1 Method

The investor has the option to invest at any time, with dynamic variance in returns. We tried to produce analytical solutions for the solution, but the differential equations derived from the Bellman equation had a similar structure to those for American options, for which there are no known closed-form solutions. So we solve for the investor's and government's decisions by numerical analysis using a tree method. Dempster (2006) notes that real options relating to announcements could be formulated and solved in this way, although she does not do so, and her options belong to companies rather than investors.

The disclosure period is divided into *sn* steps, with each step corresponding to the disclosure of information on one quality component. Each step corresponds to a time period of $T/(sn)$. For each step, the value of known quality increases by H if the quality is disclosed to be high and 0 otherwise. Thus, at step *m*, the disclosed quality $D_{mT/(sn)}$ takes a value $MH \in \{0, H, 2H, ..., mH\}$, while the undisclosed quality has an expected value of $U_{mT/(sn)} = (n - m)pH$. The profit of immediate investment in each state can then be calculated as $MH + (n - m)pH - CnpHs/T - 100$.

Then comes a backwards iteration to calculate the value of the option to invest.
We first calculate the value of the option in the last step *sn* for each triple (D_T, U_T, T), which is the value of immediate investment if it is positive and zero otherwise. Thus, writing the disclosed quality as $M_T H$, the value of investment is $M_T H + (n - sn)pH - CnpHs/T - 100$. At step *z*-1 ($z < sn$), with disclosed information of $D_{(z-1)T/(sn)} = M_{(z-1)T/(sn)} H$ and undisclosed information of

$U_{(z-1)T/(sn)} = (n-(z-1))pH$, the next step changes the value of the option to invest to either $V(M_{zT/(sn)}H,(n-z)pH,z \mid M_{zT/(sn)}H = M_{(z-1)T/(sn)}H)$ or $V((M_{zT/(sn)}+1)H,(n-z)pH,z \mid M_{zT/(sn)}H = (M_{(z-1)T/(sn)}+1)H)$. The probability weighted value is thus

$$
\begin{aligned}
&(1-p)V(M_{zT/(sn)}H,(n-z)pH,z \mid M_{zT/(sn)}H = M_{(z-1)T/(sn)}H) \\
&+ pV((M_{zT/(sn)}+1)H,(n-z)pH,z \mid M_{zT/(sn)}H = (M_{(z-1)T/(sn)}+1)H)
\end{aligned}
.
$$

The value of the option to invest is given by the maximum of the value of immediate investment or the value of waiting:

$$
\begin{aligned}
&V(M_{(z-1)T/(sn)}H,(n-(z-1))pH,z-1) = \\
&\max(M_{(z-1)T/(sn)}H + (n-(z-1)n)pH - CnpHs/T - 100, \\
&(1-p)V(M_{zT/(sn)}H,(n-z)pH,z \mid M_{zT/(sn)}H = M_{(z-1)T/(sn)}H) \\
&+ pV((M_{zT/(sn)}+1)H,(n-z)pH,z \mid M_{zT/(sn)}H = (M_{(z-1)T/(sn)}+1)H))
\end{aligned}
$$

We can iterate backwards on this equation to find the value of the option to invest for any triple (D_t, U_t, t). This procedure also gives the optimal choice to invest or delay in each triple.

We then calculate the optimal government design of the disclosure regulation. We first calculate the probability of reaching a triple (D_t, U_t, t) such that no earlier disclosure had triggered investment. At time zero, the probability $P(NPI \mid D_t, U_t, t=0)$ of reaching a triple $(D_t, U_t, t) = (0, npH, 0)$ with no previous investment is one. At a subsequent disclosure step *z* up to the end of the disclosure period *T*, the probability of reaching a triple without investment in which disclosure has revealed only low quality management (i.e. $P(NPI \mid 0, U_t, t = zT/(sn))$) is the product of three probabilities: the probability of no investment and only low quality management at the start of the previous step; the probability of low quality management being disclosed in the previous step; and the probability of no investment in the previous step (which is zero or one). Thus,

$$P(NPI \mid 0, U_t, t = zT/(sn))$$
$$= P(NPI \mid 0, U_t, t = (z-1)T/(sn))(1-p)P(NI \mid 0, U_t, t = (z-1)T/(sn))$$

where $P(NI \mid 0, U_t, t = (z-1)T/(sn))$ is the probability of no investment in step *z*-1.

When disclosure has revealed that some management components are high quality, we have a similar equation in which the previous step had either the same number of high quality components or one less high quality component:

$$P(NPI \mid M_{zT/(sn)}H, U_t, t = zT/(sn))$$
$$= P(NPI \mid M_{zT/(sn)}H, U_t, t = (z-1)T/(sn))(1-p)P(NI \mid M_{zT/(sn)}H, U_t, t = (z-1)T/(sn))$$
$$+$$
$$P(NPI \mid (M_{zT/(sn)} - 1)H, U_t, t = (z-1)T/(sn))\, pP(NI \mid (M_{zT/(sn)} - 1)H, U_t, t = (z-1)T/(sn))$$

Then, at the start of the disclosure period, the probability of investment at step *z* is given by

$$\sum_{M_{zT/(sn)}=0}^{z} P(NPI \mid M_{zT/(sn)}H, U_t, t = zT/(sn))\; P(I \mid M_{zT/(sn)}H, U_t, t = zT/(sn))$$

where $P(I \mid M_{zT/(sn)}H, U_t, t = zT/(sn))$ is the (zero or one) probability of investment at step *z*.

At the start of the disclosure period, the expected value of investment at step *z* is given by

$$\sum_{M_{zT/(sn)}=0}^{z} VI(W) P(NPI \mid W)\; P(I \mid W)$$

where $VI(W) = M_{zT/(sn)}H + (n - zn)pH - CnpHs/T - 100$ is where the triple $W = (M_{zT/(sn)}H, U_t, zT/(sn))$, and $VI(W) = M_{zT/(sn)}H + (n - zn)pH - CnpHs/T - 100$ is the value of investment at *W*.

The discounted expected value from all investment is then

$$\sum_{z=0}^{sn}(1+r)^{zT/(sn)} \sum_{M_{zT/(sn)}=0}^{z} VI(W)P(NPI \mid W)\, P(I \mid W)$$

The government chooses the disclosure share s and the time of disclosure T to maximise this quantity.

We implement the procedures in a Microsoft Excel spreadsheet, available from the author (and online soon).

3.2 Parameterisation

The parameterisation of our model requires information on the number of quality components, the probability of a high quality component, the income gained from high quality managerial components, the introductory time of the disclosure regulation, the extent of disclosure, the disclosure cost, and the annual discount rate. We vary several of these parameters in order to see the effect of regulation or how its optimal design changes. Where parameters are held constant, we use the parameters derived next, with references made to those relating to the Sarbanes-Oxley Act. The parameters are summarised in table 1

Table 1. Parameter descriptions and values

Parameter	Description	Value
n	Number of quality components	10
s	Share of quality components disclosed	0.5
p	Probability that a component is high quality	0.37
H	The income from a high quality component	100 divided by (np)
T	The period over which disclosure occurs	4 years
C	Multiplier for the cost of disclosure	0.015 times (T/s)
r	Annual discount rate for investment income	0.15

The number of quality components and extent of disclosure

Disclosure regulation can require information on many components of managerial quality. The Sarbanes-Oxley Act, for example, mandates disclosure of internal controls, financial expertise, and transactions involving management and principal stockholders, as well as enhancing external review, and the broad classes of disclosure are subject to more detailed requirements by the Public Company Accounting Oversight Board (Sarbanes-Oxley, 2002; Ge and McVay, 2005). However, there are likely to be other components that are not disclosed by regulation. Until a crisis reveals any omitted ones, it is not clear how comprehensive the disclosure is. To allow for the range of possible coverage, we take the total number n of quality components at ten, allowing us to vary the extent of disclosure by increments of ten percent from zero percent. When we consider the effect of introducing disclosure regulation, we hold the extent of disclosure s at 0.5.

The probability of a high quality component

As we have ten quality components, the expected income falls by ten units when one of the components is revealed to be low quality. We want to know the probability that, if disclosure of low quality occurs concerning a tenth of the managerial quality components, the resulting information leads to a decline of ten percent of the project's expected value.

One approach is to calculate the probability of all ten components having low quality, and equating that to the probability of bankruptcy. Hillegeist et al (2004) find that the probability of bankruptcy over the period 1980-2000 was 0.97 percent for US public companies. We can solve for $0.97\% = (1-p)^{10}$, giving $p = 0.37$ so that there is a 37 percent chance of a component being high quality.

Alternatively, we could estimate the probability from frequencies of adverse news following Sarbanes-Oxley, and the resulting declines in company value. Opinions of companies' internal controls are issued as part of Sarbanes-Oxley regulations by either the internal management or external auditors. A percentage of these opinions are adverse, with Audit Analytics (2008) reporting that 16.9 percent of disclosures from November 2004 to November 2005 were adverse. Hammersley et al (2008), table 4, show that the mean decline in size-adjusted returns was 0.95% following disclosure of internal control weakness. The disclosures are not necessarily comprehensive lists of internal control weaknesses for a single company, and do not include other evidence of management performance not relating to internal control weaknesses. So we assume that the disclosures are only of one tenth of managerial quality. The total expected loss of value from disclosure is then $16.9\% \times 0.95\%$ of the total expected value, while if the decline in returns following adverse disclosure was ten percent with a probability of such disclosure of $1-p$, we can equate the two probabilities to estimate *p*, $16.9\% \times 0.95\% = (1-p)*10\%$, so that $p = 0.98$ with a 98 percent chance of a component being high quality. The implied chance of bankruptcy is very low, at $(2\%)^5$.

The gap in estimated probabilities of high quality components between the two methods can be explained in a number of ways. In the period after the introduction of Sarbanes-Oxley, some of the worst behaved managements in companies like WorldCom and Enron had already exited the market. Managements may also have attempted to improve their practices given the publicity about malfeasance and the attention on them. Further, the disclosures recognised by Hammersley et al (2008) may not have related to a full tenth of total managerial quality but a smaller amount instead, which would reduce the probability *p* of high quality management.

We opt for the value of $p = 0.37$ estimated by the first method in this paper. One reason is that *p* in our model relates to the probability of managerial quality affecting the value of a company substantially, which is best described by a probability describing long term performance rather than transient behaviour. The lower value of *p* describes a normal financial environment, rather than one in which companies are perhaps temporarily altering their behaviour following a wave of bankruptcies linked to accounting malfeasance. A second reason is the uncertainty associated with the calculation in the second method. A third reason is that the investor behaviour is starker in response to disclosure regulation when the certainty of high quality management is lower.

The income gained from high quality managerial components

The income gained from high quality components is H, and the initial expected income from investment is then npH. We take the default value for the expected income to equal the price at 100 units. The expected income is then varied to see the effect of disclosure regulation on different investors. In both cases, when we vary the expected values, the values of n and p are being held constant and H is changing.

The introductory time of disclosure regulation

The introductory time for disclosure regulation is one of the variables determined by optimal design. When we are examining the effect of introducing regulation on companies, we take the introductory period T as four years. Large public companies had to comply with internal control reporting requirements under the Sarbanes-Oxley Act from the end of the second financial year after the passage of the Act, while smaller public companies had a seven year delay until compliance was necessary (Gao et al, 2009).

Cost of disclosure

Hartman (2007), page 2, reports that the annual cost of being public rose by \$1 million between 2002 and 2006 for public companies with annual revenues below \$1 billion. If we assume that these companies had an average revenue of \$500 million and a net profit margin of 8 percent[3], then their average annual profit was \$40 million. So the rise in costs after Sarbanes-Oxley's introduction was \$1 million / \$40 million, or 2.5 percent of annual profits. This is likely to overstate the long-term size of costs, as profits rise and costs stabilise. Moreover, the cost rises were smaller for larger companies (Hartman, 2007, page 7), so we take 1.5% as the ratio of disclosure costs to expected value of investment when the other parameters s and T are as given above. Thus, the value of the parameter C is given by solving $(CnpHs/T)/(npH) = 0.015$ where $s = 0.5$ and $T = 4$, so that $C = 0.12$.

The annual discount rate

We take the annual discount rate for corporate income to be 15 percent.

[3] Based on data at http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/margin.html

4. Consequences and design when regulation applies to a single company

4.1. Consequences of introduction

In this section we examine the consequences and design of disclosure regulation when regulation is applied to a single company. A potential investor is faced with the changes in the investment environment due to the regulation, namely on the investment opportunity offered by the company. We start by looking at the consequences of varying the disclosure share and the introductory period on the expected profit of the investment opportunity to the investor at the start of the disclosure introduction period. The other parameters are held constant at their values in Table 1.

Table 2. Expected profit of investment at the start of the disclosure introduction period, as functions of the disclosure introduction time and disclosure share

	Introduction time									
Disclosure share	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
0	0	0	0	0	0	0	0	0	0	0
0.1	5.0	5.1	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1
0.2	4.9	6.0	6.2	6.1	6.0	5.8	5.6	5.5	5.3	5.1
0.3	6.2	6.9	6.8	6.6	6.5	6.4	6.2	6.1	5.9	5.8
0.4	6.3	8.0	8.3	8.2	8.0	7.8	7.5	7.2	7.0	6.9
0.5	6.7	7.8	8.2	8.4	8.4	8.3	8.1	7.9	7.6	7.4
0.6	6.9	9.1	9.5	9.5	9.3	9.1	8.9	8.7	8.4	8.2
0.7	6.8	9.1	9.9	10.1	10.1	9.9	9.7	9.4	9.2	9.0
0.8	7.2	9.8	10.3	10.3	10.2	10.1	9.9	9.7	9.4	9.2
0.9	6.8	10.1	11.0	11.2	11.1	10.9	10.7	10.5	10.3	10.0
1	7.3	10.1	10.9	11.3	11.4	11.3	11.1	10.9	10.7	10.5

Table 2 shows the results. With no disclosure, investment does not take place as the expected value of income does not exceed the cost. With the base parameterisation, as the disclosure share increases with the introduction time held constant, the profit tends to increase. The highest value for the profit is when all or almost all of the managerial quality is disclosed. Disclosure gives the investor the chance to invest if the details of the managerial quality are good enough to make the opportunity profitable, and not invest otherwise. Further, with more disclosure the mean time for information release is earlier in the introduction period, so that investors can make decisions earlier and receive less discounted income. There is theoretically a trade-off between the benefits of better and earlier information on one hand and the costs of disclosure on the other, but the size of the latter is not big enough to make less than full disclosure optimal.

As the introduction time increases, the investor's profit rises and then falls. Increasing the introduction time reduces the costs associated with information release, and these costs are steep when the regulation is introduced quickly. However, earlier information release results in higher income if investment occurs. The trade-off is optimal at introduction times between one year (when only ten percent of managerial quality information is subject to disclosure) and 2.5 years (when all quality information is).

For the given parameterisation, the highest profit is realised when all quality information is disclosed over a 2.5 year period. However, total information disclosure may not be possible, for example if the full set of relevant managerial practices is not known. Thus, the highest possible profit may be obtained only at lower levels of disclosure, when the information release is more accelerated.

Figure 1. Probability of investment as a function of time since disclosure started, as assessed from the start of the disclosure period. Diamonds show probabilities when the disclosure share is at 0.1, squares when the share is 0.5, and triangles when the disclosure share is 0.9.

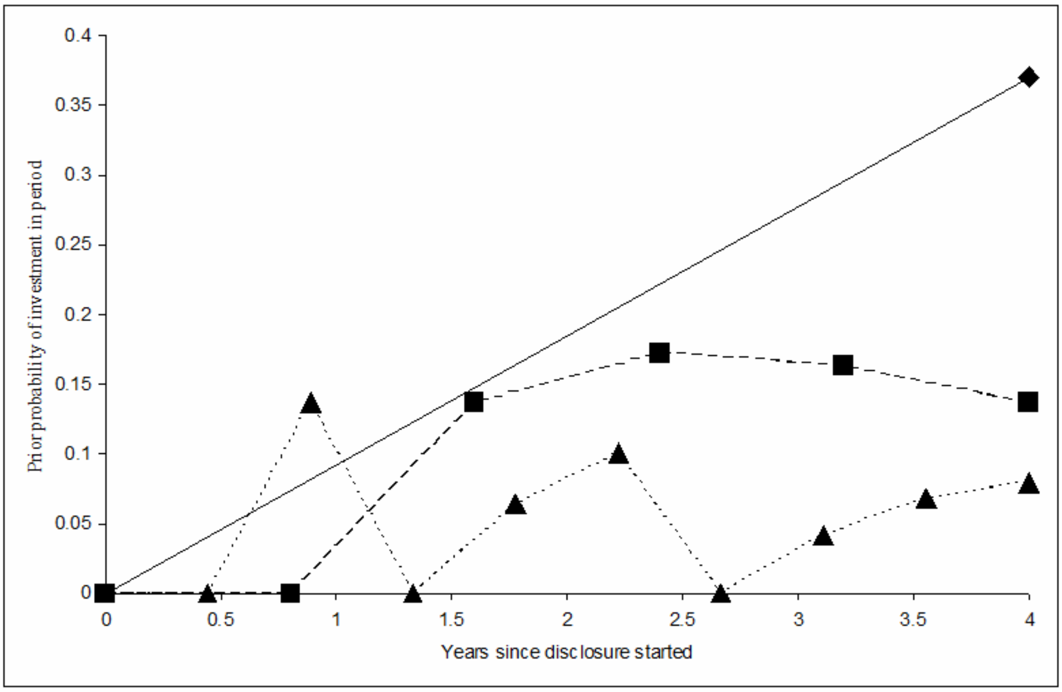

Figure 1 shows the probability of investment in each time period after disclosure regulation is introduced. With the initial expected income from investment of 100 units, the potential investor doesn't invest before its introduction. When the disclosed share of management quality rises to 0.1, there is a 37 percent probability of investment when the information is disclosed after four years, with investment occurring if the managerial quality is high enough. With the disclosed share at 0.5, the investment probability is initially zero for the couple of information releases after the regulation is introduced, but rises as the more information is revealed. The peak of expected investment happens after three information releases, 2.4 years in to the disclosure process. The total probability of investment at some time rises to 61 percent. When the disclosed share increases further to 0.9, a stop-start pattern of expected investment occurs with three peaks after 0.9, 2.2, and 4 years. The total probability of investment is 49 percent.

When the expected income from investment is slightly bigger at 101 units, the expected probabilities of investment are the same. As the expected profit from investment is positive, prior to the introduction of the regulation the investor would invest immediately. Thus, the introduction of the legislation is associated with a fall in immediate investment for this investor and opportunity, with the total amount of investment falling by a significant percentage. The investors are waiting to see if the opportunity is worth investment on the basis of detailed quality information rather than broad averages.

We can summarise our findings by saying that disclosure regulation can lead to increases in the probability of investment if an investor was not interested in an opportunity prior to the regulation, with investment likely to emerge over time as information emerges on managerial quality. For investors who were previously committed to the project, the total probability of investment as well as the probability of immediate investment may decline as investors avoid the opportunity if the managerial quality turns out to be too low. The likelihood of investment rises as information becomes available. The introduction of disclosure regulation will typically be associated with declines in immediate investment.

The decline in investment expected after introduction has implications for empirical research. Prior empirical research has often treated the effects of regulation on returns, stock prices, or investment as calculable over fairly short periods (Bargeron et al, 2010; Chhaochharia and Grinstein, 2007; Kang et al, 2010; Li et al, 2008; Zhang, 2007). Our model suggests that such an approach may be misleading, and that performance over the medium to long term should be monitored.

4.2. Optimal parameters

Table 3. Optimal disclosure shares and introduction times (in years) for disclosure regulation for one company and one investor, as a function of the expected value and the cost to expected value ratio. "No inv." denotes no investment for any design, and so no optimum. "No reg." means that it is optimal to have no regulation.

	Cost / expected value					
Expected value	0.5%	1.5%	2.5%	3.5%	4.5%	5.5%
20	No inv.	No inv.	No inv.	No inv.	No inv.	No inv.
40	1 / 1.5	1 / 2.5	1 / 3	1 / 4	1 / 4.5	1 / 5
60	1 / 1	1 / 2	1 / 2.5	1 / 3.5	1 / 4	1 / 4.5
80	1 / 1.5	1 / 2.5	1 / 3	1 / 4	1 / 4.5	1 / 5
100	1 / 1.5	1 / 2.5	1 / 3	1 / 4	1 / 5	1 / 4.5
120	1 / 1	1 / 2.5	1 / 3	No reg.	No reg.	No reg.
140	1 / 1.5	No reg.	No reg.	No reg.	No reg.	No reg.
160	No reg.	No reg.	No reg.	No reg.	No reg.	No reg.

We next consider the optimal design of disclosure regulation when there is a single company and one investor. We look for optimal values for the disclosure share (in the range [0,1] in increments of 0.1) and introduction times (for 0.5 years to five years in increments of 0.5 years). Table 3 shows the optimal parameters for different values of the expected value and the cost to expected value ratio. When the expected value is very low at 20 units, there is no investment for any regulation design. Even if all the managerial quality components were revealed to be high quality, the value of the investment would not reach the price. At an expected value of 40 units, disclosure may reveal that the managerial quality is high enough for investment to be profitable. The optimal design has the highest possible disclosure share. When costs are at the low proportion of total expectations experienced by large companies, a very rapid introduction is optimal. At the higher cost proportions experienced by smaller companies, a slower introduction is optimal. When the expected share rises further to 120 units, it is best to have full disclosure at low cost proportions. As the cost proportion rises, the optimising disclosure period increases. Once costs reach 3.5

percent of the expected value, they outweigh the financial benefits of certainty, and it is best to have no regulation at all. At an expected value of 160 units, investment occurs without regulation and is very likely to occur if regulation is introduced, so costs are incurred without much alteration of investment choices and it is best to avoid regulation.

In summary of this section, it is best to have no disclosure regulation when the expected profit from an investment is very negative or very positive. When expected profit is moderate, it is optimal to have regulation only if costs are low as a share of expected values (for example with large companies). Otherwise no regulation is optimal (for example with small companies). Disclosure regulation is most useful when profits are zero or negative (but not very negative). When disclosure regulation is optimal, the fullest possible disclosure is best, with an introductory period that increases with the disclosure cost.

5. Consequences and design when regulation applies to two companies

In the last section we saw that the optimal parameters for disclosure regulation vary according to the characteristics of the investment opportunity, and possibly those of the potential investor as well since they may act according to their subjective assessments of the relevant parameters, which may differ from the actual parameters. Given the differences in optimal parameters across opportunities, regulation whose disclosure share and introductory period vary by company to their individual optimums would give the highest possible profit. We are ignoring correlations between managerial qualities across companies, but discuss the matter briefly in the conclusion.

In practice, regulation may not be company-specific. The government may not be aware or convinced of the benefits of specificity, and it may be difficult or expensive to determine optimal parameters by company type. We next examine the optimal parameters when the government introduces regulation with the same conditions for all companies. We go on to calculate the loss of expected profit relative to the disaggregated optimum, and investment patterns over time.

The market structure we assume is of two companies each offering an investment opportunity. The sole investor is not credit constrained and can invest in either or both projects. The companies differ in their ratios of disclosure cost to expected value and their probabilities of revealing that a managerial component is high quality. All other characteristics independent of these two quantities are the same for both companies, including expected values. The ratio of disclosure cost to expected value is expected to rise with size, but we do not alter the expected value so that we can show more clearly the effect of size dispersion acting through the ratio alone. The probability of revealing that a managerial component is high quality can be taken as a measure of lower risk (since there is less probability of extreme profits or losses, the expected value being held constant).

For the first company, the probability of a component being revealed to be high quality is taken to be $0.37 - x_1$ where $x_1 \in \{-0.3, -0.2, -0.1, 0, 0.1, 0.2, 0.3\}$, while the corresponding probability for the second company is $0.37 + x_1$. The probabilities are centred on the default value of 0.37. For company one, the ratio of disclosure cost to expected value is set at $2.5\% - x_2$ where $x_2 \in \{0\%, 0.5\%, 1.0\%, 1.5\%, 2.0\%\}$, while for company two the ratio is put at $2.5\% + x_2$. By symmetry, the outcomes for positive values for x_2 are already considered.

We calculate the optimum values of disclosure share and introduction time as chosen by the government. Their objective function is the sum of the investor's profits derived from either investment opportunity. The reference optimal values are found when the two companies have the same probability of a high quality component and the same disclosure cost to expected value ratio.

Table 4 shows the optimal values as functions of the gap between the parameters of the two companies, centred on the parameters of 0.37 for the probability of a component being high quality and 2.5% for the cost to expected value ratio. The optimal disclosure share is stable for all parameter values, with full information disclosure being best. The optimal introduction time varies between 3 and 1.5 years. As the dispersion in the probabilities of high quality components rises, the introduction time falls. The opportunity with the large probability of high quality components is not risky, and the disclosure regulation increases its value by a little amount. The opportunity with a small probability of high quality managerial components is risky, and the disclosure regulation increases its value by a big amount. The characteristics of the aggregate optimum are therefore closely influenced by those of the optimum for the risky opportunity. As disclosure is valuable for this opportunity, the optimal choice in the trade-off between rapid introduction of information and high cost gives a shorter introductory period.

Table 4. Optimal disclosure shares and introduction times (in years) for disclosure regulation for two companies and one investor, as a function of the gap in the company probabilities of a high quality managerial component and the gap in the cost to expected ratio (gap = second company value – first company value). The gap in the probability of a high quality managerial component is centred on 0.37, and the gap in the cost to expected ratio is centred on 2.5%.

	Gap in cost / expected value				
Gap in probability of high quality component	0.0%	1.0%	2.0%	3.0%	4.0%
-0.6	1 / 2.5	1 / 2.5	1 / 2.5	1 / 2.5	1 / 2.5
-0.4	1 / 2.5	1 / 3	1 / 3	1 / 3	1 / 3
-0.2	1 / 3	1 / 3	1 / 3	1 / 3	1 / 3
0	1 / 3	1 / 3	1 / 3	1 / 2.5	1 / 2.5
0.2	1 / 3	1 / 3	1 / 2.5	1 / 2.5	1 / 2.5
0.4	1 / 2.5	1 / 2.5	1 / 2.5	1 / 2.5	1 / 2
0.6	1 / 2.5	1 / 2.5	1 / 2	1 / 2	1 / 1.5

When the cost to expected value ratio rises for the second company, the optimal introduction time also rises since the information is more expensive and the trade-off between rapid introduction and high cost favours a slower introduction to bring costs down. For the first company, the falling cost is associated with an accelerated introduction. If the first company also has a smaller probability of high quality management than the second company, then the falling cost to expected value ratio leads to an even shorter optimal introductory period for disclosure of the first company information, and for the whole market. If the first company has a larger probability of high quality management, then the falling cost ratio acts to offset the increase in introductory time due to the larger probability. The effect on the whole market of the falling cost ratio is then to increase the introductory time.

Table 5 shows the profit gain from applying the optimal disclosure regulations to individual companies, rather than a disclosure regulation designed to be the best possible for the aggregate market. The largest gains are to be had when the optimal parameters are most different, namely when the probability of high quality components and the cost to expected value ratio are both lower for one company. When only one of these is lower the gains are reduced, and if one of them is lower for the first company and the other is higher for the first company, the gains fall further.

Table 5. The percentage increase in profits from applying optimal disclosure regulations to individual companies, rather than to the aggregate market, as a function of the gap in the company probabilities of a high quality managerial component and the gap in the cost to expected ratio (gap = second company value – first company value). The percentage increase is (disaggregated profit-aggregated profit) / aggregated profit.

	Gap in cost / expected value				
Gap in probability of high quality component	0.0%	1.0%	2.0%	3.0%	4.0%
-0.6	0.8%	0.3%	0.2%	0.0%	0.5%
-0.4	0.7%	0.2%	0.0%	0.4%	2.1%
-0.2	0.3%	0.0%	0.4%	1.8%	4.5%
0	0.0%	0.4%	1.1%	2.3%	4.9%
0.2	0.3%	0.7%	1.6%	3.1%	6.4%
0.4	0.7%	1.2%	2.4%	4.4%	8.0%
0.6	0.8%	1.5%	2.6%	4.0%	6.2%

In summary, when the gap in risks or the ratio of costs to expected value widen across companies, the optimal disclosure parameters for the whole market are more heavily weighted towards the optimal parameters for the company with higher risks and lower costs, other things being equal. Widening gaps reduce the optimal disclosure period, unless the risk and cost effects offset each other. If regulators use the same optimal disclosure parameters for the whole market rather than company-specific parameters, the profit loss to investors can be non-negligible.

6. Conclusion

We modelled disclosure regulation as creating a real option for investors, to invest immediately or wait until better information emerges. Formulating the investor's problem as a Bellman equation, we solved it using numerical methods and found the characteristics of the investment opportunity under which regulation increases expected profits. The expected pattern of investment was calculated, and the optimal extent and period of disclosure. We then calculated optimal parameters when the regulation parameters are the same for both companies in a two company market, and the profit loss relative to regulations specific to each company.

There are alternative theoretical approaches which we could have taken, and which may yield benefits for different analytical purposes or in different model formulations. We expressed the investor's problem as a Bellman equation, which could be recast as a differential equation following the methods described in Dixit and Pindyck (1994). Our attempts with this method led to heat equations with variable exercise dates. This formulation may be preferred in some circumstances. Numerical solution could be used instead of exact solution as the transformed equations are similar to those from American options. Alternatively, algebraic approximation could be used.

Different behavioural and financial assumptions may be included into the model quite easily, and numerically solved in our spreadsheet equally readily. One modification would be to introduce Bayesian learning in response to disclosure, which would alter the dynamic in the variance of expected future income. The assumption might complement a representation of disclosure as repeated sampling of the same quality many times, rather than successive release of new information as in our model here. Other learning procedures could also substitute for the current one.

Uncertainty about the level of costs associated with disclosure could be brought into the model. Hartman (2007) reports a high level of uncertainty about the costs of the Sarbanes-Oxley Act among company executives and directors, which declined over time. Such a dynamic in cost uncertainty would increase the value to investors of waiting to see if an opportunity is profitable. We would therefore expect the immediate post-regulation decline in investment and its subsequent recovery to be emphasised further.

The model could introduce more companies in order to find optimal parameters in more fully sized markets. Additional investors could also be introduced, each evaluating the investment opportunities differently. Correlations of valuations, risk, costs, or outcomes could be allowed. These assumptions would allow us to examine in more general terms dispersion's effect on optimal parameters and profit loss from aggregation, as well as the impact of multi-agent factors such as correlation and clustering.

We have assumed that information is released by stages. Instead, a single release of information may be assumed, representing a disclosure at a particular date. The jump may be continuous or discrete. In the latter case, we looked for closed form solutions. While they are available, they tend to be subject to multiple breaks as the input parameters cross thresholds that trigger waiting for disclosure or immediate investment. The closed form solutions are complicated even when the disclosed quality may have just two different states, and with only one company and one investor. Numerical solution may therefore be preferred.

Our model assumes a steady release of information over time. A government or regulator may wish to experiment with alternative disclosure patterns. For example, they may wish to disclose at a level rate only after a period of no disclosure, in order to give companies time to prepare. It is not clear what the optimal disclosure pattern is when the pattern can be irregular, and our numerical techniques can search for the best ones.

The analysis described here naturally fits to disclosure regulation, where both the extent and timing of disclosure are to be determined. Other governmental policy and regulations often has a fixed information content, but the release of that information is discretional. For example, a government may have to release news about planned taxation levels, or about the date of a referendum or election. Delays in such information release can create a real option for investment and other business activity, and the optimal delays or staggering of information release can be calculated as described here.

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