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The Impact of Prevention Measures and Organisational Factors on Occupational Injuries

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Abstract

This paper analyses the impact of a series of managerial and organisational factors on occupational injuries. These consist of occupational safety measures, as regards both the intensity and the orientation of risk prevention in companies, and the adoption of certain work organisation practices, quality management and the use of flexible production technologies. We estimate a negative binomial regression based on a sample of 213 Spanish industrial establishments, defining a constant random parameter to take account of non-observable heterogeneity. Our results show that occupational safety measures, the intensive use of quality management tools and the empowerment of workers all help to reduce the number of injuries. We have also confirmed the presence of synergies between the organisational factors analysed and the development of an occupational safety strategy featuring participation and the extension of prevention to all levels of the organisation.

Keywords: Occupational Safety, Prevention Management, Organisational Factors

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1. Introduction

The conventional approach to occupational health and safety was largely based on the study of the chemical, physical and biological risks to which people may be exposed in the workplace. Meanwhile, other areas, such as psychological and psychosocial risks, gradually attracted researchers' attention. However, the real revolution in the field of health and safety at work was the expansion of the focus from the individual worker to the conditions of the establishment.

As Hale and Hovden (1998) explain, it was only in the 1980s that the conviction spread among those with responsibilities in the field of workplace health and safety that the traditional approach, centered around the relationship between the individual worker and technology, was not enough. These authors identified three stages in the evolution of workplace health and safety management. In the first, the sole objective was the search for technical measures to lower the risk of accidents. In the second, interest shifted to the individual, focusing on behaviour and ergonomics with the goal of shaping the workplace to suit the person. The third stage is characterized by the consideration of organisational and management issues as fundamental factors for safety improvement.

In recent years, the authorities in the developed nations have paid considerable attention to the business organisation in looking for improving preventive practices. Nevertheless, the National Institute for Occupational Safety and Health in the USA recently stressed that research into the relationship between organisational factors and accident rates is still sparse and incomplete, and sketched the priorities for further study (NIOSH, 2002). The NIOSH report underlined that organisational change and the new management practices adopted by firms in recent years have potential implications for safety that have not received sufficient attention to date. In particular, it affirms that priority should be given to the following issues: (i) changes in workload and pressure; (ii) the effects of vertical decentralisation of jobs and job enrichment; (iii) appropriate organisation of prevention services and programmes; (iv) the impact of changes in work organisation on awareness of workplace risks, as well as the preventive effort of both the employer and the worker; and (v) the effects that organisational changes have on the work/leisure balance.

Despite its unquestionable importance, the relationship between organisational parameters, intensity and the type of preventive measures implemented by firms and industrial accident rates is a line of research that has received comparatively little attention. Furthermore, the majority of papers in this field are descriptive reports that theorize about the impact of certain organisational practices on workplace risks. Empirical studies are rare, however, and are affected by significant methodological and data limitations.

This paper contributes to this literature in several ways. In the first place, we analyse the effect of various organisational parameters on injury rates. Thus, we consider three organisational dimensions, namely the technology and the organization of production, the application of quality management practices, and the empowerment of workers. Further, we construct a risk prevention index that quantifies the intensity of firm's preventive effort. The relationship between these indicators with the accident measures allows us to determine the nature of their impact on the workplace safety. Secondly, we test whether the combination of innovative preventive effort with the organisational factors helps to further reduce the number of injuries. In other words, we ask whether there are any synergies between this type of prevention and organisational factors. We analyse these issues for a sample of 213 industrial firms in Spain with over 30 employees by means of a negative binomial regression.

The paper is organised as follows. The following section discusses how prevention decisions and organisational factors relate with the accident rate, and establishes the hypotheses we shall test. The third section describes the econometric methodology. In the fourth section, we present the applied study, the variables employed and the data obtained.

The fifth section presents and comments on the results of the econometric analysis, and the paper closes with our main conclusions.

2. Risk prevention and the role of organisational factors in reducing the accident rate: some hypotheses

2.1. The intensity and the orientation of risk prevention

Reducing the risk of accidents and occupational disease means undertaking what is generally known as prevention. For example, article 4 of the Spanish Workplace Risks Prevention Act (Law 31/November 8th 1995) defines prevention as “all the steps or measures taken or planned at all stages of work in the enterprise to prevent or reduce occupational risks”. The Act requires all entrepreneurs to take “all such measures as may be necessary to protect the health and safety of their employees” (article 14). All of the measures established are by nature “minimum legal requirements”, which may be developed and enhanced in collective labour agreements (article 2.2).

If action is effective, we may expect that more intense risk prevention will result in lower accident rates. Thus, the accident rate in firms that take only the minimum preventive measures necessary to comply with the law will be significantly higher than rates in those firms that take a more proactive stance toward the development of a comprehensive workplace risk prevention system. This is confirmed by the available empirical evidence. Hunt and Habeck (1993) examined a sample of 220 firms in the US State of Michigan in order to establish the relationship between certain workplace risk prevention parameters and indices for the frequency and severity of accidents. These authors stress the need to generate and process internal information, investigate accidents and incidents fully, foster the emergence of a “prevention culture” and promote programmes to enhance workplace ergonomics. Simard and Marchand (1996) relate effective prevention with young businesses in which workplace risks are evaluated and accidents are more fully investigated on the basis of a sample of 100 industrial firms in Quebec. Chew (1988) analyses differences between safe and unsafe industries using data drawn from firms in India, Singapore and Thailand, finding that the most effective preventive measures consist of senior management involvement, specific training and audits. Simonds and Shafai-Sahrai (1977) obtained similar findings. In light of the above, we may formally establish the first of our hypotheses as follows:

> H_1: A more intense effort by the firm in the field of risk prevention is negatively related with the occupational accident rate.

The firm may, of course, adopt a range of approaches or standpoints in the design and implementation of its occupational safety management system. According to the reports published by international bodies such as the OSHA and the NIOSH, it is possible to identify two general types of prevention management systems, namely traditional and innovative systems. The traditional prevention system involves low levels of integration, hierarchical structures, the control of risks that are not related with behavioural factors and high levels of paperwork. Innovative systems, on the other hand, feature high levels of integration, structures that foster employees' involvement, special attention to the control of behaviour related risks, and relatively little paperwork.

We argue below that the innovative orientation in risk prevention is more effective in reducing occupational risks because reinforces the positive effects of other managerial and organizational practices.

2.2. Technology: Automation and flexible manufacturing systems.

In response to changes in the market and the need to adapt to ever shorter product lifecycles, firms acquire new technologies and implement flexible manufaturing systems. These new assets allow faster adjustment of production systems because they are more easily adapted to different production sequences, cutting costs at the same time as permitting the firm to maintain a more varied product range. However, the adoption of new production technologies can have a negative impact on accident rates, basically because they shorten process times, thereby increasing the pace and intensity of work. This raises risk and stress levels, leading to the emergence of ergonomic and psychosocial problems (Landsbergis et al, 1999; Harrison and Legendre, 2003).

Furthermore, the labour force must be trained to use complex new technologies. If effective training and prevention measures are not taken, older workers will make poorer use of the new than the old technology. In such cases, occupational risks will increase to the extent that workers fail to adapt to the new skills required and accident rates will suffer. We believe, however, that innovative prevention can be effective in processing, interpreting and transmitting information flows between the agents concerned in the different stages of the production process, and that they help to ensure the exploitation of the safety potential of automated and coordinated systems. Thus, Cohen (1977) concludes that people-oriented prevention systems are more effective than technology-oriented approaches. The findings of Shannon (1996) and Habeck et al (1991) point in the same direction.

In light of the above discussion, we may formulate the following hypotheses:

H_2: Automation and the implementation of flexible production technologies are positively related with accident rates.

H_3: The combination of flexible production technologies and innovative risk prevention is negatively associated with accident rates.

2.3. Quality management

The progressive implementation of ideas and techniques related with the total quality management concept is one of the clearest manifestations of organisational innovation in the industry in the last decades. From the standpoint of the risk prevention literature, it has been argued that the joint use of advanced quality management systems and occupational risk prevention management techniques generates synergies that help reduce accident rates

(Rahimi, 1995; Beechner and Kock, 1997). These synergies emerge because both quality and occupational risk management are based on the principle of prevention rather than corrective action. Consequently, we may expect that firms employing innovative risk prevention systems and advanced quality management simultaneously will present lower accident rates. These arguments form the basis for the following hypotheses:

H_4: Intensive use of quality management tools is negatively associated with accident rates.

H_5: The combination of advanced quality management and innovative risk prevention measures reduces accident rates.

2.4. Work Organisation and Empowerment

In general terms, the literature distinguishes between two approaches or alternative systems for the organisation of work. On the one hand, conventional work organisation following the Taylorist model based on the division of labour, with individual workers assigned to highly specialised jobs, involving the repetitive performance of just a few tasks, where some people think while others do, and where supervision is applied extensively within a strongly hierarchical structure.

In contrast to this approach, the new work organisation developed in recent years aims to supersede the traditional conception of the mass production worker. The aim is to create work systems capable of raising the involvement and motivation of workers with moderate use of supervision as a control instrument and horizontal organisational structures in which decision making power is displaced downward. These new work organisation systems generally entail the definition of richer and more varied jobs, the use of autonomous work teams, and higher levels of worker participation, all of which resulting in greater worker empowerment (Ichniowsky et al, 1996; Becker and Huselid, 1998).

Job enrichment means that the worker undertakes, controls, plans, organises and designs the task. In general terms, it is argued in the literature that greater empowerment of workers is a favourable factor in reducing the accident rate. The available empirical evidence shows that accident rates are negatively related with the delegation of authority, greater autonomy and involvement of workers and high levels of mutual commitment (Frieling et al, 1997; Kaminski, 2001; Shannon et al, 2001; Roy, 2003; Zacharatos et al, 2005).

Where workers are able to analyse and identify the risks inherent in their activity and the firm allows them to adapt job designs, the accident rate should fall. Additionally, we may expect that innovative risk prevention management combined with higher levels of empowerment will multiply the positive effects of worker responsibility and involvement on occupational safety. Therefore:

H_6: The empowerment of workers is negatively associated with the accident rate.

H_7: The combination of innovative risk prevention and worker empowerment reduces the accident rate.

3. Methodology: the negative binomial regression model

The majority of studies exploring the organisational factors related with occupational accidents and illnesses employ either case studies or liner regressions between the explanatory factors measured and the dependent variable (i.e. the accident rate). However, the application of linear regression models in the field of occupational safety presents some problems, because accidents are discrete events, which is to say they occur in positive, whole numbers, and not a continuous variable distributed asymptotically with regard to a standard.

Nelder and Wedderburn (1972) developed their *Generalized Linear Models* (hereinafter GLM) precisely to overcome these limitations. There are two main differences between classic linear models and GLM. Firstly, GLM allow room for the dependent variable to follow any exponential distribution, including the normal distribution. Secondly, they establish a more flexible relationship between the dependent and the explanatory variable through the introduction of a *link* function. In the classic linear model, the estimated mean

$\mu_i = E(y_i) = x_i\beta$ is a linear combination of the explanatory variables. GLM, on the other hand, relax this assumption, permitting different types of relationship in the form $\mu_i = h(x_i\beta_i)$, where $h(\cdot)$ is the link function (Fahmeir and Tutz, 1994).

Count data variables have traditionally been estimated using the Poisson regression, a technique that belongs to the GLM family. However, the Poisson regression has the drawback that the mean and variance of the sample must be equal (absence of overdispersion), but this is not actually the case with the vast majority of event variables (Breslow, 1984). Cameron and Trivedi (1999) explain that the overdispersion of count data is normally due to the presence of non-observable heterogeneity. The most commonly used alternative in cases of overdispersion is the negative binomial regression. In this model, the parameter that defines a Poisson process depends on a random variable. The best known negative binomial model allows the data to follow a Poisson distribution, but assumes that a degree of non-observable heterogeneity exists, which is distributed according to a Gamma function. Thus, the model in some way assumes that the real mean is not perfectly observable and the non-observable heterogeneity is therefore supposed to follow a given distribution.

One of the main problems with cross-section data samples is the possible existence of non-observable heterogeneity. In the presence of non-observable heterogeneity, differences between individuals display random variations that are not explained by the independent variables. The problem is normally associated with panel data sample in which the *(t)* observations made for every *(i)* individuals allow the inclusion of specific variables to control for the presence of non-observable heterogeneity. However, it is also possible to accommodate the presence of non-observable heterogeneity in cross-section data using mixture models. These take numerous different forms and allow the inclusion of a wide range of assumptions about the nature of the non-observable heterogeneity present in the data. Greenwood and Yule (1920) algebraically interpret the negative binomial model as a Poisson-

Gamma mixture model, in this case starting from a distribution of events that takes the form of a Poisson model:

$$f(y_i|\theta_i) = \frac{\exp(-\theta_i)\cdot\theta^{y_i}{}_i}{y_i!} \quad [1]$$

in which the parameter θ_i has a random constant term that multiplies the conditional mean, as follows:

$$\theta_i = \exp(\beta_0 + \sum\beta_1 x_i + \varepsilon_i) = e^{\beta_1 x_i} e^{\beta_0 + \varepsilon_i} = \mu_i \nu_i \quad [2]$$

where $\exp(\beta_0 + \varepsilon_i)$ is the constant random term, $\mu_i = \exp(\beta_0 + \beta_1 x_i)$ are the independent variables explaining the conditional mean of the dependent variable in the absence of non-observable heterogeneity, and $v_i = \exp(\varepsilon_i)$ is the non-observable heterogeneity term. The marginal distribution of *y* is obtained by integrating the function by the term ν_i :

$$h(y_i|\mu_i) = \int f(y_i|\mu_i, \nu_i) g(\nu_i) d\nu_i \quad [3]$$

In the specific case in which $f(\cdot)$ and $g(\cdot)$ are respectively a Poisson distribution and a Gamma distribution, the result of the integral in [3], which can bee found in Cameron and Trivedi (1999), is the Negative Binomial marginal distribution. The Negative Binomial regression, then, represents a solution to the problem of non-observable heterogeneity. Mixture models, however, also permit more flexible specifications of the form of non-observable heterogeneity. Specifically, it is possible to establish a random component for some of the independent variables and for others not. In this way, when the model is calculated, a coefficient β is obtained as well as a scale parameter that will depend on the distribution utilised to control non-observable heterogeneity. Thus, $\beta = \beta + \varphi\nu_i$, where ν_i is the term that may be distributed following any distribution from the exponential family.

The use of count data regressions is widespread in fields such as bio-statistics and medicine. In the field of accident analysis, it has been used to explore the effects of changes in road infrastructure and legislation concerning traffic accidents (Miaou and Lum 1993, Scuffham et al, 2000), amongst others. In the case of industrial accidents, Filer and Golbe (2003) use the methodology to calculate the relationship between a firms financial position and investment in occupational safety, while Lanoie and Tortier (1998) apply it to test the costs and benefits of mechanising a given production process.

In this study, the proposed models have been calculated utilising the Poisson-Gamma mixture model, which is to say the Negative Binomial regression. At the same time, we have considered a random parameter, which is associated with the constant term β_0 . In the absence of any variation in the observable explanatory variables, the number of accidents is determined by the constant term. This magnitude, then, in some way measures the basic risk inherent in the activity. In the case of panel data samples, the dichotomous variables distinguishing each individual or firm are introduced for the purpose of adding or subtracting a given amount from the constant term, which in turn measures the risk inherent in the undertaking in question. This solution is not possible in the case of cross section data, because the calculation cannot be performed with dichotomous variables and it is not possible to control for individual effects by transforming the sample into the difference. The problem persists, then, given that the diversity of the activities carried out by the firms in the sample implies that the inherent risk is not the same in each. It is therefore always possible that some non-observable heterogeneity will exist in the constant term. This heterogeneity can be controlled for by introducing a random term. In this study, we have tried three specifications for each random term of the constant (standard, triangular and uniform distribution) without encountering substantial differences between the results obtained in each case. In the results presented, we have opted for the coefficients calculated on the basis that the non-observable heterogeneity term follows a normal distribution.

4. The empirical study

4.1 Data and sample

The data concerning prevention measures and the basic organisational characteristics of the firms were obtained through a survey of 213 industrial facilities employing over 30 workers. These firms all conduct their operations in Navarre, an autonomous community in northern Spain. This helps to keep the homogeneity of the sample because safety and health conditions are largely affected by the general policies on the management of risk prevention established by the Public Administration of Navarre, which is the competent authority on matters concerning occupational health and hygiene.

The fieldwork was financed by the Navarre Institute for Occupational Health. The questionnaire used was based on personal interviews with prevention officers, human resources officers and plant managers held in May and June 2003. The sample obtained is representative for industry in Navarre. Table 1 reflects the distribution of the firms comprising the sample.

[Insert Table 1 about here]

The information obtained is novel in various respects. In the first place, it allows the identification of internal causes and factors determining the intensity and orientation of risk prevention measures implemented in different firms. Currently, the only source of information that is in some way related with the measures taken by firms to prevent industrial accidents and/or occupational illnesses are the audits performed by the competent authorities. These audits record breaches and/or non-compliance with the law. Numerous earlier studies have employed the number of breaches and/or instances of non-compliance as an indicator of the preventive effort made by a firm (see amongst others, Bartel and Thomas, 1985; Viscusi, 1986; Lanoie, 1992; Weil, 1996; Maré and Papps, 2002). They usually seek to estimate changes in prevention measures caused by past inspections of the firm. There are, however, two key limitations on estimates of prevention based on the number of contraventions and/or non-compliance with legislation. The first of these is that the quantified preventive effort is confined to the measures necessary to comply with occupational health and safety legislation. Consequently, any preventive effort made by a firm above and beyond the basic legal requirements will be ignored. This measure, then, fails to differentiate between firms that merely comply with minimum legal requirements and those that further develop or improve upon such standards. It is a confirmed fact that many firms in fact do develop and improve upon the minimum standards required by law, usually as a result of negotiations with trade unions, implementing enhanced preventive measures. Secondly, using the number of infringements of the law provides no information about the orientation or nature of the preventive measures applied by each company.

Another new feature of the database we have prepared is that it relates the internal organisational characteristics of each firm to the orientation and intensity of the preventive measures implemented and to the accident rate. On the national level, the data contained in the National Work Conditions Survey (ENCT) allows a diagnosis of work conditions, perceptions of risk and the preventive action taken by the worker. The scope of the sample and the nature of the information mean that the ENCT is one of the most complete and sophisticated surveys worldwide. However, this data refers only to the *results* of prevention.

Finally, data on the number of accidents occurring at each facility was provided by the Navarre Institute for Occupational Health.

4.2 Variables

The dependent variable in the regression model is the number of workplace accidents. We have included a series of explanatory variables related with the level of risk prevention in the firm and a number of organisational factors, which we describe below. We also control for the size of the firm by including the number of workers as a control variable (SIZE).

4.2.1 Intensity of preventive activities (PREV)

One of the innovations of this study is the construction of a variable that reflects the intensity of the firm's effort in risk prevention. Earlier studies always take some isolated component of preventive action, which is to say they do not systematize or measure prevention through a general indicator. The variable reflecting the intensity with which firms seek to prevent occupational risks is constructed on the basis of the six preventive dimensions, as follows:

i) Measures and activities designed to eliminate or minimize risks at source. In the questionnaire, we asked about four complementary practices usually designed to reduce risks at source in the most hazardous tasks (see *Q1* in Table 2). We construct the SOURCE variable as the sum of the number of practices implemented by each firm and therefore takes a value of between 0 and 4. Those firms that seek more intensively to prevent risks at source will obtain a higher score for this variable.

ii) *Training, communication and workers participation.* To measure the effort made by the firm in these areas we use the responses to questions *Q2*, *Q3* and *Q4* in Table 2, which have been coded as follows. In the first place, a score of 1 is assigned to all firms making a higher than average effort in each type of action and a score of 0 to those making less effort. We then summed the three variables resulting from this coding to obtain the INTEGRA variable, which identifies firms making an above average effort in each of the three actions on a scale of 0-3. We consider that firms with training, communication and involvement systems capable of exploiting the integration of these three measures will obtain higher scores in the INTEGRA variable.

iii) Risk control. The effort made by firms in activities intended to control risks is measured using an additive scale, which includes specific scores for four items (see questions

Q5 to *Q8* in Table 2). In the first place, a score of 1 was assigned to all firms undertaking periodic reviews with special intensity (*Q5*). A further point was allocated in the scale to those firms in which responsibility for the control system is shared between at least one prevention officer and the officer in charge of the work unit (*Q6*). This dual responsibility for reviews is a factor associated with greater intensity and effectiveness in the process. Finally, we assigned a score of 1 to all firms making an above average effort to control both psychosocial risks (*Q7*) as well as in overseeing health and safety (*Q8*). Hence, the firms with a higher overall score for the CONTROL variable make a greater effort to control a diverse range of risks.

• *Actions taken in view of foreseeable changes.* The survey seeks information about the number of members in teams charged with analysing the workplace health and safety repercussions of new facilities and assets. The OPEN measure is defined by the number of agents concerned in the working group (*Q9* in Table 2). More diverse teams (those including safety and health representatives, workers, supervisors, suppliers and managers) are characteristic of open and involving risk prevention systems.

• *Documentation.* The effort made to document prevention activities is measured via the number of accident/incident indices kept and calculated (*Q10* in Table 2). We consider that the effort made will be greater to the extent that firms keep and calculate a larger number of accident indices, resulting in a higher score for the DOCU variable.

• *Emergency prevention, preparedness and response.* Finally, we measure the effort invested by firms in preventive action aimed at reducing the occupational risk caused by foreseeable events. Firms responding that they review the functioning of proposed emergency procedures at least once per year were assigned a score of 1 (*Q11* in Table 2). The EMERGENCY index is the sum of the results for the proposed plans to deal with emergencies arising from series and imminent risks, first aid measures and/or medical assistance and evacuation drills. Firms that revise these three mechanisms with the proposed frequency are assigned higher scores in this index.

The preventive intensity index (PREVENTION) is defined as the arithmetic mean of the scores obtained by the firms in all six dimensions explained above. In terms of internal reliability, the PREVENTION index displays a Cronbach's alpha of 0.70.

[Insert Table 2 about here]

4.2.2. The orientation of the preventive action

We have defined the categorical variable INNOV to identify firms that make a more intensive preventive effort in the more innovative dimensions. For this purpose, we have created an additive index for the scores obtained in the dimensions: integration of training, information and involvement (INTEGRA variable), and (ii) the openness of teams set up to consider foreseeable changes in relation to risk prevention (OPEN). We consider that firms with a score above the 75 percentile in this index make a more intense preventive effort in the innovative dimensions. These firms were assigned a score of 1 in the INNOV variable, and the rest a score of 0.

4.2.3 Quality management

The survey asked whether or not the firm employed any set of quality management tools. Those responding in the affirmative were then asked about the intensity with which this technique is applied. The resulting scores were ranked on a scale of 1-10 from low to high implementation. These tools are defined in the first column of Table 3. Based on this information, we have constructed an indicator, identified as QUALITY, which is defined as the arithmetic mean of the responses given to the question concerning the level of application and implementation of quality management techniques. This indicator varies on a scale from 0 to 10, and it may be interpreted as a measure of the level of development of quality management in the firm concerned. The index has a high level of internal reliability, displaying a Cronbach's alpha of 0.87.

[Insert Table 3 about here]

(iii) Technology and production system

As in the preceding case, the questionnaire asked whether or not the firm used a given set of technologies traditionally associated with manufacturing processes (Ward and Duray, 2000). Those responding in the affirmative were then asked about the intensity with which the techniques were applied. The resulting scores were ranked on a scale of 1-10 from low to high implementation.

We have constructed the TECH indicator to encapsulate the level of technology used in the production process. This new variable is defined as the arithmetic mean of responses to the question concerning the level of utilisation and implementation of the technologies defined in the second column of Table 3. Then, this indicator varies on a scale of 0 to 10. In terms of internal reliability, the index displays a Cronbach's alpha of 0.85.

(v) Work organisation and workers empowerment

Firms were asked about the level (from zero to ten) at which their workers carry out each of the activities defined in column 3 of Table 3. We construct an index of worker empowerment (EMPOW) as the arithmetic mean of these responses. This indicator has a high internal reliability (Cronbach's alpha of 0.72).

5. Results of the econometric analysis

In order to estimate the relationship between our explanatory variables and the occupational safety we define the following model

$$a_j = \exp(\beta_0 + \beta_1 PREV + \beta_2 QUAL + \beta_3 EMPOW + \beta_4 TECH + \\ + \beta_5 TECH * INN + \beta_6 EMPOW * INN + \beta_7 QUAL * INN + \beta_8 SIZE + \varepsilon_j) \quad [4]$$

where a_j is the number of accidents in firm j and e_j is the error term. The result of the estimation of [4] by means of negative binomial regression is shown in Table 4.

[Insert Table 4 about here]

The negative sign and significance of the coefficient associated to the variable *PREV* (β_1) indicates that prevention activities are inversely related to firms' accident rates. This confirms hypothesis H_1. That is, prevention effort represents an effective tool for reducing the firm's accident rate, whatever its nature and orientation. Further, the sign of the coefficients associated to the organisational factors (β_2,β_3,β_4), meanwhile, confirm our hypotheses H_2, H_4 and H_6.

Hence, the negative sign of the coefficient associated to *QUALITY* (β_2) implies an inverse relationship between the implementation of quality management tools and occupational risk. The preventive foundations underlying quality management practices permit a simultaneous improvement in process quality and reduction in the accident rate. To some extent, this may be interpreted as meaning that a fall in the occupational accident rate is a further manifestation of quality gains. If the aim of achieving quality is to remove deviations in the production process, it is clear that the occurrence of an accident is an unforeseen and undesirable situation. Meanwhile, the implementation of quality control mechanisms reduces failures in the system, including workplace accidents.

Similar conclusions can be derived from the sign of β_3, which confirms that the enhancement of workers empowerment unambiguously contribute to reducing occupational accident rates. That is, the design of richer and more autonomous jobs requiring higher level of workers responsibilities are associated with lower number of accidents.

By contrast, the positive sign and significance of β_4 confirms that firms with more flexible and automated production technologies are affected by higher accident rates. This result suggests that the pace and speed of adjustment of such production systems worsen risk conditions, making it necessary to design effective prevention mechanisms to cushion the negative impact of new technologies on occupational risk.

The existence of complementarities between the innovative orientation of preventive action and the organisational variables is captured by the coefficients associated to the interactive terms. As Table 4 shows, the negative sign of the coefficient β_5 indicates that innovative prevention generates downward movement in the accident rate when it is combined with advanced manufacturing technology. This confirms hypothesis H_3. That is, firms can improve occupational safety by accompanying the automation and the adoption of flexible manufacturing technologies with the implementation of suitable preventive activities, namely openness of prevention system and the integration of occupational risk prevention with production activities.

The sign and significance of coefficient β_6 confirms the existence of a synergy effect between innovative risk prevention and higher worker empowerment, as established in our hypothesis H_7. This results show that a firm deciding to organise work by expanding the variety of tasks and increasing workers' responsibility for them will find that opening up its prevention system provides an effective mechanism to reduce the accident rate. The innovative prevention dimensions (openness and integration of preventive actions) provide the vehicle for obtaining additional gains in the reduction of occupational risks. By contrast, coefficient β_6 does not reveal the existence of any significant effect resulting from the combination of advanced quality management and the innovative preventive effort. We cannot then accept hypothesis H_5.

Finally, the significance of the overdispersion parameter in the proposed model confirms the inequality of the mean and the sample variance, which justifies the choice of the negative binomial regression. Further, the significance of the φ coefficient confirms the need to control for non-observable heterogeneity associated with the constant term.

6. Conclusions

In this paper we have analysed the relationship between organisational factors and preventive measures with the number of occupational injuries. We have calculated a negative binomial regression based on a sample of 213 industrial firms in Spain, defining a constant random parameter to take account of non-observable heterogeneity.

In the first place, our results confirm that the intensity of occupational risk prevention is crucial to reducing the number of accidents. Secondly, we have identified two organisational factors that contribute clearly to lowering the level of occupational risk. These are the implementation of quality management tools, and work organisation models featuring worker empowerment. Thirdly, we have observed that in the absence of innovative preventive practices, firms with more flexible and automated production technologies are affected by higher accident rates.

Finally, we have identified a clear synergy between innovative prevention practices and workers empowerment as well as with flexible manufacturing systems. In both cases, workers concentrate the benefits of training, information and involvement in the development of tasks requiring a higher level of responsibility. Our results suggest that a synergy is obtained by implicating the more skilled labour force in the occupational safety and health management system.

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Table 1. Distribution of the population and sample by industry and number of employees

NACE	Activity	Number of firms			Number of employees	
		Sample	Population	*%*	Sample	Population
15	Food and beverages	36	86	*41.8*	3 116	6 630
17,18,19	Textiles, clothing, leather and footwear	14	22	*63.6*	1 080	1 400
20,21,22	Wood, cork, paper and publishing	15	26	*57.7*	1 463	2 776
24,25	Chemicals, plastics and rubber	32	46	*69.6*	3 067	4 101
26	Other non-metal mineral products	10	24	*41.6*	786	1 853
27,28	Metalworking and metal products	41	74	*55.4*	5 993	9 249
29	Capital goods and mechanical equipment	27	44	*61.3*	3 089	6 068
31,32	Electrical machinery and materiel	3	5	*60.0*	792	1 320
34	Automotive, trailers and semi-trailers	28	45	*62.2*	8 857	11 654
36,37	Sundry manufacturing	9	16	*64.2*	810	1 147
	Total	**214**	**386**	***55.4***	**29 059**	**46 273**

Table 2. The assessment of preventive action.

Q1. In the performance of the more hazardous tasks:	
Control and supervision is intensified	1
A specific task process is designed	2
Specialists are trained/contracted	3
More intensive signage is used	4
There are no especially hazardous tasks	5
Don't know	9
Q2. At what moment or in what situations does a worker receive information about prevention? (Note: more than one answer may be chosen)	
Upon joining the firm	1
In his/her work plan (daily or weekly)	2
In each production cycle or period (monthly or quarterly)	3
Upon changing job or task	4
When the technology or organisation of tasks changes	5
Don't know	9
Q3. What communication channels do employees use to contribute to the evaluation and prevention of occupational risks? (NOTE: Please, answer 0-10 depending on how much the channel is used)	
Specific groups set up to analyse issues	
Suggestions systems incentivizing comments and recommendations	
Formal prevention questionnaires and studies	
Informal channels via immediate supervisors	
Q4. Which group of employees receives specific occupational risk prevention training from the firm? Please, use a scale of 0-10 with 0 indicating no training and 10 the maximum possible level.	
Workers performing the most hazardous tasks	
Officers in charge of units (managers or supervisors)	
Employees of subcontracting firms	
Self-employed workers	
Workers contracted directly by the firm	
Q5. What are the objectives of periodic occupational safety reviews? (NOTE: Please, answer from 0-10 depending on the level of priority. 0 indicates minimum and 10 maximum priority)	
Correct, safe performance of tasks	
Ensure technology remains in good condition	
Working conditions (tidiness and cleanliness of the workplace)	
Worker preparation (health, training, skills, etc.)	
Q6. Who is the officer or team responsible for periodic occupational health and safety reviews	
A specialist risk prevention officer or team	1
The quality officer or team	2
The maintenance officer or team	3
The work unit supervisor or manager	4
Don't know	9

Table 2 (continued)

Q7. Please, score the effort made by your firm to deal with the following from 0-10:	
Repetitive movements	
Bad posture	
Handling of heavy loads	
Long periods of immobility	
Mental fatigue in tasks requiring intense concentration	
Boredom and/or routine	
Adaptation of rigid shifts to the personal needs of employees	
Q8. Please, indicate the specific risks to workers' health and safety checked in medical examinations arranged by the firm	
Ergonomics	1
Noise	2
Exposure to hazardous chemicals	3
Screens	4
Manual load handling	5
Psychosocial	6
Other	7
Don't know	9
Q9. Who is the officer or team responsible for analysing the repercussions of new installations and equipment for occupational health and safety: (NOTE: Please, indicate ALL participants)	
The supplier	1
The prevention department	2
The officer in charge of the unit making the investment	3
The work unit supervisor or manager	4
The workers concerned	5
Don't know	9
Q10. What accident indices are kept and calculated?	
Incident index (total accidents/average number of people at risk)	1
Frequency index (working days lost/total man-hours worked)	2
Severity index (working days lost/total man-hours worked)	3
Average duration (working days lost / number of accidents)	4
None	5
Don't know	9

Q11. How often is the functioning of the following emergency procedures reviewed:	Never	Occasion-ally	Once per year	Twice per year	More than twice per year	Don't know
Emergency plans for serious, immanent risks (breakage, spillage, electrical problems,…)	1	2	3	4	5	9
First aid measures / medical care	1	2	3	4	5	9
Evacuation drills (fire, serious contamination, flooding…)	1	2	3	4	5	9

Table 3. Identification of organisational factors

1. QUALITY MANAGEMENT		2. PRODUCTION TECHNOLOGY AND ORGANISATION		3. WORK ORGANISATION
Could you tell me which of the following quality management techniques are currently in place at this facility? Please, use a scale of 0 to 10 with 0 indicating no implementation and 10 maximum implementation. Please, indicate if any of the techniques mentioned are not applicable at the plant.		What is the level of implementation of the following technologies in this facility? Please, use a scale of 0 to 10 with 0 indicating no implementation and 10 maximum implementation. Please, indicate if any of the techniques mentioned are not applicable at the plant.		To what extent do direct (not all) workers at your plant perform the following tasks in the course of their normal work? Please, use a scale from 0 to 10 (where 0 means that they never perform the task and 10 that they do so frequently).
Basic statistical techniques (*"histograms"*, *"Pareto"*, *"cause-effect diagrams"*, etc.)		Robots or programmable automata		Preparation of the machinery used
Experiment design (*"Taguchi"*, *"ANOVA"*)		Automated systems for the storage of materials (AS/RSs)		Maintenance of equipment
Failure Mode and Effects Analysis (FMEA)		Computer assisted design (CAD) and/or computer assisted engineering (CAE)		Analysis of work data
Error prevention systems (*"poka-yoke"*)		Computer integrated manufacturing (CIM)		Autonomous planning and organisation of work
Engineering and value analysis		MRP		Collaboration in training new workers
5S Methodology		JIT at plant (*kanban*)		Collaboration in the introduction of new technology
Control of quality costs		LAN computer for use at the plant		Participation in job design
QFD (*Quality Function Deployment*)				
Business process management (BPM)				
Statistical process control (SPC)				

Table 4. Estimates of Negative Binomial Regression.

Variable	Coefficient[1]
Constante (β_0)	-1.553** (.172)
$\varphi(k(n))$	.229** (.032)
PREV (β_1)	-1.137* (.518)
QUAL (β_2)	-.190** (.035)
EMPOW (β_3)	-.060* (.034)
TECH (β_4)	.148** (.039)
TECH*INN (β_5)	-.150* (.074)
EMPOW*INN (β_6)	-.162* (.062)
QUAL*INN (β_7)	.103 (.066)
SIZE (β_8)	.834** (.038)
Overdispersion parameter	2.843** (.231)
Log Likelihood	-653.23
Chi Squared	651.16

[1]Standard errors are in parenthesis.
**Significant at the 1% level; * Significant at the 5% level

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