The effects of occupational safety and health interventions

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This study examines the effectiveness of government legislation in reducing the incidence of workplace accidents and other health and safety risks in New Zealand. A simple model of the relationship between firms and the Occupational Safety and Health Service, which enforces these regulations, is outlined. Administrative data for the 1993/94–1996/97 period are then used to test the relationship between interventions and health and safety outcomes at both firm and industry level. Overall, somewhat inconclusive evidence is found regarding the effectiveness of interventions. Although a modest specific deterrence effect is detected, it is not robust to controls for endogeneity. Inconsistent evidence is also found regarding general deterrence factors. Concerns that are raised over the quality of the health and safety data suggest the need for improvements in recording processes of workplace and other accidents.

1 Introduction

IN RECENT DECADES, many countries have enacted legislation with the aim of reducing the incidence of workplace occupational illnesses and injuries. In New Zealand, the Occupational Safety and Health Service of the Department of Labour (OSH) was established in 1988 and currently performs a range of preventative and reactive functions in the workplace, under the provisions of the Health and Safety in Employment Act 1992. As noted by McCaffrey (1983), the expenses involved in the operation of OSH and the compliance costs faced by businesses "may well be worthwhile if they make employment substantially safer and healthier" (p 131). However, to date no research in New Zealand has assessed whether OSH interventions have an effect on outcome measures, such as accident rates. The aim of this study is to examine the nature of the interaction between government health and safety regulations and firms and to test this relationship using New Zealand administrative data.

The next section of the paper provides a brief overview of previous empirical work on the effectiveness of health and safety interventions that has been

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conducted overseas. This includes a discussion of the various factors that may induce bias in estimated effectiveness. Section Three outlines the regulatory structure that exists in New Zealand and governs the operations of OSH. A simple model of the relationship between firms and OSH is then presented in Section Four. Section Five introduces the occupational health and safety administrative data that are used in this paper and provides some basic descriptive statistics that are derived from these. Finally, some statistical evidence is reported concerning the effects of health and safety interventions. This draws on a combination of econometric techniques and involves analysis at both firm and industry level. Section Six is followed by a conclusion, which includes an outline of the issues that future work should address.

2 Existing empirical studies of the relationship between interventions and risk outcomes

The general evidence from existing studies of the relationship between health and safety regulatory enforcement and injury rates is that the effects are small. Where a statistically significant relationship is found, it is not generally robust to changes in specification, time period or measures used to capture interventions and outcomes.

The largest academic research literature dealing with these questions of health and safety effectiveness concerns North America and focuses primarily on the activities of the United States Occupational Safety and Health Administration (OSHA) and the *Commission de la Santé et de la Sécurité du Travail* (CSST) in the Canadian province of Quebec. The US Occupational Safety and Health Administration was established in 1970 to promote workplace safety and chose the approach of setting new safety standards and enforcing them by inspections, fines and prosecutions. The CSST was established in 1980 with a similar function to that of OSHA, but with a greater focus on prevention and protection.[1]

The UK Health and Safety Executive (1991) summarised the relevant United Kingdom research on the effectiveness of health and safety activities and concluded that the studies highlight the problems of measuring achievement of final outputs. Only three studies have attempted to quantify or test the link between inspections and risk variables and none found a significant effect.[2]

Australian studies are similarly rare and inconclusive. Section M of Industry Commission (1995) identified only three studies that consider the link between health and safety outcomes and enforcement activities. Only one of these studies

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[1] See Lanoie (1991, 1992a, 1992b) for a fuller description of the CSST.

[2] The three studies are: a firm-level study to test the effects of lead-related inspections on blood lead levels; a 'micro study' of the effect of planned inspections on accident rates in two sets of matched premises; a 'macro study' of the link between inspections and accidents in general (Studies 3, 14 and 19). The last two studies were presented in Health and Safety Executive (1985).

suggested a link and that was confined to New South Wales cotton gins and did not control for any factors other than that there was a two-year programme to reduce accidents in this industry.

To the best of the authors' knowledge, there are no relevant New Zealand studies quantifying the link between health and safety outcomes and the effects of government interventions.

Most of the empirical studies have focused on the relationship between a risk measure, such as injury rates,[3] and some measure of inspections or penalties.[4] A commonly found relationship is that firms or industries with high inspection rates generally have high rates of injuries. This does not, however, reflect a harmful effect of inspections but, rather, points to the importance of factors other than inspections. The challenge of empirical research in this area is to control for a range of factors that may bias the estimated relationship between inspections and injuries. There are four main potential sources of bias that existing studies have, in various ways, attempted to control for: heterogeneity, endogeneity, reporting problems and dynamic effects.

2.1 *Heterogeneity*

There is considerable heterogeneity in injury rates across industries or firms. In the United States, OSHA targets its inspections on high-injury rate industries. This generates a positive relationship between inspections and injury rates that is independent of the effectiveness of inspections in reducing injury rates. In order to control for this bias, most studies have used fixed effects estimators or have relied on measures of the change in injury rates over time.

In order to employ these techniques, studies have used variation across time to identify the effects of OSHA interventions. All of the studies referred to in this paper have used panel data on industries or firms over at least three years. Most of the studies use firm-level data and control for heterogeneity by using dummy variables at the industry level.[5]

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[3] Injury rates (number of injuries divided by some measure of employment, for example, employees, full-time employees, hours worked) are the most commonly used risk measure. Other common measures are fatality rates, permanent disability rates, lost worktime injury rates or lost workdays per measure of employment.

[4] The number of inspections per plant or per employee is most frequently used. Other measures use the number of inspections with penalties or the size of penalties.

[5] Studies that have taken this approach include Smith (1979), McCaffrey (1983), Bartel and Thomas (1985), Ruser and Smith (1991) and Weil (1996). Scholz and Gray (1990) and Gray and Scholz (1993) used manufacturing/construction industry data but did not include industry dummies (Scholz and Gray (1990) used industry-averaged variables and Gray and Scholz (1993) used plant-level dummies). Lanoie (1991, 1992b) and Viscusi (1979, 1986) drew on observations at the industry, rather than plant, level and used industry dummies to control for heterogeneity. Viscusi also restricted his attention to manufacturing industries.

2.2 *Endogeneity*

In addition to the general bias caused by OSHA targeting industries that have historically had high injury rates, there is a more specific targeting bias that arises because a plant or industry that experiences a high injury rate in a particular period is likely to be inspected by OSHA as a consequence. Viscusi (1986) discounted the significance of this form of bias, noting that 86 percent of all OSHA inspections are general programmed inspections and are unrelated to the current year's industry injury rate. Only 2 percent of inspections (in response to fatalities) are prompted by current-year injuries. Nevertheless, many studies at least perform a statistical test of whether inspections are endogenously determined (for example, Viscusi (1986) and Lanoie (1992b)) and some select a specification that explicitly controls for potential endogeneity. These controls can take a number of forms.

Bartel and Thomas (1985) posited an explicit model of inspection patterns and used two-stage least squares estimates to control for the endogeneity of inspection rates in an injury rate equation. The two-stage least squares approach replaces the measure of inspections with an estimate that is a (least squares regression) linear combination of variables that are not jointly determined with the injury rate.

Scholz and Gray (1990) used a related approach to estimate the impact of general and specific deterrence.[6] For their measure of general deterrence, the authors used predicted, rather than actual, inspections and argued that this procedure yields a measure that is unaffected by current injury rates.[7] They also used the percentage change in predicted inspections rather than the actual prediction, which they justified with the observation that the likelihood of inspection is correlated with current injury rates but not with the percentage change in injury rates.[8]

In an influential early study, Smith (1979) used an innovative approach to deal with the endogeneity of inspections. Rather than trying to control for endogeneity, he ensured that the (endogenous) relationship between inspections and injury rates was present for both his control group and his treatment group. He then considered differences between the two groups. More specifically, Smith took a sample of firms, all of which had been inspected in a particular year, accepting

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[6] General deterrence refers to the response of a firm to the probability that it will get inspected. Specific deterrence refers to the response of a firm to being inspected. If the general deterrence effect is strong, firms will maintain a high level of safety and will be less likely to change their behaviour in response to experiencing an actual inspection. The specific deterrence effect will therefore be weak.

[7] The predictions were based on a combination of industry-average inspection probabilities and firm-specific variables, including the firms' lagged injury rates and changes in injury rates.

[8] To estimate the degree of specific deterrence they also included current and lagged firm-level inspection measures, without any specific allowance for endogeneity at the plant level.

that some of these inspections would be a response to, rather than a determinant of, injury rates. He hypothesised that if OSHA inspections had any effect in reducing injuries, annual declines in injury rates should be greater for firms inspected early in a year than for firms inspected late in the year. Smith found evidence of a negative impact of inspections on injury rates. Later studies using the same technique (McCaffrey (1983) and Ruser and Smith (1991)) did not find any significant impact.

2.3 *Reporting bias*

Firms may under-report their accident or injury rates especially if, by doing so, they reduce their chances of inspection or penalty. For instance, during the early-to-mid 1980s, OSHA based its decision on whether to inspect firms partly on the firms' own accounts of their injury experience.[9] There was, therefore, an incentive to under-report injuries among firms that had a high probability of being inspected. This would generate a negative correlation between inspections and injuries, even if inspections had no effect. Ruser and Smith (1988, 1991) found evidence of some under-reporting but concluded that it does not significantly bias estimates of the relationship between injury rates and inspections. One common approach to dealing with this potential bias is to consider types of injuries that are less liable to be misreported, for example, fatalities or serious safety violations.

2.4 *Dynamic effects*

A number of studies have found evidence of the lagged effects of interventions on injury rates, of heterogeneity across firms or industries and of various forms of autocorrelation in injury rates.

Studies that have allowed for inspections to affect not only contemporaneous but also subsequent injury rates have generally found weak evidence of a lagged effect. Smith (1979) and Ruser and Smith (1991) found evidence of a lagged negative effect only for small firms (fewer than 100 employees), while McCaffrey (1983) found no significant evidence of a lagged effect. Gray and Scholz (1993) reported evidence of lagged effects of enforcement (inspections with penalties) on lost workdays and the number of lost workday injuries for up to three years after enforcement, even after controlling for plant-level fixed effects. They also found that inspections without associated penalties did not affect safety outcomes. Viscusi (1986) uncovered a significant negative effect of inspections on lost-work days or injuries after one year, however, this was almost exactly counteracted by a *positive* estimated contemporaneous effect. Finally, Weil (1996) found that accumulated past penalties, but not accumulated past time of inspections, have a large impact on the current compliance behaviour of a plant.

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[9] Ruser and Smith (1988, 1991) described the nature of this decision. High-risk firms in some states were approached for inspection and would not be inspected if their recorded injury rate was sufficiently low.

Smith (1979) showed that the weak estimated effects one year after inspection could be masking effects at higher frequencies. He noted that his results are consistent with a lag of three to five months between inspections and their effects and with continuing effects for up to 18 months.

Panel data studies have found evidence of firm heterogeneity and mean reversion. As noted above, firms with high injury rates in one period tend to have high injury rates in subsequent periods. For a particular firm over time, however, there is evidence of negative autocorrelation or 'reversion to the mean'. If a firm experiences an unusually high injury rate one period, their injury rate in the subsequent period tends to revert to that firm's long-term average injury rate. This can be expressed in econometric notation as follows, where e_{it} is an injury rate measure, u_i is a firm-specific or industry-specific effect and e_{it} is a random error term:

$$e_{it} = u_i + \varepsilon_{it}, E(\varepsilon_{it}\varepsilon_{is}) < 0, E(e_{it}e_{is}) = \sigma_i^2 + E(\varepsilon_{it}\varepsilon_{is}). \tag{1}$$

Ruser (1995) investigated the degree of mean reversion in a model linking injury rates to workers' compensation benefits and found that establishments with high unexplained injury rates (residuals) in 1979 continued to have high unexplained rates for at least five years.[10] For smaller establishments with high initial residuals, there was a marked decline in the size of residuals after one year. Declines in residuals were, however, seen for all establishments over the five-year period considered. More importantly, residuals for these high-initial residual establishments remain positive throughout the five-year sample period.

There are a number of explanations for these observed patterns. The rapid decline for small establishments suggests that there is at least an element of 'bad luck', that is, establishments that had a bad year in 1979 would not be expected to have a second bad year in 1980. This pattern is also consistent with a 'fire-fighting' model, as outlined by Scholz and Gray (1990), wherein firms make improvements to safety in response to incidents rather than as part of continuous safety management. The persistence of positive residuals suggests that this is not the whole story. Ruser identified two possible explanations: partial adjustment and unobserved heterogeneity. If firms invest over time in safety equipment or methods, one would expect these investments to reduce injury rates gradually. However, if firms differ in ways that are not observed, the persistently high residuals may reflect these persistent differences. The more rapid decline in residuals for smaller establishments and their higher initial residuals suggest that bad luck may be a greater factor in the pattern of small establishment residuals than it is for those of larger firms.

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[10] Ruser considered separately four different size classes of establishment and controlled for industry injury rates, wage levels, hours, employment growth, workforce composition and premium variables.

3 New Zealand institutional details

The Health and Safety in Employment Act 1992 provides the basic framework of the workplace health and safety system in New Zealand. Rather than establish minimum standards of health and safety, the Act was designed to return the ‘ownership’ of health and safety management to employers, employees and others in control of the workplace. The role of government was changed to that of advising participants of their responsibilities, facilitating (as opposed to providing) industry-specific solutions and undertaking compliance enforcement where legislative breaches or accidents causing “serious harm”[11] have occurred. This approach is less prescriptive than that of many overseas agencies and it remains an important empirical question whether this discrepancy in approach is associated with differences in estimated effectiveness of interventions or in workplace health and safety outcomes.

The Occupational Safety and Health Service of the Department of Labour is responsible for administration in New Zealand of the Health and Safety in Employment Act 1992. The Service comprises a head office and 18 branches and its field officers visit approximately 10 percent of all New Zealand workplaces each year. The Service has a range of tools with which it may influence workplace health and safety outcomes. Its primary aim is to encourage employers to institute and maintain effective safety management systems. To this end OSH provides information, education and advice to workplaces. In addition, an inspection regime is designed to ensure that hazards are identified in compliance with the Health and Safety in Employment Act 1992. Where non-compliance is detected, OSH inspectors may issue an infringement notice, prohibit an activity or initiate a prosecution.[12] These interventions are targeted at workplaces that are involved in high-risk operations and those that are more likely to be non-compliant by reason of their size, commercial motivation and resources. High-risk industries that are currently targeted nationally are agriculture, construction, forestry and mining.

In addition to its proactive operations, OSH has a reactive compliance function in administering the Health and Safety in Employment Act 1992. Employers are obliged to notify OSH of any incident actually causing serious harm to their employees and to record other less serious incidents. In turn, OSH is required to respond to all complaints, accident reports and notifications of workplace fatalities. In addition, investigations of all notifications of suspected occupational

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[11] Schedule One of the Health and Safety in Employment Act 1992 defines “serious harm”. It includes specified conditions that amount to or result in: permanent loss of bodily function or temporary severe loss of bodily function; amputation; burns requiring specialist treatment; loss of consciousness from lack of oxygen; loss of consciousness or acute illness from absorption, inhalation or ingestion of any substance; and any harm that leads to hospitalisation of 48 hours or more.

[12] Less than 2 percent of all investigations resulted in prosecutions in the 1998/99 year. Of these, 88 percent were successful for OSH.

diseases or illnesses are undertaken. These are voluntarily reported by health professionals, with OSH maintaining a Notifiable Occupational Disease System (NODs).

4 A model of health and safety regulation

In order to understand the relationship between OSH interventions and health and safety outcomes, a simple model of firm and OSH behaviour is outlined. Like most economic analyses of regulatory compliance, this theory draws on the crime models of Becker (1968) and Stigler (1970).

The general structure of the model is that profit-maximising firms choose how much to spend on accident reduction, taking into account the likelihood that they will be inspected by OSH. Accidents attract a penalty, which is levied only if the accident is detected by an inspection. The Service is able to set an inspection rate and aims to reduce the social cost of accidents. The Service takes into account the firms' responses to the chosen inspection rate.

4.1 Firms' management of health and safety

Firms are characterised as profit maximising. In the absence of any expenditure on safety equipment, the firm would have a certain number of accidents, denoted a_0. There is a cost associated with accidents, λ, due to lost working time or the need to pay compensating differentials to workers. Reducing accidents, a, requires firms to allocate some resources to safety equipment, s. For ease of exposition, all accidents are assumed to be of the same intensity, for instance, fatality. The measurement of safety equipment is normalised so that each unit of safety equipment is the amount required to avoid one more accident. If r denotes accident reductions, this means that $r = s$. The number of accidents that the firm experiences is therefore $a = a_0 - r$.

The cost of accident reductions is increasing in the number of accidents reduced and the cost of reductions is equal to the expenditure on safety equipment:

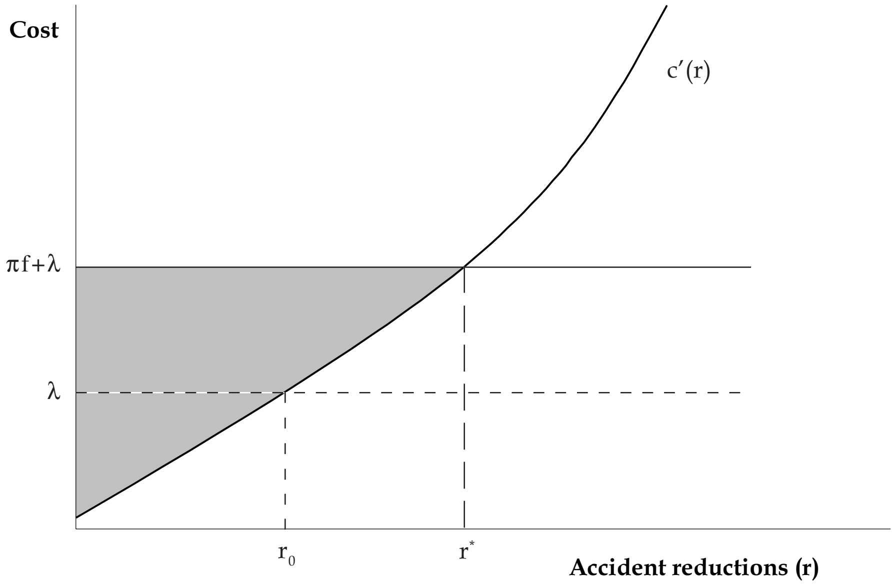
$$c(r) = c(s),\ c'(\cdot) > 0,\ c''(\cdot) > 0\ . \tag{2}$$

If the firm is inspected by OSH, the inspection itself imposes a cost, d. In addition, the firm faces a penalty in the form of a fine for each accident that is detected by the inspection. The expected penalty depends on the probability of getting inspected, π, and the size of the fine per accident, conditional on being inspected, f. It is assumed that the same fine is levied on each accident. The expected penalty is therefore $\pi f a$.

In choosing how much to invest in accident reductions, the firm weighs up the marginal cost of accident reductions, $c'(r)$, against the reduction in expected penalties and the reduced cost of accidents. Formally, firms maximise the following profit function:

$$\begin{aligned} \Pi &= -\lambda a - c(r) - \pi(fa + d) \\ &= -\lambda(a_0 - r) - c(r) - \pi(f(a_0 - r) + d). \end{aligned} \tag{3}$$

FIGURE 1: The safety decision made by the firm



The firm will choose the level of reductions that maximises its profits. The first order condition is:

$$\begin{aligned} &\Pi_r = 0 \\ &\Rightarrow \lambda - c'(r) + \pi f = 0 \\ &\Rightarrow r^* = c'^{-1}(\pi f + \lambda) \equiv h(\pi f + \lambda). \end{aligned} \tag{4}$$

In the absence of any inspections or fines, the firm may still find it worthwhile to invest in safety equipment and will choose a level of reductions denoted in Figure 1 by r_0, where the marginal reduction in accident costs, λ, is equal to the marginal cost of accident reduction. In general, with positive fines and inspection probability, the firm will invest in safety equipment up to the point r^*, where the cost of an extra reduction is just equal to the reduction in expected penalty, $\pi f+\lambda$. For any point to the left of r^*, the gain from paying for an additional reduction in accidents is the gain of avoiding an expected fine and accident cost $\pi f+\lambda$. This is larger than the cost of achieving an additional reduction, $c'(r)$. The shaded area in Figure 1 depicts the net savings to the firm from purchasing r^* units of safety equipment. Faced with a π probability of inspection, the firm's reaction function is defined as:

$$r_\pi^* = fh'(\pi f + \lambda). \tag{5}$$

For a given probability of inspection, all firms will choose r^* so that the marginal cost of accident reduction $c'(r^*)$ equals $\pi f+\lambda$. Differences across firms will lead to different choices of r^* but not of $c'(r^*)$.

4.2 The allocation of resources made by OSH

The operations of OSH are characterised as maximising the social value of accidents avoided, for example, lives saved, while taking into account the total costs of inspections. To achieve this goal, OSH chooses the probability that firms are inspected π.[13]

The number of firms in the economy is denoted by N. Each firm invests s^* in safety equipment, saving $r^* = s^*$ lives. Society places some value on each life saved, which is denoted by v. The total value of reductions is therefore Nvr. If each firm has a π chance of being inspected, the total number of inspections is $N\pi$. The marginal cost per inspection incurred by OSH is assumed to increase with the number of inspections and the cost to OSH of inspections is denoted by $k(N\pi)$. In addition, OSH takes into account the cost of reductions, $c(r)$, and the per-inspection costs, d, that inspections impose on firms. In summary, OSH maximises the following value function:

$$V = Nvr - Nc(r) - k(N\pi) - N\pi d. \tag{6}$$

The first order condition is:

$$\begin{aligned} &V_\pi = 0 \\ &\Rightarrow Nvr_\pi - Nc'(r)r_\pi - Nk'(N\pi) - Nd = 0 \\ &\Rightarrow (v - c')r_\pi = k'(N\pi) + d. \end{aligned} \tag{7}$$

The Service will choose π so that the marginal value of lives saved by an increase in π, net of the marginal cost of additional reductions, $(v\text{-}c'(r))r_\pi$, shown in Figure Two as IB (Inspection Benefit schedule), is equal to the marginal cost of inspections needed to raise π, $k'(N\pi)+d$, shown in Figure 2 as IC (Inspection Cost schedule). This optimal probability of inspection is denoted in Figure 2 by π^*.

Recall that firms choose safety expenditures. The Service incorporates the firm's optimisation and reaction function in its optimisation, so the position and shape of the $(v - c'(r^*))r^*_\pi$ curve will thus depend on firm characteristics: the cost function for safety expenditures, the base level of accidents, a_0, and the cost of accidents, λ. More specifically, because $c'(r^*) = \pi f + \lambda$ for all firms, the only link between the firm marginal cost curve and the IB curve is through r^*_π which depends on the responsiveness of the firm to a change in the inspection rate. This responsiveness is determined by the *slope* of the $c'(r)$ curve at r^*. The steeper the $c'(r)$ curve is, the smaller will be the effect of increasing πf. In the extreme case, when $c'(r)$ is vertical, r^* does not change at all as πf changes. A steep $c'(r)$ curve in Figure 1 is thus associated with a lower r_π and a lower IB curve in Figure 2. This

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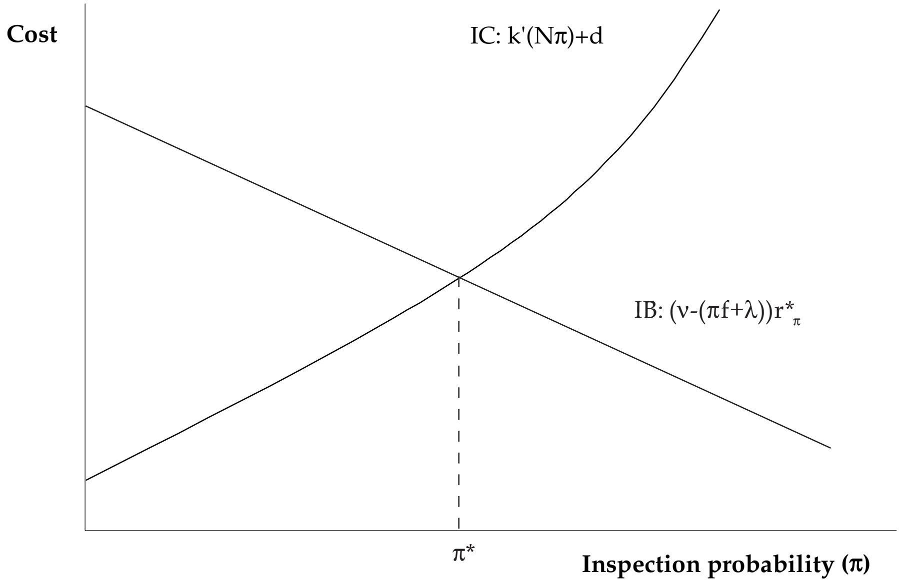
[13] It is assumed that OSH does not set the level of fines. If it did, it would choose to make as few inspections as possible and impose a fine that is large enough to induce non-inspected firms to make safety expenditures. In effect, πf is raised by a combination of very low π and very high f.

FIGURE 2: The inspection decision made by OSH



implies that OSH would choose a lower level of inspections for such firms. It is not attractive to target inspections at firms that are less likely to adjust safety expenditures in response to inspections.

4.3 Insights from the model

This model (as summarised in Figures 1 and 2) captures the essential elements of the decisions made by the firm and OSH and illustrates why firms are expected to improve safety when faced with a regime of inspections and fines. It also illustrates the logic of health and safety interventions in reducing the social cost of accidents.

The model focuses attention on the logic of accident reductions as opposed to the accident rate *per se*. Firms care only about the costs and benefits of accident *reductions*. The firm's base level of accidents, a_0 does not enter into its optimisation, so accident rates can be different in different firms, even if they choose the same level of accident reductions. Similarly, OSH chooses its rate of inspection based not on where the greatest number of accidents occurs, but on where it can effect the greatest reductions at the least cost.

When estimating the empirical relationship between OSH interventions and workplace safety, however, we observe accidents rather than accident reductions. We also consider interventions other than inspections. It is therefore worth discussing briefly how the model guides us in our empirical work. Our discussion will deal with firm heterogeneity and with other forms of intervention.

Firm heterogeneity

In the model it is assumed that all firms are identical. Three important ways that firms may differ are by hazardousness of activity, by the cost of achieving accident reductions and by size.

(a) Different inherent hazard

Some firms operate with technologies or practices that are inherently more dangerous. This difference would show up in the model as a difference in a_0 in Equation Three. As noted above, optimisation does not depend on the value of a_0. Empirically, we need to allow for different firms and industries to have different underlying accident rates in order to focus on changes over time for firms with a given underlying rate.

(b) Different costs of accident reductions

Different firms will have different $c(r)$ functions. The effects of differences can be discussed with reference to Figure 1, which shows the first derivative of $c(r)$.

Consider first a vertical shift in the $c'(r)$ curve, as would arise for a firm that faced higher marginal costs of accident reductions. The firm would have a lower chosen level of reduction, r^*, for any given inspection rate. The impact of the higher marginal cost on OSH's inspection decision will depend on the slope of the $c'(r)$ curve at the new optimum. If the $c'(r)$ curve is convex, the rise would move the firm onto a flatter portion of their $c'(r)$ curve, which affects the choice of inspection rate made by OSH. Specifically, r^*_π would be higher, leading to a higher IB curve, and a higher inspection rate.

Empirically, allowing for different underlying accident rates serves to control for differences in the height of marginal cost curves. The estimated relationship between inspections and accidents will reflect the average slope of the $c'(r)$ curve around the optimum r^*. A weak relationship would be consistent with a steep curve. A strong negative relationship would be consistent with a flat $c'(r)$ curve.

(c) Different firm size

In this model, firm size affects the decisions made by the firm and OSH only to the extent that the marginal cost curve differs across firms of different sizes. It is plausible that economies of scale exist in accident reduction, such that the average cost of accident reductions declines as the number of employees increases (although *not* necessarily as the number of accident reductions increases). For example, building a shield to isolate a physical hazard costs the same whether one or 1,000 workers are isolated from the hazard. The marginal cost curve would therefore be flatter for larger firms, and we would expect greater investment in safety equipment, and a consequently higher chosen level of reductions, r^*. The impact on the choice made by OSH of π^* depends on the slope of the $c'(r)$ curve at the new optimum. If the marginal cost curve were flatter at the new optimum this would result in a higher r_π and, hence, a higher IB curve, which would lead OSH to choose a higher probability of inspection for larger firms.

Different interventions

In the model, the probability of inspection is the only intervention variable that is represented. The level of fines is incorporated but set exogenously and is not a choice variable. Given that fines and the provision of information and advice are measures that are observed in practice, it is worth discussing how each of these affects the analysis of the model.

(a) Effects of fines

An increase in the level of fine, *ceteris paribus*, would cause firms to increase their level of accident reductions. As can be seen from Figure 1, a rise in f would lead to a higher value of $\pi f+\lambda$, causing a rise in r^*. However, this does not take into account the response by OSH to the higher fine. The higher costs imposed by the increased fine would be recognised by OSH and the IB curve in Figure 2 would be lower, leading to a reduction in π^*. Furthermore, if the firm's $c'(r)$ curve were convex, as drawn in Figure 1, a higher fine would move the firm onto a steeper part of its $c'(r)$ curve, where a change in inspection rates will have a smaller impact on reductions (that is, r^*_p is lower). This reduction in OSH effectiveness would be reflected in Figure 2 by a further lowering of the $(v\text{-}c'(r^*))r^*_\pi$ curve, which would lead OSH to reduce further the chosen level of inspections.

(b) Effects of information provision

Providing information and advice on health and safety issues can be characterised as a decline in the cost to the firm of reducing accidents, $c'(r)$. In the simplest case, if information provision lowers marginal costs by the same amount regardless of the level of reductions, this would cause a vertical downward shift in $c'(r)$ which, as noted above, leads to increased accident reductions for the firm. The Service would also choose a different inspection rate, π^*. The cost of providing information would need to be added to the IC curve in Figure 2, leading to a decline in inspections. The impact on the IB curve will depend on the curvature of the $c'(r)$ curve. If firm marginal costs are convex, the IB curve will drop, further reducing inspections.

Inspections, fines and information provision are substitutes in the production of reduced accidents, so it is not surprising that increasing one form of intervention leads to reductions in the use of other forms. Note that π and f enter the firm's decision in exactly the same way. This suggests that a 10 percent increase in the probability of inspection has the same impact as a 10 percent increase in the level of fine. There is some evidence in the literature that this is not the case.

Table 1 summarises the key insights from this section.

TABLE 1: The effects of changing the model's assumptions on the decisions of firms and OSH

	Firm decision: level of r	*OSH decision: level of π*
Firm attributes		
Higher accident rate (high a_0)	0	0
Responsiveness of reductions to inspections (flatter $c'(r)$ at r^*)	0	+
Higher costs of accident reduction (vertical rise in $c'(r)$)	–	? (depends on $c''(r^*)$)
Economies of scale in accident reduction (flatter $c'(r)$, for given a_0)	+	? (depends on $c''(r^*)$)
Interventions		
Fines/information provision	+	–
Probability of inspection, π	+	1

5 Data

The primary data source used in this study is an administrative database that was maintained by OSH until 1998 and known as PAC.[14] This database recorded all interventions by OSH staff and also details about the firms to which the interventions related. The PAC data provide a complete record of OSH activities and are available for the period 1992–1998, although the 1992 data are believed to be less reliable than those for subsequent years. The data used in this project therefore relate to all of New Zealand, for each six-month period between July 1993 and June 1997.[15]

5.1 Risks

The OSH data provide some measures of risk outcomes. An investigation is opened by OSH whenever it is notified of an accident, incident or illness or when it receives a complaint. The record of investigations, therefore, also comprises a record of reported outcomes. During the period from 1 July 1993 to 30 June 1997,

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[14] PAC refers to the 'Prevention and Compliance' database of activities undertaken by OSH. More recent data are available from the Health and Safety Accident Research Database (HASARD), which superseded PAC in 1998.

[15] Hence, only firms with which OSH has had some contact between these dates are included in the panel. Table 5 indicates that these incorporate most employees in New Zealand.

TABLE 2: Number of OSH investigations opened by event type, 1993/94–1996/97

Event type	*Number of investigations*	*Percent of total*
Accident	8,542	29.2
Incident	6,164	21.1
Notifiable Occupational Disease (NOD)	3,131	10.7
Other event	11,029	37.7
Not specified	355	1.2
Total	29,221	100.0

OSH opened 29,221 investigations. Table 2 summarises the nature of the events that gave rise to these investigations. Approximately 30 percent of investigations are opened as the result of an accident, however, the single most frequent cause of investigations is 'other' reasons, a category that includes complaints.

An advantage of considering more than one outcome measure is that it provides some information on the likely biases that are present because of reporting problems or the volatility of rare events. A comparison of alternative outcome measures also provides an indication of the extent to which the pattern of risks varies according to the type or severity of injury. Accidents, incidents and diagnosed illnesses are all usable measures of risk outcomes. In addition, the number of fatalities is available from PAC. The use of a strict fatality indicator has the advantage that it is unlikely to be affected by misreporting, that is, it is hard to fake a death, but also the statistical disadvantage that it is a relatively infrequent event. Each year in New Zealand OSH attends approximately 50 fatal accidents and these are concentrated in a small number of industries.[16]

It is possible from the PAC database to identify the characteristics and history of each firm that is investigated, including the past pattern of outcomes and OSH interventions. Therefore, in order to identify workplaces that are consistently high-risk workplaces, previous investigations were linked by workplace.

5.2 Interventions

Investigations are not the only activity that OSH undertakes. As Table 3 shows, investigations account for only about a fifth of the time that OSH staff spend on client-related activities. Compliance assessment and education, information and advice each account for a greater proportion of the Service's time. The tasks listed in the first column of Table 3 will serve as the main measures of OSH

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[16] Other possible outcome variables would be the number of lost workday events or the number of lost workdays. The latter would also provide some weighting for severity. However, neither of these measures is readily available.

TABLE 3: Percentage distribution of OSH hours by industry and type of intervention, 1993/94–1996/97

Type of intervention	*One-digit industry group* 1	2	3	4	5	6	7	8	9	*Total*
Investigation	1.9	0.0	6.6	0.2	2.9	1.5	1.1	0.6	3.3	18.2
Compliance assessment	4.8	0.2	13.5	0.4	8.8	3.4	1.5	0.8	7.3	40.5
Information	2.3	0.0	8.2	0.3	3.1	2.1	1.0	0.6	5.6	23.3
Administration	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.2	0.6
Other	1.6	0.1	5.7	0.3	2.7	1.6	0.9	0.4	4.1	17.4
Total	10.7	0.4	34.1	1.1	17.6	8.6	4.6	2.4	20.5	100.0
Employment in 1996	9.8	0.3	15.2	0.6	6.1	23.8	5.7	14.0	24.6	100.0

Notes: The industry groups are: agriculture, hunting, forestry and fishing (1); mining (2); manufacturing (3); electricity, gas and water (4); construction (5); wholesale and retail trade (6); transport, storage and communication (7); business and financial services (8); community, social and personal services (9)

interventions. In the analysis, the possibility that the different sorts of tasks have different effects on outcome variables will be investigated.

It is also evident from Table 3 that OSH activities are concentrated in manufacturing industries, but are also significant in other industries.[17] An indication of the extent to which OSH targets certain industries may be found by comparing the distribution of hours of interventions across sectors with the distribution of employees across sectors, as reported in the 1996 Census of Population and Dwellings, which is given in the final row of Table 3. This suggests that OSH spends over twice as much time with firms in the manufacturing and construction industries as is warranted by their employment levels. Conversely, many fewer OSH hours are spent in conjunction with the wholesale and retail trade and business and financial services industries than would be expected given the size of these sectors. For other industries, the distribution of interventions approximately matches the distribution of employment.

Ideally, the analysis would also incorporate a variable to reflect the financial incentives associated with Accident Compensation Corporation (ACC) premia. The experience rating scheme that was in place during the period encompassed by the data determined the extent to which premium costs increased as claims costs increased and *vice versa*. However, the formula that was used to determine the

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[17] This is the same pattern that has been observed for OSHA in the United States. As noted above, most of the OSHA studies have concentrated on manufacturing or manufacturing/construction industries, where the greatest number of accidents occur.

loading or discount applied to individual firms' premia was the same across all industries. There is, therefore, no simple way of identifying the effect that experience rating had on the accident rate of firms, without linking PAC data to ACC records at the firm level.

5.3 Control variables

Unfortunately, no additional time-varying information was obtainable from PAC to describe relevant characteristics of the firm such as the nature of the workforce and the wage bill.[18] However, later in the paper, the data are analysed at the industry level, thereby allowing control variables to be incorporated in regressions in an attempt to explain the remaining variation in investigation rates. These variables were derived from two sources: the *Quarterly Employment Survey* and the Annual Business Frame Update.

Although the frequency of the *Quarterly Employment Survey* permits observations that correspond to the biannual PAC data, only those from the February survey were used, thereby creating an annual series. The reason for this selection is that the February survey is a full-coverage survey, with information being obtained from all business locations in surveyed industries that employ more than two full-time equivalent employees, in contrast to the May, August and November surveys, which use a representative sample of about 28,000 of these business locations. The survey also excludes a number of industries, most importantly those connected with agriculture, hunting and fishing. The total number of full-time equivalent employees in each 3-digit industry was obtained from the *Quarterly Employment Survey*, along with the percentage of female workers.

The Business Frame is updated every February, thereby allowing annual observations only. It is also restricted to businesses that are deemed to be 'economically significant',[19] although it has a greater level of industrial coverage than the *Quarterly Employment Survey*. This is used as the source of information on the number of 'geographic units' in each industry.[20]

5.4 Data summary and analysis

Table 4 presents aggregate annual values of measures of the various activities undertaken by OSH, both those that are interpretable as accident or injury rates

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[18] The number of employees per workplace *is* recorded by PAC, however, this is constant over time, therefore limiting its usefulness.

[19] To be economically significant a business must satisfy one of a number of criteria, normally meaning that it has either annual Goods and Services Tax expenses or sales in excess of $30,000 or more than two full-time equivalent paid employees.

[20] A geographic unit is defined as a separate operating unit engaged in predominantly one kind of economic activity from a single physical location.

TABLE 4: Total levels of outcome and intervention variables by year

Variable	*1993/94*	*1994/95*	*1995/96*	*1996/97*	*Total*
Outcome variables					
Hours of investigations	11,031	31,365	32,481	31,899	106,775
Accidents	3,839	4,951	16,990	15,702	41,482
Incidents	2,601	17,939	1,625	939	23,104
Notifiable Occupational Diseases	623	471	4,661	4,677	10,433
Other events	3,105	8,004	9,204	10,581	30,894
Number of fatalities	34	23	101	78	236
Intervention variables					
Hours of compliance assessments	77,501	63,676	50,534	45,310	237,021
Hours of education, information or advice	42,043	34,641	32,928	28,740	138,351
Hours of administration	0	239	1,490	1,865	3,594
Hours of other OSH interventions	24,664	24,863	27,675	29,354	106,557
Number of observations, *N*	88,659	88,659	88,659	88,659	354,636

Notes: The number of observed firms is constant because annual information is recorded for all firms that feature in PAC, regardless of whether they have contact with OSH in any particular year.

and those that reflect the provision of health and safety services.[21] This reveals some problems with the PAC data. In particular, there is evidence of under-reporting of investigations in the 1993/94 year.[22] In addition, the large increase in accidents reported between 1994/95 and 1995/96 and corresponding decline in incidents suggests a change in reporting definitions concerning the two categories over this period.[23]

Of the investigation categories for which a cause is specified, accidents and incidents together typically form the largest group. However, a decline in the number of investigations in this group over the last three years of the sample is matched by an increase in cases of notifiable occupational diseases, such as occupational overuse syndrome, and other events. In concordance with Table 3,

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[21] Although six-monthly data were obtained and are used in the following section, the values here relate to full years, beginning in July. It would be somewhat misleading to present the variables in Table 4 as rates, whereby the hours spent on each activity is expressed as a proportion of the number of employees, because of the fact that the number of employees per workplace, as recorded in PAC, is constant over time.

[22] Given the small number of time periods that was available from PAC, it would be extremely costly to drop the observations for this year from the sample. Fortunately, regressions in the following section are able to control for systematic differences in reporting between periods through the inclusion of time-specific dummy variables.

[23] This is allowed for in regressions in the next section by grouping accidents and incidents together.

compliance assessments are clearly the most common form of intervention, although the incidence of such activities fell sharply over the four years spanned by the data. The number of hours spent by OSH giving education, information and advice also fell, while time attributed to administration and other interventions rose over the four-year period.

To obtain some idea of the co-movements of the risk and intervention rates of firms, correlations between the two sets of variables were calculated.[24] The data encompass a range of firm sizes, which, as noted in Section Four, may result in different average safety management costs. Consequently, the correlations were weighted by the number of employees in the workplace.[25] This preliminary evidence suggests that there is a weak positive relationship between injuries and interventions. Each risk measure exhibits a positive contemporaneous correlation with each category of interventions. A similar pattern is revealed when the correlations between injury rates and six-month lags of intervention rates are computed. A relatively high degree of persistence is exhibited by the major injury rates, as demonstrated by a strong correlation between current and lagged values.

Other, potentially instructive, variables were obtained from PAC. These variables are summarised in Table 5, which gives average values over the full sample period at both the firm and employee levels. These are compared with corresponding values for the total population in 1996. The mean number of employees working for firms that are included in PAC is approximately 12.5, somewhat larger than the population average of around five. The statistics suggest that PAC includes a low proportion of firms but a high proportion of employees. Therefore, those firms that are excluded must generally be small in size.[26]

The distribution of employees across industries in PAC is broadly similar to the distribution of hours spent by OSH in each sector, which was recounted in Table 3, although the numbers are different because Table 3 uses census data whereas Table 5 reports shares from the Annual Business Frame Update. The Annual

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[24] The six-monthly data were used to obtain these correlations. Each variable was expressed in terms of hours per employee, although this is subject to the concern that the latter is constant over the sample period.

[25] Note that this is not the same as computing the correlation between the hours of risks and interventions. The estimated correlation coefficient here is:

$$\hat{\rho} = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T} n_i(a_{it}-\bar{a})(\pi_{it}-\bar{\pi})}{\sqrt{\sum_{i=1}^{N}\sum_{t=1}^{T} n_i(a_{it}-\bar{a})^2}\sqrt{\sum_{i=1}^{N}\sum_{t=1}^{T} n_i(\pi_{it}-\bar{\pi})^2}}$$, where n is the number of employees in the firm and a and π are the injury and intervention rates, respectively.

[26] The data suggest that excluded firms have an average of 1.28 employees.

Business Frame Update excludes most firms in the agriculture, hunting, forestry and fishing industries, meaning that this sector is under-represented in the population distribution in Table 5. Nevertheless, there is further evidence that OSH concentrates its activities on the manufacturing and construction industries, at the expense of firms and employees involved in wholesale and retail trade or business and financial services.

It was found that the Hamilton (in Waikato) and Christchurch North (in Canterbury) OSH offices consistently managed the greatest number of cases, while the New Plymouth (in Taranaki) and Tauranga (in Bay of Plenty) branches dealt with the least. At a regional level, Table 5 suggests that the Service contacts fewer firms and workers in Auckland and Wellington than its share of the national population warrant. Conversely, the PAC data over-sample businesses in less populous regions.

6 Results and analysis

The focus of the empirical investigation is to determine the nature of the relationship between OSH interventions and health and safety outcomes. As noted in the previous section, the data are at the firm level and follow firms over eight six-month periods. The main estimating equation will be of the following form, where *i* represents the firm or industry; *t* represents the time period; γ_I and η_t are error components relating to industry/firm and time, respectively; a_{it} is an outcome variable; $\boldsymbol{\pi}_{it}$ is a vector of current and lagged intervention variables; $\mathbf{X}_{it}$ is a vector of covariates, including the lagged risk variable, $a_{i(t-1)}$, and other industry control variables:[27]

$$\begin{aligned} a_{it} &= \boldsymbol{\alpha}\boldsymbol{\pi}_{it} + \boldsymbol{\delta}\mathbf{X}_{it} + e_{it} \\ e_{it} &= \gamma_i + \eta_t + \varepsilon_{it}\ . \end{aligned} \tag{8}$$

The resulting estimates will be interpreted in the light of the model as presented in Section Four of this paper.[28] Changes in risk outcomes will be interpreted as the stochastic response of accident reductions to firms' investments in safety equipment. Increases in interventions, corresponding to the probability of inspection in the model, are expected to induce higher safety expenditures and, thus, lower risk outcomes. The model is set out for the case of a single firm or for a set of identical firms. In practice, firms and industries have markedly different underlying accident rates, reflecting variation in production processes and the

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[27] A range of treatments will be used for the error components. Time variation will be dealt with by the inclusion of time-varying covariates or by the use of time dummies. Similarly, industry- or firm-specific variation will be dealt with by the inclusion of industry- or firm-specific covariates that capture heterogeneity or by the use of fixed effects.

[28] Given that $a = a_0 - r$, Equation Eight is simply a restatement of Equation Four, where the level of fines, *f*, is assumed constant and firm heterogeneity is controlled for.

TABLE 5: Means of control variables compared with population characteristics, 1993/94–1996/97

	Firms		Employees	
Variable	PAC	*1996 Population*	PAC	*1996 Population*
Number of employees in firm	12.566	5.197	–	–
Agriculture, hunting, forestry and fishing	0.114	0.032	0.067	0.021
Mining	0.005	0.002	0.003	0.003
Manufacturing	0.171	0.085	0.270	0.192
Electricity, gas and water	0.008	0.003	0.012	0.008
Construction	0.318	0.123	0.204	0.071
Wholesale and retail trade	0.104	0.253	0.089	0.246
Transport, storage and communication	0.044	0.058	0.042	0.064
Business and financial services	0.020	0.302	0.027	0.150
Community, social and personal services	0.178	0.142	0.229	0.244
Northland	0.037	0.033	0.034	0.027
Auckland	0.256	0.345	0.265	0.336
Waikato	0.084	0.087	0.093	0.083
Bay of Plenty	0.087	0.057	0.118	0.052
Taranaki	0.031	0.025	0.021	0.026
Hawke's Bay/Gisborne	0.044	0.044	0.032	0.043
Manawatu	0.050	0.053	0.050	0.057
Wellington	0.105	0.122	0.089	0.134
Nelson/Marlborough	0.051	0.033	0.053	0.030
Canterbury/West Coast	0.140	0.131	0.142	0.139
Otago	0.074	0.047	0.056	0.048
Southland	0.040	0.023	0.048	0.026
Total number, *N*	88,659	255,260	1,114,075	1,326,627

Notes: The 1996 population distributions of firms and employees are calculated from the 1996 Annual Business Frame Update.

The regional PAC statistics listed here assume that all investigations conducted by OSH offices relate to firms within the particular local government region(s) that they are located, as listed above. A sample examination of data collected by the Manukau branch suggests that this is a reasonable assumption.

inherent riskiness of their activities. The fact that firms and industries with high accident rates also have high intervention rates should not be interpreted as evidence that interventions cause accidents. Therefore, this study will rely on changes in both risk and intervention variables over time for particular firms and industries. This is achieved by including a firm- or industry-specific intercept, γ_i, in the regressions presented in this section. In addition, variation in the relationship between interventions and outcomes across sub-groups of employers will be allowed by generating separate estimates for different industries and firm sizes.

6.1 Results using firm level data

Initially, the total number of investigations conducted by OSH for each firm is used as the measure of health and safety outcomes, a_{it}. It is included as a dummy variable that captures whether a firm was the subject of an investigation or not.[29] The estimates thus indicate the strength of specific rather than general deterrence. General deterrence occurs if the firm responds to the probability of inspection, whereas specific deterrence occurs if the firm further changes its behaviour in actual response to being inspected.

The components of $\boldsymbol{\pi}_{it}$ are dummy variables recording the provision of compliance assessments, education, information or advice, administration or other interventions by OSH. The first column of Table 6 presents the results of ordinary least squares estimation of Equation Eight. Only the first lags of the intervention variables are included in $\boldsymbol{\pi}_{it}$, while $\mathbf{X}_{it}$ comprises the first lag of the dependent variable. Dummies for each period are included, along with controls for each firm, in a two-way fixed effects specification.

Each form of OSH intervention has an impact on a firm's likelihood of being investigated in the next period that is small in magnitude. Compliance assessment and 'information, education or advice' are found to have a significant effect at the 1 percent level and both show an anomalously positive coefficient. Investigations exhibit a negative first-order dynamic effect, with the occurrence of an investigation in one period reducing the probability that the firm will be investigated in the following period.

Unfortunately, the fixed effects estimation of a dynamic panel data model, such as that estimated in the first column of Table 6, does not yield consistent estimates of the parameters in the presence of error components. The problem

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[29] A dummy variable specification was chosen for a_{it} because approximately 99.5 percent of the variation in the number of interventions across firms is between values of 0 and 1. Ideally, a binary dependent variable model should be used in this case, such as the well-known logit or probit models. However, due to the importance of controlling for endogeneity among the regressors, as will be seen later, a standard linear probability model was employed.

TABLE 6: Results of estimating the investigation equation with firm level data

Regressor	*(1)* *OLS* *1994i–1997i*	*(2)* *IV* *1994ii–1997i*	*(3)* *IV* *1994ii–1997i*	*(4)* *IV* *1995i–1997i*
Lag of investigation	–0.118^{c}	0.034^{c}	0.011^{c}	0.005
	(0.001)	(0.002)	(0.002)	(0.006)
Compliance assessment	–	–	0.048^{c}	0.077
			(0.001)	(0.095)
Education	–	–	0.040^{c}	0.247
			(0.001)	(0.176)
Administration	–	–	–0.017^{c}	0.651
			(0.007)	(0.408)
Other intervention	–	–	0.084^{c}	0.051
		(0.001)	(0.161)	
Lag of compliance assessment	0.002^{c}	–0.028^{c}	–0.004^{c}	–0.003
	(0.001)	(0.001)	(0.001)	(0.004)
Lag of education	0.006^{c}	–0.018^{c}	–0.002^{a}	–0.012^{b}
	(0.001)	(0.001)	(0.001)	(0.005)
Lag of administration	0.006	–0.012^{a}	–0.018^{b}	–0.025
	(0.007)	(0.007)	(0.008)	(0.016)
Lag of other intervention	0.001	–0.045^{c}	–0.004^{c}	–0.001
	(0.001)	(0.001)	(0.001)	(0.006)
1994ii	0.013^{c}	–	–	–
	(0.001)			
1995i	0.016^{c}	–0.014^{c}	–0.014^{c}	–
	(0.001)	(0.001)	(0.001)	
1995ii	0.017^{c}	–0.013^{c}	–0.013^{c}	–0.001
	(0.001)	(0.001)	(0.001)	(0.003)
1996i	0.016^{c}	–0.015^{c}	–0.018^{c}	–0.008^{c}
	(0.001)	(0.001)	(0.001)	(0.002)
1996ii	0.017^{c}	–0.012^{c}	–0.013^{c}	0.001
	(0.001)	(0.001)	(0.001)	(0.002)
1997i	0.019^{c}	–0.012^{c}	–0.012^{c}	0.002^{a}
	(0.001)	(0.001)	(0.001)	(0.001)
AIC	–3.454	–2.863	–2.908	–2.748
SC	–1.834	–2.862	–2.908	–2.747
$\bar{R}^2$	0.017	0.006	0.022	0.017
Number of observations, *N*	620 613	531 954	531 954	443 295

Notes: Significance at the 1 percent, 5 percent and 10 percent level is denoted by ^{c}, ^{b} and ^{a}, respectively. Standard errors are in parentheses.

Specification 1 is estimated in levels and also includes a full set of firm dummies. All other specifications are estimated in first differences with instruments specified in the text.

To ensure that they are well defined, the $\bar{R}^2$ values reported for all instrumental variables regressions are equal to the squared correlation coefficient between the observed and predicted dependent variable.

arises due to the presence of the firm-specific effects, γ_i. Because $a_{i(t\text{-}1)}$ is a function of γ_i, the lagged dependent variable is correlated with the error term. This variable appears as a regressor in the estimating equation, rendering ordinary least squares biased and inconsistent, even if the ε_{it} are not serially correlated. One solution involves first differencing as follows, in order to eliminate the firm effects, γ_i:

$$\begin{aligned} \Delta a_{it} &= \boldsymbol{\alpha}\Delta\boldsymbol{\pi}_{it} + \boldsymbol{\delta}\Delta\mathbf{X}_{it} + \Delta e_{it}\,, \\ \Delta e_{it} &= \Delta\eta_t + \Delta\varepsilon_{it}\ . \end{aligned} \tag{9}$$

In Equation Nine, $\Delta a_{i(t\text{-}1)}$ will still be correlated with $\Delta\varepsilon_{it}$, due to the common factor $\varepsilon_{i(t\text{-}1)}$.[30] However, instrumental variables estimators are able to overcome this problem. Following the approach of Anderson and Hsiao (1981), the second lag of the risk variable, $a_{i(t\text{-}2)}$, may be used as an instrument for $\Delta a_{i(t\text{-}1)}$. This instrument will be valid so long as ε_{it} is not autocorrelated and the procedure generates consistent, but not necessarily efficient, estimates of the parameters of the model.

The results of estimating the investigation equation with the Anderson-Hsiao first-differencing method are presented in the second column of Table 6. The same regressors are used as in the first specification. Consistent estimation of the effects of OSH interventions is found to produce coefficients that have a higher level of significance. All estimates of the parameters in $\boldsymbol{\alpha}$ are negative, suggesting that any form of intervention in one period results in a reduction in the chance of being investigated in the next, thus supporting one prediction of the theoretical model in Section Four. In addition, the first-order investigation dynamic term is now found to be positive, but very small in magnitude.

It is likely that current interventions by OSH also influence the probability that a firm is investigated. If this is the case, and if intervention variables are serially correlated, the estimates of $\boldsymbol{\alpha}$ obtained thus far will be biased. A more appropriate specification would therefore include the current values of the four intervention variables in $\boldsymbol{\pi}_{it}$. The results of estimating such a regression equation are presented in the third column of Table 6, with the Anderson-Hsiao method being employed again and $a_{i(t\text{-}2)}$ used to control for the endogeneity of the lagged investigation variable. Interventions continue to have a favourable effect on the incidence of investigations six months later, although the magnitude of this effect is found to be much lower than before. In contrast, a positive contemporaneous relationship is found between investigations and three of the four intervention categories.

The effect of lagged interventions on current outcomes may capture the transitory effects of interventions on investigations. One approach is to model the dynamic specification as involving the 'intervention-adjusted' propensities of firms to be investigated. This interpretation implies that the persistent effects of OSH interventions are given by combinations of the parameter estimates presented

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[30] Δ denotes the difference operator.

in the third column of Table 6.[31] These effects are found to be very similar to the estimated coefficients on the lagged intervention variables and are generally significant at the 1 percent level, suggesting that work done by OSH with firms induces a lasting reduction in reported workplace accidents, albeit a reduction of relatively minor importance.

By treating contemporaneous interventions as exogenous, the above regressions ignore the potential simultaneity of investigations and firms' safety behaviour. However, it is possible that the incidence of an OSH investigation may affect the likelihood of a firm experiencing other forms of interventions in a given period. In this case, the regressors in $\boldsymbol{\pi}_{it}$ will be correlated with the error term, $\Delta\varepsilon_{it}$. To overcome this problem, the final column of Table 6 reports the results of adding $\boldsymbol{\pi}_{i(t\text{-}2)}$ and $\boldsymbol{\pi}_{i(t\text{-}3)}$ to the set instruments in order to control for the potential endogeneity of the intervention variables. The precision of the estimates is found to fall markedly, suggesting that $\boldsymbol{\pi}_{i(t\text{-}2)}$ and $\boldsymbol{\pi}_{i(t\text{-}3)}$ are relatively weak instruments. As a result, although the estimates of the parameters in $\boldsymbol{\alpha}$ are generally larger than the corresponding values in the third column, all are found to be insignificant at the 1 percent level.

It is unclear whether it is appropriate to include investigations arising from reports of notifiable occupational diseases in the outcome variables used. It is likely that the firm will need to take a quite different approach to managing such hazards and there are likely to be longer time lags between firms' actions and changes in outcomes. The third and fourth rows of Table 7 report the results of estimating the investigation equation separately for this group and for investigations that are due to accidents or incidents. The Anderson-Hsiao method is used again, controlling for endogeneity in the lagged investigation term only.[32] The estimated coefficients for the two dependent variables are relatively similar, although there is a low level of significance.

Table 7 also reports estimates of the effects of the various types of interventions for different industry groups and firms of different sizes. Administration, along with education, information and advice, appears to have the largest impact on accident rates, although only for certain sectors. There is no discernible link between the extent to which OSH targets an industry, as identified in Tables 3 and 5 and the responsiveness of firms in that industry to health and safety interventions. Small firms, defined as those with fewer than 10 workers, are far more prevalent than firms that have more than 100 employees. Small firms also tend to be more responsive to interventions by OSH than larger firms.

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[31] In particular, if α_1 denotes the coefficient on lagged interventions, α_0 the contemporaneous effect of interventions and δ the first-order investigation dynamic effect, the overall impact of each intervention is given by $\alpha = \alpha_1 + \delta\alpha_0$.

[32] In other words, Table 7 replicates the regression underlying the third column of Table 6 for various sub-groups of investigation data.

TABLE 7: Estimates of the total effects of interventions, α, for different sub-groups without controlling for endogeneity of independent variables, 1993/94–1996/97

Sub-group	*Compliance assessment*	*Education*	*Administration*	*Other intervention*	*N*
Total	–0.003[c]	–0.001	–0.018[b]	–0.003[b]	531,954
Accidents and incidents	–0.001[b]	0.000	–0.012[b]	–0.001	531,954
NODs	–0.001[b]	0.000	–0.008[c]	0.000	531,954
Agriculture, forestry, fishing	0.000	–0.001	0.001	0.001	60,462
Mining	0.003	0.010	–	–0.001	2,574
Manufacturing	–0.008[c]	–0.004	–0.041[a]	0.001	91,026
Electricity, gas, water	–0.003	–0.193[a]	0.026[c]	0.008[a]	4,446
Construction	0.002[b]	0.001	–0.023	0.002	168,912
Wholesale, retail	–0.003	0.063	–0.013[b]	–0.001[c]	55,536
Transport, communication	0.004	–0.005	–0.175[c]	–0.006	23,502
Business, finance	–0.009	–0.056	–0.022	0.004[a]	10,440
Community, social, personal	–0.012[c]	0.001	0.004	–0.007[b]	94,734
Small firms (<10 workers)	–0.002[c]	–0.002	–0.007	–0.005[c]	411,258
Large firms (>100 workers)	0.004	0.022	–0.064	–0.005	6,840

Notes: Significance at the 1 percent, 5 percent and 10 percent level is denoted by [c], [b] and [a], respectively.

As noted in footnote 32, the total effect of an intervention is given by $\alpha = \alpha_1 + \delta\alpha_0$, where α_1 denotes the coefficient on lagged interventions, α_0 the contemporaneous effect of interventions and δ the first-order investigation dynamic effect.

6.2 Results using industry level data

The health and safety experiences of individual firms will be relevant if inspections have a 'specific' deterrence effect, whereas industry measures of the probability of inspection capture the effects of both 'general' and 'specific' deterrence. As a result, intervention variables are measured at the 3-digit industry level as well as at the firm level. The former approach enables the inclusion of other control variables that represent the general characteristics of industries. As noted in the previous section, these were obtained from both the *Quarterly Employment Survey* and the Annual Business Frame Update.

Table 8 presents the results of a series of regressions using the 3-digit industry level data. There is sufficient information to produce observations for

TABLE 8: Results of estimating the investigation equation with industry level data

	(1)	*(2)*	*(3)*	*(4)*
	WLS	*IV*	*IV*	*IV*
Regressor	*1994ii–1997i*	*1994ii–1997i*	*1995i–1997i*	*1994ii–1997i*
Lag of investigation	0.155[c]	–0.794[c]	–0.309	–0.456[c]
	(0.057)	(0.183)	(0.260)	(0.115)
Compliance assessment	0.041[a]	0.023	–0.216	0.033[b]
	(0.023)	(0.017)	(0.319)	(0.014)
Education	0.149[c]	–0.034	0.222	–0.020
	(0.031)	(0.026)	(0.423)	(0.021)
Administration	0.061	0.279	0.986	0.226
	(0.251)	(0.251)	(3.518)	(0.224)
Other intervention	0.089[a]	0.201[c]	–0.592	0.127[c]
	(0.036)	(0.048)	(0.760)	(0.034)
Lag of compliance assessment	–0.013	0.073[c]	0.014	–0.060[c]
	(0.023)	(0.019)	(0.046)	(0.015)
Lag of education	0.082[c]	–0.084[c]	0.071	–0.050[b]
	(0.029)	(0.030)	(0.154)	(0.023)
Lag of administration	0.312	0.379	–0.208	0.117
	(0.297)	(0.266)	(0.889)	(0.222)
Lag of other intervention	0.063[a]	0.289[c]	–0.154	0.140[c]
	(0.032)	(0.081)	(0.155)	(0.053)
Logarithm of number of workplaces	–	–	–	–0.001[c]
				(0.000)
Logarithm of number of employees	–	–	–	0.001[a]
				(0.000)
Logarithm of percentage of female employees	–	–	–	–0.001[c]
				(0.000)
1995i	0.015[c]	0.001	–	–0.000
	(0.004)	(0.001)		(0.001)
1995ii	0.016[c]	0.000	–0.001	–0.001
	(0.004)	(0.001)	(0.003)	(0.001)
1996i	0.006[c]	–0.002[a]	–0.000	–0.002[c]
	(0.005)	(0.001)	(0.002)	(0.001)
1996ii	0.006[c]	–0.002[b]	–0.001	–0.002[c]
	(0.005)	(0.001)	(0.002)	(0.001)

continued

TABLE 8: continued

Regressor	(1) WLS 1994ii–1997i	(2) IV 1994ii–1997i	(3) IV 1995i–1997i	(4) IV 1994ii–1997i
1997i	0.011[b]	–0.001	–0.001	–0.001
	(0.004)	(0.001)	(0.002)	(0.001)
AIC	–8.577	–10.008	–9.288	–10.461
SC	–7.752	–9.888	–9.159	–10.312
$\overline{R}^2$	0.961	0.140	0.000	0.085
Number of observations, *N*	534	534	445	514

Notes: Significance at the 1 percent, 5 percent and 10 percent level is denoted by [c], [b] and [a], respectively.

Standard errors are in parentheses.

Specification 1 is estimated in levels and also includes a full set of industry dummies. All other specifications are estimated in first differences with instruments specified in the text.

To ensure that they are well defined, the $\overline{R}^2$ values reported for all instrumental variables regressions are equal to the squared correlation coefficient between the observed and predicted dependent variable.

89 industries.[33] The outcome and intervention variables used in Table 8 now refer to the *proportions* of firms that are the subject of interventions undertaken by OSH in the given period for each industry.

The first column refers to a two-way fixed effects estimate of the investigation equation, where each observation is weighted by the number of firms in the particular industry. The regression fit is much better than that of the corresponding equations with firm-level data: an expected result of aggregation.

In the second column, the Anderson-Hsiao first differencing method is implemented, with the second lag of the risk variable being used as an instrument for the lagged dependent variable. This change causes the adjusted coefficient of determination to fall markedly, suggesting that most of the observed variation between industries is captured by fixed effects. Nonetheless, three out of four forms of OSH intervention appear to have a significant effect on the likelihood of a workplace accident occurring in the following six-month period. However, in contrast to the pattern that was found with firm-level data earlier, some positive effects are found, perhaps indicating a more important endogeneity problem in the aggregate data.

As with the firm-level data, controlling for potential endogeneity of the eight intervention variables in the third column of Table 8 results in an explosion of

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[33] Thirty-eight of these 3-digit industries are not included in PAC because OSH has no contact with any constituent firms. As a consequence, all intervention propensities for these industries are zero.

standard errors and most coefficients being rendered insignificant. Accordingly, the final column of the table returns to the previous specification, where only the lagged investigation term is instrumented. Now, however, the three industry demographic variables referred to above are added to the set of regressors.[34]

The size of an industry, as measured by its total number of employees, is found to have a marginally significant effect on the propensity of investigations in an industry. The number of workplaces in an industry is nonetheless found to be important, with a significant negative coefficient revealed. According to the estimate reported, a 10 percent increase in the number of workplaces in an industry is likely to reduce the possibility of firms in the industry being investigated by 1 percentage point, *ceteris paribus*. Taken together, these results are surprising because they suggest that industries with smaller firms tend to have fewer health and safety concerns, in contrast to the prediction made in Section Four under the assumption of economies of scale in safety production. Finally, the percentage of female employees is found to have a negative effect on the number of investigations, in concordance with previous results.

7 Conclusions

This study has investigated the effectiveness of government health and safety legislation. A simple model was presented to illustrate the relationship between the inspection decisions of the Occupational Safety and Health Service and the safety management decisions of firms. This model generated a variety of implications.

Both firm and OSH decisions were based not on the prevalence of accidents, but on the marginal costs and benefits of accident *reductions*. A higher marginal cost leads firms to invest less in accident reduction. The Occupational Safety and Health Service focuses its efforts where it can have the greatest impact on reductions, which is where firms respond most to inspections. If there are economies of scale in achieving accident reductions, larger firms will pursue greater reductions. Furthermore, because small changes in inspection probabilities can induce large responses by firms, OSH will also choose a higher rate of inspection. Inspections, fines and information provision are substitute means of inducing a reduction in accidents, so increases in one form of intervention will generally be associated with decreases in the use of other forms.

Firm-level data supplied by OSH were used to examine one prediction of the model, namely that the probability of a firm being inspected has a positive effect on the safety improvements made by firms and, hence, the level of accidents. By employing dynamic panel data methods, tentative evidence was found that four types of OSH intervention have a small favourable effect on health and safety

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[34] Only those observations for which both *Quarterly Employment Survey* and Business Frame data are available are used.

outcomes six months later, as measured by a fall in the incidence of investigations. However, when instrumental variables estimation was used to control for the potential endogeneity of the investigation term, the estimated coefficients generally became insignificant. In addition, no pattern was identified in the effectiveness of interventions across industry groups, although small firms were found to be more responsive to interventions than larger ones.

The analysis was repeated with the data aggregated within 3-digit industries and the variables expressed as the proportion of firms that were subject to an OSH intervention. This alternative specification allowed for the inclusion in the regression equation of other variables that might be expected to affect health and safety outcomes. Inconclusive evidence was reported regarding the effects of the various forms of intervention, with a mixture of positive and negative coefficients estimated. While, as predicted, the proportion of female employees was found to have a favourable effect on health and safety outcomes, the number of workplaces in an industry exhibited an unanticipated negative relationship with the accident rate of an industry.

Overall, the findings are similar to those in the international literature, despite the quite different approach to health and safety management that is embedded in the Health and Safety in Employment Act 1992. The less prescriptive approach to regulation has not generated markedly different findings.

This project has highlighted limitations in existing datasets and points to the importance of obtaining better data. Case studies of particular firms or industries are essential for understanding the specifics of firm health and safety management, but to understand the overall impact of health and safety regulation there is a need for broad-based representative data. The administrative records that were used in the study revealed a number of inconsistencies and were limited to four years of information. These problems might be solved by an analysis of data from HASARD, the database that has been used by OSH since 1998. However, any firm-level estimates of the effects of health and safety legislation would also ideally include controls for a variety of firm characteristics. Only then would one be able to determine credibly whether or not the activities of government have an effect on the occupational health and safety outcomes of firms.

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