Journal of Agricultural and Resource Economics 47(1):57–76 ISSN: 1068-5502 (Print); 2327-8285 (Online)

doi: 10.22004/ag.econ.307454

Occupational Injury and Workdays Lost in Northern Ireland's Farming Sector

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This paper employs a dataset of 7,500 Northern Irish farms over the period 2015–2019 to investigate the factors that affect the number of workdays lost in agriculture, one of the most hazardous sectors in terms of occupational injuries. Results indicate that public policies aimed at improving farm safety should focus on dairy farms, young workers, family members other than the main farmer, and dangerous working practices related to machineries and vehicles. Additionally, results indicate that more than 18,000 workdays are lost every year on Northern Irish farms.

Key words: days of work lost, family farm, farm safety, interval regression, minor injuries, near misses, sample selection, social norm

Introduction

Globally, more than 317 million work-related accidents are reported each year; this equates to an estimated annual GDP loss of 4% (Pouliakas and Theodossiou, 2013). Such accidents not only have direct costs for the individuals involved but also for society. The costs associated with work-related accidents include the loss of present and future earnings, treatment and medical fees alongside the longer-term consequences of nonfatal injuries in relation to physical and mental impacts which can ultimately contribute to a reduced life expectancy (Andreoni, 2012).

Across developed, transitional, and developing economies, the agricultural sector makes up approximately half of the world's labor force (Caffaro et al., 2018). It is also one of the most hazardous occupational sectors in which to work, contributing to 170,000 of fatalities each year (International Lanour Organization, 2020). Compared to other sectors, agriculture also exhibits a higher rate of nonfatal injuries, resulting in more workdays per accident being lost (International Lanour Organization, 2020). In the Republic of Ireland (ROI), for example, recent figures indicate that 10 workdays per accident are lost in the dairy and cattle sector (Sheehan and Deasy, 2018).

Across Europe, public authorities have allocated financial and nonfinancial resources aimed at improving safety levels on farms. EU Directive 89/39/EEC requires mandatory risk assessments in the workplace and guarantees minimum requirements for health and safety in all the member states. Similarly, the United Kingdom has adopted several policies aimed at improving farm safety employing both mandatory and voluntary risk assessments, providing guidance on construction requirements, and setting in place regulatory requirements around handling hazardous materials, livestock, and machinery.

This paper focuses on examining the safety of the farming sector in Northern Ireland (NI), a region of the United Kingdom. Compared to the agricultural sector in the rest of the United

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This research was supported by the Department of Agriculture and Rural Affairs of Northern Ireland, grant number E-I 18-01-19.

Review coordinated by Darren Hudson.

Kingdom, agriculture in Northern Ireland makes a higher contribution to GDP and employs more of the labor force (DAERA, 2019). There are just under 25,000 farms in Northern Ireland, and a majority of these are small, family-operated businesses, predominantly livestock based (mainly dairy, beef, and sheep enterprises) and employing, on average, no more than one unit of labor. Dairy farms make an important contribution to the regional economy, contributing just over 30% of the gross output of the NI agriculture sector and some 15% of overall UK dairy output (DAERA, 2020). Returns to agricultural enterprises in Northern Ireland are often low and volatile and as businesses they tend to rely on using extended family labor at busy times. Northern Ireland agriculture has accounted for the majority of workplace injuries and fatalities in each of the past 5 years (HSENI, 2017). Farming is characterized by long working hours, often undertaken alone, which can contribute to an increased risk of accidents and injuries occurring. Further, due to the nature of family businesses, the farm is both a workplace and the location of the family home. For this reason, children who grow up on farms can be exposed to a higher level of risks from an early age compared to those from non-farming households (Lehtola et al., 2008; Nilsson, 2016).

In the last decade, the devolved administration in Northern Ireland has been actively engaged in initiatives aimed at developing public engagement around improving safety on farms. These have included ongoing advertising campaigns through both traditional and digital media such as "Stop and Think Safe" and "Making It Safer." They have also created what are known as "Safety Ambassadors" to promote farm safety in annual talks and weekly events (HSENI, 2017). Further, online self-assessments around farm safety called Farm Safety Action Plans (FSAP) were made mandatory for all farmers planning to participate in government-funded schemes. To improve awareness around keeping children and young people safe on farms, DAERA and HSENI distributed more than 82,000 farm safety packs over 2017–2020 and continued to promote the Child Farm Safety Education in 250 primary schools reaching more 24,000 pupils. These initiatives were aimed at trying to effect behavioral change around farm safety attitudes and practices in order to reduce farm related accidents and injuries. Central to creating such behavioral changes is the need for farmers to cooperate and understand the need to change their attitudes, behaviors, and approaches to safe working practices on the farm. From this perspective, this paper aims to identify the main causes of accidents on NI farms and their severity and impact in terms of workdays lost.

We employed data from Farm Safety Partnership Survey (FSPS) for the years 2015 and 2019, covering approximately 7,500 farms in total. Our approach jointly estimates a system of two equations. The first equation represents accident occurrence and was employed to correct for sample selection in the number of days off work. In the second equation, we controlled for the censored nature of the outcome and accommodated the number of days lost being reported by interval (interval regression). Although there is a substantial body of literature and research on work-related accidents in agriculture (Nordlöf et al., 2015; Caffaro et al., 2018; Shortall, McKee, and Sutherland, 2019), to our knowledge this is one of the first studies to investigate the number of days off work in the sector (Dillon, Friedman, and Serneels, 2021). The estimation of the effect of different attributes on the number of workdays lost due to injury provides a mean of quantifying, in monetary terms, the economic cost of work-related accidents and can therefore provide policy makers with an evidence base with which to inform initiatives aimed to improve farm safety.

The results indicate that falls, slips, and trips have the most detrimental impact, with those involved often experiencing traumas characterized by multiple injuries and fractures that require hospital treatment, especially if young, employed on dairy farms, or members of the farmer's family. At an aggregate level, more than 18,000 workdays were lost to nonfatal accidents in NI agriculture per year. Evaluated as missed labor earnings, this corresponds to a loss of USD1.6 million per year.

Background

Globally, agricultural production is very heterogeneous in nature due to variations in climatic conditions, soil typologies, farm size and structure, and the scale of production (Stevenson et al., 2019). Despite this variation, as an industry across countries, similar and consistent patterns emerge in relation to the level and nature of work-related injuries within the sector. Previous studies have identified that agricultural work practices around machineries and vehicles (Reynolds and Groves, 2000; Caffaro et al., 2018), animal handling (Lindsay, 2004; Lindahl et al., 2016), and the use of substances such as pesticides and slurry (Alavanja et al., 2001) are the most hazardous in terms of accidents and injuries. The most frequently occurring accidents relating to machineries and vehicles use include tractors, harvesters, quads, and small hand tools. Using machinery on an incline has been shown to be a significant risk in situations in which the equipment can roll over. Linked to machinery are also those accidents occurring around the unsafe use of power take-off (PTO) shafts (McNamara et al., 2019). Regarding animal handling, a significant number of agricultural injuries are due to an animal's unexpected behavior and on occasions when they are under increased levels of stress (e.g., being moved into a confined area or during practices such as hoof trimming) (Douphrate et al., 2013). Slurry and other toxic substances have also been shown to cause fatalities and potentially life-changing injuries (e.g., industrial asthma due to the inhalation of toxic fumes and dermatitis due to physical contact) (Alavanja et al., 2001).

The relationship between workload and time availability to undertake tasks contributes to a worker's level of physical and mental stress, which has been shown to affect worker performance, increase error rates, and lead to detrimental consequences in terms of accident occurrences and their severity. In many developed countries, structural change in farming has increased working time pressures, following the trend that since the mid-1990s has seen average farm size grow and the number of active farmers fall (Kallioniemi et al., 2009). The nature of the farming enterprise adds to working time pressures. Dairy farmers, for example, tend to farm on a relatively large scale in terms of areas farmed and size of the dairy herd, and this scale requires undertaking a range of often time-pressurized tasks that must be repeated daily (Douphrate et al., 2013). Other researchers have shown that work-related pressures can be seasonal, where the end of summer and months around harvest time require farmers to undertake long workdays to complete key tasks, which increases accident and injury rates (Kogler, Quendler, and Boxberger, 2016). In addition, many farm household members, including farmers themselves (particularly those where the returns to farming are more marginal) engage in off-farm employment to supplement their household income. In many of these cases, the main farm work becomes concentrated into those periods of time outside of their employment hours, often in the evenings and on weekends. All of these situations can result in increased workloads with higher levels of fatigue, exhaustion, and stress being observed; it has been shown that these factors increase the chances of being involved in a work-related accident (Lyman et al., 1999; Kallioniemi et al., 2009).

Moreover, the global markets in which agriculture now operates mean increased competition and a higher degree of volatility in the returns to agricultural production, resulting in lower profit margins. This can increase farmers' financial concerns and levels of mental stress, increasing the risk of being involved in a work-related accident (Health and Safety Executive, 2019).

Farmers who have previously been involved in a farming-related accident, whether major or minor, or who had recorded a near miss (i.e., cases in which a major accident was narrowly avoided) have been shown to be statistically at higher risk for further injuries (Browning et al., 1998; Nordlöf et al., 2015; Caffaro et al., 2018). This is influenced by risk tolerance at both the farm and individual level. At the farm level, risk tolerance represents a series of non-written social norms that are adopted and reiterated within the workplace setting (Nordlöf et al., 2015). At the individual level, the repetition of a dangerous behavior over time causes reinforcement of the behavior, at which point it becomes routine (Gilovich, Griffin, and Kahneman, 2002). This influences farmers to assess hazardous situations not on the basis of the real danger but according to their biased judgment. Overall, this creates an environment in which social norms and risk behaviors are perpetuated and reinforced. This makes agriculture and family farm businesses potentially more dangerous than other sectors of the economy, where the presence of regulations, unions, and weaker social relationships can mitigate the feedback between social norms and risky behaviors (Nordlöf et al., 2015).

Occupational injuries sustained in agriculture tend to be more serious than those acquired in other sectors and require more days to recover and convalesce (Alwall Svennefelt, Hunter, and Palsdottir, 2019). The specific types of trauma injury experienced by farmers fall into three main areas: fractures, lacerations, and contusions (Lindsay, 2004; Douphrate et al., 2013). Upper and lower limbs—including hands, feet, arms, and legs—are the most common body parts affected. As expected, traumas involving factures require more days to recover than other types of injuries (Jadhav et al., 2016).

The average number of workdays missed due to being involved in a farming accident varies depending on the country of study, ranging from 8.4 days in Australia (Athanasiov, Gupta, and Fragar, 2006) to 12.4 days in the United States (McCurdy and Carroll, 2000). As in other industries with high accident rates—such as construction and transportation—in agriculture, the median number of workdays lost appears to be lower than the *average* number of workdays lost (Health and Safety Executive, 2019), with some studies highlighting that the self-employed nature of farming and the necessity for tasks to get done and deadlines to be met can prevent farmers from taking the necessary days off work to allow for proper recovery (Shortall, McKee, and Sutherland, 2019).

The age of someone working in agriculture had been shown to play a crucial role in relation to the number of workdays lost due to an accident. Among younger farmers, lack of experience and lower risk aversion can expose them more frequently to accidents generally and more serious accidents specifically relative to older farmers (Westaby and Lee, 2003). However, other studies have contradicted this finding by highlighting the fact that younger farmers—who tend to be more physically fit—will recover more quickly from accidents and the injuries sustained compared to older farmers (Pickett et al., 1995; Browning et al., 1998).

Across developed countries, similarities in the types of accident experienced by farmers and their repeated occurrence over time indicate that preventative policies to date have been fairly limited in their effectiveness at reducing accident occurrence (Pouliakas and Theodossiou, 2013). On this basis, limiting the risks of both adult agricultural workers and farm family members being exposed to and affected by farm-related accidents is an important area for the industry to address and give attention to and has been the focus of research across many countries (Athanasiov, Gupta, and Fragar, 2006; Jadhav et al., 2016). However, there is a gap in the research knowledge around understanding the factors that contribute to accident occurrence and the impact in relation to workdays lost, particularly at the farm level. Drawing on a robust secondary dataset and undertaking econometric analysis, this study adds to the literature by identifying the factors that contribute to the likelihood of accidents with a view to ascertaining where policy instruments can be best directed in order to reduce the impact of occupational injuries within agriculture.

Empirical Methodology

As previously indicated, we aim to model the number of days a person is unable to work as a result of an on-farm accident. For a series of practical reasons, we consider the number of days as a continuous outcome instead of a discrete variable, as may be reported in many surveys. First, except from when the accident occurred at the very beginning or end of the workday, a fraction of a day will be lost the day of the accident. Second, it is possible that a person returns to work gradually after an accident (e.g., on a part-time basis for the first week or so); therefore, a person may round to the closest integer their estimate of full-time-equivalent days lost.

For worker i, we define the *desired* number of days off work as d_i^*. The number of missed days of work is the result of objective causes (e.g., physical trauma, inability to work) and subjective causes since a person may be interested in anticipating or delaying their return to work (e.g., because of financial need, physiological distress). We assume that d_i^* is a linear function of a series of individual, accident, and farm characteristics, $\boldsymbol{x}_i$, and an error term with variance σ^2:

$$d_i^* = \boldsymbol{x}_i'\boldsymbol{\beta} + \sigma \times u_i. \tag{1}$$

We do not observe directly d_i^*. Instead, we observe the number of days reported in the survey, d_i, as a nonnegative variable. In many surveys, the number of days of work lost is reported in intervals or some combination of intervals and day points. In the dataset employed in this study, observations were reported in four groups: 0 days, 1–30 days, 31–60 days, and 61 or more days. Standard techniques of interval regression can be employed once the relationship between d_i^* and d_i is mapped out. Consequently, we employ the following rule:

$$\begin{array}{ll} d_i = 0 & \text{if } d_i^* \in (-\infty; 0.5) \\ d_i \in [\,1\,;\,30] & \text{if } d_i^* \in [0.5; 30.5) \\ d_i \in [31\,;\,60] & \text{if } d_i^* \in [30.5; 60.5) \\ d_i \geq 61 & \text{if } d_i^* \in [60.5; \infty) \end{array} \tag{2}$$

Rule (2) assumes that the desired number of days is equivalent to the reported values ± 0.5. In other words, rule (2) defines a regression that is left censored at 0.5, right censored at 60.5, and with two intervals between 0.5 and 60.5.

So far, we have focused on observations that reported at least an accident. Although related to a specific farm, these observations identify a specific person injured on the farm. In general, it is reasonable to consider that unobserved factors related to the severity of an accident are linked to unobserved factors suitable to generate the accident (e.g., lack of attention, psychomotor coordination). Besides, farm characteristics can influence attitudes to risk at the farm level. As in other developed countries, the agricultural sector of Northern Ireland is characterized by family-run farms, often operating with low profit margins (DAERA, 2020). At times of financial constraint, farm managers may curtail the number of workdays lost when accidents occur in order to minimize the impact on labor costs. Further, when operating within restricted financial margins, evidence suggests that expenditures on maintaining health and safety standards and practices within the workplace are reduced, increasing the likelihood of accident occurrences (Pouliakas and Theodossiou, 2013). In other words, we should anticipate that the accident occurrence and the number of workdays lost are correlated and that when this link is omitted from the estimation, results will be biased and inconsistent. Consequently, we define the following selection equation:

$$a_i = 1[\boldsymbol{w}_i'\boldsymbol{\delta} + v_i > 0], \tag{3}$$

where a_i takes value of 1 if at least an accident occurred in the past 12 months and 0 otherwise, $\boldsymbol{w}_i$ is a vector of farm and individual characteristics, and $\boldsymbol{\delta}$ is the relative parameter vector. The combination of equation (1) with rule (2) and equation (3) is an example of Heckman selection correction model for interval regression and was jointly estimated in one step via maximum likelihood by assuming that u_i and v_i follow a bivariate standard normal distribution with correlation ρ, as shown in the appendix. With respect to a two-step estimator, a one-step estimator is computationally more intensive but improves the efficiency of the estimates. In many settings, the selection equation is associated with a utility maximization problem. Given that accident occurrence is associated with a disutility, we should expect ρ to be negative.

Regarding the partial effects on the expected number of workdays lost, we need to consider the selection mechanism and the fact that the number of days is nonnegative. Consequently, the following expressions were employed:

$$E\left[Days_i | Accidents = Yes\right] = \mu_i = \boldsymbol{x}_i'\hat{\boldsymbol{\beta}} + \sigma \times \rho \times \phi\left(\boldsymbol{w}_i'\hat{\boldsymbol{\delta}}\right) / \Phi\left(\boldsymbol{w}_i'\hat{\boldsymbol{\delta}}\right); \tag{4a}$$

$$E\left[Days_i\,| Accidents = Yes \text{and} Days \rangle\, 0\right] = \Phi\left(\frac{\mu_i}{\sigma}\right) \times \left(\mu_i + \sigma \times \phi\left(\frac{\mu_i}{\sigma}\right) / \Phi\left(\frac{\mu_i}{\sigma}\right)\right). \tag{4b}$$

Expression (4a) is the expectation with sample selection, while expression (4b) controls for nonnegative days and was employed to calculate the partial effects. These equations were used to calculate the partial effects on the number of workdays lost, while the model parameters were estimated in one step via maximum likelihood, as shown in the appendix.

Data and Descriptive Statistics

Data Source and Variable Definitions

In this study, we employed data from FSPS for the years 2015 and 2019. Data were collected through a postal questionnaire administrated by the DAERA. The FSPS survey is conducted every 4 years and includes 3,750 farms that are nationally representative of the agricultural sector in Northern Ireland. A two-stratum random sampling technique was employed to select farms. The sampling mechanism was based on farm size and farm type. A pilot postal exercise was carried out using a sample of 1,000 farm businesses in 2014. The structure of the data is almost cross-sectional, with 24% of all the farms present in each year of data and fewer than 0.007% of them reporting at least one accident in each year of data. The FSPS combines detailed information on the characteristics of the accident, type of injury, and cause of the accident with demographic variables on the injured person such as age and family status (farmer, family member, and nonfamily member). Since age was provided in seven intervals, we used the middle year of each interval to define a continuous variable.

In the survey, accident occurrence is defined as one or more *nonfatal* accidents in the past 12 months requiring medical attention. Similarly, the number of workdays in the past 12 months a person was unable to work because of the accident was used as the variable of main interest in this study. The survey also includes questions on dangerous work practices, barriers to improving farm safety, and the occurrence of minor injuries and near misses. Minor injuries are defined as accidents not requiring specialist medical attention (attending hospital or a general practitioner's surgery), while near misses indicate that a major accident was narrowly avoided. To catch the degree of tolerance to accidents, we employed binary indicators for each of these variables to detect whether at least one minor injury/near miss occurred in the past 12 months.

The FSPS data were augmented with additional data provided by DAERA, such as farm size,[1] farm type, land type, part-time/full time farmer, and number of cows per worker.

In most instances, the categorical variables employed in this study were used without any aggregation. However, when the number of categories were large, the residual category 'Other' was employed to combine options with limited frequency. For instance, the categorical variable Main Cause of Accident includes 13 options, but only the first five categories represent 75% of cases were used as they are provided while the other options were combined in the residual category "other cause." Appendix Table A1 reports the variable definitions.

Descriptive Statistics of Nonfatal Accidents in Northern Ireland Agriculture

Table 1 shows that 4.7% of farms in Northern Ireland experienced one or more accidents that required medical attention (major accidents). The rate is higher in Northern Ireland than in the rest of the United Kingdom, where the occurrence was 4.1% in 2019 (Health and Safety Executive, 2019). In contrast, the rate in ROI was 5.1% in 2015 (Health and Safety Authority, 2015). Over time, the accident rate in Northern Ireland varied, from 5% in 2015 to 4.4% in 2019.

With respect to the causes of trauma, Table 1 indicates that "hit or trampled by an animal" represents the main source of accidents (27%), followed by "slip or trip at ground level" (18%), and "falls from height" (9%). Animal-related traumas are usually associated with limb fracture (e.g., tibia, fibula, and hip) (Sheehan and Deasy, 2018), but the most common types of injury were lacerations (37%), fractures (26%), and bruising (18%).

Regarding objective factors contributing to the cause of accidents, dangerous work practices related to "machineries and vehicles" make up 59% of reported cases, "lack of protection" 51%, "animals" 41%, and "slurry gases" 36%. "Financial cost" represents the most common barrier to

[1] In the United Kingdom, farm size measured by Standard Labour Requirement (SLR) is defined as the amount of labor calculated by applying labor coefficients to farm enterprises.

Table 1. Descriptive Statistics

Category	Variable	Mean	Std. Dev.	Min.	Max.
Accidents	Dependent variable	0.05	0.21	0	1
Type of farm	Cattle	0.22	0.41	0	1
	Dairy	0.14	0.35	0	1
	Sheep	0.51	0.50	0	1
	Other	0.13	0.34	0	1
Type of land	Severely disadvantaged land (SDA)	0.36	0.48	0	1
	Disadvantaged land (DA)	0.29	0.45	0	1
	Lowland	0.36	0.48	0	1
Other farm characteristics	Farm size (SLR)	1.18	1.37	0.50	7
	Cow–worker ratio	0.69	1.08	0	15.78
	Part-time farmer	0.39	0.49	0	1
Characteristics of injured person	Age	53.20	15.19	22	75
	Farmer	0.76	0.43	0	1
	Family member	0.16	0.37	0	1
	Nonfamily member	0.08	0.27	0	1
Accident characteristics	Hospital treatment	0.19	0.39	0	1
	Number of multiple injuries	1.19	0.47	1	4
Main injury	Laceration	0.37	0.48	0	1
	Fracture	0.26	0.44	0	1
	Bruising	0.18	0.38	0	1
	Other type of injury	0.20	0.40	0	1
Primary cause of accident	Slip or trip at ground level	0.18	0.39	0	1
	Falls from height	0.09	0.28	0	1
	Hit or trampled by an animal	0.27	0.44	0	1
	Contact with machinery	0.10	0.30	0	1
	Injured using a hand tool	0.11	0.31	0	1
	Other cause	0.26	0.44	0	1
Used to accidents	Minor injuries	0.10	0.30	0	1
	Near misses	0.10	0.30	0	1
Barriers to improve farm safety	Pressure from on-farm activity	0.55	0.50	0	1
	Pressure from off-farm activity	0.27	0.44	0	1
	Financial cost	0.71	0.46	0	1
Dangerous work practices	Machineries and vehicles	0.59	0.49	0	1
	Animals	0.41	0.49	0	1
	Lack of protections	0.51	0.50	0	1
	Slurry gases	0.36	0.48	0	1
No. of obs.	Selection equation: accidents	7,471			
	Intensity equation: days	352			

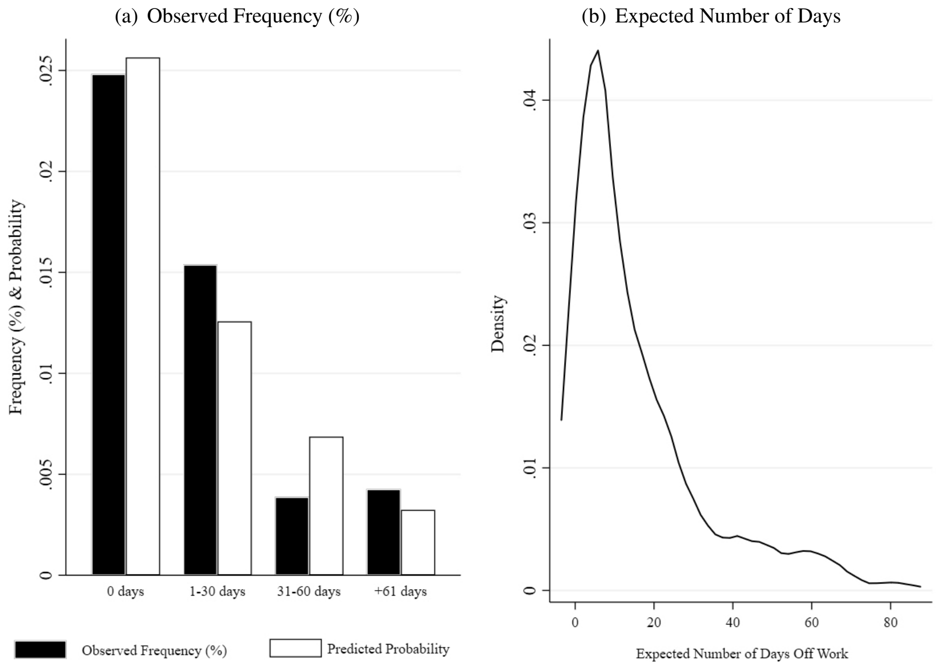

Figure 1. Observed Frequency, Estimated Probability, and Expected Number of Days of Work Lost because of an Accident

Notes: Panel A: Observed frequency (%) = ratio between the number of observations in a group of missed days of work and the number of observations in the sample (with and without accidents). Predicted probability = unconditional probability (with and without accidents) that an observation is in a group of days of work lost.
Panel B: Expected number of days calculated from equation (4b).

improve farm safety (71%), followed by "pressure from on-farm activity" (55%). Farmers are by far more involved in accidents (76%) than their family members (16%) and nonfamily members (8%). The injured person is most commonly in their fifties (29%), forties (24%), and early sixties (23%).

Panel A of Figure 1 presents the observed frequency of missed days of work as reported in the survey (black bars). More than half of the accidents reported 0 missed days in the past 12 months (51%), approximately one-third reported 1–30 days (31%), and the remaining workers experienced a more substantial number of days off work: 31–60 days (8%) and +61 days (9%). For comparative analysis, it can be useful to consider other countries. For instance, in 2018 ROI recorded 10 workdays lost per accident in the dairy and cattle sector (Sheehan and Deasy, 2018). In Great Britain and across all industries, work-related accidents resulted in an average of 15.1 days off work in 2018 (Health and Safety Executive, 2019). Table 1 summarizes the descriptive statistics and indicates that the sample size is 7,471 observations/farms, of which 351 experienced work-related accidents.

Results and Discussion

Accident Occurrence

Appendix Table A2 reports the estimates of the interval regression with sample selection. This section discusses the partial effects on the selection equation that represents the accident occurrence. Table 2 reports the changes on the probability (multiplied by 100). Overall, the best predictors of accident occurrences are minor injuries and near misses. Specifically, working on a farm where minor injuries have occurred increases the probability of being involved in an accident that required medical attention by 0.09. This effect is particularly large in magnitude since the increase in

Table 2. Average Partial Effects (APEs) on the Probability of Accident Occurrence (hundreds)

Category	Variable	APE	Std. Err.
Type of farm (base: cattle)	Dairy	3.02**	1.51
	Sheep	0.34	1.18
	Other	0.25	1.43
Type of land (base: severely disadvantaged land)	Disadvantaged land	0.21	0.98
	Lowland	1.65*	0.96
Other farm characteristics	Farm size	0.35	0.33
	Cow–worker ratio	−0.35	0.56
	Part-time farmer	−1.40*	0.83
Dangerous work practices	Machineries and vehicles	2.66***	0.83
	Animals	0.86	0.85
	Lack for protections	2.25***	0.83
	Slurry gases	1.46*	0.85
Used to accidents	Minor injuries	9.06***	1.42
	Near misses	3.60***	1.34
Barriers to improve farm safety	Pressure from on-farm activity	2.30***	0.83
	Pressure from off-farm activity	−1.63*	0.95
	Financial cost	0.26	0.90

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level. Observed frequency and predicted probability of one or more accidents that required medical attention in the last 12 months equal to 4.7%. Standard errors calculated using the delta method.

probability is almost twice the observed probability that an accident occurred (0.047). Near misses show a similar effect but with a smaller magnitude (0.036). These results confirm previous studies on the strong link between risk-taking and social norms for occupational accidents in agriculture (Nordlöf et al., 2015; Caffaro et al., 2018).

Regarding subjective factors that impact on farm safety, “pressure from on-farm activity” increases the probability of accident occurrence by 0.023. In contrast, “pressure from off-farm activity” is statistically significant at the 10% level but has a negative sign, meaning that workers on farms where there is a higher pressure from nonfarm activity are less likely to be involved in an accident (−0.016). We interpret this result to be a consequence of the fact that workers spend less time on the farm and are therefore less exposed to accident risks. The sign of the partial effect of being a part-time farmer (−0.014) in Table 2 confirms this interpretation. No significant effect has been detected for financial cost as the main barrier to improving farm safety, even though it is the most reported problem (Table 1).

Regarding objective risk factors, dangerous work practices (DWPs) relating to “machineries and vehicles” increased accident occurrence by 0.027. Similarly, DWPs due to “lack of protections” and “slurry gases” increased the probability of accidents by 0.0225 and 0.0146, respectively. Our results did not find any statistical significance of DWPs in relation to “animal handling.”

In terms of farm characteristics, two elements are worth highlighting. First, those working on dairy farms exhibit a higher probability of being involved in an accident relative to those working on other types of farm enterprises. For someone working on a dairy farm, the probability of sustaining an injury through an accident increases by 0.03. Similarly, those working on farms located in lowland-designated areas have a higher probability of experience accidents than those on farms located in a Severely Disadvantaged Area (SDA) or Disadvantaged Area (DA). In Northern Ireland, lowland farms are more often dedicated to dairy production; in 2019, the share of dairy cows in lowland farms was 81% compared to just 45% in farms located elsewhere (DAERA, 2019).[2] This confirms previous studies indicating that those working on dairy farms are more exposed to accidents compared to other farm enterprises (Lindsay, 2004). There are a number of reasons why those who work on dairy farms are more susceptible to accidental injury. The process of milking cows involves more and repeated animal contacts relative to other cattle enterprises. Moreover, since dairy cows are moved so often, they also experience more problems with their hooves, requiring more frequent trimming. There is a substantial body of research indicating that hoof trimming is a factor of stress for cows and the primary source of injury for workers (Lindahl et al., 2016).

The picture that emerges from this study is that factors associated with risk-taking behavior and acceptable social norms within farming culture are strong predictors of accident occurrence. Interestingly, we did not find any statistical significance for objective risk factors directly associated with animal keeping, including the concentration of cows per worker and the relatively dangerous work practices.

Days of Work Lost because of an Accident

This section discusses the partial effects on the intensity equation (i.e. the number of workdays lost because of an accident). The intensity equation (days) can be estimated with the same set of covariates as that used in the selection equation. Nevertheless, it is a good practice to specify at least one exclusion restriction (Terza, 1998). Appendix Table A2 reports the model estimates and identifies the variables employed in each equation. Some of the variables used in the days equation are related to the characteristics of the accident and the injured person. These variables indicate the severity of the injury and human factors affecting the duration of recovery and thus should be highly correlated with the number of days lost. These variables are not observed if the accident did not occur and they are candidates to be used as an instrument in the intensity equation. Overall, Appendix Table A2 shows that 14 variables of this type were employed to estimate the model.

Table 3 reports the partial effects on the expected number of missed days from work due to a farming-related accident. In terms of the cause of the accident, "falls from height" have the largest negative effect, with 10.2 days of work lost, followed by "slip or trip at ground level" (7.1 days), "contact with machinery" (6.8 days), and "hit or trampled by an animal" (5.4 days). As expected, fractures have the most detrimental effect (7.05 days), while lacerations exhibit the least negative impact (−9.8 days) with respect to sprains, burns, and infections (i.e., "other type of injuries").

In most cases, only one injury per accident was reported. Nevertheless, some accidents involved up to four multiple injuries. Evaluated at the average number of injuries per accident, this means that passing from one to two injuries increases the number of days off work by 5.4. A similar pattern is observed if the accident required hospital treatment or the need to attend a general practitioner's surgery, but with a larger impact (26.5 days). In terms of farm characteristics, the only enterprise that showed a statistical significance was dairying. Those working on dairy farms missed 6.5 more days of work than those from other farm types.

In relation to the individual sustaining the injury, farm family members were the only group that showed a statistically significant result, missing 5 more days of work than the main farmer. In contrast, we did not find any difference in term of missed days of work between the farmer and other workers, mainly hired labor.

The effect of age merits some discussion. Specifically, Table 3 reports that the partial effect of age averaged over all the observations (APE) is not statistically significant because the largest share of observations with accidents is observed for the group aged 50–59 years, which is in the

[2] There are other differences, as farms in lowland areas are relatively more concentrated on crop and poultry production while farms in other areas are more focused on pig production. Nevertheless, we could not find any statistical significance for these farm characteristics in the model specifications that employed a more detailed classification of farm type.

Table 3. Average Partial Effects (APEs) on the Expected Number of Missed Days of Work

Category	Variable	APE (days)	Std. Err.
Type of farm	Dairy	6.53**	3.31
	Sheep	4.79	2.98
	Other	2.41	3.38
Type of land	Disadvantaged land	−2.74	2.65
	Lowland	−1.39	2.45
Other farm characteristics	Farm size (SLR)	−0.23	0.67
	Cow–worker ratio	1.48	0.99
	Part-time farmer	−0.68	2.18
Characteristics of injured person	Age	−0.01	0.05
	Family member	5.04*	3.03
	Nonfamily member	3.08	3.59
Accident characteristics	Hospital treatment	26.47***	7.83
	Number of multiple injuries	5.43**	2.46
Main injury	Laceration	−9.79**	4.72
	Fracture	7.05*	4.06
	Bruising	−3.58	3.41
Main cause of accident	Slip or trip at ground level	7.10**	3.19
	Falls from height	10.20**	4.85
	Hit or trampled by an animal	5.45**	2.86
	Contact with machinery	6.81*	3.96
	Injured using a hand tool	−0.99	3.11
Dangerous work practices	Machineries and vehicles	3.49*	2.26
	Animals	−1.45	2.38
	Lack for protections	−3.16	2.66
	Slurry gases	−0.28	2.05

Notes: APEs based on equation (4b). Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level. Standard errors calculated using the delta method.

neighborhood of the maximum, where the partial effect is supposed to be 0.[3] Figure 2 illustrates the marginal effects at the mean calculated at specific points of age and illustrates this mechanism. For each one of these points, Figure 2 shows the statistical significance of the marginal effects and the share of observations. Approximately 75% of accidents involved workers between 40 and 64 years, where a very weak statistical significance is present at best (i.e., it is around its maximum). In terms of interpretation, the number of days off work increases with age for workers between 16 and 39 years (i.e., just for young workers). On average, one more year of age increases the number of days off work by 0.40 for workers below 39 years. This result could be attributed to the lack of experience of young workers on executing agricultural tasks that can be learned only on the job (DeBarr et al., 1998; Watson et al., 2017). After 40 years, aging-related factors push farmers and workers to delegate some of the most physically demanding tasks to more fit workers. At the other extreme of the age spectrum, one more year of age decreases the number of days off work by −0.45.

[3] Appendix Table A2 shows the model coefficients, which indicate that the effect of age on the number of workdays has a maximum around 55 years.

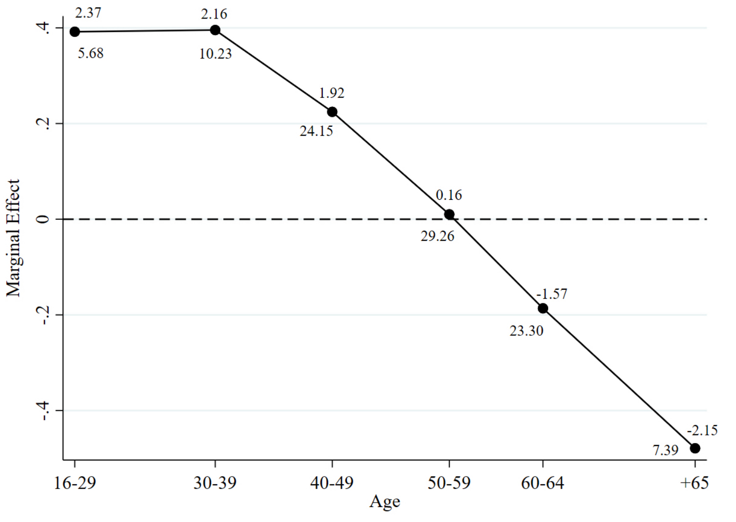

Figure 2. Effect of Age on the Number of Days of Work Lost because of an Accident

Notes: Marginal effects at the mean of *Age* on the expected number of days of work lost. Marginal effects are calculated by keeping all the other covariates fixed at their average values. The numbers on top of the bullet points indicate the corresponding value of the two-sided t-test for H_0: partial effect = 0 while the numbers below the bullet point indicate the observed frequency (multiplied by 100) of each age group..

Although old farmers require more time to recover from accidents, year after year they are less involved in physical tasks and thus miss fewer workdays.

Panel B of Figure 1 shows the distribution of the expected number of days off work employed to calculate the partial effects in Table 3. Overall, a worker injured in agriculture in Northern Ireland takes 15.7 days off work per year. This estimate is in line with other studies. For instance, on average, in 2018 ROI recorded 10 workdays per accident lost in the dairy and cattle sector (Sheehan and Deasy, 2018). Similarly, the annual average number of days off work in Great Britain across all sectors due to work-related injuries was 15.1 in 2018 (Health and Safety Executive, 2019).

It is outside the purpose of this study to estimate the economic cost of work-related injuries in agriculture. Nevertheless, the loss of labor income is the minimum threshold and the estimated number of days off work can be employed for this purpose. Table 4 shows that this estimate implies 18,317 days of work are lost every year on NI farms because of nonfatal accidents. Evaluated at the average hourly wage, this means that USD 1,603,235 are lost every year. On top of this estimate, it is necessary to add the loss of future labor earnings, medical and legal expenses, psychological distress, and macroeconomic factors (e.g., output loss, increased prices).[4]

Conclusions

The primary purpose of occupational safety and health campaigns is to reduce the number of accidents and their detrimental effects on workers, families, and society. In the last decade, the efforts made by NI authorities to improve farm safety have required an increasing amount of funding spent in public campaigns, safety events, training courses, and stakeholder engagements. Self-assessment programs of farm safety have also been made mandatory for applicants to public grants. These initiatives aim to promote behavioral change within the farming sector to encourage the adoption of safer farming work practices. Unfortunately, this behavioral change can only be achieved with the farmers' cooperation, and this has not proved to be a quick and easy fix (Pouliakas and Theodossiou, 2013). For this reason, understanding why accidents occur and their impact in terms of lost workdays is an important research focus.

[4] See Andreoni (2012) for an overview of the economic cost of work-related accidents.

Table 4. Annual Labor Cost due to Nonfatal Accidents in Northern Irish Farms, 2015–2019

Calculation	Description	Amount/Percentage
A	Number of farms	24,823
B	Percentage of farms with accidents	4.7%
C	Number of days off work per farm accident	15.7
$D = A \times B \times C$	Total annual days of work lost	18,317
E	Hired labor hourly pay	$10.97
F	Hours worked per day	7.98
$D \times E \times F$	Total annual cost	$1,603,235

Notes: Annual averages in 2015–2019 (DAERA, 2019). Monetary values based on CPI (2015 = 100), USD/GBP exchange rate 1.31.

In this study, we found that individuals working on farms with a high rate of minor injuries and near misses have the highest increase in probability of experiencing a future work-related accident. From a policy perspective, this suggests that focusing on indicators related to these factors in self-assessment programs and safety advertising campaigns could help to reduce the number of farm accidents and injuries. Dairy farming shows the highest increase in probability of accidents compared to other farming types. Advertising campaigns and training courses should highlight the fact that major accidents are a result of poor maintenance and safety standards when operating vehicles and machinery, insufficient protection when working on ladders and tin roofs, and remaining beside underground slurry tanks while mixing. As expected, exposure to work-related risks increases the chances of occupational injury. Therefore, key stakeholders involved in promoting farm safety and accident prevention should consider focusing their efforts specifically on full-time farmers and account for those seasonally busy periods when farmers are under further time pressure.

As measured by the number of days off work, falls, slips, and trips have the most detrimental consequences on farm workers in terms of fracture, multiple injuries, and hospital treatment. Age is a predictor of days of work lost: Among young farmers (less 30 years) and middle-age farmers (30–39 years), the expected number of workdays increases with age. Public campaigns and training courses to improve farm safety should highlight that the combination of lack of experience and workload are likely to increase accident severity. Family members—such as farmers' spouse and children—take more days off work because of accidents. This study does not examine whether this phenomenon is related to the severity of the injury or because these subjects are less under pressure from the on-farm activity and can take more days off work. Future self-assessment programs should include age and family status to better quantify the risk of exposure to farm-related accidents.

Future research should examine effective mechanisms to promote farm safety. Subsidizing investments in occupational safety can be effective when the supply of safety equipment also increases to maintain prices at an affordable level and expand this type of investment. Both public and private insurance companies can also differentiate their premiums according to farmers' decision to promote safe choices, similar to approaches used in results-based agri-environment schemes in which payments are linked to environmental performance (Strong, 2013). The estimates shown in the paper can be employed to calculate the effect of different attributes of the injured person, injury, and farm on the number of workdays lost. This can be used as a base to monetarize the economic loss due to farm accidents and thus provides an additional tool to increase self-awareness and the responsibility of policy makers, key stakeholders, farmers, and the wider agricultural industry toward farm safety.

[First submitted August 2020; accepted for publication October 2020.]

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Appendix A: Log-Likelihood Function

In this appendix, we derive the log-likelihood function employed to estimate jointly equation (1) and equation (3) according to rule (2). Definitions and notations are given in the methodology section. As usual, the log-likelihood function is composed by two parts according to the accident occurrence:

$$\text{(A1)} \qquad LLF = \sum_{i \notin accidents} \ln(LF_i) + \sum_{i \in accidents} \ln(LF_i)$$

For farms without accidents, the likelihood function is equal to $\Phi(-\boldsymbol{w}_i'\boldsymbol{\delta})$, where $\Phi(\cdot)$ is the cumulative univariate standard normal distribution. For farms that experienced accidents, the likelihood function needs to consider the selection mechanism together with the fact that the number of days is provided in intervals according to rule (2):

$$\text{(A2)} \qquad \sum_{i \in accidents} \ln(LF_i) = LLF1 + LLF2 + LLF3 + LLF4,$$

where

$$\text{(A3)} \qquad LLF1 = \sum_{d_i=0} \ln\left(\boldsymbol{\Phi}\left[\begin{pmatrix}\left(0.5-\boldsymbol{x}_i'\boldsymbol{\beta}\right)/\sigma \\ -\infty\end{pmatrix}, \begin{pmatrix}\infty \\ -\boldsymbol{w}_i'\boldsymbol{\delta}\end{pmatrix}, \rho\right]\right);$$

$$\text{(A4)} \qquad LLF2 = \sum_{d_i\in[1;30]} \ln\left(\boldsymbol{\Phi}\left[\begin{pmatrix}\left(30.5-\boldsymbol{x}_i'\boldsymbol{\beta}\right)/\sigma \\ \left(0.5-\boldsymbol{x}_i'\boldsymbol{\beta}\right)/\sigma\end{pmatrix}, \begin{pmatrix}\infty \\ -\boldsymbol{w}_i'\boldsymbol{\delta}\end{pmatrix}, \rho\right]\right);$$

$$\text{(A5)} \qquad LLF3 = \sum_{d_i\in[31,60]} \ln\left(\boldsymbol{\Phi}\left[\begin{pmatrix}\left(60.5-\boldsymbol{x}_i'\boldsymbol{\beta}\right)/\sigma \\ \left(30.5-\boldsymbol{x}_i'\boldsymbol{\beta}\right)/\sigma\end{pmatrix}, \begin{pmatrix}\infty \\ -\boldsymbol{w}_i'\boldsymbol{\delta}\end{pmatrix}, \rho\right]\right);$$

$$\text{(A6)} \qquad LLF4 = \sum_{d_i\geq 61} \ln\left(\boldsymbol{\Phi}\left[\begin{pmatrix}\infty \\ \left(60.5-\boldsymbol{x}_i'\boldsymbol{\beta}\right)/\sigma\end{pmatrix}, \begin{pmatrix}\infty \\ -\boldsymbol{w}_i'\boldsymbol{\delta}\end{pmatrix}, \rho\right]\right);$$

where $\boldsymbol{\Phi}()$ is the cumulative bivariate standard normal distribution with correlation ρ and the values in the two dimension-column vectors indicate the intervals of integration with respect to u_i and v_i.

Table A1. Variable Definitions

Variable	Definition
Accidents	
Dependent variable	1 if one or more accidents in the past 12 months that required medical attention, 0 otherwise
Days	
Dependent variable	As a result of the accident, how many days the person was unable to work in the past 12 months: 0, 1–30, 31–60, 61+
Type of farm	
Cattle	1 if cattle farm, 0 otherwise
Dairy	1 if dairy farm, 0 otherwise
Sheep	1 if sheep farm, 0 otherwise
Other	1 if other type of farm, 0 otherwise
Type of land	
Severely disadvantaged	1 if severely disadvantaged land, 0 otherwise
Disadvantaged	1 if disadvantaged land, 0 otherwise
Lowland	1 if lowland, 0 otherwise
Other farm characteristics	
Farm size (SLR)	Farm size in standard labor requirement (SLR)
Cow–worker ratio	Ratio between the number of cows (in hundreds) and the number of workers in SLR per farm
Part-time farmer	1 if farmer part-time, 0 otherwise
Characteristics of injured person	
Age	Age of the person injured 16–29 (22), 30–39 (34), 40–49 (44), 50–59 (54), 60–64 (62), +65 (75)
Farmer	1 if injured person farmer, 0 otherwise
Family member	1 if injured person family member, 0 otherwise
Nonfamily member	1 if injured person nonfamily member, 0 otherwise
Accident characteristics	
Hospital treatment	1 if medical attention hospital-in, 0 otherwise
Number of multiple injuries	Number of injuries
Main injury	
Laceration	1 if main type of injury laceration, 0 otherwise
Fracture	1 if main type of injury fraction, 0 otherwise
Bruising	1 if main type of injury bruising, 0 otherwise
Other type of injury	1 if other type of injury, 0 otherwise
Main cause of accident	
Slip or trip at ground level	1 if main cause slip or trip at ground level, 0 otherwise
Falls from height	1 if main cause fall from height, 0 otherwise
Hit or trampled by an animal	1 if main cause hit or trampled by an animal, 0 otherwise
Contact with machinery	1 if main cause due to contact with machinery, 0 otherwise
Injured using a hand tool	1 if main cause due to use of a hand tool, 0 otherwise
Other cause	1 if main other cause, 0 otherwise

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Table A1. – continued from previous page

Variable	Definition
Used to accidents	
Minor injuries	1 if one or more injuries that did not required medical attention in the past 12 months, 0 otherwise
Near misses	1 if one or more injuries were possible but narrowly avoided in the past 12 months, 0 otherwise
Barriers to improve farm safety	
Pressure from on-farm activity	1 if pressure from on-farm work is the main barrier to farm safety, 0 otherwise
Pressure from off-farm activity	1 if pressure from off-farm work is the main barrier to farm safety, 0 otherwise
Financial cost	1 if financial cost is the main barrier to farm safety, 0 otherwise
Dangerous work practices (at least once in the past 12 months)	
Machineries and vehicles	1 if driven a quad without a helmet, carried out maintenance or cleared blockage in a machine without it being turned off, carried a child on a tractor, and/or operated a vehicle with defective brakes (foot or parking), 0 otherwise
Animals	1 if worked in a house/pen with a loose bull and/or treated cattle which were not restrained using cattle handling facilities, 0 otherwise
Lack for protections	1 if worked in a ladder not footed by someone or something and/or walked on asbestos, tin roof without roof ladder, 0 otherwise
Slurry gases	1 if remained beside underground slurry tank while mixing and/or mixed slurry in a slatted tank without removing livestock in house, 0 otherwise

Table A2. Estimates of the Interval Regression Model with Sample Selection

Category	Variable	Coefficient	Std. Err.
Equation: Days $\boldsymbol{x}_i'\hat{\boldsymbol{\beta}}$			
Type of farm	Dairy	12.59	7.17
	Sheep	10.80	6.83
	Other	5.72	8.24
Type of land	Disadvantaged land	−5.99	5.48
	Low land	−3.95	4.89
Other farm characteristics	Farm size	−0.71	1.40
	Cow–worker ratio	3.38**	1.76
	Part-time farmer	−0.51	4.79
Characteristics of injured person	Age	2.49***	0.87
	Age squared	−0.02***	0.01
	Family member	10.11**	5.09
	Nonfamily member	6.41	6.90
Accident characteristics	Hospital treatment	42.83***	5.29
	Number of multiple injuries	11.56***	4.05
Main injury	Laceration	−23.40**	5.88
	Fracture	11.67**	6.01
	Bruising	−7.11	5.97

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Table A2. – continued from previous page

Category	Variable	Coefficient	Std. Err.
Main cause of accident	Slip or trip at ground level	15.61***	5.61
	Falls from height	21.11***	8.00
	Hit or trampled by an animal	12.40**	5.42
	Contact with machinery	15.06**	6.87
	Injured using a hand tool	−2.71	8.57
Dangerous work practices	Machineries and vehicles	5.87	5.46
	Animals	−3.63	4.82
	Lack for protections	−8.10*	4.64
	Slurry gases	−1.56	4.31
Year fixed effect		−2.63	3.80
Constant		−69.25**	31.00
Sigma σ		29.18***	3.55
Equation: Accidents $\boldsymbol{w}_i'\hat{\boldsymbol{\delta}}$			
Type of farm	Dairy	0.20**	0.10
	Sheep	0.03	0.09
	Other	0.02	0.11
Type of land	Disadvantaged land	0.02	0.07
	Low land	0.11*	0.07
Other farm characteristics	Farm size	0.02	0.02
	Cow–worker ratio	−0.02	0.04
	Part-time farmer	−0.10*	0.06
Dangerous work practices	Machineries and vehicles	0.20***	0.06
	Animals	0.06	0.06
	Lack for protections	0.16***	0.06
	Slurry gases	0.10*	0.06
Risk tolerance	Minor injuries	0.55***	0.07
	Near misses	0.23***	0.08
Barriers to improve farm safety	Pressure from on-farm activity	0.16***	0.06
	Pressure from off-farm activity	−0.12*	0.07
	Financial cost	−0.02	0.06
Year fixed effect		−0.02	0.05
Constant		−2.24***	0.12
Correlation ρ		−0.39*	0.22
Log-likelihood function		−1,586.51	

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at 10%, 5%, and 1% level based on the robust standard errors clustered at the farm level.