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RESEARCH ARTICLE

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Asymmetries in safety outcomes and learning from failure in subcontracting hierarchies

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Abstract

Subcontracting distributes production activities across firm boundaries, but little is known about how positions within subcontracting hierarchies are associated with occupational safety outcomes and learning from failure. Drawing on resource dependence theory and organizational learning research, this study examines workplace-level panel data from South Korean manufacturing between 2015 and 2019. Conditional fixed-effects Poisson models show that prime contractors and prime subcontractors experience fewer industrial accident casualties than noncontractors, whereas subcontractors do not differ significantly from them, revealing an asymmetric rather than monotonic pattern across positions. Learning from failure also varies by position. The negative relationship between prior own accident experience and subsequent casualties is stronger for subcontractors than for noncontractors, consistent with stronger direct learning. In the fully specified model, the negative relationship between other workplaces' accident experience and subsequent casualties is stronger for prime contractors, consistent with stronger vicarious learning. These findings identify subcontracting position as a structural condition associated with both recorded safety outcomes and the source of failure experience most closely related to subsequent improvement. They also suggest that safety-learning systems should be tailored to firms' positions and connect local accident learning with cross-firm coordination.

KEYWORDS
industrial accidents, learning from failure, occupational safety, organizational learning, resource dependence theory, subcontracting

INTRODUCTION

On May 1, 2017, two cranes collided at Samsung Heavy Industries' Geoje Shipyard in South Korea, killing six subcontracted workers and injuring 25 others. A subsequent government investigation identified multitiered subcontracting as an important structural condition contributing to safety problems in the shipbuilding industry (Ministry of Employment and Labor, 2018). Although the accident occurred in a specific industrial context, it illustrates how subcontracting may distribute not only production activities but also the occupational safety risks associated with those activities unevenly across firms.

Subcontracting is widely used as an interfirm production arrangement that enables firms to access specialized capabilities, adjust production capacity, increase flexibility, and reduce costs. It is often portrayed as mutually beneficial: prime contractors gain operational efficiency and flexibility, while subcontractors obtain access to markets, technologies, and continuing business opportunities (Organisation for Economic Co-operation and Development [OECD], 2008; Rama & Holl, 2013). More broadly, interfirm collaboration can generate joint value through relation-specific investments, knowledge-sharing routines, complementary resources, and effective governance (Dyer & Singh, 1998). However, mutual economic benefit

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and relational collaboration do not necessarily give participating firms equal influence over which activities are performed by which organization. Because production activities differ in the equipment, materials, processes, and working conditions they involve, allocating those activities across organizational boundaries can also distribute direct exposure to occupational hazards unevenly across firms. Occupational-safety outcomes may therefore be distributed asymmetrically across participating firms even when interfirm relationships remain collaborative (Johnstone et al., 2001; Mayhew et al., 1997; Nenonen, 2011).

Much of the research on subcontracting has focused on its economic and operational benefits and on economic risks associated with demand volatility and excess capacity (Abraham & Taylor, 1996; Rama & Holl, 2013; Tan & Gershwin, 2004). Although prior research has documented adverse occupational safety and health consequences associated with subcontracting and outsourcing, less attention has been paid to how the allocation of production activities across firms structures the interorganizational distribution of work-related risks (Mayhew et al., 1997; Min et al., 2013; Nenonen, 2011). This gap matters because understanding the safety implications of subcontracting requires considering not only its economic outcomes but also which organizations are directly exposed to the safety risks associated with production.

Existing occupational safety research identifies several structural problems associated with outsourced work, including economic and scheduling pressures, fragmented responsibility, difficulties in interorganizational coordination, and limited safety resources among subcontractors (Johnstone et al., 2001; Mayhew et al., 1997; Mayhew & Quinlan, 2006; Nenonen, 2011). Research on interorganizational accident risk has similarly identified economic pressure, disorganization, diluted competence, and organizational differences as recurring safety challenges in outsourced work arrangements (Grusenmeyer, 2022; Milch & Laumann, 2016; Pilbeam, 2024). Evidence from South Korea has likewise linked subcontracting arrangements and subcontractor status to hazard exposure and adverse occupational safety and health outcomes (Shin, 2021). Taken together, this literature indicates that subcontracting can shape working conditions and safety outcomes. However, it provides less insight into how industrial accident outcomes vary across distinct positions within subcontracting hierarchies or how position conditions learning from prior accident experience.

Reducing industrial accidents requires more than identifying how risks and accident outcomes are distributed across organizations. It also requires understanding how organizations respond to accident experience and whether they change their practices in ways that prevent recurrence. Industrial accidents constitute consequential failure experiences because they expose weaknesses in work practices, equipment, safety routines, and coordination processes. Organizations may learn directly by investigating accidents within their own workplaces or vicariously by observing accidents experienced by other organizations. Both own and others' failure experiences can provide valuable learning opportunities and have been associated with reductions in subsequent failure (Dahlin et al., 2018; Haunschild & Sullivan, 2002; Kim & Miner, 2007; Madsen, 2009; Madsen & Desai, 2010). However, this research has focused primarily on experience within focal organizations or across organizational populations. Recent research on safety learning at interorganizational worksites shows that organizational conditions can shape whether safety knowledge is identified and applied (Griegel et al., 2025). Yet, it remains unclear whether an organization's position within an interfirm production structure shapes the relevance and actionability of different sources of accident experience for subsequent improvement.

This issue is particularly important in subcontracting relationships. Resource dependence theory suggests that asymmetries in control over critical resources create differences in firms' influence over exchange conditions and interdependent activities (Hillman et al., 2009; Pfeffer & Salancik, 1978). Firms in different subcontracting positions may therefore differ in their exposure to operational hazards and in their opportunities to access and act on accident-related information. These positional differences provide a common structural basis for understanding both variation in accident outcomes and learning from failure.

This study addresses two related research questions. First, how do industrial accident outcomes vary across positions within a subcontracting hierarchy? Second, how does hierarchical position condition organizational learning from failure?

We examine these questions by integrating resource dependence theory with research on organizational learning from failure. Using workplace-level panel data from South Korean manufacturing between 2015 and 2019, we test our theoretical arguments in a setting characterized by vertically differentiated subcontracting relationships among interdependent firms (Amsden, 1989; Nugent & Yhee, 2002). We distinguish among prime contractors, prime subcontractors, and subcontractors, using noncontractors as the reference category.

The results reveal three main patterns. First, prime contractors and prime subcontractors experienced fewer industrial accident casualties than noncontractors. Subcontractors, however, did not differ significantly from noncontractors. Second, subcontractors showed stronger direct learning from their own accidents than noncontractors. Third, prime contractors showed stronger vicarious learning from other workplaces' accidents than noncontractors, although this difference was statistically significant only in the fully specified model.

This study makes two theoretical contributions. First, it moves beyond a binary view of subcontracting by

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showing that occupational safety outcomes vary across positions within multitiered subcontracting hierarchies. Second, it extends research on learning from failure by identifying a firm's position within a subcontracting hierarchy as a structural condition that shapes the relevance and actionability of failure experience for subsequent improvement. Together, these contributions connect the distribution of occupational safety outcomes with learning from failure within a common interorganizational framework.

THEORY

Safety outcomes across positions in subcontracting hierarchies

Subcontracting organizes production across firm boundaries by assigning selected production activities or related services to legally separate firms (OECD, 2008). Firms use subcontracting to access specialized capabilities, adjust production capacity, increase flexibility, and reduce costs, while subcontractors gain access to markets, technologies, and continuing business opportunities (OECD, 2008; Rama & Holl, 2013). Beyond these economic benefits, subcontracting may also structure the distribution of occupational safety risk across organizational boundaries. Because production activities differ in the equipment, materials, processes, and working conditions they involve, the allocation of work across firms can create differences in which organizations are directly involved in hazard-exposed operations (Johnstone et al., 2001; Mayhew et al., 1997; Nenonen, 2011). These differences may be asymmetric because firms occupying different positions within subcontracting relationships vary in their influence over how production activities are organized and allocated (Emerson, 1962).

Subcontracting in South Korean manufacturing provides a particularly relevant context for examining such asymmetry. During the state-led industrialization of the 1970s, the government concentrated financial and strategic support on large firms while promoting production linkages with small- and medium-sized enterprises (Amsden, 1989; Nugent & Yhee, 2002). These arrangements created growth opportunities for smaller firms but also made many of them dependent on a limited number of large firms that controlled access to contracts and markets. As subcontracting relationships developed, prime contractors gained greater influence over production decisions and contract terms, whereas subcontractors had less bargaining power and fewer alternative business partners (Nugent & Yhee, 2002). Over time, repeated transactions and the expansion of multitiered subcontracting reinforced these unequal relationships. Korean subcontracting thus developed into a vertically differentiated hierarchy in which firms occupy unequal positions in terms of resource control, dependence, and influence over the coordination and allocation of production activities.

These characteristics of Korean subcontracting relationships can be understood through resource dependence theory. Organizations depend on external actors for resources critical to their operations and survival, and this dependence provides a basis for power (Pfeffer & Salancik, 1978). A firm becomes more dependent when another firm controls important resources and few alternative sources are available. When dependence is unequal, the less dependent firm gains greater influence over the conditions of exchange, while the more dependent firm faces greater constraints in resisting or renegotiating those conditions (Casciaro & Piskorski, 2005; Hillman et al., 2009).

Resource dependence also affects influence over the coordination of interdependent production activities. Relationships among legally independent firms are governed through combinations of formal and informal coordination mechanisms rather than through homogeneous market exchanges (Grandori & Soda, 1995). Firms with greater control over critical resources may therefore exercise greater influence not only over contractual terms but also over how production responsibilities are divided and coordinated across organizational boundaries (Casciaro & Piskorski, 2005; Hillman et al., 2009).

This logic is particularly relevant to vertically structured subcontracting relationships. Subcontractors may depend on prime contractors or prime subcontractors for contracts, market access, and continuing business opportunities, while prime contractors often have greater discretion in choosing among potential suppliers. This asymmetry gives prime contractors greater influence over which activities are retained internally, which are subcontracted, and how interdependent production activities are coordinated across firms (Casciaro & Piskorski, 2005; Grandori & Soda, 1995). Subcontractors with limited alternative business partners, by contrast, face greater constraints on their ability to reject assigned work or renegotiate the conditions under which it is performed (Hillman et al., 2009; Pfeffer & Salancik, 1978).

Firms consider specialization, cost, capacity, and coordination when deciding which production activities to subcontract. Prime contractors may also deliberately assess which activities are particularly hazardous and weigh these hazards alongside other considerations. Because production activities differ in their hazard profiles, discretion over which activities are performed internally and which are subcontracted can create systematic differences in firms' direct operational involvement and occupational safety outcomes (Johnstone et al., 2001; Mayhew et al., 1997). Prior research similarly documents differences in hazard exposure, working conditions, accident risk, and safety management across subcontracted and outsourced work arrangements (Manu et al., 2013; Mayhew & Quinlan, 2006; Nenonen, 2011).

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To examine how these differences vary across subcontracting positions, we distinguish four structural positions: prime contractors, prime subcontractors, subcontractors, and noncontractors. Noncontractors operate outside subcontracting relationships and serve as the benchmark category. Our argument concerns position-specific contrasts with noncontractors rather than a strict rank ordering among the three subcontracting positions. Each position combines a distinct pattern of dependence, influence over work allocation, and direct operational involvement.

Prime contractors occupy the top position within the subcontracting hierarchy. Their control over access to contracts and continuing business opportunities gives them greater discretion over which activities are performed internally and which are carried out through subcontracting relationships (Casciaro & Piskorski, 2005; Pfeffer & Salancik, 1978). This discretion allows prime contractors to shape the composition of their direct operations and may limit their involvement in some activities involving greater exposure to occupational hazards (Johnstone et al., 2001; Nenonen, 2011).

> **Hypothesis 1a.** *Prime contractors experience fewer industrial accident casualties than noncontractors.*

Prime subcontractors occupy a dual position. Although they depend on prime contractors for contracted work, they also retain some discretion to allocate portions of that work to lower tier subcontractors. Their discretion is more constrained than that of prime contractors, but it nevertheless gives them some latitude over the composition of activities performed directly within their organizational boundaries (Casciaro & Piskorski, 2005; Hillman et al., 2009). This partial discretion over work allocation is expected to be associated with lower direct involvement in some hazard-exposed operations and, consequently, fewer industrial accident casualties than among noncontractors (Mayhew & Quinlan, 2006; Nenonen, 2011).

> **Hypothesis 1b.** *Prime subcontractors experience fewer industrial accident casualties than noncontractors.*

Subcontractors, by contrast, occupy a highly dependent position within the focal hierarchy. They rely on prime contractors or prime subcontractors for contracts and continuing business opportunities while lacking the discretion to subcontract the assigned work further. When alternative business partners are limited, this dependence constrains their ability to reject unfavorable assignments or renegotiate production conditions (Casciaro & Piskorski, 2005; Pfeffer & Salancik, 1978). At the same time, they directly perform the contracted activities assigned to them, placing them in closer operational contact with the hazards associated with performing that work (Johnstone et al., 2001; Mayhew et al., 1997; Nenonen, 2011). This combination of dependence, limited work-allocation discretion, and direct operational involvement leads us to expect subcontractors to experience more industrial accident casualties than noncontractors. Consistent with this argument, prior research in the Korean context has documented elevated occupational health risks among subcontracted workers (Min et al., 2013; Moon, 2022).

> **Hypothesis 1c.** *Subcontractors experience more industrial accident casualties than noncontractors.*

Taken together, these positional asymmetries in resource control and operational involvement provide a structural basis for differences in industrial accident casualties across subcontracting positions. These differences may reflect work-allocation decisions driven primarily by specialization, cost, or capacity, as well as decisions in which firms deliberately consider occupational hazards alongside these factors. In either case, the allocation of production activities across firm boundaries may shape occupational safety outcomes through differences in direct operational involvement.

Subcontracting hierarchies and learning from failure

Organizations learn in order to improve performance and adapt to changing environments. Organizational learning theory explains how organizations interpret and process experience and translate it into changes in organizational knowledge, routines, and practices over time (Argote et al., 2021; Levitt & March, 1988). Failure experience is particularly informative in this process. By revealing discrepancies between expected and actual outcomes, failures can expose weaknesses in existing assumptions, routines, and practices that might otherwise remain unnoticed. Such exposure can stimulate search, diagnosis, and corrective change aimed at preventing recurrence (Dahlin et al., 2018; Sitkin, 1992). Accordingly, a substantial body of research has examined organizational learning from failure by assessing whether prior adverse experience is associated with reductions in subsequent failure. Across diverse empirical contexts, studies have found that prior accidents and other adverse events can be associated with lower rates of subsequent failure, providing evidence consistent with learning from failure (Haunschild & Sullivan, 2002; Kim & Rhee, 2017; Madsen, 2009; Madsen & Desai, 2010).

Industrial accidents represent an important form of failure experience because they reveal problems in safety-related work practices, routines, equipment, and coordination processes. Organizations can learn directly from

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accidents occurring within their own workplaces by identifying their causes and modifying relevant practices (Park et al., 2023; van Marrewijk & van der Steen, 2024). Direct experience alone, however, can provide a limited basis for learning. Serious accidents occur relatively infrequently, minor incidents and errors may remain unreported, and even when accident information is available, the complexity of technologies and work processes can make underlying causes difficult to diagnose (Dahlin et al., 2018; Haunschild & Sullivan, 2002). Organizations can therefore complement direct learning with vicarious learning by attending to accidents experienced by other organizations and applying relevant lessons to their own practices (Argote & Ingram, 2000; Baum & Dahlin, 2007; Kim & Miner, 2007).

The extent to which accident experience produces subsequent improvement varies across organizations. The same accident experience can produce different learning outcomes, depending on organizations' opportunities to access relevant information, their motivation to respond, and their ability to interpret its implications and translate lessons into corrective action (Cohen & Levinthal, 1990; Dahlin et al., 2018). Learning from accidents therefore depends not only on experience itself but also on the conditions under which organizations encounter, interpret, and respond to accident-related information (Desai, 2016).

As discussed above, subcontracting positions differ in resource dependence, work-allocation discretion, direct operational involvement, and coordination scope (Casciaro & Piskorski, 2005; Grandori & Soda, 1995; Pfeffer & Salancik, 1978). These structural differences can shape the relevance and accessibility of accident-related information, as well as firms' incentives and opportunities to translate it into corrective action (Argote & Miron-Spektor, 2011;Dahlin et al., 2018; Desai, 2016). We therefore argue that firms in different subcontracting positions vary in how strongly prior own and others' accident experiences are associated with subsequent reductions in industrial accident casualties. Accordingly, we develop position-specific hypotheses for direct and vicarious learning relative to noncontractors.

Learning from one's own accidents begins with connecting the information an accident generates to the work process that produced it (Cannon & Edmondson, 2005; Desai, 2016). Organizations then use this understanding to revise the relevant practices and routines. For subcontractors, own accidents arise from contracted production activities in which they are directly involved. Their own accidents therefore provide specific evidence of problems in the work processes they perform, exposing weaknesses in existing safety practices and routines (Argote et al., 2021).

The same dependence that constrains subcontractors' discretion over assigned work may also strengthen their incentives to respond to the problems revealed by their own accidents. Subcontractors depend on contracting firms for continued access to contracts and business opportunities (Pfeffer & Salancik, 1978). Industrial accidents can disrupt production, and when safety problems recur, they can also lead contracting firms to question a subcontractor's reliability, threatening the continuation of the exchange relationship. Subcontractors therefore have strong incentives to correct the problems revealed by their own accidents (Dahlin et al., 2018). This is not only because the resulting information is directly relevant to their operations but also because failing to act may jeopardize their continued access to work.

This argument does not assume that subcontractors possess superior learning capabilities or more developed safety systems. Rather, their structural position combines two conditions conducive to learning from own accidents. Accident information is directly relevant to the work they perform, and they face strong incentives to respond to what that information reveals (Dahlin et al., 2018; Desai, 2016). We therefore expect prior own accident experience to be translated more strongly into subsequent safety improvement among subcontractors than among noncontractors.

> **Hypothesis 2.** *The negative relationship between a workplace's own industrial accident experience and subsequent industrial accident casualties is stronger for subcontractors than for noncontractors.*

Learning from others' accidents requires organizations to reach beyond their own experience—to encounter information about accidents that occurred elsewhere, judge its relevance, understand its causes, and adapt applicable lessons to their own practices. Vicarious learning therefore depends not only on the availability of external accident information but also on organizations' capacity to access, interpret, and apply it (Cohen & Levinthal, 1990; Dahlin et al., 2018; Kim & Miner, 2007).

Prime contractors are comparatively well positioned to access and use accident information generated beyond their own workplaces. They coordinate interdependent production activities across multiple organizational boundaries and maintain relationships with multiple firms (Grandori & Soda, 1995). This broader coordination scope gives them more opportunities to encounter, compare, and interpret external accident information (Argote & Ingram, 2000; Cohen & Levinthal, 1990; Kim & Miner, 2007). It also increases the relevance of such information to their role in coordinating interdependent activities across firms.

Prime contractors' advantage in learning from others' accidents therefore follows from their structural position rather than from any general organizational superiority. We expect them to respond more strongly to others' accident experience than noncontractors.

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Hypothesis 3. *The negative relationship between others' industrial accident experience and subsequent industrial accident casualties is stronger for prime contractors than for noncontractors.*

METHODS

Sample and data

We tested our hypotheses using workplace-level panel data from South Korean manufacturing. This setting provides variation in subcontracting positions and repeated observations of industrial accident casualties over time. To empirically examine these dynamics, we used data from the Workplace Panel Survey (WPS; Korea Labor Institute, 2022), which has been conducted biennially by the Korea Labor Institute (KLI) since 2005. The WPS provides workplace-level information on workplace characteristics, employment structures, subcontracting arrangements, industrial accidents, and safety practices. We used the 2015, 2017, and 2019 waves because they provided consistent measures of the variables required for the analysis. The sample was restricted to manufacturing workplaces with more than 30 employees.

The initial dataset contained 3880 workplace-year observations from 1505 workplaces observed between 2015 and 2019. After applying the lag structure and the data requirements for the variables included in the analysis, the final analytical sample comprised 2821 workplace-year observations from 1324 unique workplaces. Using two-digit Korean Standard Industrial Classification codes, we classified the analytical sample into four manufacturing sub-sectors: light manufacturing ($n = 754$), chemical manufacturing ($n = 574$), metal and automobile manufacturing ($n = 950$), and electrical, electronics, and precision manufacturing ($n = 543$). Of the 2821 observations, 65% were noncontractors, 18% were prime contractors, 12% were prime subcontractors, and 5% were subcontractors. Appendix 1 (Panel A) reports the composition of the analytical sample by manufacturing sub-sector and subcontracting position. Appendix 1 (Panel B) reports the corresponding fixed-effects estimation sample.

Dependent variable

The dependent variable is the number of industrial accident casualties recorded at each workplace in a given year. The WPS measure includes workers reported as injured or killed in industrial accidents and workers reported as affected by occupational disease. It therefore captures the number of workers harmed rather than the number of accident events or an accident rate. Higher values indicate a greater number of reported industrial accident casualties at the workplace.

Independent variables and interactions

The key independent variable in this study is the subcontracting position held by each workplace. The WPS categorizes workplaces based on their main subcontracting arrangement, defined as the transaction type generating the highest revenue in the previous year. Based on this classification, we construct four dummy variables: noncontractor, prime contractor, prime subcontractor, and subcontractor. Noncontractors neither receive subcontracted work nor subcontract work to other firms. Prime contractors subcontract work to other firms but do not receive subcontracted work. Prime subcontractors both receive subcontracted work and subcontract work to other firms. Subcontractors receive subcontracted work but do not subcontract work further. Although subcontracting relationships may contain multiple hierarchical tiers, the WPS does not distinguish more detailed tier levels within these four categories. Noncontractors serve as the reference category.

To examine how subcontracting positions are associated with learning from failure, we use two lagged measures of accident experience. Own accident experience is the lagged number of industrial accident casualties reported by the focal workplace. Others' accident experience is the total number of casualties reported by all other manufacturing workplaces in the sample, excluding the focal workplace. Both measures are lagged by one survey wave, corresponding to 2 years, thereby preserving the temporal ordering between prior accident experience and subsequent casualties. For the sub-sector-specific analyses reported in Appendix 3, others' accident experience was recalculated using casualties reported only by other workplaces within the same manufacturing sub-sector.

We interact each lagged accident-experience measure with the three subcontracting-position indicators, with noncontractors as the reference category. The interactions with own accident experience test whether the relationship between a workplace's prior casualties and its subsequent casualties differs by subcontracting position. The interactions with others' accident experience test whether the relationship between casualties reported outside the focal workplace and its subsequent casualties differs by position.

Control variables

We include workplace characteristics and safety-related conditions that may be associated with industrial accident casualties. Workplace age accounts for differences associated with organizational experience and the age of

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established routines and facilities. Workplace size, measured by the number of employees, accounts for differences in the overall number of workers potentially exposed to occupational injury. Establishment size may also be associated with injury rates through differences in safety resources and organizational systems (Fabiano et al., 2004). The share of production workers accounts for differences in the proportion of employees directly involved in manufacturing operations. The unionization rate, calculated as the proportion of unionized employees, is included because unions may influence both workplace safety practices and the reporting of occupational injuries (Morantz, 2013).

We further control for workplace hazard exposure and three safety-related organizational characteristics. Hazard exposure is measured as the average proportion of workers exposed to seven types of workplace hazards, including physical, chemical, and biological risks. We also include a summed hazard management system index, which covers hazard monitoring and safety training. Safety investment is measured in millions of Korean won, and a separate indicator captures whether the workplace has a dedicated safety department.

Analysis

Given the longitudinal nature of the data, unobserved workplace-specific characteristics—such as safety culture, internal policies, and management practices—may influence both subcontracting position and accident casualties. Failing to account for this unobserved heterogeneity could bias the estimates. Because the dependent variable is a nonnegative count measure, we estimated conditional fixed-effects Poisson models (Cameron & Trivedi, 2013; Hausman et al., 1984). These models estimate relationships using changes within workplaces over time while controlling for time-invariant workplace-specific heterogeneity.

We compared fixed-effects and random-effects Poisson specifications (Hausman et al., 1984). The fixed-effects model permits workplace-specific effects to be correlated with the explanatory variables, whereas the random-effects model assumes that they are uncorrelated. Hausman specification tests were used to assess this assumption (Cameron & Trivedi, 2013). Across the estimated models, the tests rejected the null hypothesis that the random-effects estimates were consistent, with χ^2 statistics ranging from 53 to 222 ($p < 0.001$). We therefore use the fixed-effects Poisson model as the primary specification.

Conditional fixed-effects Poisson estimation does not use workplaces that report zero industrial accident casualties in every observed period because these workplaces do not contribute information to the conditional likelihood (Cameron & Trivedi, 2013). The resulting estimation sample comprised 875 workplace-year observations (Appendix 1, Panel B). Accordingly, the fixed-effects estimates describe within-workplace relationships for workplaces that contribute to the conditional likelihood, rather than differences across the full analytical sample.

For comparison, we also estimated random-effects Poisson models. Because the random-effects model retains workplaces with all-zero accident outcomes and uses both within- and between-workplace variation, we report these estimates as a supplementary analysis in Appendix 2. These models allow us to assess whether the principal findings are sensitive to the treatment of workplace-specific heterogeneity.

Finally, we estimated separate fixed-effects Poisson models for each of the four manufacturing sub-sectors. Appendix 3 reports these estimates, which assess whether the direct- and vicarious-learning relationships are consistent across manufacturing contexts.

RESULTS

Descriptive statistics and correlations are presented in Table 1. The mean number of industrial accident casualties was 1.45, and prior own accident experience averaged 1.00. The average workplace was approximately 27 years old and employed 215 workers, with production workers accounting for 60% of employment. Unionization was relatively limited in the sample, with a mean unionization rate of 17% and unions present in 742 of the 2821 workplace-year observations. Union presence was highest among prime contractors (40%) and lowest among subcontractors (17%). Across manufacturing sub-sectors, union presence was lowest in electrical, electronics, and precision manufacturing (13%).

Correlations among most variables were modest. Industrial accident casualties were most strongly associated with prior own accident experience ($r = .467$) and showed smaller positive correlations with workplace size, unionization rate, hazard exposure, the hazard management system, safety investment, and the presence of a safety department. The strongest correlation among the explanatory variables was between hazard exposure and the hazard management system ($r = .625$). All variance inflation factors were below 10, with a mean VIF of 1.25, indicating no serious multicollinearity.

The results from the fixed-effects Poisson regression models are presented in Table 2. Model 1 reports baseline estimates with control variables and the two measures of prior accident experience. Workplace age and the share of production workers are positively and significantly associated with accident casualties, whereas workplace size and unionization rate are not statistically significant. The share of workers exposed to hazards and the hazard management system index are negatively associated with casualties. Safety investment and the presence of a dedicated safety department are positively associated with casualties.

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TABLE 1 Descriptive statistics and correlations.

Variables	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11
Dependent Variable													
1. Industrial accident casualties	1.45	14.96											
Independent and moderating variables													
2. Subcontracting position	0.57	0.88	−0.0027 (0.888)										
3. Own accident experience	1.00	9.54	0.4667 (0.000) ***	0.0270 (0.152)									
4. Others' accident experience	1,011	485	0.0198 (0.292)	−0.0182 (0.334)	0.0213 (0.257)								
Control variables													
5. Workplace age	27.03	14.29	0.0217 (0.250)	0.0434 (0.021) *	0.0185 (0.325)	−0.0112 (0.552)							
6. Workplace size	215	449	0.1705 (0.000) ***	0.2335 (0.000) ***	−0.0119 (0.529)	0.0194 (0.302)	0.1666 (0.000) ***						
7. Share of production workers	0.60	0.24	0.0338 (0.073)	0.051 (0.007) **	0.0185 (0.327)	0.0117 (0.534)	−0.0340 (0.071)	0.0710 (0.000) ***					
8. Unionization rate	0.17	0.30	0.0895 (0.000) ***	0.1118 (0.000) ***	−0.0185 (0.327)	0.0346 (0.066)	0.3737 (0.000) ***	0.3056 (0.000) ***	0.193 (0.000) ***				
9. Share of workers exposed to hazards	48.07	61.61	0.0888 (0.000) ***	0.0805 (0.000) ***	0.0825 (0.000) ***	0.0650 (0.001) ***	0.0267 (0.156)	0.0771 (0.000) ***	0.1771 (0.000) ***	0.1122 (0.000) ***			
10. Hazard management system	1.59	1.53	0.1037 (0.000) ***	0.1009 (0.000) ***	0.0706 (0.000) ***	0.0864 (0.000) ***	0.1468 (0.000) ***	0.1637 (0.000) ***	0.1557 (0.000) ***	0.2087 (0.000) ***	0.6248 (0.000) ***		
11. Safety investment	99.52	596	0.1660 (0.000) ***	0.2900 (0.000) ***	−0.0575 (0.002) **	0.0441 (0.019) *	0.0553 (0.003) **	0.2356 (0.000) ***	−0.0090 (0.633)	0.1003 (0.000) ***	0.0239 (0.205)	0.0900 (0.000) ***	
12. Safety department	0.43	0.49	0.0585 (0.002) **	0.0617 (0.001) **	0.0045 (0.811)	0.0967 (0.000) ***	0.1083 (0.000) ***	0.1979 (0.000) ***	0.0253 (0.180)	0.2426 (0.000) ***	0.1524 (0.000) ***	0.0863 (0.000) ***	0.2536 (0.000) ***

Note: $N = 2821$ workplace-year observations. p-Values are reported in parentheses.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

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TABLE 2 Fixed-effects Poisson regression models for industrial accident casualties in the Korean manufacturing sector.

	Model 1	Model 2	Model 3	Model 4	Model 5
Control variables					
Workplace age	0.3888***	0.1002***	0.1738***	0.4185***	0.4090***
	(0.059)	(0.016)	(0.019)	(0.058)	(0.060)
Workplace size	0.0001	0.0002**	0.0001	0.0002**	0.0001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Share of production workers	1.2039***	1.1462***	0.9265**	1.2495***	0.9687**
	(0.331)	(0.337)	(0.345)	(0.337)	(0.347)
Unionization rate	−0.1438	−0.1041	−0.1795	−0.1693	−0.3702
	(0.396)	(0.394)	(0.415)	(0.399)	(0.426)
Share of workers exposed to hazards	−0.0020**	−0.0023**	−0.0024**	−0.0022**	−0.0022**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Hazard management system	−0.0982***	−0.0903***	−0.0982***	−0.0804**	−0.0947***
	(0.027)	(0.026)	(0.027)	(0.027)	(0.028)
Safety investment	0.0002***	0.0001***	0.0002***	0.0001***	0.0002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Safety department (0/1)	0.2527**	0.2751**	0.2795**	0.3025**	0.2986**
	(0.093)	(0.093)	(0.094)	(0.094)	(0.096)
Own accident experience	−0.0074***		−0.0087***		−0.0086***
	(0.001)		(0.001)		(0.001)
Others' accident experience	−0.0007***			−0.0009***	−0.0006***
	(0.000)			(0.000)	(0.000)
Independent and moderating variables					
Prime contractor		−0.2058*	−0.0992	−0.0886	0.2944
		(0.097)	(0.104)	(0.161)	(0.167)
Prime subcontractor		−0.4537***	−0.7360***	−0.6514***	−0.7754***
		(0.128)	(0.149)	(0.196)	(0.223)
Subcontractor		0.3652	0.4775	0.5606	0.1541
		(0.268)	(0.276)	(0.392)	(0.515)
Own experience × prime contractor			−0.0021		−0.0006
			(0.002)		(0.003)
Own experience × prime subcontractor			0.0022		0.0039
			(0.002)		(0.003)
Own experience × subcontractor			−0.1083**		−0.1302*
			(0.037)		(0.056)
Others' experience × prime contractor				−0.0001	−0.0004**
				(0.000)	(0.000)
Others' experience × prime subcontractor				0.0002	0.0000
				(0.000)	(0.000)
Others' experience × subcontractor				−0.0002	0.0003
				(0.000)	(0.000)
N	875	875	875	875	875
Log likelihood	−1020	−1060	−1010	−1040	−995

Note: Noncontractors are the reference category. Standard errors are reported in parentheses.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

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Both own accident experience and others' accident experience are negatively and significantly associated with subsequent casualties. Exponentiating the coefficients yields incidence rate ratios (IRRs), which indicate proportional changes in expected casualty counts. For own accident experience, the coefficient of −0.0074 corresponds to an IRR of 0.9926, indicating that one additional prior casualty within the focal workplace is associated with a 0.74% reduction in expected subsequent casualties. For others' accident experience, the coefficient of −0.0007 corresponds to an IRR of 0.9993, indicating a 0.07% reduction in expected subsequent casualties for each additional casualty reported by other workplaces. These negative relationships are consistent with direct and vicarious learning from prior accident experience.

Model 2 incorporates dummy variables for each subcontracting position, with noncontractors serving as the reference category. This model estimates positional differences without including the accident-experience variables or their interactions. The coefficients for both prime contractors and prime subcontractors are negative and significant, indicating that these groups experience fewer industrial accident casualties than noncontractors. This supports Hypotheses 1a and 1b, which predict fewer industrial accident casualties for these workplaces. The coefficient for subcontractors is positive but statistically nonsignificant, offering no support for Hypothesis 1c, which anticipated more industrial accident casualties for this group.

The prime contractor coefficient is not statistically significant in the fully specified Model 5. However, because Model 5 includes both accident-experience variables and their interactions, its subcontracting main effects are conditional on own and others' accident experience being zero and are therefore not directly comparable with the coefficients in Model 2. Accordingly, Hypotheses 1a–1c are evaluated using Model 2.

To illustrate these effects, Figure 1 presents IRRs comparing each subcontracting position with noncontractors (IRR = 1). Prime contractors show an IRR of 0.8140, corresponding to an 18.60% reduction in expected accident casualties, and prime subcontractors show an IRR of 0.6353, corresponding to a 36.47% reduction. Subcontractors have an IRR of 1.4408, but this estimate is not statistically significant. The results therefore indicate position-specific differences in industrial accident casualties but do not support a monotonic pattern across subcontracting positions.

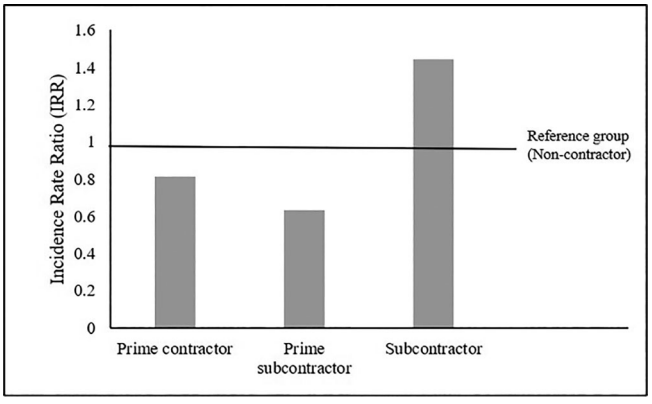


FIGURE 1 Incidence rate ratios for subcontracting positions (Table 2, Model 2).

Model 3 includes interaction terms between own industrial accident experience and each subcontracting position, with noncontractors as the reference category. The interactions for both prime contractors and prime subcontractors are not statistically significant, indicating no meaningful difference in the relationship between prior own accident experience and subsequent casualties relative to noncontractors. In contrast, the interaction between own experience and subcontractors is negative and significant, indicating that the negative relationship between prior own accident experience and subsequent casualties is stronger for subcontractors than for noncontractors. This interaction remains negative and statistically significant in the fully specified Model 5, supporting Hypothesis 2.

Model 4 includes interaction terms between others' industrial accident experience and each subcontracting position, with noncontractors as the reference category. None of the interaction terms are statistically significant. However, in Model 5, the interaction between others' experience and prime contractors becomes negative and significant, indicating that the negative relationship between others' accident experience and subsequent casualties is stronger for prime contractors than for noncontractors. The interactions involving prime subcontractors and subcontractors remain statistically nonsignificant. Thus, Hypothesis 3 is supported in the fully specified Model 5, although the interaction is not statistically significant in Model 4. The evidence for Hypothesis 3 is therefore contingent on the specification that simultaneously accounts for both sources of accident experience.

Because Model 5 simultaneously includes both sets of interaction terms, the IRRs and predicted relationships reported below are based on this fully specified model. For direct learning, the IRR for the subcontractor interaction is 0.8779 (exp[−0.1302]), indicating that the IRR associated with prior own accident experience is 12.21% lower for subcontractors than for noncontractors. One additional prior own casualty is associated with an approximately 0.86% reduction in expected subsequent casualties among noncontractors. Combining the main and interaction coefficients, the corresponding reduction among subcontractors is approximately 12.96%. This pattern is consistent with stronger direct learning among subcontractors.

For vicarious learning, the IRR for the prime contractor interaction is 0.9996 (exp[−0.0004]), indicating that the IRR associated with others' accident experience is 0.04% lower for prime contractors than for

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noncontractors. One additional casualty reported by other workplaces is associated with an approximately 0.06% reduction in expected subsequent casualties among noncontractors. Combining the main and interaction coefficients, the corresponding reduction among prime contractors is approximately 0.10%. Although the estimated difference per additional casualty is small, this pattern is consistent with stronger vicarious learning among prime contractors.

To help interpret the moderating relationships, Figures 2 and 3 present predicted log casualty counts across subcontracting positions and levels of own and others' accident experience, respectively, based on Model 5. The figures facilitate comparison of the estimated slopes across positions. Figure 2 shows negative slopes across subcontracting positions, with subcontractors (thick dashed line) exhibiting a steeper decline than noncontractors (solid line), consistent with the significant subcontractor interaction. Figure 3 likewise shows a steeper decline for prime contractors (dashed-dot line) than for noncontractors, consistent with the significant prime contractor interaction.

We further examined whether the relationships between prior accident experience and subsequent casualties differed across manufacturing sub-sectors. As reported in Appendix 3, prior own accident experience was negatively and significantly associated with subsequent casualties in all four sub-sectors, whereas others' accident experience was significant only in light manufacturing. These findings suggest that direct learning is comparatively stable across manufacturing contexts, while vicarious learning is more context-dependent and may rely on the relevance and comparability of others' experience.

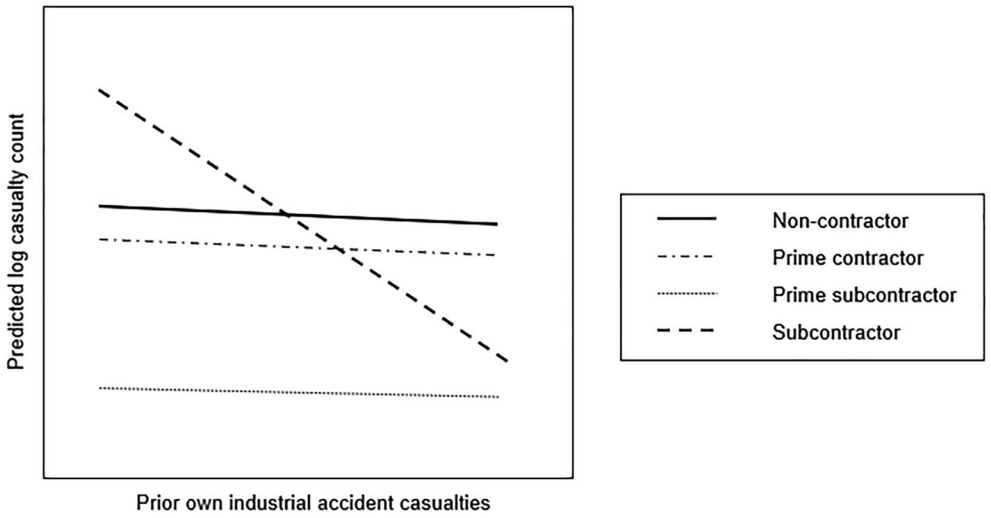


FIGURE 2 Moderating effects of subcontracting on direct learning (Table 2, Model 5).

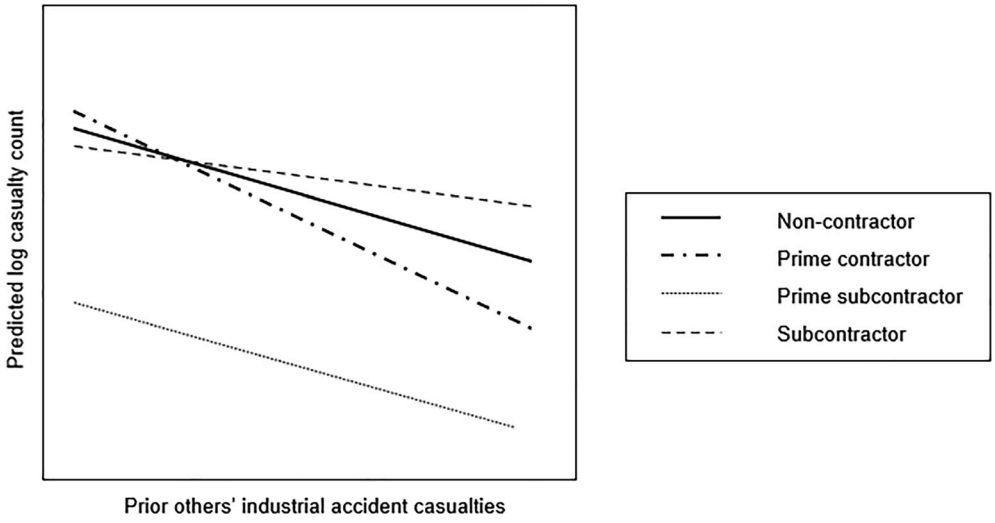


FIGURE 3 Moderating effects of subcontracting on vicarious learning (Table 2, Model 5).

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DISCUSSION

This study examined how positions within subcontracting hierarchies are associated with industrial accident casualties and learning from prior accident experience. Three key findings emerged. First, prime contractors and prime subcontractors experienced significantly fewer industrial accident casualties than noncontractors, whereas subcontractors did not differ significantly from the reference group. Second, subcontractors showed a stronger negative relationship between their own prior accident experience and subsequent casualties, consistent with stronger direct learning. Third, prime contractors showed a stronger negative relationship between other workplaces' accident experience and subsequent casualties, although this relationship was statistically significant only in the fully specified model that included all interaction terms simultaneously. Taken together, these findings show that subcontracting hierarchies are associated not only with differences in accident casualties but also with differences in the source of experience most closely related to subsequent safety improvement.

The first finding—that prime contractors and prime subcontractors experienced fewer accident casualties than noncontractors—is consistent with a resource dependence theory interpretation of subcontracting hierarchies. Firms occupying higher positions within subcontracting hierarchies may exercise greater influence over production arrangements, contractual conditions, and the coordination of interdependent work (Casciaro & Piskorski, 2005; Pfeffer & Salancik, 1978). Such influence may give firms greater discretion over which activities are performed internally, which are assigned to other firms, and how work is coordinated across organizational boundaries (Grandori & Soda, 1995). Prime contractors and prime subcontractors may therefore have greater discretion over the conditions shaping their operational involvement through decisions about work allocation and interorganizational coordination. Prime subcontractors occupy a position that combines operational involvement and some discretion over work allocation to other firms: They receive work from contracting firms, perform part of that work directly, and may assign other parts to lower tier subcontractors.

However, the observed coefficients did not reveal a monotonic pattern in recorded accident casualties across subcontracting positions. Prime contractors and prime subcontractors experienced fewer accident casualties than noncontractors, whereas subcontractors did not differ significantly from noncontractors. Thus, the results point to position-specific differences in recorded casualties rather than a simple rank ordering across the subcontracting hierarchy. This observed pattern, however, should not be interpreted as evidence that actual safety risk itself is distributed non-monotonically. Because this study did not directly measure work allocation or task-specific hazard exposure, it cannot identify the specific mechanisms underlying the observed differences across positions.

The nonsignificant coefficient for subcontractors warrants particular attention. It indicates that the recorded number of accident casualties among subcontractors in this sample was not statistically distinguishable from that among noncontractors, but it does not rule out the possibility that their actual risk exposure differs from that of noncontractors. Three possibilities should be considered when interpreting this result.

The first possibility concerns sample design. Because the sample excludes workplaces with 30 or fewer employees, very small subcontractors are not represented. Prior research indicates that smaller firms often experience less favorable occupational injury outcomes (Fabiano et al., 2004), while research on construction subcontractors shows that smaller firms tend to have less developed safety-management programs (Dale et al., 2020). Accordingly, the subcontractors included in this study may have been more likely to possess formal safety-management practices than very small subcontractors, potentially attenuating the observed differences from noncontractors.

The second possibility concerns heterogeneity within the subcontractor category. This category may include firms engaged in a wide range of production processes, installation, maintenance, logistics, and other support activities. Thus, subcontractors may differ substantially in the processes they perform, the equipment they use, the proportion of on-site work, and their exposure to hazardous factors. If such within-category heterogeneity is substantial, workplaces with high and low levels of hazard exposure may be combined within a single category, making differences from noncontractors less visible on average.

The final possibility concerns accident-reporting practices. When accident disclosure is perceived to carry employment or organizational costs, some incidents may be less likely to enter official records. Prior research documents such disincentives in injury reporting (Kyung et al., 2023) and in decisions not to pursue workers' compensation claims following reported accidents in Korea (Oh et al., 2019). These reporting and claiming disincentives may contribute to discrepancies between actual casualties and recorded casualties. Taken together, these possibilities may help explain why subcontractors did not differ significantly from noncontractors in recorded accident casualties.

The second finding was that the negative relationship between subcontractors' prior accident experience and subsequent casualties was stronger than that among noncontractors. This pattern is consistent with stronger direct learning among subcontractors. Because subcontractors directly perform assigned production activities, their own accidents may reveal specific problems related to equipment, work routines, task sequencing, work practices, and on-site hazard controls. Experience-based learning is

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more likely when organizations can connect observed outcomes to the actions and routines that produced them and apply corrective measures to identifiable processes (Argote et al., 2021; Desai, 2016; Levitt & March, 1988).

Dependence on contracting firms may further increase the importance of such experience. For subcontractors that rely heavily on a limited number of buyers, recurrent accidents may threaten contractual continuity, reputation, and access to future business opportunities. Resource dependence theory suggests that dependent organizations are particularly responsive to the demands and evaluations of actors controlling critical resources (Pfeffer & Salancik, 1978). Accidents may therefore provide not only diagnostic information about operational problems but also strong incentives to demonstrate corrective action and safety improvement to contracting partners (Dahlin et al., 2018). The combination of direct operational involvement and pressure arising from dependence may make subcontractors' own accident experience particularly relevant and actionable (Argote & Miron-Spektor, 2011; Dahlin et al., 2018).

This interpretation does not mean that subcontractors generally possess superior learning capabilities. Rather, their position may make their own accident experience more directly connected to identifiable work routines and corrective targets, while also making an effective response important for sustaining exchange relationships. The finding is therefore better understood as position-specific direct learning than as a general learning advantage.

The third finding was that the negative relationship between other workplaces' accident experience and subsequent casualties was stronger among prime contractors than among noncontractors. This result is consistent with the interpretation that the broad coordinating position of prime contractors may facilitate the use of others' accident experience. Their broader coordination scope may provide opportunities to obtain, compare, and integrate accident information generated beyond their own workplaces (Grandori & Soda, 1995). Such information may allow them to identify recurring risk factors and incorporate relevant lessons into safety standards, monitoring procedures, contractual requirements, and production-related decisions. Thus, vicarious learning among prime contractors may be related to occupying a coordinating position that facilitates the integration of accident information generated across multiple organizations.

However, access to information about others' accidents is not sufficient for vicarious learning. Organizations must determine whether external accidents are relevant to their own technologies, processes, and hazard environments, extract applicable lessons, and incorporate them into their own routines and management systems (Cohen & Levinthal, 1990; Kim & Miner, 2007; Madsen & Desai, 2018). Research on safety learning in temporary organizations likewise emphasizes that learning depends not only on information sharing but also on interpreting dispersed knowledge and embedding it in practice (Griegel et al., 2025). Thus, although the broader coordination scope of prime contractors may provide opportunities for vicarious learning, translating such experience into actual safety improvement may depend on the technical and safety expertise needed to interpret and apply external information.

The interaction effect for prime contractors, however, was statistically significant only in the fully specified model that included both the direct- and vicarious-learning interactions. This result should therefore be interpreted more cautiously than the direct-learning finding for subcontractors and should not be taken to indicate that prime contractors are generally superior at vicarious learning.

The manufacturing sub-sector analysis further suggests possible contextual limits to the relationships between prior accident experience and subsequent casualties. Prior own accident experience was negatively related to subsequent casualties in all four sub-sectors, whereas other workplaces' accident experience was significant only in light manufacturing. This pattern suggests that the negative relationship associated with own accident experience is relatively consistent across manufacturing contexts, whereas the relationship associated with others' accident experience is more context-dependent. Vicarious learning may therefore depend more strongly on how closely external accidents resemble the focal organization's technologies, production processes, and hazard environment (Haunschild & Sullivan, 2002; Kim & Miner, 2007; Madsen & Desai, 2018).

Beyond these position- and context-specific patterns, the findings for unionization raise a related issue concerning the role of institutional protection in occupational safety. The coefficient for unionization rate was consistently negative in the fixed-effects models but was not statistically significant. Unions may contribute to improved safety by strengthening employee voice and promoting attention to safety practices, thereby reducing actual occupational injury risk (Morantz, 2013). At the same time, unions may strengthen workers' ability and willingness to report incidents, thereby increasing the likelihood that accidents are formally recorded. Unionization may therefore operate in opposite directions: Reducing actual injuries while increasing the completeness of recorded injury counts. These countervailing pathways may obscure the net relationship between unionization rate and recorded accident casualties.

More broadly, these findings suggest that the presence of formal institutional protection alone may not translate straightforwardly into occupational safety outcomes in subcontracting settings. Collective representation may strengthen workers' bargaining power, but safety outcomes also depend on authority over work processes, access to hazard information, on-site supervision, and coordination across organizational boundaries. Accordingly, the role of unions in subcontracting safety systems may depend not only on the formal presence of

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representation but also on whether workers and their representatives can exert substantive influence over the operational conditions under which hazards arise and are controlled (Nichols et al., 2007).

Theoretical contributions

This study makes two primary theoretical contributions. First, it extends research on subcontracting by conceptualizing subcontracting not simply as a binary distinction between contractors and subcontractors but also as a vertically differentiated interorganizational structure associated with variation in occupational safety outcomes. Prior research has examined subcontracting mainly in terms of efficiency, specialization, flexibility, and the coordination of interdependent activities across organizational boundaries (Grandori & Soda, 1995). Research on occupational safety has further shown that dividing work among legally separate organizations can fragment responsibility, complicate hazard management, and create coordination and control problems (Johnstone et al., 2001; Manu et al., 2013; Milch & Laumann, 2016; Quinlan, 2024). Yet, this literature has paid comparatively less attention to variation among the multiple positions that constitute subcontracting hierarchies.

By distinguishing prime contractors, prime subcontractors, subcontractors, and noncontractors, this study shifts attention from whether a firm participates in subcontracting to where it is positioned within the arrangement. These positions differ in their dependence on exchange partners, discretion over work allocation, direct operational involvement, and scope of interorganizational coordination. Resource dependence theory explains how such asymmetries affect organizations' ability to negotiate exchange conditions and exercise discretion over interdependent activities (Casciaro & Piskorski, 2005; Hillman et al., 2009). Extending this logic to occupational safety, the findings show that recorded casualty outcomes vary across positions within subcontracting hierarchies rather than following a monotonic hierarchical pattern. The study thereby extends subcontracting research by showing that firms' positions within subcontracting arrangements are associated with position-specific patterns of recorded safety outcomes.

Second, the study develops a position-conditioned account of learning from failure. Organizational learning research has established that organizations can learn from both their own experience and the experience of others, but that experience does not automatically translate into knowledge or performance improvement. Its learning value depends on the context in which it is encountered, interpreted, and applied (Argote & Miron-Spektor, 2011; Dahlin et al., 2018; Levitt & March, 1988). Research on vicarious learning likewise shows that the usefulness of external experience depends on its accessibility and applicability to the focal organization (Kim & Miner, 2007). The present study extends this literature by identifying position within a subcontracting hierarchy as a structural condition that shapes how own and others' failure experiences are related to subsequent improvement.

Subcontracting positions differ in organizations' proximity to production activities, dependence on exchange partners, and opportunities to obtain information through coordination relationships. Direct involvement in production may make organizations' own accident experience more immediately relevant and actionable. By contrast, a broader coordination scope may provide greater opportunities to obtain, compare, and integrate accident experience from other workplaces. The contribution, therefore, is to show that direct and vicarious learning are not homogeneous processes detached from subcontracting structure. Rather, position within a subcontracting hierarchy may shape the relevance, accessibility, and actionability of own and others' failure experience, thereby shaping which source of experience is more closely associated with subsequent improvement.

Overall, this study identifies position within a subcontracting hierarchy as a structural condition associated with both variation in recorded safety outcomes and differences in whether own or others' accident experience is more closely related to subsequent improvement.

Practical implications

The findings suggest that occupational safety interventions should be tailored to organizations' positions within subcontracting hierarchies rather than applied uniformly across firms. For subcontractors, systems that translate on-site accident experience into corrective action may be particularly valuable. Such systems can include structured incident reviews, worker participation in root cause analysis, and timely revision of work procedures. Where subcontractors face resource constraints, prime contractors can support these efforts through technical guidance, safety training, joint hazard assessments, and stronger safety-management practices (Dale et al., 2021; Manu et al., 2013; Zhang et al., 2024). Such support can strengthen subcontractors' capacity to identify and address local hazards.

Prime contractors may play a complementary role by facilitating learning across organizational boundaries. They may be well positioned to collect and compare accident information from multiple workplaces and incorporate relevant lessons into production planning, contractor management, risk assessment, and preventive standards. Because vicarious learning is more useful when external experience is relevant and comparable to the focal context (Haunschild & Sullivan, 2002; Kim & Miner, 2007), information-sharing systems should provide contextual

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details on technologies, work processes, contributing factors, and preventive responses rather than aggregate accident counts alone (Nenonen, 2011). Prime contractors also need sufficient technical and safety expertise to interpret such information and assess whether lessons generated elsewhere are applicable to their own operations and contracting relationships (Cohen & Levinthal, 1990; Pilbeam, 2024).

Beyond the firm level, safety learning may also be strengthened through industry- and policy-level governance arrangements that connect local experience with cross-firm coordination (Madsen & Desai, 2018). Shared incident databases, common reporting standards, and cross-firm learning forums can help convert localized accident experience into broadly usable preventive knowledge. To complement direct information sharing between prime contractors and subcontractors, regulators and industry associations can provide confidential or anonymized reporting channels. These channels may help capture accident-related information that might otherwise remain undisclosed because of concerns about ongoing business relationships. They can also broaden the information available for industry-level learning while strengthening workers' access to hazard information and participation in decisions affecting operational safety.

Limitations and future research

This study has several limitations that suggest directions for future research. First, the analysis identifies differences in industrial accident casualties across subcontracting positions but does not directly test the mechanisms underlying these differences. The lower expected casualty counts for prime contractors and prime subcontractors relative to noncontractors provide some support for the interpretation that these firms consider occupational hazards alongside other factors in subcontracting decisions. However, the absence of information on task-specific hazards and work-allocation decisions prevents us from establishing this mechanism conclusively. The observational design also does not support causal claims that subcontracting position itself produced the observed differences in casualty outcomes. Future research should combine task-level hazard information with records of subcontracting decisions to test the proposed mechanism directly.

Second, workplace-level casualty counts do not capture the specific circumstances of individual accidents. They do not show which tasks were being performed, what types of workers were involved, or how work was supervised and hazards were managed at the time of the accident (Nenonen, 2011). Reporting practices may also vary when accident disclosure threatens business relationships, organizational reputation, or employment security (Kyung et al., 2023; Oh et al., 2019). A more accurate understanding of subcontracting-related safety outcomes therefore requires reliable accident reporting and more detailed records of the work and employment conditions surrounding each incident. Future research should combine workplace panel data with incident-level records, worker reports, compensation data, or site-level accident information.

Third, the conditional fixed-effects Poisson estimator excludes workplaces that reported zero casualties in every observed period. The fixed-effects estimates therefore capture within-workplace relationships among workplaces that contributed to the conditional likelihood rather than relationships estimated from the full analytical sample. Future research could assess the generalizability of the findings using longer observation periods, alternative estimators, or data containing greater within-workplace variation in both accident outcomes and subcontracting position.

Finally, the study focuses on South Korean manufacturing, where subcontracting has developed within a distinctive institutional and industrial context. The findings may therefore vary across industries and countries with different regulatory responsibilities, production technologies, reporting systems, and subcontracting arrangements. The sub-sector results also suggest that the relationship associated with others' accident experience may depend more strongly than that associated with own accident experience on the comparability of external experience. Future research should examine more detailed industry categories, direct measures of technological and hazard similarity, and cross-national differences in subcontracting governance to identify the conditions under which subcontracting position is associated with recorded occupational safety outcomes and learning from failure.

CONCLUSION

This study shows that positions within subcontracting hierarchies are associated with differences in recorded industrial accident casualties. These positions are also associated with differences in whether subsequent safety improvement is more closely related to organizations' own accident experience or to the experience of other workplaces. By linking resource dependence theory with organizational learning from failure, the study highlights safety outcomes and learning as relational phenomena embedded in multitiered subcontracting networks.

ACKNOWLEDGMENTS

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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DATA AVAILABILITY STATEMENT

The data analyzed in this study are publicly available through the Korea Labor Institute (https://www.kli.re.kr/wps), subject to the institute's data use policies.

ETHICS STATEMENT

This study used secondary data from the Korean Workplace Panel Survey (WPS), which are publicly available and anonymized. Therefore, ethical approval was not required.

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APPENDIX 1: Distribution of the Analytical and FE Estimation Samples

Panel A. Analytical sample, $N = 2821$

Manufacturing sub-sector	Noncontractor	Prime contractor	Prime subcontractor	Subcontractor	Total
C1 Light manufacturing	516	146	68	24	754
C2 Chemical manufacturing	416	101	35	22	574
C3 Metal and automobile manufacturing	533	179	172	66	950
C4 Electrical, electronics, and precision manufacturing	370	80	66	27	543
Total	1835	506	341	139	2821

Panel B. FE estimation sample, $N = 875$

Manufacturing sub-sector	Noncontractor	Prime contractor	Prime subcontractor	Subcontractor	Total
C1 Light manufacturing	163	56	29	7	255
C2 Chemical manufacturing	136	37	22	9	204
C3 Metal and automobile manufacturing	164	68	65	18	315
C4 Electrical, electronics, and precision manufacturing	64	17	15	5	101
Total	527	178	131	39	875

Note: Panel A presents the full analytical sample. Panel B presents the fixed-effects estimation sample after applying the model's data requirements and excluding workplaces that reported zero casualties in all observed periods.

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APPENDIX 2: Random-Effects Poisson Regression Models for Industrial Accident Casualties in the Korean Manufacturing Sector

	Model 1	Model 2	Model 3	Model 4	Model 5
Control variables					
Workplace age	0.0060	0.0146 *	0.0180 **	0.0074	0.0077
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Workplace size	0.0003 ***	0.0005 ***	0.0005 ***	0.0005 ***	0.0005 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Share of production workers	1.2531 ***	1.0737 ***	1.0728 ***	0.9505 ***	0.9045 ***
	(0.242)	(0.242)	(0.251)	(0.242)	(0.250)
Unionization rate	1.5799 ***	1.3003 ***	1.2411 ***	1.3277 ***	1.3335 ***
	(0.219)	(0.221)	(0.224)	(0.222)	(0.229)
Share of workers exposed to hazards	−0.0001	−0.0002	−0.0004	−0.0002	−0.0002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Hazard management system	−0.1036 ***	−0.0741 **	−0.0766 **	−0.0830 ***	−0.0950 ***
	(0.025)	(0.024)	(0.025)	(0.025)	(0.025)
Safety investment	0.0002 ***	0.0001 ***	0.0003 ***	0.0002 ***	0.0003 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Safety department (0/1)	0.3126 ***	0.3311 ***	0.3279 ***	0.3265 ***	0.3187 ***
	(0.083)	(0.083)	(0.084)	(0.084)	(0.085)
Own accident experience	−0.0050 ***		−0.0037 ***		−0.0062 ***
	(0.001)		(0.001)		(0.001)
Others' accident experience	0.0003 ***			0.0002 ***	0.0004 ***
	(0.000)			(0.000)	(0.000)
Independent and moderating variables					
Prime contractor		−0.3915 ***	−0.3404 ***	−0.1949	0.0319
		(0.090)	(0.095)	(0.153)	(0.158)
Prime subcontractor		−0.3927 ***	−0.5420 ***	−0.5611 **	−0.5896 **
		(0.114)	(0.126)	(0.184)	(0.191)
Subcontractor		0.0584	0.1132	0.4435	0.1692
		(0.228)	(0.231)	(0.363)	(0.439)
Own experience × prime contractor			−0.0015		−0.0023
			(0.002)		(0.002)
Own experience ×prime subcontractor			0.0027		0.0024
			(0.002)		(0.002)
Own experience × subcontractor			−0.0660		−0.0972
			(0.036)		(0.051)
Others' experience × prime contractor				−0.0002	−0.0004 **
				(0.000)	(0.000)
Others' experience × prime subcontractor				0.0002	0.0001
				(0.000)	(0.000)
Others' experience × subcontractor				−0.0004	0.0000
				(0.000)	(0.000)
N	2,821	2,821	2,821	2,821	2,821
Log likelihood	−2940	−2950	−2940	−2940	−2920

Note: Noncontractors are the reference category. Standard errors are reported in parentheses.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

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APPENDIX 3: Sub-Sector-Specific Fixed-Effects Poisson Estimates of Learning From Failure

Variables	C1 light manufacturing	C2 chemical manufacturing	C3 metal/automobile manufacturing	C4 electrical/electronics/precision manufacturing
Own accident experience	−0.0233***	−0.0147*	−0.0141***	−0.6463***
	(0.0026)	(0.0074)	(0.0041)	(0.0971)
Others' accident experience within the same sub-sector	−0.0026**	−0.0105	−0.0013	−0.0090
	(0.0008)	(0.0066)	(0.0011)	(0.0072)
Controls	Yes	Yes	Yes	Yes
N	255	202	313	96
Log likelihood	−244.45	−199.15	−347.83	−43.15

Note: Models are estimated separately by manufacturing sub-sector. Sample sizes exclude workplaces that reported zero casualties in all observed periods and observations with missing values. Standard errors are reported in parentheses.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

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