Small Bus Econ (2023) 60:85–104
https://doi.org/10.1007/s11187-022-00638-1

Evolution of micro and small enterprises' work safety behavior in high-risk industries

Wen Li · Tong Zhou · Qiang Mei · Xiangyang Liu · Muhammad Imran

Accepted: 14 April 2022 / Published online: 19 May 2022

Abstract Due to external regulations and limited resources, micro and small enterprises' (MSEs) work safety behavior in China's high-risk industries is passive behavior under constraints. Based on stakeholder theory, this paper describes the attributes and behavior rules of MSEs, the government safety supervision department and work safety service agencies using the agent-based simulation methods. We construct an evolution model to study this behavior. The software platform Netlogo is used for simulation exercises. Under the four factors of enterprise work safety resource strength, government supervision, government subsidies, and organization service level, the evolution of MSEs' work safety behavior in high-risk industries is simulated and the results are discussed. It further reveals internal and external drivers of work safety of MSEs in high-risk industries, strengthens the scientific supervision and effective support of government safety supervision departments, and improves work safety service quality of service agencies multi-dimensionally.

Plain English Summary In recent years, the input of work safety of MSEs is rather limited, and owners with decision-making power have a visual attitude towards work safety. "Accident occurrence-Inspection and rectification-Shutdown" has become government's usual practice in handling accidents in China, and it is difficult for control measures to address accidents at the source. Local government provides insufficient subsidies. The service level of work safety service agencies is low. Combined with internal resources and external constraints, this paper describes the interaction process of MSEs' work safety behavior in high-risk industries and constructs an evolution model to study it, based on agent-based simulation methods. The research results are follows. MSEs in high-risk industries need to improve their work safety resources, increase their investment in work safety, and progressively develop their awareness of independent work safety behavior. Government safety supervision departments need to strengthen supervision of MSEs and control penalty levels. MSEs can then gain more work safety benefits and develop internal drivers to implement work safety actively. For those companies who have intentions to pursue work safety behavior but lack funds, a service subsidy from local government will provide essential support. Given improvement of service levels from

W. Li · T. Zhou · Q. Mei
School of Management, Jiangsu University, Zhenjiang 212013, Jiangsu, China

Q. Mei
SME Project Research and Training Base, Jiangsu University, Zhenjiang 212013, Jiangsu, China

X. Liu · M. Imran (✉)
Information Research Institute, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250014, Shandong, China
e-mail: imran@sdas.org

work safety service agencies, MSEs will purchase high-level work safety services and acquire more professional technical services to help them meet government standards. Thus, the results are conducive to the transformation of MSEs from passive restraint behavior to active work safety behavior.

Keywords MSEs · Work safety behavior · High-risk industries · Evolution · Agent-based simulation methods

JEL Classification L25 · M10 · H32

1 Introduction

Micro and small enterprises (MSEs) are the lifeblood of economic and social development. They play a pivotal role in promoting economic growth, in transformation and upgrading, optimizing economic structure, expanding employment, increasing income, improving people's livelihood, and promoting stability (Legg et al., 2014). Compared with large and medium-sized enterprises, MSEs, as the most dynamic group in China's economy, are also the most vulnerable (Ren et al., 2018). Most of them are in a disadvantageous position in terms of technology, capital, talent, information, and market. They are at the low end of the industrial chain with small scale, weak ability, and poor anti risk ability, which are very vulnerable to the economic situation and market environment. For example, one of work safety accidents occurred in Xiantao Lanhua Silicone Co., Ltd (from Xiliuhe Town, Xiantao City, Hubei Province in China) in August 2020. Due to lack of sufficient understanding of the dangerous characteristics of ethyl methyl ketone oxime hydrochloride, an explosion occurred in the workshop, resulting in six deaths and four injuries. The accident reveals that MSEs in high-risk industries have problems, such as implementation failure for work safety responsibilities, poor safety awareness, and confusion in safety management (Targoutzidis et al., 2014). In order to minimize operating costs, the plant infrastructure of the MSEs is primitive with hidden dangers. Production technology is backward, and the work environment adverse. Owners prefer "gambling" with work safety, which leads to serious accidents hurting others and themselves that occur frequently (Zhang et al., 2017). According to statistics of the Ministry of Emergency Management in China, in recent years, more than 70% of major accidents are concentrated in MSEs, especially high-risk industries such as coal production, transportation, and construction engineering.

Just as the European Union has the *Occupational Safety and Health Management System* (*OHSAS*) *18,001:2007* (British Standards Institute, 2007), the American National Standards Institute (ANSI) (2012) has *Z10-2012* and the American Industrial Hygiene Association (AIHA) adopts *Occupational Safety and Health Standard Voluntary Protection Project*, so China adopts the *Basic Specification for Work Safety Standardization of Enterprises* to set work safety standards for all enterprises. In order to meet work safety standards, some MSEs adopt active work safety behavior, but, due to the limited safety production resources of enterprises, most MSEs need to rely on third-party service institutions (Tremblay & Badri, 2018). Because of the specificity of work safety factors, MSEs are unable to fully learn from the experience and mode of work safety of large and medium-sized enterprises.

In high-risk industries in China, MSEs are faced with financing difficulties, labor shortages, and high operating costs. It is therefore difficult for those with limited profit margins to guarantee work safety. They also have limited resources and can rarely receive appropriate support, which makes their work safety a mere formality (Liu et al., 2015; Tetsuji, 2000). Employees are not fully aware of the risks inherent in their jobs, and the market mechanism cannot avoid occupational injury risks (Brockner et al., 2004). When conducting supervision, the government pays too much attention to quantitative indicators and the time when firms reach standards, making the work safety in MSEs a "passive reaction" model (Bibbings, 2003; Mei, Wang, et al., 2018; Mei, Zhong, et al., 2018). Third-party work safety service agencies, which lack supervision and restraints, are more concerned with meeting standards more easily. Hence, we can say that in high-risk industries, MSEs, government safety supervision departments, and work safety service organizations are too formalistic in work safety (Kines et al., 2013), as follows.

MSEs in high-risk industries have weak work safety resources. First, there are many potential safety hazards in their infrastructure. Unlike large and

medium-sized enterprises, these firms have limited financial strength. In a fiercely competitive market, they focus on firm expansion, technology upgrades, production, and operations, but pay little attention to infrastructure (Chen & Zorigt, 2013). As a result, there are fewer invested resources and many hidden dangers in their production, especially in locations with large distribution density. Second, business owners have a poor awareness of work safety. Some lack the ability to find and eliminate potential safety hazards, and their understanding of "safety" only comes from government regulatory requirements (Hohnen & Hasle, 2018; Jiang et al., 2017; Wang, 2019). They carry out work safety management based solely on experience. Finally, there are hidden risks: some enterprises disregard employees' rights to work safety, reduce work safety training for front-line workers, and cut down on training processes. For risk source posts, management methods of occupational safety and health are relatively backward (Dakkoune et al., 2018). Firms are unable to coordinate work safety, leading to the failure to develop a comprehensive security system (Zhong, 2016).

The supervision by government departments on the work safety behavior of MSEs in high-risk industries is obviously inadequate. On the one hand, they are unable to curb accidents by punishment or rectification (Cunningham & Sinclair, 2015; Ma & Zhao, 2018). When an accident occurs, the government requires the enterprise to stop production for rectification or even close down, which has become a common response in China. But MSEs often see serious accidents, which means it is difficult to prevent accidents completely. In some chemical industry parks, after serious work safety accidents, all enterprises stop production for rectification for over 6 months (Hausken & Zhuang, 2016; Huang & Liang, 2013). No matter whether or not enterprises meet work safety standards, the government department responsible adopts a one-size-fits-all measure. Some MSEs are indeed forced to close down and dismantle their production workshops (Huang et al., 2013; Dakkoune et al., 2018). On the other hand, enterprises take a negative attitude towards regulatory policies of local safety supervision departments (Xiao et al., 2018). China has gradually standardized the compliance requirements for MSEs in high-risk industries and raised the standard of accident compensation. However, business owners have a poor awareness of work safety and lack the initiative and ability to ensure work safety (Liu et al., 2016; Yu, 2019). Enterprises are therefore likely to cope with inspections by safety supervision departments passively, and refusal to rectify and undertaking perfunctory rectification are quite frequent.

Local governments provide insufficient subsidies. They offer various forms of work safety subsidies to enterprises that have purchased services or entrusted them to implement standards. In order to ensure enterprises meet work safety standards, the local government will give a one-time subsidy or pay half of the service fee, and so on. The subsidy standard varies and depends on the financial strength of the local government (Chen & Chen, 2012; Tudor et al., 2007). However, MSEs in high-risk industries are under great pressure to survive. Faced with risks, they believe that the requirements for and costs of implementing the standards are relatively high, and they are unable to meet the standards by themselves. Moreover, the costs of purchasing related services are too high and there is a great gap between subsidies and implementation costs. All this makes them unwilling to implement work safety.

The service level of work safety service agencies is low. The *Law of People's Republic of China on Work Safety*, revised in 2014, makes it clear that it is urgent for MSEs in China's high-risk industries to introduce third-party entities and standardize the implementation of related standards (Hohnen & Hasle, 2018). Firms need to purchase work safety services from the market to meet the standards. However, work safety service agencies vary in qualifications and service quality. Some local safety supervision departments may recommend two or three agencies. But most are attached to government departments, with limited service content and low service level. There may also be collusion between enterprises and service agencies (Mei et al., 2009; Mullen et al., 2017).

These problems have an impact on the decision-making of MSEs in high-risk industries, leading to unsafe work behaviors. Moreover, a casual attitude and limited resources make the work safety of MSEs a passive behavior under constraints (Ma et al., 2016;

Mei et al., 2017). To transform this process into an active one, we need to enhance the work safety resource strength of enterprises, strengthen government regulation, increase government subsidies, and improve the services of related agencies. Based on stakeholder theory (Freeman, 1984; Santos et al., 2013), this paper investigates the multi-agent interaction among MSEs in high-risk industries, government safety supervision departments, and work safety service organizations. The implementation process of work safety in MSEs is described through computational exercises. By observing the evolution law of the work safety behavior of these enterprises through exercises, we can explore effective ways for different entities to encourage firms to ensure work safety.

2 Evolution model construction

In business work safety behavior, there are three main players: MSEs in high-risk industries, government safety supervision departments, and work safety service agencies. Both regulators and the regulated may demonstrate rational or irrational behaviors. Each is highly intelligent and has self-learning ability (Cardenas, 2009; Ma et al., 2009). In order to standardize the work safety behavior of MSEs, they are intertwined with each other and have defined their own behavioral features, thus forming a complex system where "human beings are involved in nature and play a leading role" (Epstein, 2005; Sheng & Li, 2010; Jiang & Sheng, 2009). Each entity in this complex system interacts in a specific way, in which MSEs guide them to choose work-safe behavior based on their self-learning abilities (Wang et al., 2007). They take the internal driving forces and external binding forces into account and finally implement work-safe behavior (b_1) or work-unsafe behavior (b_2). They can purchase services to implement work safety behavior (service work safety behavior, b_{11}) or meet the standards independently (independent work safety behavior, b_{12}).

2.1 Problem description and assumptions

2.1.1 Problem description

At the initial stage, the work safety system produces a certain number of enterprises firm agent (Bankes, 2009). The production process and work safety process are carried out simultaneously. MSEs in high-risk industries implement production tasks after obtaining resources such as capital, raw materials, and labor. Under the internal drivers (work safety resource strength, risk consciousness, enterprise past behavior, and work safety attitude) and external constraints (from government safety supervision departments, work safety service agencies, and social environment), this forms an initial work safety attitude S_A and the work safety critical value S_{A_0}. Here, S_A is the initial attitude of the MSE's owners. The work safety attitude of business owners shows that business owners attach importance to work safety, which largely determines the investment level of work safety and has a direct impact on the behavior decision-making around work safety (Liu et al., 2017). The value of S_A is randomly generated by the system in a certain range (0,1), and the value of S_{A_0} decides whether the enterprise implements work safety behavior or work-unsafety behavior. Because of the casual attitude from the MSEs' business owners in high-risk industries, the value of S_{A_0} is a relatively low level. Here, the value of S_{A_0} is 0.2 (Liu et al., 2020). When $S_A \geq S_{A_0}$, the firm agent will perform work safety behavior; otherwise, it will conduct work unsafety behavior.

When an enterprise is engaged in work safety behavior, it can judge whether to purchase services based on its work safety income, which is affected by internal and external environmental factors. If it decides to do so, it should choose the most appropriate work safety service agencies (service agent) in the market and determine the type and form of the service in the contract. Then it can obtain the technology and resources needed for work safety assessment, training, and testing. Hence, the agency can help and encourage the enterprise to carry out work safety behavior (Awwad et al., 2016). If the firm does not choose to purchase services, the work safety behavior will be realized by using its own resources, including special safety supervision personnel, work safety funds, and work safety resources.

Whether or not the MSEs implement work safety behavior, the government safety supervision department (government agent) will conduct regular supervision and may check for hidden dangers.

For those that meet the standards, the government will provide cash rewards or policy tendencies (e.g., the department gives priority to the extension of work safety licenses or provides tax reductions and fee reductions) (Nelson & Winter, 2002). If an enterprise reaches the work safety standard through work safety services, the government will further offer it special subsidies. If work-unsafe behavior is found in the supervision process, the department will impose a fine and compel the firm to meet the standards before it can resume operations.

When a work safety accident occurs in an MSE, the government will immediately intervene to ensure rescue, undertake a qualitative analysis of reasons, identify the responsible person(s), and investigate casualties. Then it will impose economic penalties and sanction the firm. For high-risk industries studied in this paper, the local government takes a one-size-fits-all approach, ordering all firms to suspend production for rectification, even shutting down all firms until all of them meet work safety standards.

According to the account above, the interaction process of MSEs in high-risk industries, the government safety supervision department, and work safety service agencies is defined as shown in Fig. 1.

2.1.2 *Assumptions*

The actual operation process of enterprise work safety is complex. In order to accommodate the work safety situation of MSEs in high-risk industries and simplify the evolution model, the following assumptions are made:

(1) In the work safety system, all MSEs are manufacturing corporations. Taking the costs and accident losses into account, the benefits can be calculated based on the Cobb–Douglas production function.
(2) There are only two types of resources required for production and operation: raw materials and human resources. The supply of raw materials from the market is sufficient and there is no price fluctuation. Enterprises can hire employees conveniently in the human resource market and wages remain unchanged.

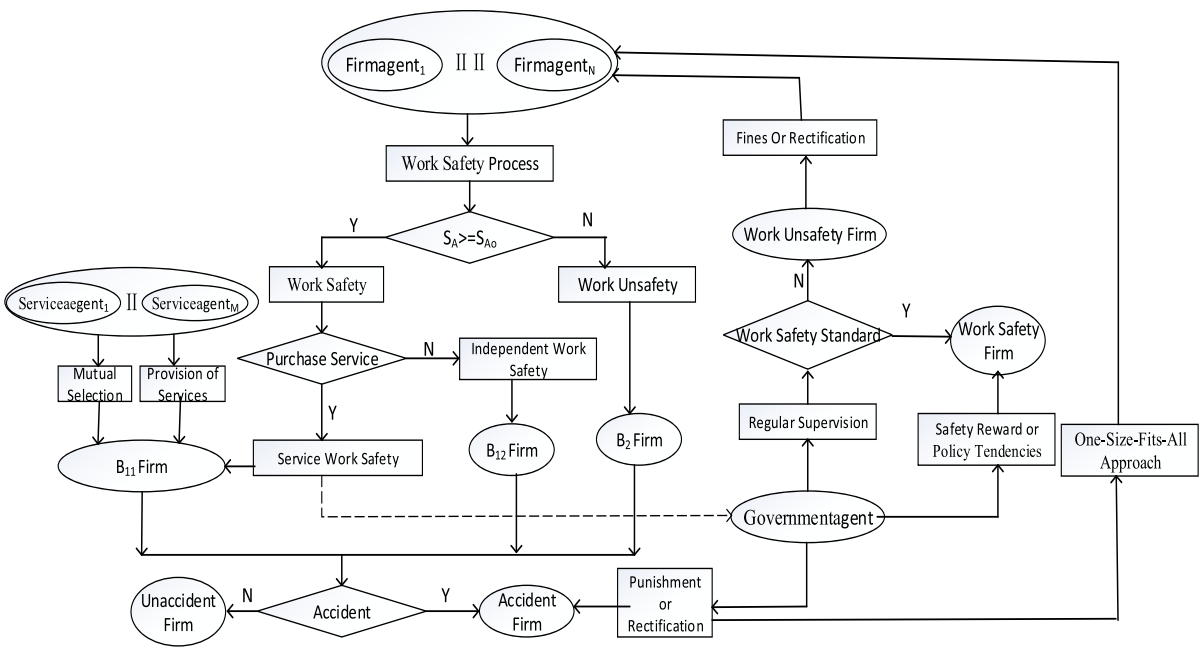

Fig. 1 Interaction process of three main entities in work safety behavior system of MSEs in high-risk industries

(3) The products have the same quality. Once they are launched on the market, the demand exceeds the supply and the sales price is stable.
(4) The choice of work safety behavior is limited and rational. Because of information asymmetry, the enterprises cannot obtain complete external information, thus leading to erroneous judgments, wrong behavior, and finally the failure to implement work safety (Mei, Wang, et al., 2018; Mei, Zhong, et al., 2018).
(5) The government safety supervision department is a single entity. We take no account of the multi-dimensional and all-round control of provinces, cities, counties (districts), and towns.
(6) In the service market, there are numerous work safety service agencies and their services are standardized. Malicious competition and price reduction are ignored. MSEs can obtain work safety services with quality and quantity after signing a contract.

2.2 Main entities of complex system

In the work safety system for MSEs in high-risk industries, there are three main entities: MSEs with some work safety resources, government safety supervision departments that provide supervision and service subsidies for work safety, and work safety service agencies that provide technology and monitoring. These entities interact in a specific way in complex systems. With the change of external environmental constraints (Mei et al., 2015), each entity guides MSEs to choose work safety actions based on its self-learning mechanism. We discuss three abstract entities in this paper: MSEs (firm agent), government safety supervision departments (government agent), and work safety service agencies (service agent).

2.2.1 Firm agent

(1) Production and operation

The MSEs in high-risk industries researched are manufacturing enterprises. The combination, distribution, and use of their own production factors enable different enterprises to realize the production and sales of final products, thus gaining earnings ($E_{i,t}$), where t represents the period (the value range is 1, 2, …, T). It is assumed that the profit $E_{i,t}$ is uniformly distributed within a certain range $E_{i,t} \sim U(e_1, e_2)$.

(2) Costs in work safety

MSEs must invest resources to achieve work safety, which will affect the enterprise's work safety level $SD_{i,t}$ (or safety degree). Based on the cost function (Luo, 2007; Walker & Tait, 2004), the safety degree can be deduced and expressed as $SD_{i,t} = 1 - {}^{c}\!\Big/_{\ln(SI_{i,t}+C_0)} - lnC$, where $SI_{i,t}$ is the work safety capital input, C_0 is the cost of safety engineering facilities, C is the other costs, and c is a constant (C_0, C, and c>0). The value of C_0 is based on the investment proportion of safety engineering facilities in different industries in China (the minimum one is 1%).

Work safety costs include capital input ($SI_{i,t}$) and personnel cost (L_C), and the holding of safety resources will influence the work safety behavior of business owners. The relationship between the demand for safety services and the strength of safety resources (Liu et al., 2016) is that the greater the strength of safety resources, the greater the cost in work safety. Therefore, the work safety cost is $SI_{i,t} = P_t * R_S$, where R_S (0,1) is the standardization of the maximum cost that the enterprise can bear. P_0 is the initial investment of safety infrastructure (Aven & Hiriart, 2013) and based on the investment proportion of work safety expenses in different industries in China (the minimum one is 1%). P_0 is related to safety service costs of the service agent ($Scost_{j,t}$) with the increasing of t. In the t period, P_t (cost in work safety infrastructure) is expressed as:

$$P_t = \begin{cases} P_0 \ \ if\ t = 1 or (t \geq 2\ and\ (b = b_2\ or\ b = b_{12})) \\ k * S\cos t_{j,t} \ \ if\ t \geq 2\ and\ (b = b_{11}) \end{cases} \tag{1}$$

where k is an adjustment parameter of work safety input. In the first period, P_t is the initial cost in work safety infrastructure — P_0. If the enterprises then implement work safety service (b_{11}), the cost will be adjusted according to the operating cost ($Scost_{j,t}$) of purchased services. If enterprises want to realize work safety by chance or

Table 1 Work safety status

Work safety status	Safe	Unsafe
Probability	$SD_{i,t}$	$1 - SD_{i,t}$
Total value	$SD_{i,t}$	1

are lacking in work safety resources, they will not cost in work safety or implement independent work safety, and they will maintain the initial infrastructure (Song & Mu, 2013).

(3) Work safety output

When MSEs choose service work safety, the work safety output can be determined as in Walker and Tait (2004), i.e.:

$$Y_{i,t} = B * SI_{i,t}^{\alpha_1} * L_C^{\beta_1} * e^{u} \tag{2}$$

where B represents the level of work safety, α_1 represents the output elasticity when implementing work safety service, β_1 describes the output elasticity under the human resources cost of work safety management departments required for work safety service, and e^u is random interference factors affecting output.

When they choose independent work safety, the work safety output can be determined as:

$$Y_{i,t} = B * SI_{i,t}^{\alpha_2} * L_C^{\beta_2} * e^{u} \tag{3}$$

where α_2 represents the output elasticity when implementing independent work safety, β_2 represents the output elasticity under the human resources cost of work safety management departments required for independent work safety, and e^u represents the random interference factors affecting output.

Here, the values of these parameters are determined by *the assessment coefficient method of work safety responsibility system*.

(4) Income from work safety

According to the calculation standard of work safety income ($E_{i,t}^{a}$) in Luo (2017), it is considered that the difference between work safety output and input is the value-added income obtained after the implementation of work safety. The expression is shown as:

$$E_{i,t}^{a} = Y_{i,t} - SI_{i,t} \tag{4}$$

(5) Work safety accidents

The causes of accidents in MSEs in high-risk industries are complex. If we use $SD_{i,t}$ to express the work safety probability, the greater the value, the higher the work safety degree, and the smaller the accident probability. Usually, the probability of accidents can be simulated by roulette (Luo, 2017), and the specific steps are as follows:

Step 1: Determine the safety status table according to $SD_{i,t}$ values of work safety accidents of MSEs, as shown in Table 1.

Step 2: Generate a random number γ, $\gamma = random(0, 1)$.

Step 3: Compare γ with $SD_{i,t}$. When $\gamma \le SD_{i,t}$, work safety accidents do not occur, and when $SD_{i,t} < \gamma < 1$, accidents happen.

In the case of a work safety accident, the accident loss can be calculated by using the loss function $L(SD_{i,t})$ in the safety economics model, and the expression is shown as (Luo, 2007, 2017):

$$L\left(SD_{i,t}\right) = L * exp\left(\frac{l}{SD_{i,t}}\right) + L_0 \tag{5}$$

The accident loss is compensation excluding casualties, and the compensation for casualties will be paid according to the regulation policy of the government agent. Here, L is the economic loss of enterprises, L_0 is the accident loss before implementing safety act, l is the regulation parameter, L, L_0, and l are all greater than 0, and $SD_{i,t}$ is the set work safety level of enterprises.

(6) Profit expectation

MSEs aim to gain profits and maximize profits through legal production. Therefore, when calculating the expected profit of the enterprise, we should consider the enterprise's production income $E_{i,t}$, work safety income $E_{i,t}^{'}$, the fine lines $P_i(t)$, and accident fine $P_i^f(t)$ when government supervision $M_{i,t}$ is not up to standard (the standard is S_0), the government subsidy $Subsidy_{i,t}$ for work safety service, and the loss caused by the accident $L(SD_{i,t})$(Liuetal.2020). In the process of calculating expected profit, an indicative function $I(\bullet)$ (valued 1 or 0) is used to represent different results caused by different conditions. The calculation expression is shown as:

Table 2 Law of probability adjustment of work safety input in MSEs

Change of safety cost compared with the previous period	Change of corporate income compared with the previous period	Change of probability
Increase	Increase	$\left(p_d+\omega\to p_d, p_i+\frac{\omega}{2}\to p_i, p_c-\frac{\omega}{2}\to p_c\right)$
	Reduce (or remain unchanged)	$\left(p_d-\omega\to p_d, p_i+\frac{\omega}{2}\to p_i, p_c+\frac{\omega}{2}\to p_c\right)$
Reduce	Increase	$\left(p_d-\frac{\omega}{2}\to p_d, p_i+\omega\to p_i, p_c-\frac{\omega}{2}\to p_c\right)$
	Reduce (or remain unchanged)	$\left(p_d+\frac{\omega}{2}\to p_d, p_i-\omega\to p_i, p_c+\frac{\omega}{2}\to p_c\right)$
Unchanged	Increase	$\left(p_d-\frac{\omega}{2}\to p_d, p_i-\frac{\omega}{2}\to p_i, p_c+\omega\to p_c\right)$
	Reduce (or remain unchanged)	$\left(p_d+\frac{\omega}{2}\to p_d, p_i+\frac{\omega}{2}\to p_i, p_c-\omega\to p_c\right)$

$$Profit_{i,t}=\begin{cases}E_{i,t}+E^a_{i,t}-P_i(t)\ *\ I\left(M_{i,t}=1,\ SD_{i,t}<S_0\right)+Subsidy_{it}-\left(L\left(SD_{i,t}\right)+P^f_i(t)\right)*I(accident=1) & if\ b=b_{11}\\ E_{i,t}+E^a_{i,t}-P_i(t)\ *\ I\left(M_{i,t}=1,\ SD_{i,t}<S_0\right)-\left(L\left(SD_{i,t}\right)+P^f_i(t)\right)*I(accident=1) & if\ b=b_{12}\\ E_{i,t}-P_i(t)\ *\ I\left(M_{i,t}=1,\ SD_{i,t}<S_0\right)-\left(L\left(SD_{i,t}\right)+P^f_i(t)\right)*I(accident=1) & if\ b=b_2\end{cases} \tag{6}$$

When MSEs implement work safety behavior (b_{11} or b_{12}), the expected profit of the enterprise should include work safety income $E^a_{i,t}$. When MSEs purchase services to implement work safety behavior (b_{11}), the profit should consider the $Subsidy_{i,t}$ provided by the local government. When MSEs choose the service work safety behavior (b_{11}), if the enterprise's work safety level is not up to standard ($SD_{i,t}<S_0$), the enterprise will receive a fine $P_i(t)$. When an accident happen, enterprises will receive the loss caused by the accident $L(SD_{i,t})$and the accident fine $P^f_i(t)$.

(7) Self-evolution mechanism

As an adaptive entity, MSEs will alter work safety decisions with changes of the external environment. Therefore, their safety cost $SI_{i,t}$ and work safety service demand *Sdemand* will change periodically according to previous results.

2.3 Adjustment of work safety cost

Step 1: Set the probability vector $p=(p_d,p_i,p_c)$ for the change of enterprise work safety cost, where p_d indicates the probability of reducing the cost in the next period, p_i shows the probability of increasing the cost in the next period, and p_c represents the probability of maintaining the same cost in the next period, then $p_d+p_i+p_c=1$.

Step 2: The enterprise should judge whether to increase or decrease the cost in this period based on the situation of the previous period, and whether the income in this period is increasing or decreasing. A comprehensive judgment with the probability adjustment rules is provided in the following Table 2.

Step 3: By comparing with the previous period, we can determine the input adjustment strategy in this period. A random number $\gamma'=[0,1]$ is introduced to judge which strategy the enterprise should choose, as shown:

$$SI_{i,t}=\begin{cases}SI_{i,t-1}-F_d & 0\le\gamma'<p_d\\ SI_{i,t-1}+F_i & p_d\le\gamma'<p_i+p_c\\ SI_{i,t-1}*1 & p_i+p_c\le\gamma'\le 1\end{cases} \tag{7}$$

where F_d and F_i represent the reduction and increase amount of the enterprise's safety cost in this period respectively.

2.4 Adjustment of work safety service demand

The self-evolution mechanism of work safety service demand *Sdemand* is similar to that of enterprise work safety cost, so we will not repeat the explanation.

2.4.1 Government safety supervision department

Supervision of the government department The government department carries out daily inspections on MSEs. If any enterprises that fail to meet the standards are found, they will be ordered to rectify and receive a fine ($P_{i,t}$). The amount of the fine is determined by the gap between the work safety standard (S_0) formulated by the government and that of the enterprise. The larger the gap, the greater the punishment. The specific rules are shown in Eq. (8):

$$P_{i,t} = \begin{cases} \delta * \left|SD_{i,t} - S_0\right| & M_{i,t} = 1 \ and \ SD_{i,t} < S_0 \\ 0 & M_{i,t} = 1 \ and \ SD_{i,t} \geq S_0 \\ 0 & M_{i,t} = 0 \end{cases} \quad (8)$$

where $\delta(\delta > 0)$ is the extent to which the government punishes the enterprise (the quantity is adjusted according to how seriously the work safety is not up to standard), and $M_{i,t}$ is the supervised situation of the enterprise in the t period. When the value is 1, it is supervised; when the value is 0, it is not supervised.

In addition, when a work safety accident occurs in an MSE, the government department will subsequently determine the responsibility. It will identify the accident, determine the person in charge, consider the casualties, and impose and economic punishment ($P_i^{'}(t)$) on the enterprise, which is expressed as:

$$P_i^{'}(t) = \begin{cases} PH_{i,t} & accident = 1 \\ 0 & accident = 0 \end{cases} \quad (9)$$

where $accident = 1$ indicates that the enterprise has a work safety accident, and $accident = 0$ denotes that it has no such accident.

"One-size-fits-all" measures of the government department Owners of MSEs in high-risk industries have poor awareness of and limited resources for safety in production. This type of enterprise, especially MSEs in the chemical industry which have constant potential safety hazards, is prone to accidents in production. Despite law enforcement, supervision, and rectification, MSEs tend to "muddle through" their work, even commit fraud, and eventually this leads to great disasters. After a major or particularly serious production accident, the government often takes a "one-size-fits-all" approach and shuts them all down. Moreover, in the process of park management, both enterprises with work safety and those with potential safety hazards will all be rectified. If the rectification fails, the relevant enterprises in this industry will be shut down directly.

Special subsidies for work safety ($Subsidy_{i,t}$) In addition to mandatory supervision, the government safety supervision department will also give incentives and subsidies to enterprises. This paper only considers the standard definition of special subsidies for enterprises that meet the standards after seeking socialized service of work safety service institutions. The normative expression of the subsidy is:

$$Subsidy_{i,t} = \begin{cases} \rho * Sincome_{j,t} & if \ SD_{i,t} \geq S_0 \ and \ b = b_{11} \\ 0 & if \ SD_{i,t} < S_0 \ or \ b = b_{12} \ or \ b = b_2 \end{cases} \quad (10)$$

where ρ indicates the extent to which the government subsidizes the purchase of services by enterprises, and $Sincome_{j,t}$ denotes the business turnover of work safety services.

2.5 Work safety service agencies

Providing work safety services According to the content and scope of services provided, service agencies will sign agreements with MSEs and determine relative responsibilities. Then the agencies will provide enterprises with a series of technologies and resources required for safety training and evaluation. In each period, the work safety service agencies determine their business income ($Sincome_{j,t}$) through contracts with several enterprises. The specific expression is shown below:

$$Sincome_{j,t} = SI_{i,t} * \vartheta \quad (11)$$

where ϑ indicates the proportion of services purchased by enterprises in its total work safety input (SF_{C0}), and the value is between 0 to 1.

Table 3 Range of values and assignment rules of global variables required in simulation exercises

Variable name	Semantic interpretation	Value range	Define rules
S_{A_0}	Critical value of work safety attitude of MSE owners	0.2	Constant, fixed value
P_0	Initial investment of safety infrastructure (unit: yuan)	10,000	Results of multiple tests and trainings
k	Adjustment parameter of work safety input	500	Results of multiple tests and trainings
B	Work safety level	3	Results of multiple tests and trainings
α_1	Output elasticity of MSEs in implementing service-oriented work safety (b_{11})	0.5	Results of multiple tests and trainings
α_2	Output elasticity of MSEs in implementing independent work safety (b_{12})	0.3	Results of multiple tests and trainings
β_1	Labor output elasticity required for service-oriented work safety (b_{11})	0.5	Results of multiple tests and trainings
β_2	Labor output elasticity required for independent work safety (b_{12})	0.3	Results of multiple tests and trainings
L_C	Number of safety officers (unit: person)	1–3	According to the *Work Safety Law* and the characteristics of high-risk industries
L	Economic losses of MSEs (unit: yuan)	5000	Constant, fixed value
L_0	Accident loss before the work safety behavior of MSEs (unit: yuan)	500	Constant, fixed value
F_d	Reduced amount of work safety investment of MSEs in current period (unit: yuan)	50	Constant, fixed value
F_i	Increased amount of work safety investment of MSEs in current period (unit: yuan)	25	Constant, fixed value
S_0	Work safety standard	0.3	Constant, fixed value
C_O	Cost of safety engineering facilities (unit: yuan)	10,000	Results of multiple tests and trainings
C	Other costs (unit: yuan)	500	Results of multiple tests and trainings

On the basis of contractual constraints and funds paid by the enterprise, the service agency determines the cost of the enterprise's work safety service ($Scost_{j,t}$). The agency will in turn also consider its own service level σ ($0<\sigma<1$). The cost of work safety service is expressed as follows:

$$Scost_{j,t} = \sigma * Sincome_{j,t} \tag{12}$$

Determining profits of the service agency The actual profit of the service agency is calculated by considering the business income ($Sincome_{j,t}$) and the actual business expenditure ($Scost_{j,t}$). It is calculated by:

$$Sprofit_{j,t} = \sum_{j=1}^{M} Sincome_{j,t} - \sum_{j=1}^{M} Scost_{j,t} \tag{13}$$

The service agency will determine the service objects and contents of the next period by analyzing the benefits and responsibilities of the current period.

3 Parameter definition and simulation analysis

3.1 Parameter definition of simulation exercises

In simulation exercises, we set the number of main entities at three: MSEs in high-risk industries (*num-firm*), service organizations (*num-service*), and the government safety supervision department (only 1). Based on this, we further defined the global variables needed for the computer-based simulation and related variables involving the government department and service agencies. Combined with the actual situation and objective

facts, we selected some variables and set relevant parameters; some parameters, which are difficult to quantify, are obtained after many tests and training and comparing the actual situation (Camerer & Ho, 2010), as shown in Table 3.

3.2 Simulation exercises and result analysis

Based on agency-based modeling (ABM) technology (Sheng & Zhang, 2011; Liu et al., 2009), a dynamic and self-learning system for work safety is constructed in this paper. Simulation exercises were carried out on the Netlogo5.3.1 platform. The programming was realized by Logo language, and exercises were conducted in a 32*32 two-dimensional view. Considering different decision-making results of work safety behavior, the MSEs of service-oriented work safety (b_{11}) are set to be red, those enterprises of independent work safety (b_{12}) to be yellow, and those of work-unsafety (b_2) to be green. The parameters were adjusted under four conditions: work safety resources of enterprises, government supervision intensity, service subsidy degree, and work safety service level.

3.2.1 Effect of work safety resources change of MSEs on work safety behavior

Simulation exercises provide external environment with low government punishment and limited access to resources, and studies how work safety resources change influence work safety behavior. We changed the value of enterprise work safety resource (R_S) and fixed other parameters of this model. R_S varied between 0 and 1, and four interval values were set for comparison, which were (0.1,0.2), (0.2,0.4), (0.4,0.7), and (0.7,0.9). In addition, we fixed other parameters of this model: the government punishment intensity (δ) is 1000, the service level (σ) is 0.1, and the service subsidy (ρ) is 0.1. The number of iterations was set to be 200, and this was the same in the following three exercises.

With the safety resources of MSEs improving, the work safety profit ($Profit_{i,t}$) is gradually increasing, but the development of growth rate and income is not obvious. When the R_S value is within the range of (0.1,0.2), the external environment resources are scarce, the work safety strength of MSEs is at a low level, and the work safety investment is relatively low. Therefore, the average income of enterprises is lower, at only around 10,000 yuan. Low income will lead to low enthusiasm of MSEs to implement work safety, which will further generate the mainstreaming of work-unsafety behavior. When R_S is within the ranges of (0.2,0.4) and (0.4,0.7), with the improvement of the enterprises' work safety resources and their willingness to increase investment in work safety, their average income shows a gradual increase, approaching the highest point of 35,000 yuan. High income will stimulate enterprises to implement work safety. However, when the value of R_S is within (0.7,0.9), the average income of MSEs is decreasing. It further shows that, when the external environment is under low control and the subsidies are limited, the enthusiasm of the enterprises to implement work safety is inadequate, which greatly hinders them from practicing work safety.

With the work safety resources increasing, MSEs have gradually changed from work unsafety to work safety. They gradually rely on their own strength to realize independent work safety instead of seeking services, as shown in Fig. 2.

When the evolution becomes stable, it is found that, when the parameters of the external environment are at a low level, more MSEs gradually change their attitude towards work safety with the increase of work safety resources. They are willing to increase their investment in work safety, and pursue work safety behavior. The average value of work safety income is constantly improving, which means their initiative and enthusiasm for work safety are improving steadily. However, due to the low level of service provided by service agencies, MSEs tend to conduct work safety independently.

3.2.2 Effect of the change of government supervision on work safety behavior

In simulation exercises, the punishment level δ implemented by government agent for enterprises was changed to 1000, 3000, 6000, and 9000, respectively. When government does not provide a work safety subsidy, the other parameters of this model are fixed. In this case, enterprises' work safety resources strength R_S is distributed proportionally between (0, 1), the service subsidy provided by the

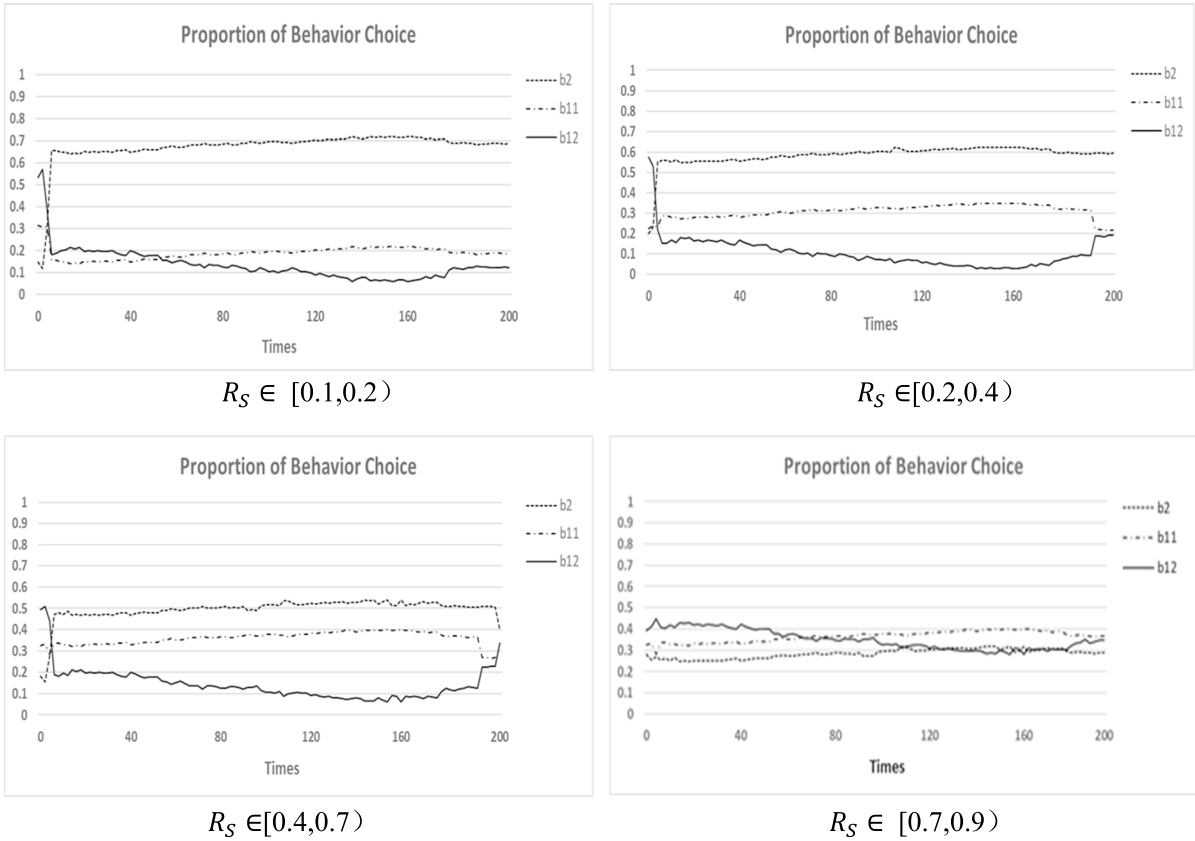

Fig. 2 Work safety behavior change of MSEs under different strength of work safety resources in high-risk industries

government is $\rho = 0$, and the service level of service agent is $\sigma = 0.5$.

In simulation exercises, fine or penalty is the main way of government supervision. When $\delta = 1000$, the increase trend of enterprise work safety ($Profit_{i,t}$) is not obvious. It can be seen that at this stage, the government supervision is inadequate and work safety subsidy is insufficient. Meantime, most MSEs take chances to ignore work safety standards and hazard sources, which may cause violations from time to time. When the value of δ is 3000, the average income increases obviously. The government strengthens supervision, the penalty amount is higher, and the enterprises are willing to buy services to practice work safety. When δ is 6000 and 9000, the work safety income of the enterprises hardly changes, the overall average value is declining, and the income displays a significant decreasing trend. It can be seen that, if the government agent controls its punishment in a certain range, strengthening the penalty is conducive to guiding the work safety behavior of MSEs. However, when the punishment is too strict, the supervision will not guide work safety effectively due to limited work safety resources of companies.

When δ is 1000, the supervision is low, MSEs are likely to take risks and break rules, thus causing a large proportion of work-unsafety. With supervision strengthened, the proportion of enterprises implementing service-oriented work safety is gradually increasing. But the automatic work safety behavior changes little. This is because government's requirements for MSEs in high-risk industries are mandatory and those companies' strength is limited, and they can only seek the support of service agents to implement work safety behavior. However, when δ is 9000, the number of work safety enterprises decreases slightly, while work-unsafety enterprises increases slightly. This further indicates that too strict government

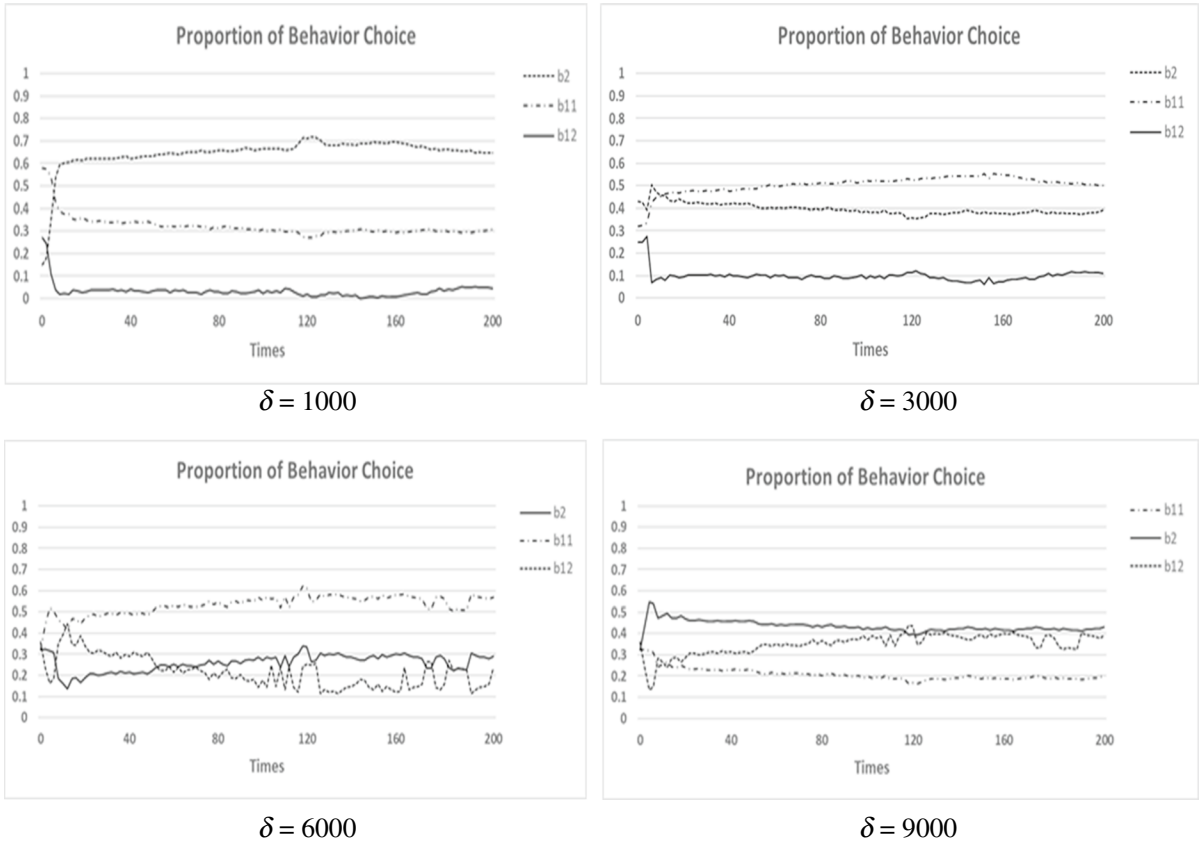

Fig. 3 Trend chart of MSEs' work safety behavior change under different supervision levels in high-risk industries

supervision may not be able to effectively guide MSEs to carry out work safety, as shown in Fig. 3.

3.2.3 Effect of the adjusting government subsidy on work safety behavior of MSEs

In simulation exercises, the value of the service subsidy ρ provided by the government agent is changed, and the different levels of government service subsidy are set as 0.2, 0.5, and 0.8, respectively. The strength of enterprise work safety resources R_S was distributed in proportion between (0, 1), the punishment adopted by government on enterprises $\delta = 3000$, and the service level of organizations is $\sigma = 0.5$.

With the value of ρ increasing gradually, the enterprise work safety ($Profit_{i,t}$) increases significantly. This shows that, if the government agent increases the service subsidy, MSEs who are willing to purchase work safety service will further increase their investment in work safety. Thus, those companies' strength of work safety resources will be enhanced, the implementation of safe standards will be accelerated, and the profit of work safety will be promoted accordingly. Therefore, raising the level of government service subsidy will help improve the internal driving force of MSEs to manufacture safely.

After the government implements three types of subsidy policies (high, medium, and low), the enterprises that employ service-oriented work safety behavior are in the majority. With the increase of the subsidy, the proportion of enterprises that adopt automatic work safety behavior changes little, while the proportion that does not employ work safety decreases. Therefore, a service subsidy has little influence on those enterprises that intend to implement autonomous work safety behavior. With the improvement of the service subsidy, more and more

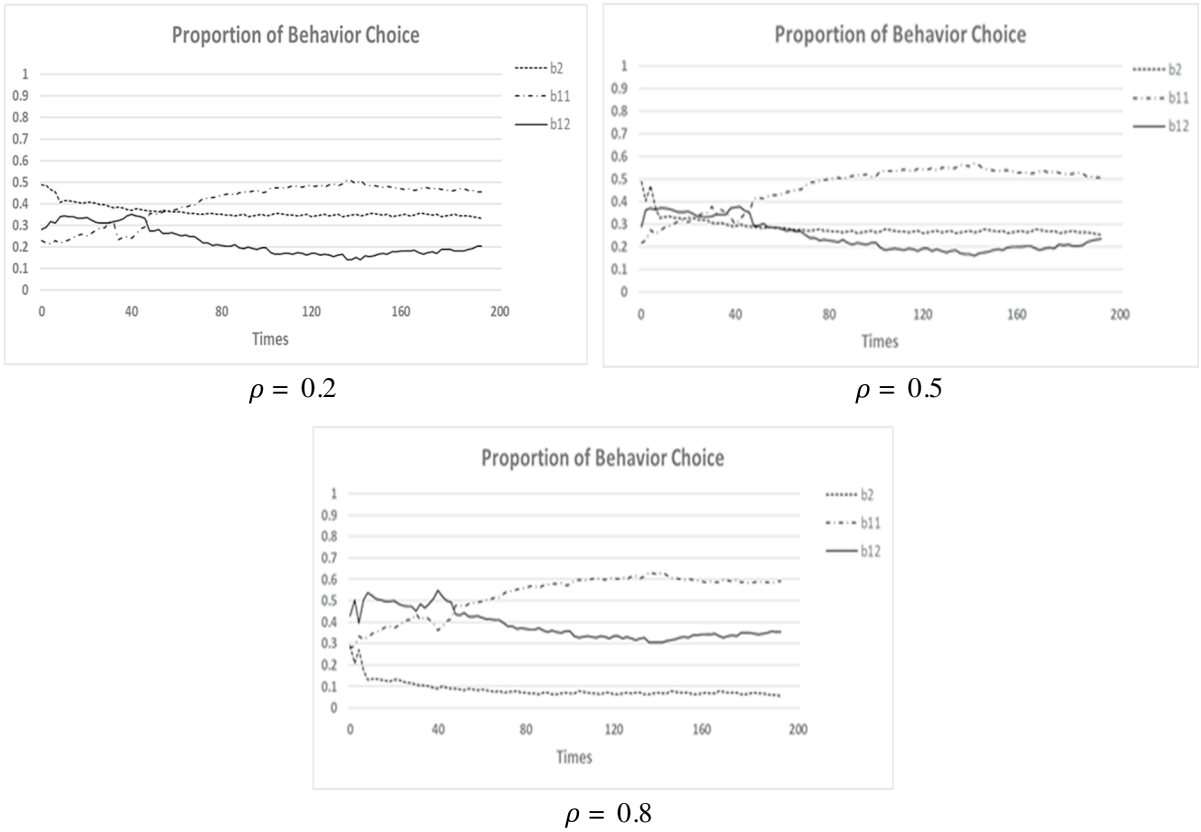

Fig. 4 Trend chart of MSEs' work safety behavior change under different service subsidy levels in high-risk industries

enterprises are willing to implement service-oriented work safety, as shown in Fig. 4.

3.2.4 Effect of service agent's promotion of work safety service level on MSEs' work safety behavior

In simulation exercises, we changed the value of service agent (σ). Considering the proportion of enterprises with resource strength, four values (0.2, 0.4, 0.6, and 0.8) were set to represent the different service levels of service agent. The government agent only provided a work safety service subsidy for enterprises that purchased services and met the standards. The government punished enterprises with intensity $\delta = 5000$ and the work safety service subsidy is $\rho = 0.5$.

With the value of σ increasing, the value of $Profit_{i,t}$ rises gradually. From the results after stabilization, the average value changes from 23,600 to 78,800, showing an obvious upward trend. It is found that, after purchasing high-quality work safety services, enterprises will enhance their work safety awareness through work safety training, on-site guidance, and other measures. These approaches help enterprises identify hazards effectively and avoid those that are hidden. Enterprises are more willing to increase investment in work safety to change their work environment, provide their employees with security measures and supplies, avoid damage that may be caused by accidents as much as possible, and further improve the work safety level to meet government standards. Through such measures, enterprises are likely to benefit more from work safety and stimulate a stronger awareness of work safety.

With service agents improving their service level, the number of MSEs that implement service-oriented work safety behavior increases rapidly. These enterprises enjoy an absolute advantage when σ is 0.8. As the value of σ grows, the number of enterprises that

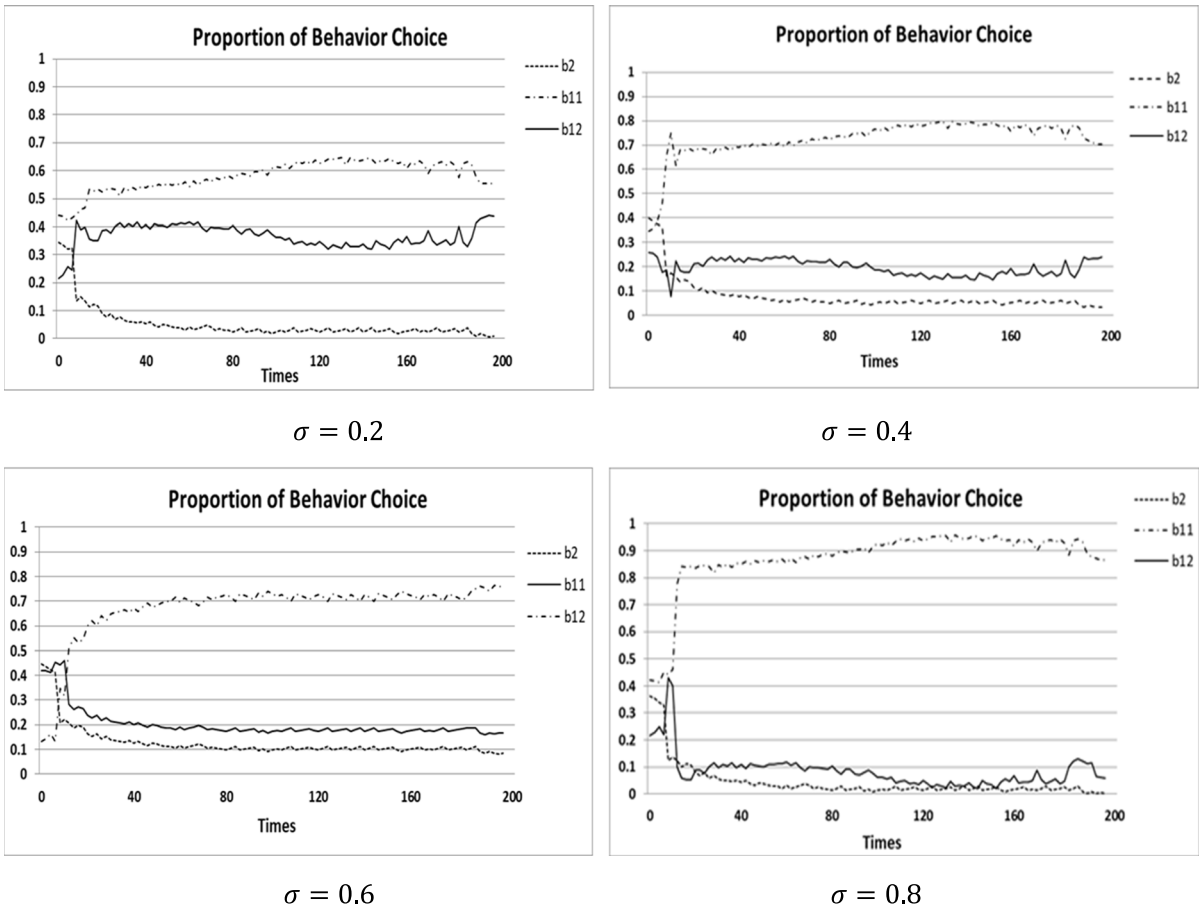

Fig. 5 Changes of MSEs' work safety behavior under different work safety service levels in high-risk industries

adopt work safety decreases sharply, and the proportion of companies that implement automatic work safety behavior decreases gradually, as shown in Fig. 5.

3.3 Robustness

In our simulation models, considering the actual situation of MSEs' work safety behavior in high-risk industries, we designed the simulation exercise with various parameters at a low level and observed the evolution trend of enterprise work safety behavior by adjusting the strength of enterprises' work safety resources, government supervision, any service subsidy provided by government agents, and the work safety service level of service agents. It is found that MSEs have gradually changed from work-unsafe behavior to work-safe behavior. This transformation is realized under the interaction and constraints of the three main agents: MSEs (firm agent), government safety supervision departments (government agent), and work safety service agencies (service agent). It can be seen that the changes in the conditions of the enterprise's internal resources and society's external environment will form interference factors and continue to act on the complex system. To ensure the robustness of our results, we model a case where the MSEs' work safety behavior in high-risk industries can transition from work-unsafe behavior to work-safe behavior (Bhawe et al., 2021).

The newly revised *Work Safety Law* (*2021*) in China proposes new norms, emphasizing that business owners are the primary persons responsible for work safety. It requires enterprises in high-risk industries to purchase safety liability insurance. The government must strengthen supervision, and the fines

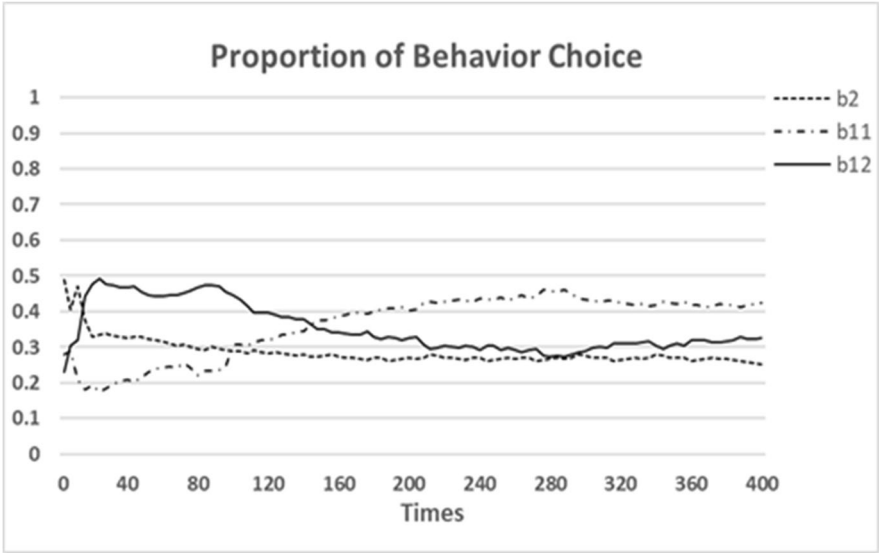

Fig. 6 Evolution trend of MSEs' work safety behavior at a high level in high-risk industries

for illegal acts should reach 40% or even 100%. The law requires local government to increase incentives for work safety enterprises. Local government should strengthen the supervision of work safety service agencies. Work safety service agencies must make public reports of safety assessment, monitoring, certification or inspection and are not allowed to issue false reports. According to these specified requirements, we simulated the exercise. The value of enterprise work safety resource (R_S) is within (0.4,0.7), the government punishment intensity (δ) is 7000, the service level (σ) is 0.6, and the service subsidy (ρ) is 0.8.

As seen from Fig. 6, at the beginning, the proportion of enterprises that choose work unsafety behavior is higher than those that choose work safety behavior. Due to the increased supervision of the government, business owners gradually pay attention to enterprise work safety and increase the investment of work safety resources. The proportion of enterprises that choose work safety is far higher than that of work unsafety enterprises. At the same time, the local government gives higher subsidies to enterprises that meet the work safety standards. However, the ability of MSEs to realize safety production standardization is weak, so that MSEs tend to choose work safety service agencies to provide services. These results are close to the evolution trend addressed by our previous exercises, and they confirm the evolution trend of work safety behavior under the high level of resources and constraints.

4 Discussion

4.1 Results and policy implications

In this paper, we use computational models and a computer-based simulation to conduct simulations on complex systems of work safety behavior of MSEs in high-risk industries. In this study, four factors — strength of enterprises' work safety resources, government supervision, service subsidy provided by government agent, and work safety service level of service agent — are changed. The evolution trends and results are analyzed, and conclusions are as follows.

(1) When government punishment is not severe and enterprises' access to resources is limited, we obtain findings by changing the strength level of MSEs' work safety resources. It is found that, without government subsidy for work safety, MSEs tend to strengthen their consciousness of actively seeking work safety behavior and increase investment to improve the level of work safety, which help promote their work safety income. With the increase of the strength of work safety resources, more MSEs gradually change their attitude towards work safety away from inaction, they are willing to increase investment in work safety and choose work safety behavior. With the average value of work safety income

increasing, the initiative and enthusiasm for work safety among MSEs are constantly improving. However, due to the low level of service provided by work safety service agencies, MSEs tend to pursue independent work safety behavior.

(2) When the government safety supervision department does not provide a work safety subsidy, findings are obtained by changing the government's supervision level. We find that, without a government subsidy for work safety, MSEs tend to strength their awareness of actively seeking work safety behavior and increase investment to improve the level of work safety, which help promote their work safety income. However, when supervision punishment is harsh, the number of MSEs implementing work safety behavior does not increase but decreases, due to their limited investment. Therefore, it is necessary to strengthen the supervision of MSEs, but its level and the punishments for breaking rules need to be controlled. Under appropriate external constraint pressure, MSEs can gain more work safety benefits and form internal driving forces to actively implement work safety.

(3) In the case of low penalties and general service level by the government agent, by adjusting the service subsidy we find that, when the government supervision is not strict, more and more MSEs hope to obtain a government service subsidy in order to adopt work safety behavior. However, there is a gap in the financial strength of local government and the service subsidy given to MSEs is different. For those companies who have an intention of employing work safety behavior but lack funds, the government's service subsidy will provide great support, but the subsidy needs to be controlled properly.

(4) If most MSEs have inadequate work safety resources, by changing the work safety service level of service agent, it is found that, when low-quality services are provided, enterprises with strong work safety awareness and production resources are more willing to choose independent work safety behavior, while enterprises lacking work safety awareness are more likely to take risks to implement work safety behavior. To a certain extent, the local government needs to set up a work safety service market access mechanism to provide MSEs with a "resource pool" of work safety service agencies through star rating system. MSEs will purchase high-level work safety services and get more professional technical services to help them satisfy government standards. In this way, the number of enterprises that choose to implement service work safety behavior will increase rapidly.

4.2 Limitations and future research

Based on the analysis of the impact mechanism of work safety behavior of MSEs in high-risk industries, we defined the evolution model of enterprise behavior. It only analyzed and studied the interaction behavior of three agents: MSEs, government safety supervision departments, and work safety service agencies. In reality, the work safety behavior of MSEs in high-risk industries is not only affected and constrained by these three agents but also includes social public opinion, constraints of industry associations, industry park management, the demonstration role of neighboring enterprises, normative constraints of upstream and downstream enterprises in the supply chain, etc. (Dearmond et al., 2011; Marucheck et al., 2011). The construction of the enterprise work safety behavior evolution model should consider a large amount of information and large numbers of complex interactions. In order to simplify the model, this has been regarded as the environmental background. In the current research field of work safety behavior of small enterprises, many experts and scholars also pay more and more attention to the work-safe production of small enterprises under the constraint mechanism of core enterprises in the supply chain. These factors outlined can be added to deepen the research into small-enterprise behavior in future research.

At the same time, when studying the evolution of work safety behavior of MSEs in high-risk industries, consideration is given to the constraints and support from government safety supervision departments and work safety service agencies for effects on enterprise work safety behavior. The evolutionary model only sets out that MSEs have self-learning ability. The firm agent is an adaptive agent, and the government agent and service agent are changing agents. However, the real situation is more complex. When the decision-making behavior of enterprises changes, it will also

affect the evolution of the respective behavior of the government safety supervision department and work safety service agencies. In the future, study should be expanded to the multi-agent self-learning mechanism in the research process of small-enterprise behavior (Behnaz et al., 2018; Huang et al., 2018), which make the problem in research more suitable to the real world and better able to show a simulation effect.

Acknowledgements We thank the anonymous reviewers' and editors' precious comments and suggestions to improve the readability of the manuscript. We thank Prof. Qi-zhi Yang for his help to contact MSEs in high-risk industries. We also thank all the MSEs that have participated in the study.

Funding This research is financed by National Nature Science Foundation of China (71874072, 72074099, and 72004081) and the Innovation Fund Project for Postgraduates of Jiangsu Province of China (CXLX12_0680).

Data availability The datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

Declarations

Informed consent Informed consent was obtained from all subjects involved in the study.

Conflict of interest The authors declare no competing interests.

References

American National Standards Institute (2012). American National Standard for Occupational Health and Safety Management Systems. Washington, DC: American National Standard Institute

Aven, T., & Hiriart, Y. (2013). Robust optimization in relation to a basic safety investment mode with imprecise probabilities. *Safety Science, 55*(2), 188–194. https://doi.org/10.1016/j.ssci.2013.01.011

Awwad, R., Shdid, C. A., & Tayeh, R. (2016). Agent-based model for simulating construction safety climate in a market environment. *Journal of Computing in Civil Engineering, 31*(1), 1–12. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000612

Bankes, S. (2009). Models as lab equipment: Science from computational experiments. *Computational and Mathematical Organization Theory, 15*(1), 8–10. https://doi.org/10.1007/s10588-008-9046-y

Bhawe, N., Zahra, S. A., Chao, C., & Bruton, G. D. (2021). Protectionist policies and diversity of entrepreneurial types. *Small Business Economics, 56*, 789–807. https://doi.org/10.1007/s11187-019-00269-z

Behnaz, H., Nima, K., & Genserik, R. (2018). Multi-plant emergency response for tackling major accidents in chemical industrial areas. *Safety Science, 102*, 275–289. https://doi.org/10.1016/j.ssci.2017.11.003

Bibbings, R. (2003). Strategy for meeting the occupational safety and health needs of small and medium size enterprises (SMES): A summary of Rospa's views. *Safety Science Monitor, 79*(1), 1–13.

British Standards Institute. (2007). *Occupational Health and Safety Assessment Series18001, Occupational Health and Safety Management system Standard – Requirements*. British Standards Institute.

Brockner, J., Higgins, E. T., & Low, M. B. (2004). Regulatory focus theory and the entrepreneurial process. *Journal of Business Venturing, 19*(2), 203–220. https://doi.org/10.1016/S0883-9026(03)00007-7

Camerer, C., & Ho, T. H. (2010). Experience-weighted attraction learning in normal form games. *Econometrica, 67*(4), 827–874. https://doi.org/10.1111/1468-0262.00054

Cardenas, J. C. (2009). Experiments in environment and development. *Annual Review of Resource Economics, 1*, 157–182. https://doi.org/10.1146/annurev.resource.050708.144056

Chen, C. F., & Chen, S. C. (2012). Scale development of safety management system evaluation for the airline industry. *Accident Analysis and Prevention, 47*, 177–181. https://doi.org/10.1016/j.aap.2012.01.012

Chen, J., & Zorigt, D. (2013). Managing occupational health and safety in the mining industry. *Journal of Business Research, 66*(11), 2321–2331. https://doi.org/10.1016/j.jbusres.2012.04.013

Cunningham, T. R., & Sinclair, R. (2015). Application of a model for delivering occupational safety and health to smaller businesses: Case studies from the US. *Safety Science, 71*, 213–225. https://doi.org/10.1016/j.ssci.2014.06.011

Dakkoune, A., Vernières-Hassimi, L., et al. (2018). Risk analysis of French chemical industry. *Safety Science, 105*, 77–85. https://doi.org/10.1016/j.ssci.2018.02.003

Dearmond, S., Smith, A. E., Wilson, C. L., et al. (2011). Individual safety performance in the construction industry: Development and validation of two short scales. *Accident Analysis and Prevention, 43*(3), 948–954. https://doi.org/10.1016/j.aap.2010.11.020

Epstein, J. M. (2005). *Generative social science: Studies in agent-based computational modeling*. Princeton University Press.

Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman Publishing.

Hausken, K., & Zhuang, J. (2016). The strategic interaction between a company and the government surrounding disasters. *Annals of Operations Research, 237*(1–2), 27–40. https://doi.org/10.1007/s10479-014-1684-5

Hohnen, P., & Hasle, P. (2018). Third party audits of the psychosocial work environment in occupational health and safety management systems. *Safety Science, 109*, 76–85. https://doi.org/10.1016/j.ssci.2018.04.028

Huang, J., Chen, G., & Li, Y. (2013). Problems, causes and countermeasures of work safety law enforcement and supervision. *Chinese Journal of Safety Science, 23*(3), 3–9. https://doi.org/10.16265/j.cnki.issn1003-3033.2013.03.029

Huang, L., & Liang, D. (2013). Development of safety regulation and management system in energy industry of China: Comparative and case study perspectives. *Procedia Engineering, 52*(2), 165–170. https://doi.org/10.1016/j.proeng.2013.02.122

Huang, L., Wu, C., Wang, B., et al. (2018). Big-data-driven decision-making: A conceptual framework and its influencing factors. *Safety Science, 109*, 46–56. https://doi.org/10.1016/j.ssci.2018.05.012

Jiang, C. Z., & Sheng, Z.-H. (2009). Case-based reinforcement learning for dynamic invention control in a multi-agent supply-chain system. *Expert Systems with Applications, 36*, 6520–6526. https://doi.org/10.1016/j.eswa.2008.07.036

Jiang, Z. X., Liu, Q. Q., & Cai, M. (2017). Construction of business park safety production supervision system—A case study of the Universal Business Park of Beijing. *Safety and Environmental Engineering, 24*(2), 132–136. https://doi.org/10.13578/j.cnki.issn.1671-1556.2017.02.022

Kines, P., Andersen, D., Andersen, L. P., et al. (2013). Improving safety in small enterprises through an integrated safety management intervention. *Journal of Safety Research, 44*(1), 87–95. https://doi.org/10.1016/j.jsr.2012.08.022

Legg, S., Laird, I., Olsen, K., et al. (2014). Guest Editorial: Special Issue – Understanding small enterprises: Healthy lives in healthy business. *Small Enterprises Research*, *21*(2), 139–147. https://doi.org/10.1016/j.ssci.2015.04.023

Liu, S. X., Cheng, Y., Mei, Q., et al. (2020). Research on the evolution of strategy choice for work safety of enterprises in the industrial park—From the perspective of spillover effect. *System Engineering-Theory & Practice, 40*(12), 3284–3297. https://doi.org/10.12011/SETP2019-0542

Liu, S. X., Xu, J. F., Mei, Q., et al. (2016). Evolution and supervision of the production safety behavior of enterprise in industrial cluster. *Industrial Engineering and Management, 21*(1), 49–54. https://doi.org/10.19495/j.cnki.1007-5429.2016.01.008

Liu, S. X., Zhu, Y., & Mei, Q. (2017). Relationships between perception of loss, safety attitude and enterprises' work safety behavior. *China Safety Science Journal, 10*, 123–129. https://doi.org/10.16265/j.cnki.issn1003-3033.2017.10.021

Liu, X., Huang, G., Huang, H., et al. (2015). Safety climate, safety behavior, and worker injuries in the Chinese manufacturing industry. *Safety Science, 78*(6), 173–178. https://doi.org/10.1016/j.ssci.2015.04.023

Liu, X. F., Chen, G. H., Zhang, X. C., et al. (2009). Simulation evolutionary dynamics in complex adaptive retail networks. *Journal of Information and Decision Science, 4*(3), 243–256.

Luo, Y. (2007). *Safety production cost management*. Coal Industry Press.

Luo, Y. (2017). *Security Economics*. Chemical Industry Press.

Ma, T. J., Grubler, A., & Nakamori, Y. (2009). Modeling technology adoptions for sustainable development under increasing returns, uncertainty and heterogeneous agents. *European Journal of Operational Research*, *195*(l): 296–306. https://doi.org/10.1016/j.ejor.2008.01.036

Ma, Y., Zhao, Q., & Xi, M. (2016). Decision-makings in safety investment: An opportunity cost perspective. *Safety Science, 83*, 31–39. https://doi.org/10.1016/j.ssci.2015.11.008

Ma, Y., & Zhao, Q. (2018). Decision-making in safety efforts: Role of the government in reducing the probability of workplace accidents in China. *Safety Science, 104*, 81–90. https://doi.org/10.1016/j.ssci.2017.12.038

Marucheck, A., Greis, N., Mena, C., et al. (2011). Product safety and security in the global supply chain: Issues, challenges and research opportunities. *Journal of Operations Management, 29*(7), 707–720. https://doi.org/10.1016/j.jom.2011.06.007

Mei, Q., Li, Z., & Liu, S. X. (2015). Research on safety regulation effect of small and medium-sized coal mine based on multi-agent modeling method. *Industrial Engineering and Management, 20*(4), 142–151. https://doi.org/10.19495/j.cnki.1007-5429.2015.04.021

Mei, Q., Ma, G. J., Du, J. G., et al. (2009). A study of the evolution route of supervising safety in SME production. *Chinese Journal of Management Science, 17*(4), 160–168. https://doi.org/10.16381/j.cnki.issn1003-207x.2009.02.004

Mei, Q., Wang, Q., Liu, S., et al. (2018a). Effects of organizational safety on employees' proactivity safety behaviors and occupational health and safety management system in Chinese high-risk small scale enterprises. *International Journal of Occupational Safety and Ergonomics*, 1-39https://doi.org/10.1080/10803548.2018a.1470287

Mei, Q., Zhang, J. J., Liu, S. X., et al. (2017). Formation mechanism of objective deviation in the process of the safety evaluation system. *Management Review, 29*(5), 216–225. https://doi.org/10.14120/j.cnki.cn11-5057/f.2017.05.020

Mei, Q., Zhong, J. J., Zhang, J. J., et al. (2018b). Evolutionary path of work safety strategies in cluster's enterprises under spillover eEffect. *Systems Engineering Theory: Methodology, Applications, 27*(1), 40–49.

Mullen, J., Kelloway, E. K., & Teed, M. (2017). Employer safety obligations, transformational leadership and their interactive effects on employee safety performance. *Safety Science, 91*, 405–412. https://doi.org/10.1016/j.ssci.2016.09.007

Nelson, R. R., & Winter, S. G. (2002). Evolutionary theorizing in economics. *Journal of Economic Perspectives, 16*(2), 23–46. https://doi.org/10.2307/2696495

Ren, X., Inglei, Li, X., & Gao, C. (2018). Analysis and prospect: 2017–2018 report on the survival and development of China's small, medium and micro enterprises. Beijing: China Economic Publishing House. https://doi.org/10.16622/j.cnki.11-3709/d.2018.03.001

Santos, G., Barros, S., Mendes, F., et al. (2013). The main benefits associated with health and safety management systems certification in Portuguese small and medium enterprises post quality management system certification. *Safety Science, 51*(1), 29–36. https://doi.org/10.1016/j.ssci.2012.06.014

Sheng, Z.-H., & Li, J. (2010). *Basic course of social science computing experiment*. Sanlian Bookstore Press.

Sheng, Z.-H., & Wei, Z. (2011). Computational experiments in management science and research. *Journal of Management Sciences in China, 14*(5), 1–10.

Song, X., & Mu, X. (2013). The safety regulation of small-scale coal mines in China: Analyzing the interests and influences of stakeholders. *Energy Policy, 52*(1), 472–481. https://doi.org/10.1016/j.enpol.2012.09.069

Targoutzidis, A., Koukoulaki, T., Schmitz-Felten, E., et al. (2014). The business case for safety and health at work: Cost-benefit analyses of interventions in small and medium-sized enterprises. Luxembourg: European Agency for Safety and Health at Work. https://doi.org/10.2802/32988

Tetsuji, O. (2000). *Government-firm relationship in Postwar Japan: Success and failure of the Bureau-Pluralis*. University of Tokyo.

Tremblay, A., & Badri, A. (2018). Assessment of occupational health and safety performance evaluation tools: State of art and challenges for small and medium-sized enterprises. *Safety Science, 101*, 260–267. https://doi.org/10.1016/j.ssci.2017.09.016

Tudor, T., Adam, E., & Bates, M. (2007). Drivers and limitations for the successful development and functioning of EIPs (eco-industrial parks): A literature review. *Ecological Economics, 61*(2), 199–207. https://doi.org/10.1016/j.ecolecon.2006.10.010

Walker, D., & Tait, R. (2004). Health and safety management in small enterprises: An effective low cost approach. *Safety Science, 42*(1), 69–83. https://doi.org/10.1016/S0925-7535(02)00068-1

Wang, F.-Y., Carley, K. M., Zeng, D., et al. (2007). Social computing: From social informatics to social intelligence. *IEEE Intelligent Systems, 22*(2), 79–83. https://doi.org/10.1109/MIS.2007.41

Wang, Q. W. (2019). *Study of the impact of employees' proactivity safety behaviors to the safe production of small scale enterprises - Based on analytical framework of dual-effects*. Doctoral Thesis, Jiangsu University, China. https://doi.org/10.27170/d.cnki.gjsuu.2019.000019

Xiao, Y., Yaoshan, X., & Yongjuan, L. (2018). Resource depletion perspective on the link between abusive supervision and safety behaviors. *Journal of Business Ethics*, 1-16https://doi.org/10.1007/s10551-018-3983-2

Yu, Z. C. (2019). *Study on operation issues and countermeasures of work safety specialized trusteeship in industrial park*. Master's Thesis, Jiangsu University, China.

Zhang, H., Duan, H., & Zuo, J. (2017). Characterization of post-disaster environmental management for hazardous materials incidents: Lessons learnt from the Tianjin warehouse explosion, China. *Journal of Environmental Management, 199*, 21–30. https://doi.org/10.1016/j.jenvman.2017.05.21

Zhong, J. J. (2016). *Study on formation mechanism and cultivation strategies of work safety service market for small and micro-sized enterprises*. Doctoral Thesis, Jiangsu University, China.