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A policy-making model for evolutionary SME behavior during a pandemic recession supported on game theory approach

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ABSTRACT

The global economy has experienced a tremendous shock caused by the Covid-19 pandemic and its effects on the normal activities of SMEs, which provide essential driving economic force. Considering that there is currently no precise prediction about the end of this pandemic, many SMEs must make critical decisions about whether to remain in the market during the pandemic or to leave it, investing their assets in a more secure sector of the economy. However, in order to convince SMEs to remain in the market, thus maintaining the damaged economy, governments may variously apply punitive or supportive measures. In this regard, the interaction between SMEs strategies and government measures can be considered as an evolutionary game, in which the governments impose various policies after observing the evolutionary behaviors of SMEs. An evolutionary stable strategy (ESS) is derived through a replicator dynamic system, and the available payoff of each player is calculated by Nash equilibrium (NA). Finally, a numerical example is presented, and related managerial insights are proposed at the end of the current study. For instance, contrary to general belief, it can be inferred from investigating possible scenarios that punitive policies are more effective than supportive measures in convincing SMEs to remain in the market.

1. Introduction

The Covid-19 pandemic has created multiple obstacles for human society. Many people lost their lives and jobs. New working and living conditions are noticeable for instance; the use of digital technology is increased drastically (Madani, Boutebal, & Bryant, 2020). In addition to being an intimidating global health threat, it is also a large-scale economic menace worldwide. Examples of its diverse effects on the global economy include: negative global GDP growth in the first quarter of 2020, recession in the financial market and travel sectors; and a disruption to supply chain entities (JPMorgan Chase Bank NA).[4] Furthermore, estimates indicate that, based on the severity of the outbreak, the decrease in the global economy may become even more severe than the current situation.[5] In this regard, the International Monetary Fund (IMF)[6] declared that the worst recession since the Great Depression would be experienced by the global economy in 2020, with concurrent increases in unemployment. The costs that are and will be imposed on the global economy can be categorized into short- and long-term ones. While the short-term costs include a temporary reduction in productive capacity, and decreased current and anticipated demand, the long-term costs include labor force reduction, physical and human capital degradation, alterations in risk patterns and preferences, and trade disruption.[7] These costs can also be classified based on the sectors that have been affected, such as agriculture and petroleum as

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[4] J.P. Morgan, the day Earth stood still, https://bit.ly/3dBCunE.
[5] OECD Interim Economic Assessment, Coronavirus: The world economy at risk, https://bit.ly/3cFNC28.
[6] International monetary fund, Word economic outlook, Chapter1: the greatest lockdown, https://bit.ly/2Z1azsW.
[7] BoF Economics Review, dealing with the costs of the COVID-19 pandemic – what are the fiscal options? https://bit.ly/3bxoYPS.

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primary sectors (extracting or providing raw materials), manufacturing as secondary sectors (producing final merchandise), and education and finance as tertiary sectors (providing services) (Nicola et al., 2020). These categorizations are widely used by economists. However, from the supply chain management point of view, the affected zones can be grouped into three main sections: production-side, supply-side, and demand-side.[8] Within this paper, the focus is on enterprises in the supply-side, specifically small and medium enterprises (SMEs).

As a major generator of income and employment, SMEs has a very important role in the economies around the world. For instance, in all 30 countries of the Organization for Economic Co-Cooperation and Development (OECD), more than 50 % of existing jobs are provided by SMEs, and almost 99 % of all enterprises in the European Union are SMEs.[9] Their ability to control internal risks (obtained by appropriate risk management and treatments) enables them to play such a pivotal role in the global economy. However, since external risks are out of the SMEs' control, they are more vulnerable than large enterprises to external risks, such as economic as well as environmental risks (Asgary, Ozdemir, & Özyürek, 2020). The most severe problem that SMEs in the supply-side are faced with is available labor shortages and disruption of supply chains (Centre et al., 2020). In the Covid-19 pandemic, many of these problems have been caused by governmental disease-controlling measures such as quarantine and social distancing. Therefore, during this difficult period, governments measures and SMEs' strategies must work together to minimize economic damage.

Uncertainty has made classical models inefficient for long period (Guo & Han, 2021; Hazarika & Gupta, 2020). Despite the fact that several studies have focused on identifying governments measures or SMEs strategies, the question remains unanswered as to how these measures and strategies interact in critical socio-economic situations. Hence, in this study, SMEs and government are respectively considered as the populations and policymaker of an evolutionary game (EG). Adopting EG, the behavior of a population of SMEs is investigated with regard to government measures (as the game leader). Thus, the evolutionary stable strategy (ESS) of the game is derived through a replicator dynamic system (RDS). As a result, finding the best punitive and/or supportive government measures in order to convince SMEs to remain in the market during and after the Covid-19 outbreak is the aim of the current study.

The reminder of the paper is structured as follows. In Section 2, after proposing the available SME strategies and government measures, recent applications of evolutionary games in industry sector models are surveyed. In Section 3, some preliminary and basic mathematical concepts are reviewed. The ESS, related RDS, and government intervention models are developed in Section 4. Next, a numerical example and some managerial insights are proposed in Section 5. Finally, in Section 6, the conclusion and some suggestions for future research are propounded.

2. Literature review

In order to develop an evolutionary game theory (EGT) model, identifying the players' strategies is of utmost importance. Therefore, in the following section, first the practical strategies of key players are briefly surveyed, based on economic instruments, then the latest applications of the EGT are reviewed, considering governments and SMEs as players.

Dealing with disruption in business, as well as executing special protection plans for the safety and the wellbeing of employees, are among the main necessary duties of SMEs during the pandemic.[10] The population members behave differently during a recession therefore, Hernandez-Matamoros et al., (2020) studied the behavior of population during covid-19 pandemic in separate geographical regions. The pandemic has resulted a complex situation to model therefore agent-based methods can be used to model complex systems (Mei, Zarrabi, Lees, & Sloot, 2015). With regard to the current study, the following section reviews the strategies that SMEs should pursue to survive during the contraction of the global economy and its corresponding supply chain disruption. The small business preparedness checklist (SBDC)[11] provides a preparedness checklist for SMEs which includes strategies at the operations level, finance level, and human resource level during the recession caused by the pandemic. On the financial level, it is suggested that the enterprises should identify potential options during the disruption, updating the information about receiving loans and financial help from commercial banks, investigating possible assistance loans dedicated to affected enterprises, etc. In another study, Nseobot (2020) mentioned that the current economic situation may become more complicated before it gets better. Hence, they suggest that businesses must accept the current reality, and consider the following recommendations: restricting existing loans and avoiding new ones; valuing business activities and determining which one(s) should be terminated; amending the operating business model; adjusting expenses and expectations; seeking alternative suppliers or customers; consulting current customers; and finally, seeking advice with regard to relevant managerial obstacles. A bulletin published by the Institute of Management Accountants (IMA)[12] recommends that, due to the unknown time horizon of the pandemic, the most essential concern of SMEs should be cash flow assessment. Based on the size of the cash flow, entrepreneurs can make decisions about continuing or shutting down a business. IMA also suggested that owners should apply strategies to reassess the cash flow: documenting the amount of revenue and expenses through the given time horizon; improving cash flow; applying the 80/20 rule; cutting extra expenses as much as possible; etc.

In addition to what SMEs and business owners can do, there are several actions that governments can take to protect societies and SMEs. As mentioned earlier, preventive and therapeutic measures are beyond the scope of this study, so in the following section, the latest governmental measures to financially support SMEs are briefly surveyed. The International Labor Organization(ILO)[13]divided governmental supportive policies into three district phases: (I) when the preventive policies, such as quarantine and social distancing are executed, (II) when the virus exists and SMEs must re-start their economic activities, and (III) when the outbreak is over and SMEs are in a recovery period. The first phase includes: general supportive activities; helping SMEs to temporarily convert their products and services to items essential for controlling the pandemic; dealing with their fixed costs; adapting to new market situations. The second phase includes providing access to financial and credit services, rolling out a demand policy, and making the environment of business more responsive and agile. The last phase consists of upgrading infrastructure, and providing business services, such as technical schools, helping to effectively manage finances, etc. The ILO classification style indicates the pivotal role of financial policies in the first two phases. In general, governments have two types of financial measures to protect SMEs, namely fiscal policies (taxing,

[8] Samuel Neaman Institute for National Policy Research, The global economic impact of Covid-19: A summary of research, https://bit.ly/2Z2s6kt.

[9] OECD Interim Economic Assessment, The Impact of the Global Crisis on SME and Entrepreneurship Financing and Policy Responses https://bit.ly/2LBu9DT.

[10] Department of health & human services. USA, Prepare your small business and employees for the effects of COVID-19 https://bit.ly/3dP2T0X.

[11] University of Pittsburgh, The institute for entrepreneurial excellence, Covid-19 small business preparedness checklist https://bit.ly/3dUH00q.

[12] The association of accountants and financial professionals in business, small business planning during Covid-19 https://bit.ly/2TcX7hQ.

[13] International labor organization, Interventions to support enterprises during the COVID-19 pandemic and recovery https://bit.ly/2TdPuaM.

spending, or borrowing), and monetary policies (merchandizing securities, money lending to banks, and providing interest on bank reserves) (Federal Reserve Bank of Richmond[14]). In its policy update, the National Bank of Canada[15] categorized the fiscal and monetary policies of developed countries, such as Canada, the US, the Eurozone, UK, Japan, and China. Several financial monthlies and weeklies have also investigated the latest effect of Covid-19 on the global economy (specifically SMEs) and governments' financial policies. These include Global Policy Responses to Covid-19,[16] SME Policy Responses,[17] Covid-19 Government Support Measures,[18] etc.

After reviewing the possible strategies of government and SMEs as the populations of an EG, in the following, a brief literature of this type of games, and its latest usages, are reviewed. Analyzing the interactions of players (populations) and their payoffs is the main focus of an EG (Nowak & Sigmund, 2004). The frequencies of the strategies adopted by players is considered as decision-making evaluator to find an equilibrium in EG (Ji et al. 2015). Based on the hierarchical levels of players, two type of equilibriums may develop. The Stackelberg equilibrium is mostly applied for leader–follower situations, when a group of players are rule-makers or acting first, and their followers (other groups of players) select their strategies after observing the leader's strategy (Yin et al.2010). Zhao et al.(2020), Salvioli et al.(2021), Yu et al.(2021), and Wölfl et al.(2021) provide recent examples of Stackelberg equilibrium usage in EG models. The Nash equilibrium is utilized for cases in which the players do not have to obey any player as leader. Guo and Han (2021), Martinez-Piazuelo et al. (2021), Schauf & Oh (2021), and Zhang et al. (2021) are recent instances of Nash equilibrium applications in EG models.

Table 1 proposes the other essential findings of the latest studies in which governments and enterprises are considered as players of an EG. In this table, P and *Pm* respectively stand for player and policymaker, which represent the possible roles of governments in an EG. In addition, RDE and SD respectively indicate the replicator dynamic system and the system dynamic as strategies of analyzing player performance. The other abbreviations are represented in Table 2.

According to the studies surveyed about the effect of Covid-19 upon the global economy and SMEs, various possible government measures and SME strategies are identified. However, there is no study which considers these measures and strategies simultaneously, and investigates their impacts upon each other. None of the studies mentioned has directly considered the importance of SMEs in the global economy, and their vulnerability under societal risks (they mostly consider enterprises as a general term). Furthermore, it is inferred from the studies proposed in Table 1 that EG is a well-known, effective approach, by which the behavior of governments and enterprises can be analyzed. Additionally, based on the objectives of these papers, EG has not frequently been applied for investigating the stability of markets, supply chains, or the global economy, specifically when the normal situation of the global economy is disturbed by a pandemic. In this regard, it seems that there is a significant research gap between the studies that have investigated the effect of the pandemic on the economy, and articles that utilize EG for analyzing the behaviors of governments and enterprises. To fill this gap, the most efficient government measures and SME strategies are identified to be included in the game theoretical framework. In particular, the ESS of SMEs is determined in response to government measures aimed at alleviating the severe economic impact of the pandemic.

3. Problem statement and assumptions

3.1. Problem statement

The outbreak of COVID-19 has caused severe disruption in market demand in many industries. Abandoning the market can be regarded as a rational decision for an SME, since they are financially vulnerable, and may fail to withstand the crisis. The reluctance of many downstream SMEs to contribute to the market can impose large costs to a national economy. Therefore, the government is required to take financial measures to reduce the losses caused by an SME going bankrupt. The government may adopt two types of measures: labor-based policies (one element of which is considered a punitive policy) and production-based policies. In labor-based policies, the government tries to prevent businesses from exiting the market by imposing punitive and supportive rates, according to the number of workers employed by the SMEs. In production-based policies, however, it provides SMEs with financial support according to their production quantity to encourage them to continue their production processes.

To formulate the model, a population of SMEs is considered, who compete to increase their profit in the market. Thus, four scenarios are formulated according to government measures. Each SME is authorized to set an appropriate production quantity; hence the production quantity is considered as the decision variable of the SMEs while the decision variables of the government alters according to the policy that the government dictates. The details of all parameters as well as decision variables are presented in Sub-section 4.1.

Fig. 1 illustrates the effects of these measures on strategies of SMEs in a market under a pandemic recession. All the assumptions and notations that are used to conduct the model are introduced in the following subsections.

3.2. Assumptions

Assumption 1. *A homogeneous population of similar SMEs with symmetric information share is considered* (Hafezalkotob, 2018). *Whole parameters are considered to be fully known by the players. Each SME is authorized to decide whether to remain in the market or abandon it. SMEs may have a reluctance to share information. However, symmetric information sharing will assist in studying the behavior of SMEs during the recession.*

Assumption 2. *It is noteworthy that the production of SMEs is completely substitutable. Cournot competition is adopted to model the final market price of the products. We introduce p_{ij} as the market price of the product if the SME chooses strategy i, as well as if the rival chooses strategy j and q_{ij} as the production quantity if the SME chooses strategy i and the rival chooses strategy j. Representing p_{ij} as a function of q_{ij}, the most commonly used function among related studies is presented* (Hafezalkotob, 2018; Kogan and Tapiero, 2009; Sheu, 2011; Sheu and Chen, 2012; *Boonman et al.*, 2015; *Tabrizi et al.*, 2018).

$$p_{ij}^{(k)}\left(q_{ij}^{(k)}\right) = a - b\left(q_{ij}^{(k)} + q_{ij}^{\prime(k)}\right) \tag{1}$$

Parameter a in Eq. (1) represents the market baseline for a certain product, and b denotes the product's price sensitivity to the quantity of production. The reversely related p_{ij} and q_{ij} state that an increase in q_{ij} diminishes the product price.

Assumption 3. *Similar to* Sarikaya and Ercetin (2019), *two types of workforce are considered for each SME*: *skilled workforce* (l) *for unit production that contributes to the production process directly and are experts and difficult to replace them, and a general workforce* (L) *who are indirectly*

[14] Federal Reserve Bank of Richmond, Fiscal Policy & Monetary Policy: What's the difference? https://bit.ly/3cMja6I.

[15] National Bank of Canada, Policy Update – Tracking the global policy response to COVID-19, https://bit.ly/2TdsrNA.

[16] Cushman & Wakefield, global policy responses to Covid-19 https://cushwk.co/2Awf6Jr.

[17] OECD Interim Economic Assessment, Coronavirus (COVID-19): SME policy responses, https://bit.ly/2X4CwNJ.

[18] LexMundi world reality, Covid-19 government support measures https://bit.ly/3fW4NyH.

Table 1
Classification of studies related to EG modeling approach for a government intervention.

Reference	Government Contribution			Evolutionary Game Properties			Industry Sector & Player(s)	
	Role	R[1]	*P*[2]	Obj	Pop	Strategy	Industry	Enterprise (player)
(Zhao et al. 2016)	*Pm*	✓		CER	Two	RDE & SD	Manufacturing	Air conditioner
(Allameh & Saidi-Mehrabad, 2019)	*Pm* & P	✓	✓	SBO	Three	RDE	Energy	Bio-refinery & Farmland
(T. Zhao & Liu, 2019)	*Pm* & P	✓	✓	CER	Two	RDE	Energy	Power plant
(Chen et al. 2019)	*Pm*	✓		OI	Two	RDE & SD	Energy	Electricity Network
(Zhang et al. 2019)	*Pm* & P		✓	CER	Two	RDE & SD		Manufacturer
(da Silva Rocha & Salomão, 2019)	*Pm* & P		✓	APR	Two	RDE		
(Fu et al. 2020)	*Pm* & P	✓		SBO	Two	RDE	Recycling	Recycler
(Mahmoudi & Rasti-Barzoki, 2018a)	*Pm* & P	✓	✓	CER	Two	RDE	Textile	Producer & Retailer
(Kang, Zhao, Zhang, & Qiang, 2019)	*Pm*	✓		CER	Two	RDE		Manufacturer & Retailer
(Sun et al. 2019)	*Pm*	✓		CER	Two	RDE		Supplier & Retailer
(Wang et al. 2020)	*Pm* & P	✓	✓	SBO	Three	RDE	Recycling	Recycler
(Xing & Cao, 2019)	*Pm*	✓	✓	DGBI	Three	RDE	Construction	Constructor
(Fang et al. 2018)	*Pm* & P		✓	CER	Three	RDE	Energy	Power plant
(Fang et al.2019)	*Pm* & P	✓	✓	APR	Two	RDE	Energy	Heat supplier
(Gu et al. 2019)	*Pm*		✓	SBO	Single	RDE	Steel	Manufacturer
(Ji et al. 2019)	*Pm* & P	✓	✓	SBO	Two	RDE	Automobile	Manufacturer
(Li et al. 2019)	*Pm* & P	✓	✓	CER	Three	SD	Automobile	Manufacturer
(Long et al. 2019)	*Pm* & P	✓	✓	SBO	Three	RDE & SD	Recycling	Recycler
(Tong et al. 2019)	*Pm*	✓		CER	Two	RDE & SD	Appliance	Manufacturer & Retailer
(Xin-gang et al. 2018)	*Pm*	✓	✓	DRE	Two	RDE	Energy	Producer
(Yin et al. 2019)	*Pm* & P	✓	✓	DGBI	Three	RDE	Construction	Constructor
(Yang et al. 2018)	*Pm* & P	✓	✓	SBO	Three	RDE		
(Liu et al. 2019)	*Pm* & P		✓	ISL	Two	RDE & SD	Mining	Coal mine
(He et al. 2018)	*Pm* & P	✓	✓	DGTI	Three	RDE	Tourism	
(Shen & Wang, 2018)	*Pm* & P		✓	RHI	Two	RDE		
(Z. Sun & Zhang, 2019)	*Pm* & P	✓	✓	RGI	Three	RDE		
(Xie & Jin, 2019)	*Pm* & P		✓	SBO	Two	RDE	Agriculture I	Farmland
(Xu et al. 2019)	*Pm* & P	✓	✓	CER & PA	Three	RDE	Energy	Power plant
(Zhao et al. 2020)	*Pm* & P	✓	✓	IRWG	Two	RDE		
(Cui et al. 2018)	*Pm* & P			CER	Two	RDE	Energy	Power plant
(Wanting Chen & Hu, 2018)	*Pm* & P	✓	✓	CER	Two	RDE	Food	Producer
(Fang et al. 2019)	*Pm*	✓	✓	ISEU	Three	RDE		Manufacturer & Retailer
(Shi et al. 2020)	*Pm*	✓	✓	CER	Two	RDE	Automobile	Manufacturer
(Sheng et al. 2020)	*Pm* & P		✓	IEER	Three	RDE		
(Liu et al. 2021)	*Pm* & P	✓		OSWP	Three	RDE	Safety Service market	Safety Service Agencies & SMEs
This Study	*Pm*	✓	✓	SWM	Single	RDE		

[1] Reward.
[2] Punsihment.

Table 2
Coding system of Table 1.

Obj	Acronym	Obj	Acronym	Obj	Acronym
Carbon Emission Reduction	CER	Developing Green Tourism Industry	DGTI	Developing Renewable Energy	DRE
System Behavior Observation	SBO	Reducing Haze Issue	RHI	Improving Safety Level	ISL
Developing Green Building Industry	DGBI	Reducing Greenwashing Issue	RGI	Increasing Solar Energy Usage	ISEU
Air Pollution Reduction	APR	Poverty Alleviation	PA	Improving the Effectiveness of Environmental Regulations	IEER
Optimal Investment	OI	Improving Recycling of Waste Goods	IRWG	Social welfare maximization	SWM
Optimizing Safety in Work Places	OSWP				

involved in the production process and can be replaced easily. The skilled-workforce are trained to contribute in the process of production such as assembling, and packing while general workforce lacks the essential skills to contribute in the process of production, hence they do formalities. It is necessary to mention that regarding to each type of workforce the salary amount varies (SMEs are obliged to pay the skilled workforce more). Unlike general workforce, the number of required skilled workforce depends on the quantity production Therefore, the total cost of the workforce is presented by:

$$c_2 l q_{ij}^{(k)} + c_3 L. \tag{2}$$

Assumption 4. *The stochastic rate of the market baseline $\widetilde{\alpha}$ refers to uncertainty in the market element during the recession period $\left(\widetilde{p}_{ij}^{(k)}\left(q_{ij}^{(k)}\right) = \widetilde{\alpha}a - b(q_{ij}^{(k)} + q_{ij}^{\prime(k)}), 0 < \widetilde{\alpha} < 1\right)$. Concerning the profit uncertainty (λ as the absolute risk aversion constant of the SMEs) $\widetilde{\Pi}_{ij}^{(k)}$ caused by $\widetilde{a}_i$, and SME attitudes toward this uncertainty, the following utility function is considered* (*Tsay*, 2002, *Gan et al.*, 2005, *Hafezalkotob*, 2017):

$$U_{ij}^{(k)} = E\left(\widetilde{\Pi}_{ij}^{(k)}\right) - \lambda var\left(\widetilde{\Pi}_{ij}^{(k)}\right). \tag{3}$$

4. Mathematical modeling

In the following, first, parameters and decision variables are introduced in Section 4.1. Afterward, the research problem is investigated under four scenarios: the evolutionary game-theoretic model is conducted to compute the ESS in Section 4.2, the utility functions (payoff function) of SMEs are formulated under each scenario in Sections 4.3 and 4.4. Finally, alternative models for government intervention are presented in Section 4.5.

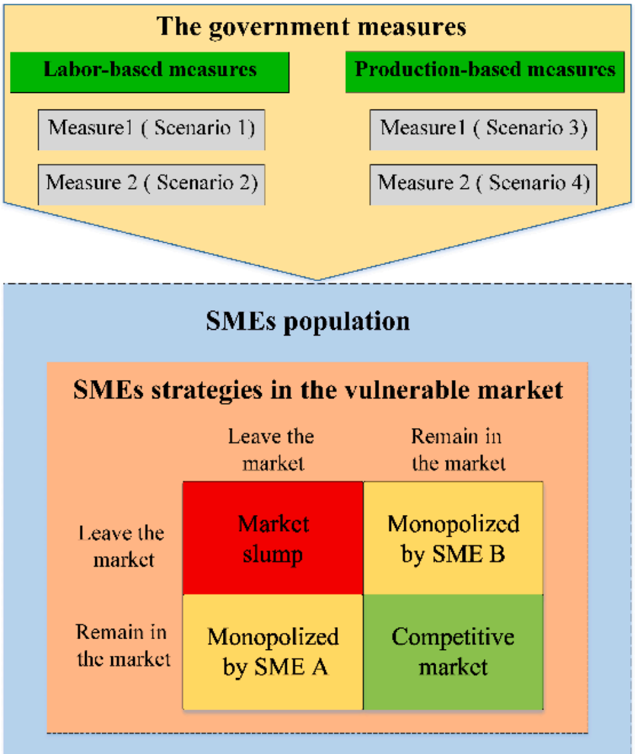

Fig. 1. The schematic structure of the interaction between government and SMEs population.

4.1. Parameters and decision variables

To formulate the game model, index $i = 1,2$ are introduced as SME A strategies, while $j = 1,2$ represent SME B strategies. According to Barron's (2013), Friedman (1998) and Alexander (2002) homogeneous systems, the game is formulated for single population with homogeneous members. It is noteworthy to mention that all SMEs have similar functions and features and compete in the same market. Hence, there is no superiority in playing order. Therefore, there is no need to consider any index for SMEs. The parameters and decision variables that are used to formulate the model are presented below:

Parameters

N: number of SMEs in the population;
k: number of scenarios;
a: market baseline for a certain product;
b: product's price sensitivity to the quantity of production;
c_1: production cost per unit, $c_1 > 0$;
C: fixed production cost, $C > 0$;
C_0: SME's cost of abandoning the market,.$C_0 > 0$
l: required skilled workforce number for *unit* production ,$l > 0$;
L: required general workforce number,$L \geq 0$;
c_2: cost of skilled workforce per person ,$c_2 > 0$;
c_3: cost of general workforce per person, $c_3 > 0$;
I: required budget of an SME to remain in the market, $I > 0$;
$\widetilde{\alpha}$: uncertainty rate, indicating the severity of the economic recession, $0 < \widetilde{\alpha} < 1$;
$\widetilde{r}$: stochastic interest rate of available budget, $0 < \widetilde{r} < 1$;
q_0: production quantity of an SME;
p_{ij}^k: market price of the product if the SME chooses strategy i,
as well as if the rival chooses strategy j, under Scenario k $i,j = 1,2$;
$\widetilde{\Pi_{ij}}^k$: stochastic profit of the SME if it chooses strategy i, as well as if the.
rival chooses strategy j, under Scenario k $i,j = 1,2$;
${U_{ij}}^k$: utility function of the SME if it chooses strategy i and.
the rival chooses strategy j, under Scenario k $i,j = 1,2$;
GNE: government net expenditure;
SW: social welfare;
CS: The customer surplus;
SS: The SME's surplus;
$E(Q)$: average production quantity;
D: market demand;
E: maximum quantity of unemployed workers;
λ: absolute risk aversion constant of the SMEs;
Ω: coefficient enabling a tradeoff between the SW and GNE, $0 \leq \Omega \leq 1$;

Decision variables.

$q_{ij}^{(k)}$: production quantity if the SME chooses strategy i and the rival. chooses strategy j under Scenario k $i,j = 1,2$;
$q_{ij}^{'(k)}$: production quantity if the rival SME chooses strategy i and. the other SME chooses strategy j under Scenario k $i,j = 1,2$;
t_1: financial penalty for each skilled workforce member laid off, $t_1 > 0$;
t_2: financial penalty for each general workforce member laid off, $t_2 > 0$;
t_3: penalty rate for abandoning the market, $0 < t_3 < 1$;
$1 - \beta$: portion of skilled workforce salary that is paid by the government, $0 < \beta < 1$;
s: subsidy per unit product, $s > 0$;
I_G: amount of loan provided by the government for SMEs, $I_G > 0$;
θ: repayment rate of the government loan I_G,.$0 < \theta < 1$

4.2. The evolutionary game model

An evolutionary theoretic model should be established to analyze the ESS under each scenario. The majority of the population is going to adopt a strategy that results in a greater and better achievement than the average payoff of the game matrix (Montibeller & Parnel, 2013). The evolutionary game theory allows for an examination of the impact of players' decisions on the game equilibrium (Babu & Mohan, 2018). In addition, evolutionary games are used to study the behavior of population to be able to maximize the enterprises profit (Mahmoudi & Rasti-Barzoki, 2018) .

$\widetilde{\Pi}_{ij}^{(k)}$ represents the SME's pay-off if player A adopts i and player B adopts j strategy. $\widetilde{\Pi}_{11}^{(k)}$ represents SME A payoff if they choose Strategy 1, while their rival chooses Strategy 1. The other inputs of the game matrix are calculated in the same manner. Since $\widetilde{\Pi}_{11}^{(k)}$ takes a stochastic quantity, utility functions are used to conduct the model. Eq. (18) provides a suitable trade-off between the mean and variance of the stochastic profit while λ represents the absolute risk aversion constant of the SMEs. The more an SME is willing to take risks, the lower λ becomes (Xiao & Yang, 2008). The other matrix inputs are calculated similarly. The payoff matrix of the player A is represented by $U_{ij}^{(k)}$ if player A adopts i and player B adopts j th strategy.

$x_1(t) = x$ is defined as the probability of adopting strategy V_1 (leaving the market), while $x_2(t) = (1-x)$ is the probability of adopting strategy V_2 (remaining in the market). Concerning the assumptions, whereby similarity of players and symmetrical information sharing are considered, matrixes **A** and **B** are thus represented as the payoff matrixes of players A and B, respectively, where $\boldsymbol{B} = \boldsymbol{A}^T$ and we have the following matrix:

$$\boldsymbol{A} = \begin{bmatrix} U_{11}^{(k)} & U_{12}^{(k)} \\ U_{21}^{(k)} & U_{22}^{(k)} \end{bmatrix} \tag{4}$$

According to Montibeller & Parnel (2013), the expected payoff of Player A adopting strategy V_1 against Player B's behavior is:

$$E(V_1) = x_1 U_{11}^{(k)} + x_2 U_{12}^{(k)} \tag{5}$$

Additionally, the expected payoff of Player A adopting strategy V_2 against Player B's behavior equals:

$$E(V_2) = x_1 U_{21}^{(k)} + x_2 U_{22}^{(k)} \tag{6}$$

According to Montibeller & Parnel (2013) and Eqs. (5) -(6), the average payoff can be written as:

$$\overline{EV} = (x_1, x_2)\begin{bmatrix} U_{11}^{(k)} & U_{12}^{(k)} \\ U_{21}^{(k)} & U_{22}^{(k)} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

$$= \left(U_{11}^{(k)} x_1 + U_{21}^{(k)} x_2\right) x_1 + (U_{12}^{(k)} x_1 + U_{22}^{(k)} x_2) x_2 \tag{7}$$

In order to estimate the ESS of the population, the behavior of $x_1(t)$, $x_2(t)$ in the long-term should be investigated. According to one population replicator dynamic system presented by Montibeller and Parnel (2013), the first order derivatives of $x_1(t)$ and $x_2(t)$ should first be computed as follows:

$$\frac{dx_1}{dt} = x_1(E(V_1) - \overline{EV}) \tag{8}$$

$$\frac{dx_2}{dt} = x_2(E(V_2) - \overline{EV}). \tag{9}$$

Definition 1. *We consider the probability of adopting strategy i by the players vary during time* $X = \{x_1, x_2, \cdots, x_i\} = X(t)$. *Hence,* $\frac{dx_i(t)}{dt} = x_1(t)(E(i, X(t)) - E(X(t), X(t))$ *calculates the dynamics of the probabilities. The presented formulation calculates how the population percentage adopting strategy i compared to all other strategies varies during time. It is obvious that dominant strategies have greater frequency dynamics, while worse strategies have less frequency dynamics* (Barron, 2013).

The solution pairs produced by solving $dx_1/dt = 0$, $dx_2/dt = 0$ can be introduced as the possible ESS solutions (Mahmoudi & Rasti-Barzoki, 2018). The candidate solution pairs should be expanded for all scenarios, which will be discussed in the following subsections.

$$x_1 = 0, x_2 = 1), \tag{10}$$

$$x_1 = 1, x_2 = 0)$$

$$x_1 = -\frac{U_{12}^{(k)} - U_{22}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}}, x_2 = \frac{U_{11}^{(k)} - U_{21}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}} \tag{12}$$

Definition 2. *Since there are multiple ESS candidate solution pairs, in order to investigate the appropriate solution pair that can be officially introduced as the ESS,* $\frac{dx}{dt} = f(x)$ *is considered.The equilibrium point* $(x_1, 1 - x_1)$ *is asymptotically stable and can be introduced as the ESS of the game if* $df(x_1)/dx_1 < 0$ (Gu et al., 2019; Montibeller and Parnel, 2013, Barron, 2013).

Definition 3. x^* *can be introduced as the ESS of the game officially if and only if for every y we have:* $E(x^*, x^*) \geq E(y, x^*)$ *and if* $x^* \neq y$ *as well as* $E(x^*, x^*) = E(y, x^*)$ *then* $E(x^*, y) \geq E(y, y)$.

Case 1. *If* $U_{11}^{(k)} \neq U_{21}^{(k)}$ *as well as* $U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)} = 0$ *there are two conditions:*

1: if $U_{11}^{(k)} \geq U_{21}^{(k)}$ then (1, 0) can be introduced as the only ESS of the game.

2: if $U_{11}^{(k)} \leq U_{21}^{(k)}$ then (0, 1) can be introduced as the only ESS of the game.

Proof: when $U_{11}^{(k)} > U_{21}^{(k)}$ it can be concluded that $U_{22}^{(k)} < U_{12}^{(k)}$, therefore it is a rational decision that the whole population will be converted to the (1, 0) while, when $U_{11}^{(k)} < U_{21}^{(k)}$ it can be concluded that $U_{22}^{(k)} > U_{12}^{(k)}$, thus the whole population will be converted to the (0, 1).

Case 2. *If* $U_{11}^{(k)} = U_{21}^{(k)}$ *as well as* $U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)} = 0$ *the game offers no ESS.*

Proof: We consider $x=(x_1, 1 - x_1)$ as an ESS, then for each $y=(y_1, 1 - y_1)$ there must be, $E(x,x) - E(y,x) = 0$ but it is proven that $E(x,y) - E(y,y) = (x_1 - y_1)\left[\left(U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}\right) y_1 + U_{12}^{(k)} - U_{22}^{(k)}\right] = 0 \not> 0$. In other word, when $U_{11}^{(k)} = U_{21}^{(k)}$ it can be concluded that $U_{22}^{(k)} = U_{12}^{(k)}$ therefore, there is no ESS in the game.

Case 3. *Considering* $U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)} < 0$ *as well as* $0 \leq \frac{U_{11}^{(k)} - U_{21}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}} \leq 1$, *then* $\left(-\frac{U_{12}^{(k)} - U_{22}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}}, \frac{U_{11}^{(k)} - U_{21}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}}\right)$, *can be introduced as the only ESS of the game.*

Proof: For every $y = (y_1, 1 - y_1)$, $E(x,x) - E(y,x) = 0$, while, $E(x,y) - E(y,y) = -\left(U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}\right)\left(-\frac{U_{12}^{(k)} - U_{22}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}} - y_1^{\ 2}\right)\rangle 0$. Hence, $\left(-\frac{U_{12}^{(k)} - U_{22}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}}, \frac{U_{11}^{(k)} - U_{21}^{(k)}}{U_{11}^{(k)} - U_{12}^{(k)} - U_{21}^{(k)} + U_{22}^{(k)}}\right)$ is obtainable as the official ESS of the game.

4.3. Calculating utilities of the SME

Under each scenario, the SME utility functions must be calculated to provide the game matrix. The random profit of SMEs varies according to the players' adopted strategy, as well as the government measures. Therefore, the random profit of players must be calculated under each scenario individually to obtain the payoff matrix. The deregulation policy is first investigated as a benchmark scenario (indicated by superscript (B)) and then four scenarios of Fig. 1 (indicated by superscripts (1), (2), (3), and (4)) are formulated.

4.3.1. Benchmark scenario

According to the Benchmark Scenario, the government avoids intervening in SME competition. Thus, the SMEs define their own decisions without considering government intervention. This scenario is developed to compare the effects of government measures on a freely competitive market. The profit of SMEs varies according to the strategy they both adopt, where:

$$\widetilde{\Pi}_{11}^{(B)} = (1 + \widetilde{r})I - C_0 \tag{13}$$

$$\widetilde{\Pi}_{12}^{(B)} = (1 + \widetilde{r})I - C_0 \tag{14}$$

$$\widetilde{\Pi}_{21}^{(B)} = q_{21}^{(B)} \widetilde{p}_{21}^{(B)} - (c_1 + c_2 l) q_{21}^{(B)} - C - Lc_3, \tag{15}$$

$$\widetilde{\Pi}_{22}^{(B)} = q_{22}^{(B)} \widetilde{p}_{22}^{(B)} - (c_1 + c_2 l) q_{22}^{(B)} - C - Lc_3. \tag{16}$$

According to Eqs. (13)-(14), $\widetilde{r}$ represents the minimum interest rate achieved by investing the available budget after leaving the market, while C_0 represents the cost of the bankruptcy declaration. The amount of payoff resulting from leaving the market is achieved by the subtraction of the invested budget and the costs of the bankruptcy declaration. Eqs. (15) -(16) show the profit of the SME if it decides to remain in the market, calculated by the subtraction of the income and alternative production and fixed costs.

Eqs. (17) -(20) depict the utility functions of Eqs. (13) -(16) under the absence of government intervention.

$$U_{11}^{(B)} = (1 + \overline{r})I - C_0 - \lambda I^2 \delta_r^2, \tag{17}$$

$$U_{12}^{(B)} = U_{11}^{(B)}, \tag{18}$$

$$U_{21}^{(B)} = q_{21}^{(B)}\left(\overline{\alpha}a - bq_{21}^{(B)}\right) - (c_1 + c_2 l)q_{21}^{(B)} - C - Lc_3 - \lambda a^2 {q_{21}^{(B)}}^2 \delta_\alpha^2, \tag{19}$$

$$U_{22}^{(B)} = q_{22}^{(B)}\left[\overline{\alpha}a - b\left(q_{22}^{(B)} + q_{22}^{'(B)}\right)\right] - (c_1 + c_2 l)q_{22}^{(B)} - C - Lc_3 - \lambda a^2 {q_{22}^{(B)}}^2 \delta_\alpha^2. \tag{20}$$

The following proposition represents the optimal production quantities of Player A and player B. Proofs of all propositions are presented in the Appendix.

Proposition 1. *Due to SMEs' potential and financial limits, in the Benchmark Scenario with no government intervention, the optimal quantity of production for SME A and SME B, are provided as follows:*

$$q_{21}^{*(B)} = \min\{\frac{a\overline{\alpha} - c_2 l - c_1}{2\left(a^2\lambda\delta_\alpha^2 + b\right)}, \frac{I - C - Lc_3}{c_1 + lc_2}\} \tag{21}$$

$$q_{22}^{*(B)} = q_{22}^{'*(B)} = \min\{\frac{a\overline{\alpha} - c_2 l - c_1}{2\lambda a^2\delta_\alpha^2 + 3b}, \frac{I - C - Lc_3}{(c_1 + lc_2)}\} \tag{22}$$

The financial limit can be a severe obstacle to increasing the quantity of production. Therefore, according to Proposition 1, the optimal production quantity is obtained by the minimum amount of $q_{ij}^{(B)}$ which is achieved from the competition between SMEs and $q_{ij}^{(B)max}$, that is obtained by the financial limits.

The following corollary computes the candidate solution pairs, which can be represented as the potential ESS of the game.

Corollary 1. *In the Benchmark Scenario with no government intervention, the candidate solution pairs that satisfy the condition mentioned in Definition 2 can be introduced as the ESS.*

$(x_1^{(B)} = 0, x_2^{(B)} = 1)$, (23)
$(x_1^{(B)} = 0, x_2^{(B)} = 1)$, (24)

$$(x_1^{(B)} = \frac{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(B)}}^2 + \left(\overline{\alpha}a - c_2 l - c_1 - bq_{22}^{'(B)}\right)q_{22}^{(B)} + \lambda\sigma_r^2 I^2 - (1+\overline{r})I - Lc_3 - C + C_0}{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(B)}}^2 + \left(\overline{\alpha}a - c_2 l - c_1 - bq_{22}^{'(B)}\right)q_{22}^{(B)} + q_{21}^{(B)}\left(a^2\lambda\sigma_\alpha^2 q_{21} - \overline{\alpha}a + bq_{21}^{(B)} + c_2 l + c_1\right)}, x_2^{(B)} = 1 - x_1^{(B)}). \tag{25}$$

4.3.2. Scenario 1

The unemployment rate may sharply increase a government's social costs. In these cases, the government is often forced to spend a huge amount of unemployment insurance costs to financially support the laid-off workforce. In this scenario, according to the corporate social responsibility of SMEs, they are forced to pay a part of the skilled and general workforce's salaries for a defined period if they decide to leave the market. This punitive instrument reduces socio-economic costs of unemployment dramatically, while discouraging SMEs from leaving the market. The profit functions resulting from competing SMEs under Scenario 1 are presented below:

$$\widetilde{\Pi}_{11}^{(1)} = (1+\widetilde{r})I - C_0 - t_1 lq_0 - t_2 L, \tag{26}$$

$$\widetilde{\Pi}_{12}^{(1)} = \widetilde{\Pi}_{11}^{(1)}, \tag{27}$$

$$\widetilde{\Pi}_{21}^{(1)} = q_{21}^{(1)}\widetilde{p}_{21}^{(1)} - (c_1 + c_2 l)q_{21}^{(1)} - C - Lc_3, \tag{28}$$

$$\widetilde{\Pi}_{22}^{(1)} = q_{22}^{(1)}\widetilde{p}_{22}^{(1)} - (c_1 + c_2 l)q_{22}^{(1)} - C - Lc_3. \tag{29}$$

In Eq. (26), the salary costs $t_1 lq_0 + t_2 L$ are subtracted from the payoff function. These additional costs are penalties that SMEs should be committed to pay if they undertake the strategy of abandoning the market. Since $\widetilde{\Pi}_{ij}^{(1)}$ takes stochastic amounts, the utility functions are conducted to draw up the game matrix:

$$U_{11}^{(1)} = (1+\overline{r})I - C_0 - t_1 lq_0 - t_2 L - \lambda I^2\delta_r^2 \tag{30}$$

$$U_{12}^{(1)} = U_{11}^{(1)}, \tag{31}$$

$$U_{21}^{(1)} = q_{21}^{(1)}\left(\overline{\alpha}a - bq_{21}{}^{(1)}\right) - (c_1 + c_2 l)q_{21}^{(1)} - C - Lc_3 - \lambda a^2 {q_{21}^{(1)}}^2 \delta_\alpha^2 \tag{32}$$

$$U_{22}^{(1)} = q_{22}^{(1)}\left[\overline{\alpha}a - b\left(q_{22}^{(1)} + q_{22}^{'(1)}\right)\right] - (c_1 + c_2 l)q_{22}^{(1)} - C - Lc_3 - \lambda a^2 {q_{22}^{(1)}}^2 \delta_\alpha^2. \tag{33}$$

Similar to Proposition 1, the following proposition represents the optimal production quantities of Player A and Player B .

Proposition 2. *In Scenario 1 with the government's labor-based measure, the optimal production quantity of SME A and SME B, with regard to their potential and financial limits, are provided as follows:*

$$q_{21}^{*(1)} = \min\{\frac{a\overline{\alpha} - c_2 l - c_1}{2\left(a^2\lambda\delta_\alpha^2 + b\right)}, \frac{I - C - Lc_3}{c_1 + lc_2}\} \tag{34}$$

$$q_{22}^{*(1)} = q_{22}^{'*(1)} = \min\{\frac{a\overline{\alpha} - c_2 l - c_1}{2\lambda a^2\delta_\alpha^2 + 3b}, \frac{I - C - Lc_3}{(c_1 + lc_2)}\} \tag{35}$$

$\Delta U_1^{(1)} = \Delta U_{21}^{(1)} - \Delta U_{11}^{(1)}$ is represented as the utility function achieved or lost if the first SME changes strategy while their rival adopts the first strategy. Similarly, $\Delta U_2^{(1)} = \Delta U_{22}^{(1)} - \Delta U_{12}^{(1)}$ represents the utility function change if the first SME changes strategy while their rival adopts the second strategy.

$$\Delta U_1^{(1)} = q_{21}^{(1)}\left(\overline{\alpha}a - bq_{21}{}^{(1)}\right) - (c_1 + c_2 l)q_{21}^{(1)} - C - Lc_3 - \lambda a^2 {q_{21}^{(1)}}^2 \delta_\alpha^2$$
$$-(1+\overline{r})I + C_0 + t_1 lq_0 + t_2 L + \lambda I^2\delta_r^2, \tag{36}$$

$$\Delta U_2^{(1)} = q_{22}^{(1)}\left[\overline{\alpha}a - b\left(q_{22}^{(1)} + q_{22}^{'(1)}\right)\right] - (c_1 + c_2 l)q_{22}^{(1)} - C - Lc_3 - \lambda a^2 {q_{22}^{(1)}}^2 \delta_\alpha^2$$
$$-(1+\overline{r})I + C_0 + t_1 lq_0 + t_2 L + \lambda I^2\delta_r^2. \tag{37}$$

Corollary 2. *Under the first scenario with the labor-based government measure, the following conditions exist:*

a) $\partial\Delta U_1^{(1)}/\partial t_1 > 0$ and $\partial\Delta U_2^{(1)}/\partial t_1 > 0$ demonstrate the positive effect of t_1 on the SME's utility function. An increase in t_1 will improve $\Delta U_1^{(1)}$ and, as a result, a dramatic fall in $U_{11}^{(1)}$ will persuade the SME to reconsider their adopted strategy.
b) $\partial\Delta U_1^{(1)}/\partial t_2 > 0$ and $\partial\Delta U_2^{(1)}/\partial t_2 > 0$ demonstrate the positive effect of t_2 on the SME's utility function. An increase in t_1 will improve $\Delta U_2^{(1)}$ and, as a result, a dramatic fall in $U_{12}^{(1)}$ will persuade the SME to reconsider the adopted strategy.

The following proposition computes the candidate solution pairs that can be represented as the official ESS of the game.

Corollary 3. *In Scenario 1 with the government's labor-based measure (t_1, t_2), the candidate solution pairs that satisfy the condition mentioned in Definition 2 can be introduced as the ESS:*

$$x_1^{(1)} = 0,\ x_2^{(1)} = 1) \tag{38}$$

$$x_1^{(1)} = 0, x_2^{(1)} = 1) \tag{39}$$

$$\left(x_1^{(1)} = \frac{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(1)}}^2 + \left(\overline{\alpha}a - c_2l - c_1 - bq_{22}^{'(1)}\right)q_{22}^{(1)} + \lambda\sigma_r^2I^2 + t_1lq_0 - (\overline{r}+1)I + (t_2 - c_3)L - C + C_0}{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(1)}}^2 + (\overline{\alpha}a - c_2l - c_1 - bq_{22}^{'(1)})q_{22}^{(1)} + q_{21}^{(1)}\left(a^2\lambda\sigma_\alpha^2q_{21}^{(1)} - \overline{\alpha}a + bq_{21}^{(1)} + c_2l + c_1\right)}, x_2^{(1)} = 1 - x_1^{(1)} \right) \tag{40}$$

4.3.3. Scenario 2

Under Scenario 2, the implementation of the supportive labor-based policy is introduced by the government as an advantageous tool. This policy supports SMEs to remain in business and continue their economic activity. Providing enough financial support, such as paying a portion of the skilled workforce's salary, may motivate SMEs to remain in the competitive market. Let $(1-\beta)$ percent is assumed to be paid by the government, and the rest is left to the SMEs (SMEs pay β percent of the salaries). The inputs of the game matrix are calculated in the same way as the previous scenarios. The payoff functions resulting from the SME competition are presented as follows:

$$\widetilde{\Pi}_{11}^{(2)} = (1+\widetilde{r})I - C_0 \tag{41}$$

$$\widetilde{\Pi}_{12}^{(2)} = \widetilde{\Pi}_{11}^{(2)} \tag{42}$$

$$\widetilde{\Pi}_{21}^{(2)} = q_{21}^{(2)}\widetilde{p}_{21}^{(2)} - (c_1 + \beta c_2 l)q_{21}^{(2)} - C - Lc_3, \tag{43}$$

$$\widetilde{\Pi}_{22}^{(2)} = q_{22}^{(2)}\widetilde{p}_{22}^{(2)} - (c_1 + \beta c_2 l)\widetilde{p}_{22}^{(2)} - C - Lc_3. \tag{44}$$

In Eqs. (43) and (44), β percent of the skilled workforce salary is paid by the SMEs, which is subtracted from the payoff functions. Since $\widetilde{\Pi}_{ij}^{(2)}$ takes stochastic amounts, the utility functions are conducted to draw up the game matrix:

$$U_{11}^{(2)} = (1+\overline{r})I - C_0 - \lambda I^2\delta_r^2, \tag{45}$$

$$U_{12}^{(2)} = U_{11}^{(2)}, \tag{46}$$

$$U_{21}^{(2)} = q_{21}^{(2)}\left(\overline{\alpha}a - bq_{21}^{(2)}\right) - (c_1 + \beta c_2 l)q_{21}^{(2)} - C - Lc_3 - \lambda a^2{q_{21}^{(2)}}^2\delta_\alpha^2, \tag{47}$$

$$U_{22}^{(2)} = q_{22}^{(2)}\left[\overline{\alpha}a - b\left(q_{22}^{(2)} + q_{22}^{'(2)}\right)\right] - (c_1 + \beta c_2 l)q_{22}^{(2)} - C - Lc_3 - \lambda a^2{q_{22}^{(2)}}^2\delta_\alpha^2. \tag{48}$$

Similar to Proposition 1, the following proposition represents optimal production quantities of Players A and B.

Proposition 3. *In Scenario 2 with the government's production-based measure, the optimal production quantities of SME A and SME B, with regard to SMEs' potential and financial limits, are provided as follows:*

$$q_{21}^{*(2)} = \min\left\{\frac{a\overline{\alpha} - \beta c_2 l - c_1}{2\left(a^2\lambda\delta_\alpha^2 + b\right)}, \frac{I - C - Lc_3}{(c_1 + \beta l c_2)}\right\}, \tag{49}$$

$$q_{22}^{*(2)} = q_{22}^{'*(2)} = \min\left\{\frac{a\overline{\alpha} - \beta c_2 l - c_1}{2\lambda a^2\delta_\alpha^2 + 3b}, \frac{I - C - Lc_3}{(c_1 + \beta l c_2)}\right\}. \tag{50}$$

Similar to the previous scenario, $\Delta U_1^{(2)}$ and $\Delta U_2^{(2)}$ are computed as follows:

$$\Delta U_1^{(2)} = q_{21}^{(2)}\left(\overline{\alpha}a - bq_{21}^{(2)}\right) - (c_1 + \beta c_2 l)q_{21}^{(2)} - C - Lc_3 - \lambda a^2{q_{21}^{(2)}}^2\delta_\alpha^2$$
$$-(1+\overline{r})I + C_0 + \lambda I^2\delta_r^2, \tag{51}$$

$$\Delta U_2^{(2)} = q_{22}^{(2)}\left[\overline{\alpha}a - b\left(q_{22}^{(2)} + q_{22}^{'(2)}\right)\right] - (c_1 + \beta c_2 l)q_{22}^{(2)} - C - Lc_3 - \lambda a^2{q_{22}^{(2)}}^2\delta_\alpha^2$$
$$-(1+\overline{r})I + C_0 + \lambda I^2\delta_r^2. \tag{52}$$

Corollary 4. *Under Scenario 2 with labor-based government measure (β), the following conditions exist:*

a) $\partial\Delta U_1^{(2)}/\partial\beta < 0$ and $\partial\Delta U_2^{(2)}/\partial\beta < 0$ demonstrate the negative effect of β on the SME's utility function. This means that an increase in β will diminish $\Delta U_1^{(2)}$ and $\Delta U_2^{(2)}$ and it will decrease the will of SMEs to remain in the market.
b) $\partial q_{21}^{(2)}/\partial\beta < 0$ and $\partial q_{22}^{(2)}/\partial\beta < 0$ demonstrate the negative effect of β on the SME's production quantity. An increase in β results in an increase in SMEs' costs and thus they fail to increase production quantity.

The following proposition computes the candidate solution pairs, which can be represented as the possible ESS of the game.

Corollary 5. *In Scenario 2 with the government's labor-based measure, the candidate solution pairs that satisfy the condition mentioned in Definition 2 can be introduced as the ESS:*

$$x_1^{(2)} = 0,\ x_2^{(2)} = 1) \tag{53}$$

$$x_1^{(2)} = 0, x_2^{(2)} = 1) \tag{54}$$

$$\left(x_1^{(2)} = \frac{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(2)}}^2 + \left(\overline{\alpha}a - \beta c_2l - c_1 - bq_{22}^{'(2)}\right)q_{22}^{(2)} + \lambda\sigma_r^2I^2 - (1+\overline{r})I - Lc_3 - C + C_0}{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(2)}}^2 + (\overline{\alpha}a - \beta c_2l - c_1 - bq_{22}^{'(2)})q_{22}^{(2)} + q_{21}^{(2)}\left(a^2\lambda\sigma_\alpha^2q_{21}^{(2)} - \overline{\alpha}a + bq_{21}^{(2)} + \beta c_2l + c_1\right)}, x_2^{(2)} = 1 - x_1 \right). \tag{55}$$

4.3.4. Scenario 3

In this scenario the government allocates subsidies per unit-manufactured product. This supportive production-based policy provides financial support to SMEs which are suffering from the negative consequences of the economic recession. By allocating subsidies to SMEs, their costs are reduced, causing a greater reluctance to abandon the market. The payoff functions resulting from SME competition are presented below:

$$\widetilde{\Pi}_{11}^{(3)} = (1+\widetilde{r})I - C_0 \tag{56}$$

$$\widetilde{\Pi}_{12}^{(3)} = \widetilde{\Pi}_{11}^{(3)} \tag{57}$$

$$\widetilde{\Pi}_{21}^{(3)} = q_{21}^{(3)}\widetilde{p}_{21}^{(3)} - (c_1+c_2l)q_{21}^{(3)} - C - Lc_3 + q_{21}^{(3)}s, \tag{58}$$

$$\widetilde{\Pi}_{22}^{(3)} = q_{22}^{(3)}\widetilde{p}_{22}^{(3)} - (c_1+c_2l)q_{22}^{(3)} - C - Lc_3 + q_{22}^{(3)}s. \tag{59}$$

In Eqs. (58) and (59), the subsidies per unit of production improves the payoff function of SMEs that remain in the competitive market. Since $\widetilde{\Pi}_{ij}^{(3)}$ takes stochastic amounts, the following utility functions are conducted, with regard to the risk-averse attitude of SMEs:

$$U_{11}^{(3)} = (1+\overline{r})I - C_0 - \lambda I^2\delta_r^2, \tag{60}$$

$$U_{12}^{(3)} = U_{11}^{(3)}, \tag{61}$$

$$(x_1^{(3)} = \frac{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(3)}}^2 + \left(\overline{\alpha}a - c_2l - c_1 - bq_{22}^{'(3)} + s\right)q_{22}^{(3)} + \lambda\sigma_r^2I^2 - (1+\overline{r})I - Lc_3 - C + C_0}{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(3)}}^2 + \left(\overline{\alpha}a - c_2l - c_1 - bq_{22}^{'(3)} + s\right)q_{22}^{(3)} + q_{21}^{(3)}\left(a^2\lambda\sigma_\alpha^2q_{21}^{(3)} - \overline{\alpha}a + bq_{21}^{(3)} + c_2l + c_1 - s\right)}, x_2^{(3)} = 1 - x_1^{(3)}) \tag{70}$$

$$U_{21}^{(3)} = q_{21}^{(3)}\left(\overline{\alpha}a - bq_{21}^{(3)}\right) - (c_1+c_2l)q_{21}^{(3)} - C - Lc_3 + q_{21}^{(3)}s - \lambda a^2{q_{21}^{(3)}}^2\delta_\alpha^2, \tag{62}$$

$$U_{22}^{(3)} = q_{22}^{(3)}\left[\overline{\alpha}a - b\left(q_{22}^{(3)} + q_{21}^{'(3)}\right)\right] - (c_1+c_2l)q_{22}^{(3)} - C - Lc_3 + q_{22}^{(3)}s - \lambda a^2{q_{22}^{(3)}}^2\delta_\alpha^2 \tag{63}$$

Similar to Proposition 1, the following proposition represents the optimal production quantities of Players A and B.

Proposition 4. *In Scenario 3 with the government's production-based measure (s), the optimal production quantity of Player A and Player B, with regard to SMEs' potential and financial limits, are provided as follows:*

$$q_{21}^{*(3)} = \min\left\{\frac{a\overline{\alpha} - c_2l - c_1 + s}{2\left(\lambda a^2\delta_\alpha^2 + b\right)}, \frac{I - C - Lc_3}{(c_1 + lc_2 - s)}\right\}, \tag{64}$$

$$q_{22}^{*(3)} = q_{22}^{'*(3)} = \min\{\frac{a\overline{\alpha} - c_2l - c_1 + s}{2a^2\lambda\delta_\alpha^2 + 3b}, \frac{I - C - Lc_3}{(c_1 + lc_2 - s)}\} \tag{65}$$

Similar to previous scenarios $\Delta U_1^{(3)}$ and $\Delta U_2^{(3)}$ in this scenario can be computed as follows:

$$\Delta U_1^{(3)} = q_{21}^{(3)}\left(\overline{\alpha}a - bq_{21}^{(3)}\right) - (c_1+c_2l)q_{21}^{(3)} - C - Lc_3 + q_{21}^{(3)}s - \lambda a^2{q_{21}^{(3)}}^2\delta_\alpha^2 - (1+\overline{r})I + C_0 + \lambda I^2\delta_r^2, \tag{66}$$

$$\Delta U_2^{(3)} = q_{22}^{(3)}\left[\overline{\alpha}a - b\left(q_{22}^{(3)} + q_{22}^{'(3)}\right)\right] - (c_1+c_2l)q_{22}^{(3)} - C - Lc_3 + q_{22}^{(3)}s - \lambda a^2{q_{22}^{(3)}}^2\delta_\alpha^2 - (1+\overline{r})I + C_0 + \lambda I^2\delta_r^2. \tag{67}$$

Corollary 6. *Under Scenario 3 with government's production-based measure, we have the following conditions:*

a) $\partial\Delta U_1^{(3)}/\partial s$ and $\partial\Delta U_2^{(3)}/\partial s$ may be positive or negative. It means that an increase in s may increase or decrease $\Delta U_1^{(3)}$ and $\Delta U_2^{(3)}$ depending on the problem parameters.
b) $\partial q_{21}^{(3)}/\partial s > 0$ and $\partial q_{22}^{(3)}/\partial s > 0$ denote the positive effect of s on the SME's production quantity. An increase in s results in a decrease in SME costs, and thus they succeed in increasing production quantity.

The following proposition computes the candidate solution pairs that can be represented as the candidate ESS of the game.

Corollary 7. *In Scenario 3 with the government's production-based measure (s), the candidate solution pairs that satisfy the condition mentioned in the definition 2 can be introduced as the ESS:*

$$x_1^{(3)} = 0, x_2^{(3)} = 1), \tag{68}$$

$$x_1^{(3)} = 0, x_2^{(3)} = 1), \tag{69}$$

4.3.5. Scenario 4

Scenario 4 refers to direct financial support to SMEs. Under this scenario, the government provides a loan for SMEs by providing each enterprise with an amount of I_G to each enterprise instantly. Direct government financial assistance can increase the SME's liquidity and prevent them from going bankrupt. Hence, the aggregate budget of SMEs increases to $I + I_G$. However, SMEs are committed to repaying the I_G with a rate of ϑ on a particular time-bound basis, which is assigned by the government.

$$\widetilde{\Pi}_{11}^{(4)} = (1+\widetilde{r})I - C_0 \tag{71}$$

$$\widetilde{\Pi}_{12}^{(4)} = \widetilde{\Pi}_{11}^{(4)} \tag{72}$$

$$\widetilde{\Pi}_{21}^{(4)} = q_{21}^{(4)}\widetilde{p}_{21}^{(4)} - (c_1+c_2l)q_{21}^{(4)} - C - Lc_3 - \vartheta I_G, \tag{73}$$

$$\widetilde{\Pi}_{22}^{(4)} = q_{22}^{(4)}\widetilde{p}_{21}^{(4)} - (c_1+c_2l)q_{22}^{(4)} - C - Lc_3 - \vartheta I_G. \tag{74}$$

Since $\widetilde{\Pi}_{ij}^{(4)}$ takes stochastic amounts, the following utility functions are conducted regarding the risk-averse attitude of SMEs:

$$U_{11}^{(4)} = (1+\overline{r})I - C_0 - \lambda I^2\delta_r^2, \tag{75}$$

$$U_{12}^{(4)} = U_{11}^{(4)}, \tag{76}$$

$$U_{21}^{(4)} = q_{21}^{(4)}\left(\overline{\alpha}a - bq_{21}{}^{(4)}\right) - (c_1 + c_2 l)q_{21}^{(4)} - C - Lc_3 - \vartheta I_G - \lambda a^2 {q_{21}^{(4)}}^2 \delta_\alpha^2 \quad (77)$$

$$U_{22}^{(4)} = q_{22}^{(4)}\left[\overline{\alpha}a - b\left(q_{22}^{(4)} + q_{22}^{'(4)}\right)\right] - (c_1 + c_2 l)q_{22}^{(4)} - C - Lc_3 - \vartheta I_G - \lambda a^2 {q_{22}^{(4)}}^2 \delta_\alpha^2 \quad (78)$$

Similar to Proposition 1, the following proposition represents the optimal production quantities of Players A and B.

Proposition 5. *In Scenario 4 with the government's production-based measure (I_G), the optimal production quantity of SME A and SME B, with regard to SMEs' potential and financial limits, are provided as follows:*

$$q_{21}^{*(4)} = \min\left\{\frac{a\overline{\alpha} - c_2 l - c_1}{2\left(a^2\lambda\delta_\alpha^2 + b\right)}, \frac{I + I_G - C - Lc_3}{(c_1 + lc_2)}\right\}, \quad (79)$$

$$q_{22}^{*(4)} = q_{22}^{'*(4)} = \min\left\{\frac{a\overline{\alpha} - c_2 l - c_1}{2a^2\lambda\delta_\alpha^2 + 3b}, \frac{I + I_G - C - Lc_3}{(c_1 + lc_2)}\right\}. \quad (80)$$

Similar to previous scenarios, $\Delta U_1^{(4)}$ and $\Delta U_2^{(4)}$ in this scenario can be computed as follows:

$$\Delta U_1^{(4)} = q_{21}^{(4)}\left(\overline{\alpha}a - bq_{21}^{(4)}\right) - (c_1 + c_2 l)q_{21}^{(4)} - C - Lc_3 - \vartheta I_G - \lambda a^2 {q_{21}^{(4)}}^2 \delta_\alpha^2 - (1 + \overline{r})I + C_0 + \lambda I^2 \delta_r^2, \quad (81)$$

$$\Delta U_2^{(4)} = q_{22}^{(4)}\left[\overline{\alpha}a - b\left(q_{22}^{(4)} + q_{22}^{'(4)}\right)\right] - (c_1 + c_2 l)q_{22}^{(4)} - C - Lc_3 - \vartheta I_G - \lambda a^2 {q_{22}^{(4)}}^2 \delta_\alpha^2 - (1 + \overline{r})I + C_0 + \lambda I^2 \delta_r^2. \quad (82)$$

Corollary 8. *Under Scenario 4 with the government's production-based measure (I_G), there is one of the following cases:*

Case 1. *In the case that $q_{21}^{*(4)} = \frac{a\overline{\alpha} - c_2 l - c_1}{2\left(a^2\lambda\delta_\alpha^2 + b\right)}$ and $q_{22}^{*(4)} = \frac{a\overline{\alpha} - c_2 l - c_1}{2a^2\lambda\delta_\alpha^2 + 3b}$, we have the following conditions*:

a) *$\partial\Delta U_1^{(4)}/\partial I_G < 0$ and $\partial\Delta U_2^{(4)}/\partial I_G < 0$ demonstrate the negative effect of I_G on the SME's utility function. This means that an increase in I_G will decrease $\Delta U_1^{(4)}$ and $\Delta U_2^{(4)}$, which will decrease the will of SMEs to remain in the market. We can conclude that in the case that budget is not considered as a limit for SMEs accepting the loan not only will not increase the profit but also will affect the SMEs' achievement negatively.*
b) *$\partial\Delta U_1^{(4)}/\partial\theta < 0$ and $\partial\Delta U_2^{(4)}/\partial\theta < 0$ demonstrate the negative effect of θ on SME's utility function. This means that an increase in θ will decrease $\Delta U_1^{(4)}$ and $\Delta U_2^{(4)}$, and it will decrease the will of SMEs to remain in the market.*

Case 2. *In the case that $q_{21}^{*(4)} = q_{22}^{*(4)} = \frac{I + I_G - C - Lc_3}{(c_1 + lc_2)}$, we have the following conditions*:

a) *I_G can affect $\Delta U_1^{(4)}$ and $\Delta U_2^{(4)}$ in a positive and negative way. The concert effect depends on the amount of the loan and the repayment rate.*
b) *$\partial\Delta U_1^{(4)}/\partial\theta < 0$ and $\partial\Delta U_2^{(4)}/\partial\theta < 0$ demonstrate that the repayment rate of the government's loan is going to decrease the utility functions of SMEs.*
c) *The loan provided by the government is going to increase the SME's budget. As a result, the quantity of production is going to be increased, therefore, $\partial q_{21}^{(4)}/\partial I_G > 0$ and $\partial q_{22}^{(4)}/\partial I_G > 0$.*

Corollary 9. *In Scenario 4 with the government's production-based measure, the candidate solution pairs that satisfy the condition mentioned in Definition 2 can be introduced as the ESS:*

$$x_1^{(4)} = 0,\ x_2^{(4)} = 1) \quad (83)$$

$$x_1^{(4)} = 0, x_2^{(4)} = 1) \quad (84)$$

$$x_1^{(4)} = \frac{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(4)}}^2 + \left(\overline{\alpha}a - c_2 l - c_1 - bq_{22}^{'(4)}\right)q_{22}^{(4)} + \lambda\sigma_r^2 I^2 - (1 + \overline{r})I - Lc_3 - C + C_0 - \theta I_G}{\left(-a^2\lambda\sigma_\alpha^2 - b\right){q_{22}^{(4)}}^2 + \left(\overline{\alpha}a - c_2 l - c_1 - bq_{22}^{'(4)}\right)q_{22}^{(4)} + q_{21}^{(4)}\left(a^2\lambda\sigma_\alpha^2 q_{21}{}^{(4)} - \overline{\alpha}a + bq_{21}^{(4)} + c_2 l + c_1\right)}, x_2^{(4)} = 1 - x_1^{(4)}). \quad (85)$$

4.4. The government model

In the previous section, the utility function of SMEs and the ESS under different government interventions were formulated. In this section, a mathematical model for the government is provided that allows SMEs to face the crisis.

Government net expenditure (GNE) and Social welfare (SW) are presented as two important factors to shape the government's objective function. The government tries to increase the consumers' satisfaction as well as the utility functions of SMEs that remain in the competitive market with the lowest GNE. $E(U_2)$ is represented as the average profit of an active SME, which diminishes the negative effect of the crisis. The withdrawal of SMEs will diminish the $E(U_2)$ dramatically.

$$E(U_2) = x(1 - x)U_{21} + (1 - x)^2 U_{22}. \quad (86)$$

$E(Q)$ is introduced as the average production quantity, which is calculated as below:

$$E(Q) = x(1 - x)q_{21} + (1 - x)^2 q_{22}. \quad (87)$$

Similar to Sheu (2011) and Sheu and Chen (2012) social welfare (SW) is applied, which is commonly used in the related literature as an important criterion which the government tries to maximize. The function to compute social welfare involves customer surplus (CS) and SME surplus (SS), and is presented as follows:

$$SW = CS + SS = \frac{1}{2}bE(Q)^2 + E(U_2) \quad (88)$$

Although the implementation of policies can be enormously costly for the government, failure to act promptly can cause irreparable damage to industry. As per Sheu (2011), Hafezalkotob (2018), and Sheu and Chen (2012), GNE is an appropriate factor to evaluate policy implementation. It is assumed that GNE includes all the expenditures that the government undertakes to implement the measures, and that it should be calculated for each scenario correspondingly. Thus, the general model of government is presented as follows:

$$Maxz = \Omega SW - (1-\Omega)GNE \quad (89)$$

Subject to:

$$Nx(lq_0 + L)\langle E\, i = 1,2, j = 1,\, 2 \quad (90)$$

$$NE(Q) \geq D. \quad (91)$$

The objective function of the government aims to maximize SW as well as diminish GNE. Coefficient $\Omega(0 \leq \Omega \leq 1)$ enables a tradeoff between the SW and GNE objective functions. Higher Ω represents that government emphasizes on social welfare effects of a supportive policy rather than its expenditure. E is introduced as the maximum quantity of unemployed workers, as set by the government. Constraint (90) ensures that unemployment quantity will not cross a certain threshold defined by the government. D is introduced as market demand; thus, the second constraint guarantees that demand in the market will be satisfied completely. The government model under each scenario is presented in Table 3.

5. A numerical example

A numerical example is provided to examine the practical aspects of the model (see Table 4). Food production is an industry that cannot be stopped. These production units have been obliged to produce and make food available to the public since food is considered as one of the main commodity goods. Iran has been introduced as one of the most severely affected Countries by COVID-19(Jalali, Shahabi, Bagheri Lankarani, Kamali, & Mojgani, 2020). The impact of covid-19 on food production is unclear and too complex to fully understand (Henry, 2020). The government has been expected to provide food products in sufficient quantities at a reasonable price during pandemics. Although the death of over 1 million populations has not caused a dramatic decrease in food demand, the alternation in consumption manners has caused a severe uncertainty in food demand, for instance, the demand for grains such as rice has rapidly grown (Henry, 2020). On the other hand, the poverty and job-loss resulted from COVID-19 are other factors that alert the demand (Henry, 2020).

Nowadays, convenience food has gained popularity, especially among working-class people. Daily chores and lack of time have led people to consume convenience food not as a pleasant choice but as a time-saving solution that can replace cooking (Warde, 1999). According to Iran's food industry, there are several large-sized companies that produce alternative convenience food such as burgers, salads as well as canned food. However, it is noteworthy that besides large production units there are numerous SMEs that offer different food products with a large variety.

The top consumption of convenience food takes place in offices and universities by employees and students, respectively. According to the lockdown because of the COVID-19 outbreak, a lot of companies, as well as schools and universities, have been forced to be closed while teleworking becomes a common decision which is made by several enterprises. This issue has caused a dramatic fall in the demand for convenience food.

The lack of essential resources has made these SMEs vulnerable during the pandemic as well as has made them obliged to leave the market (Sułkowski, 2020). According to Le et al. (2020) the SMEs have experienced 60.2 % decrease in revenue. 43.4 % of these SMEs have faced difficulties to remain in the market in addition 39.4 % have already left the market while this percentage is increasing.

Recently, the European Institute of Innovation and Technology (EIT[19]) has published a report regarding to the impact of Covid-19 on consumer food behaviors in Europe. The report indicates that the consumption rate of most types of food have raised, such as fruit (32 % increased vs 9 % decreased), vegetables (27 % increased vs 8 % decreased), etc. However, the report mentioned alcohol (20 % increased vs 24 % decreased) and convenience food (22 % more vs 26 % less) as only two exceptions with decreasing trend of consumptions. Another study with identical aim is accomplished by Ben Hassen et al. (2020) in Qatar. They also reported that the consumption of fast foods, packaged frozen foods, and canned food had significantly decreased, while consumption of fruits, vegetables, meat, and healthy foods had moderately increased. Finally, Rabiei et al. (2021) reported 74.8 % reduction in fast food consumption among Iranian households.

In addition, COVID-19 has caused poverty that makes purchasing convenience food uneconomical decision. All the stated issues have caused a great vulnerability in the convenience foods market. Large-sized enterprises have alternative strategies to face the recession, while SMEs are more vulnerable. Hence, many of them are forced to leave the market or lay-off their workers. Because they form a relatively large part of the Iranian convenience food industry as well as obtain a large number of workers, leaving the market would be disastrous for the government. The vulnerability of SMEs necessitates the government to act drastically to avoid a market slump.

It is important to note that, this model can be applied to any type of manufacturing SMEs concerning the model assumptions. Some essential information has been extracted from related evidence (Halat & Hafezalkotob, 2019) such as annually published data by Ministry of Industry, Mine, and Trade of Iran as well as Ali et al. (2021) and Song and Zhuang (2017). All values of the parameters for running the model are presented in the table below. All the results indicated in tables and figures were obtained using the Maple 17.00 and MATLAB R2017b packages.

The government model in each scenario (Table 3) needs to be solved to determine the optimum value for the decision variables of the government. The government decision variables obtained from solving the government models should be applied to SME competition problems in each scenario. The best values of the decision variable are shown in Table 5. Table 5 illustrates that if the government prevents the implementation of any policy, all the SMEs are going to abandon the market because the evaluated ESS equals to $x_1 = 1$ and $x_2 = 0$. Hence, government intervention is essential to prevent SMEs from abandoning the market during the recession. Under scenarios 1, 2, and 3, SMEs succeed in achieving acceptable utility to remain in the competitive market (i.e., $x_1 = 0$, $x_2 = 1$) which means that imposed policies successfully encourage SMEs to continue their business. Under Scenario 1, SMEs which leave the market are forced to pay for the laid-off skilled and indirect workforce. Table 5 demonstrates that, under Scenario 1, the entire SME population is going to remain in the market since, according to the imposed penalties, leaving the market is not affordable. In Scenario 2, the government takes a supportive approach in which (1-β) percent of the skilled workforce salary is paid by the government. Under Scenario 3, subsidies are provided for the production of each unit of the product. Both supportive policies help SMEs to remain in the competitive market because ($x_1 = 0$,$x_2 = 1$) is introduced as the ESS in both scenarios. In Scenario 4, money is provided directly to SMEs to increase their budget, although SMEs are required to repay the loan at a certain rate. Under Scenario 4, the government provides $I_G = 198$ with a return rate of $\theta = 0.05$. Analyzing Table 5, it is concluded that Scenario 4 fails to motivate SMEs to remain in the competitive market because $x_1 = 1$ and $x_2 = 0$ are represented as the ESS. It means that despite the financial aid paid by the government, leaving the market is more preferable for SMEs.

Fig. 2 sheds light to the stationary solution and the convergence process in different scenarios. The area in red illustrates the maximum convergence speed (high speed of evolution) to the steady state. The yellow colored area shows medium speed and the area in light blue shows a decrease in the convergence speed to the evolutionary stable point and the dark blue area represents very decreased speed.

The arrows in Fig. 2 illustrate the direction a trajectory and they

[19] COVID-19 study: European food behaviors (https://bit.ly/3xisUkl).

Table 3
The government measures modeling under each scenario.

Labor-based measures	
Scenario 1	$Maxz = \Omega\left(\frac{1}{2}b\left(x(1-x)q_{21}^{(1)} + (1-x)^2 q_{22}^{(1)}\right)^2 + x(1-x)U_{21}^{(1)} + (1-x)^2 U_{22}^{(1)}\right) + (1-\Omega)\left(Nx\left(t_1 l q_{ij}^{(1)} + t_2 L\right)\right)$ *Subject to:* $Nx\left(lq_{ij}^{(1)} + L\right)\langle E \forall i = 1,2, j = 1,2, N(x(1-x)q_{21}^{(1)} + (1-x)^2 q_{22}^{(1)}) \geq D,$ $t_1, t_2 > 0.$
Scenario 2	$Maxz = \Omega\left(\frac{1}{2}b\left(x(1-x)q_{21}^{(2)} + (1-x)^2 q_{22}^{(2)}\right)^2 + x(1-x)U_{21}^{(2)} + (1-x)^2 U_{22}^{(2)}\right) - (1-\Omega)N(1-x)(1-\beta)c_2 l q_{ij}^{(2)}$ *Subject to:* $Nx\left(lq_{ij}^{(2)} + L\right)\langle E, \forall i = 1, j = 1,2, N\left(x(1-x)q_{21}^{(2)} + (1-x)^2 q_{22}^{(2)}\right) \geq D, 0 < \beta < 1.$
Production-based measures	
Scenario 3	$Maxz = \Omega\left(\frac{1}{2}b\left(x(1-x)q_{21}^{(3)} + (1-x)^2 q_{22}^{(3)}\right)^2 + x(1-x)U_{21}^{(3)} + (1-x)^2 U_{22}^{(3)}\right) - (1-\Omega)(Nsq_{ij}^{(3)}(1-x))$ *Subject to:* $Nx\left(lq_{ij}^{(3)} + L\right)\langle E, \forall i = 1, j = 1,2, N(x(1-x)q_{21}^{(3)} + (1-x)^2 q_{22}^{(3)}) \geq D, s > 0.$
Scenario 4	$Maxz = \Omega\left(\frac{1}{2}b\left(x(1-x)q_{21}^{(4)} + (1-x)^2 q_{22}^{(4)}\right)^2 + x(1-x)U_{21}^{(4)} + (1-x)^2 U_{22}^{(4)}\right) - (1-\Omega)(N(1-x)(1-\theta)I_G)$ *Subject to:* $Nx\left(lq_{ij}^{(4)} + L\right)\langle E, \forall i = 1, j = 1,2, N(x(1-x)q_{21}^{(4)} + (1-x)^2 q_{22}^{(4)}) \geq D, I_G > 0, 0 < \theta < 1.$

Table 4
The inputs of the numerical example.

$\bar{r} = 0.18$	$\delta_\alpha = 0.01$	$b = 0.6$	$c_1 = 15\$$,
$\delta_r = 0.04$	$a = 3000$	$l = 40$ w	$c_2 = 20\$$,
$\lambda = 0.5$	$D = 5000$ unit product	$L = 20$ w	$c_3 = 10\$$,
E = 1000 w1	$N = 50$	$I = 1000 \times 10^2\$$	$C_0 = 200\$$, $C = 150\$$

[1]worker.

Table 5
The results obtained by running the Government's model.

Scenarios	The ESS		Government's decision variables
	x_1	x_2	
Benchmark scenario	1	0	–
Scenario1	0	1	$t_1 = 1, t_2 = 0$
Scenario2	0	1	$\beta = 0.9$
Scenario3	0	1	$s = 73$
Scenario4	1	0	$I_G = 198, \theta = 0.05$

demonstrate the time progresses are contingent upon the starting point of problem (i.e., the initial behavior of SME population at the beginning of the recession). Fig. 2 shows that the whole plot area is converged to the solution point ($x_1 = 1, x_2 = 0$) in the Benchmark and forth Scenarios inferring that the solution point can be presented as the ESS which is consistent with Table 5. We can also see in this figure that regardless the initial point (the initial strategies of SME population inside the square of $(x_1, x_2) \in (0.1) \times (0, 1)$) the trajectories will sucked into the solution point ($x_1 = 1, x_2 = 0$) in Scenarios 1, 2 and 3. This means that the point represents an ESS which is consistent with Table 5.

Fig. 3 represents the convergence speed to the ESS ($dx_1(t)/dt$) with alternative initial conditions under different scenarios. The different initial conditions are presented by different colors as they visualize the speed of the convergence to the ESS. $x_1(0) = 0$ is presented by red, $x_1(0) = 0.2$ by green and $x_1(0) = 0.4$ by blue, and $x_1(0) = 0.8$ and $x_1(0) = 1$ are presented by orange and yellow respectively. Under Benchmark Scenario and Scenario 4 when $t \to \infty$ all the population evantualy move to $x_1(t) = 1$ while all the spots on $x_1(t) = 0$ remain steady (since it was a possible ESS candidate). It is noteworthy to mention that stability is achieved before $t = 0.18$. Hence they are not considered to be suitable policies for short-term periods. Under Scenario 1, 2 and 3 all the plot area has moved to $x_1(t) = 0$ (ESS) while the spots on $x_1(t) = 1$ remain steady and the stability is achieved before $t = 0.13$. Therefore, there can be considered as appropriate policies for short-term periods.

It is obvious from the Fig. 3 that, if the government avoids intervening in the competition of SMEs or if it presents an inappropriate loan mechanism to SMEs (Scenario 4), the recession eventually causes the SMEs to leave the market. Fig. 3 also illustrates that Scenario 1 takes the shortest time, while Scenario 4 takes the longest time to reach the ESS. If the recovery time after the recession is vital for the government, implementing the labor-based policy mentioned in Scenario 1 will reach their goal most quickly.

Fig. 4 analyzes the effect on government net expenditure of the risk aversion attitudes of SMEs. Benchmark Scenario the government decides not to intervene in competitive market therefore GNE = 0 and it is excluded from the Fig. 4. λ has a positive effect on GNE under Scenarios 1 and 4. According to Fig. 4.(A), an increasing λ raises GNE, while λ affects GNE more severely under Scenario 1 than Scenario 4. Fig. 4.(B) analyses the effect of λ on GNE under Scenario 2 and 3, and shows that it has a negative effect in the area of $0 < \lambda < 4$ and a positive effect in the area of $0.4 < \lambda < 1$. Since the GNE is often increasing with the risk sensitivity of SMEs, we find that the government should incur more expenditure (in all adopted policies) to provoke highly risk-averse SMEs to continue their business.

Fig. 5 illustrates the effect of interest rate ($\bar{r}$) on the mean production quantity E(Q). Under In general, the mean production quantity of SMEs diminishes as $\bar{r}$ increases. Fig. 6 shows that leaving the market is preferable to remaining in the market, since an increase in $\bar{r}$ leads to the better achievement of a rational payoff. It is noteworthy that Scenario 1 provides maximum E(Q), while the lack of government intervention (Benchmark scenario) leads to the minimum E(Q).

Fig. 6 sheds light on the effect of Ω on government net expenditure (GNE) and social welfare (SW). In general, Ω represents the importance of SW for the government. By analyzing Fig. 6. (A) it is concluded that an increasing Ω can improve SW while SW increases under Scenarios 2 and 3 dramatically. An increasing Ω improves GNE since providing a higher SW causes greater costs. Therefore, the supportive policies (i.e., Scenarios 2 and 3) in which the government subsidizes either SME's workforce or production process may yield higher SW with relative more cost. Fig. 6. (B) illustrates that Ω increases GNE under Scenario 2 severely while it does not have a significant effect on GNE under Scenarios 1 and 4.

Fig. 7 illustrates the effects of government's decision variables on SMEs' production quantity and financial potential. Since t_1 and t_2 are obliged to the SMEs that decide to leave the market, hence according to the pay-off of this strategy they have no effect on production quantity. Therefore, scenario 1 is not included in Fig. 7. This figure does not include Scenario 1, since the government policy is dictated to the ones that withdraw from the market. According to Scenario 2, 1-β percent of the skilled workforce salaries is covered by the government; therefore, it

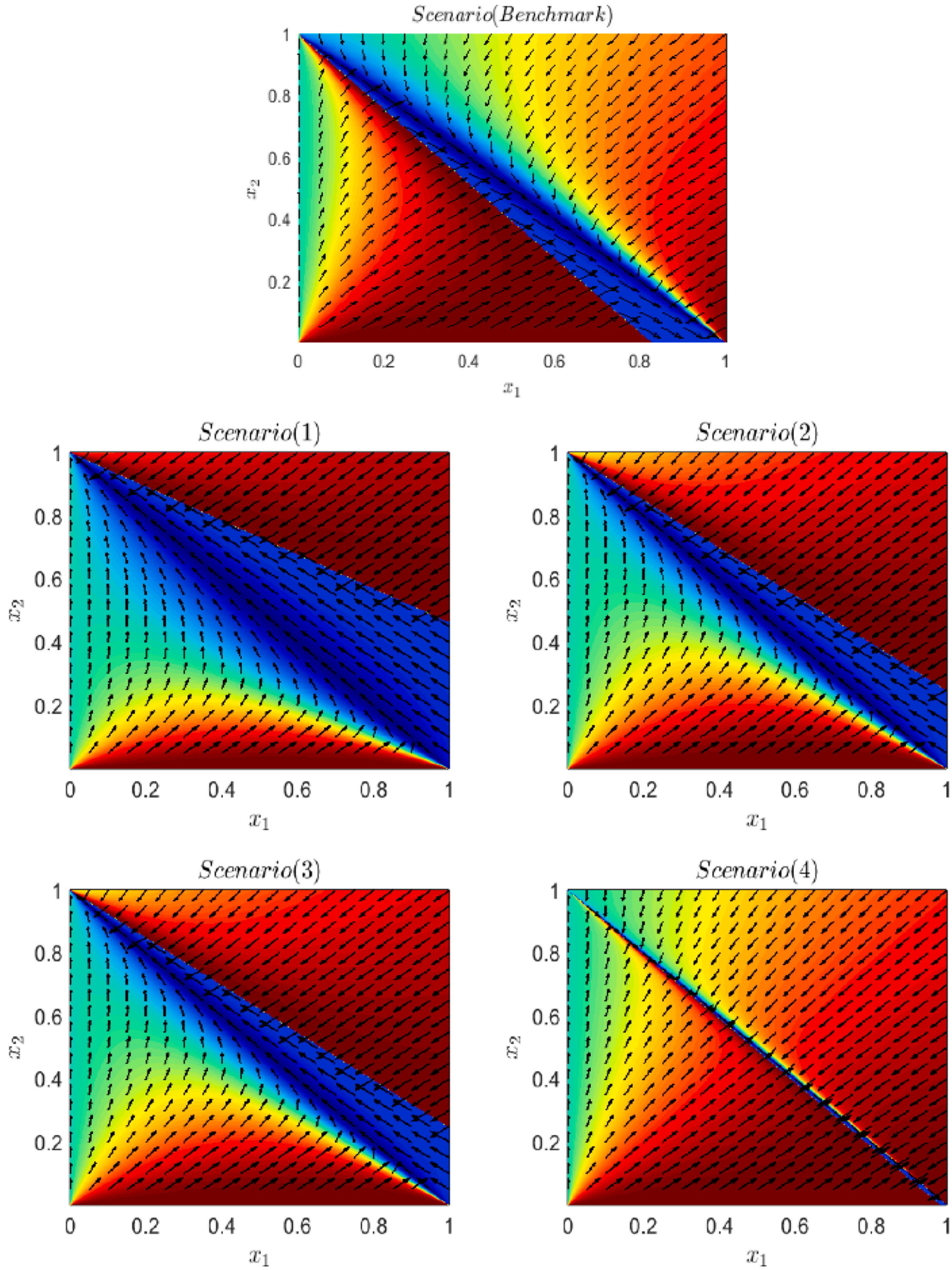

Fig. 2. The convergence of area to the ESS under different scenarios.

is rational that an increasing β will diminish the production quantity as well as financial potential of SMEs. If $0 < \beta < 0.5$, SMEs will succeed to fulfill the optimum production quantity while if $0.6 < \beta$ financial production limit will not let SMEs increase the production. In Scenario 3, the government subsidy s is able to increase both the production quantity and financial potential of the SMEs. Under Scenario 4, the government variable is not able to increase the optimal production quantity while just financially supports SMEs by providing loan (I_G) that diminishes the financial limits of the SMEs.

By analyzing Fig. 8 it can be concluded that the whole number of unemployed workers has a slight decrease by increasing I_G while the number starts increasing as I_G takes greater amount ($I_G \geq 200$. The direct loan provided for the SMEs improves SMEs financially to increase the quantity production which will result in higher profit. However, the competitive market is a sever obstacle for the SMEs. Hence, SMEs fail to reach the potential of their production, on the other hand are forced to pay back the loan with a certain repayment rate θ. Therefore, leaving the market is a rational strategy that most SMEs adopt. Since the SMEs decide to remain in the market under scenario 1, 2, and 3 the effect of λ on number of employees in each SME is analyzed in Fig. 9. According to

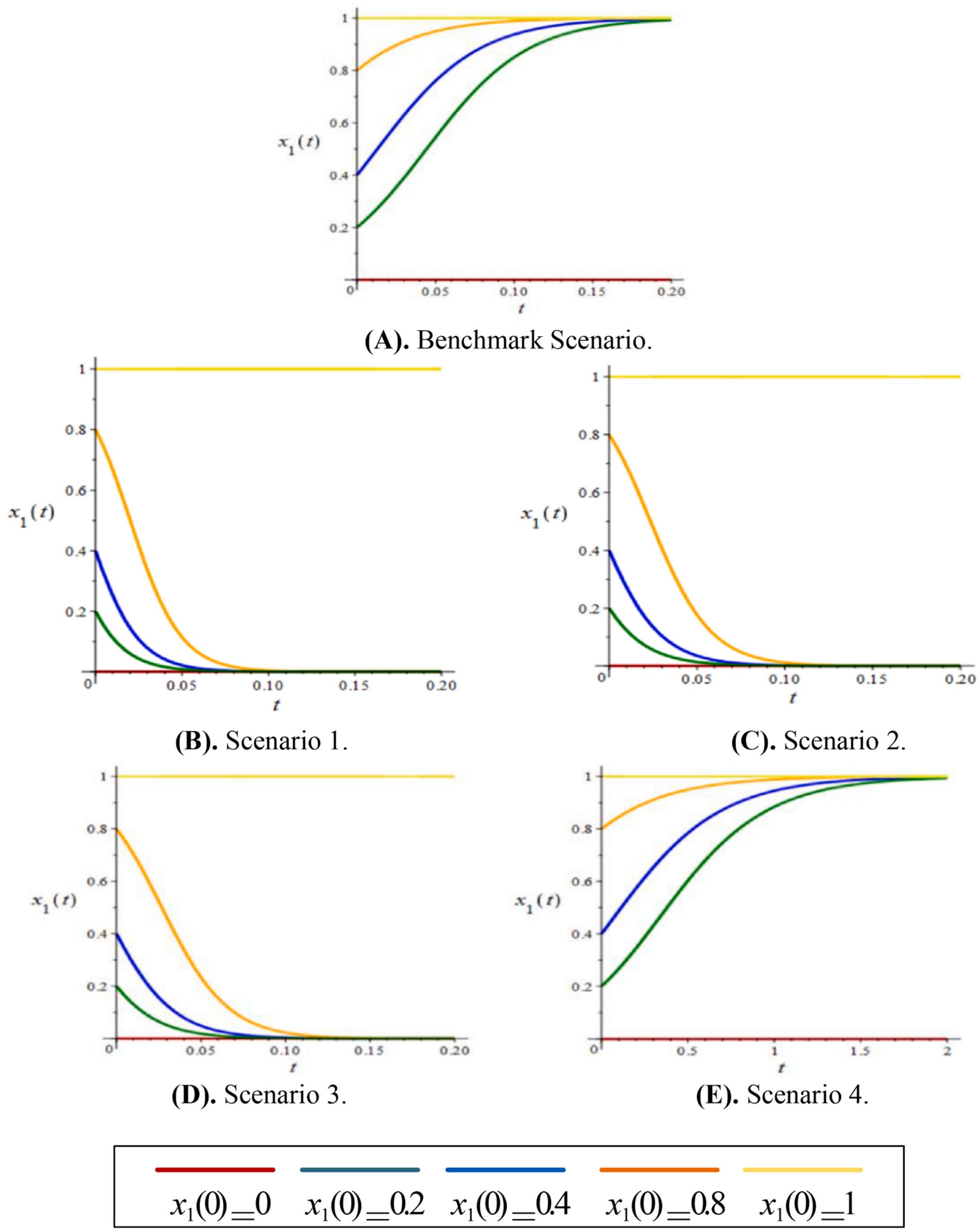

Fig. 3. Convergence of $dx_1(t)/dt$ under different scenarios.

Fig. 9 λ affects the number of employees in a negative way, while the number has a dramatic decrease in Scenario 1 compared to other scenarios.

6. Managerial insights

The findings of the evolutionary game model can be applied by SMEs and governments to fulfill their goals and diminish the negative outcomes caused by the pandemic. Some of the managerial insights achieved by solving the model are presented below:

(a) The evolutionary game model provides a strategic tool to study the effect of different policies on the population of SMEs. Being aware of the behavior of the population allows the government to affect SME responses. According to the numerical example, the government should dictate an appropriate policy to prevent a severe recession in the industry. A lack of government intervention will lead to a severe economic recession, since the majority of SMEs will eventually abandon the market.

(b) The evolutionary stable strategy of SMEs, social welfare level, government net expenditure, and recovery time after the recession are the main criteria that should be considered by the government during the policy-making process. According to the numerical example, dictating punitive labor-based policies, such as assigning penalties, and supportive labor-based policies, such as paying a portion of skilled workforce salaries, as well as production-based policies, such as providing subsidies per unit product, all can succeed in motivating SMEs to remain in the competitive market.

(c) The amount of loan and its return rate are critical factors in Scenario 4. The results of the numerical example demonstrate that providing a loan for SMEs, as well as assigning a return rate,

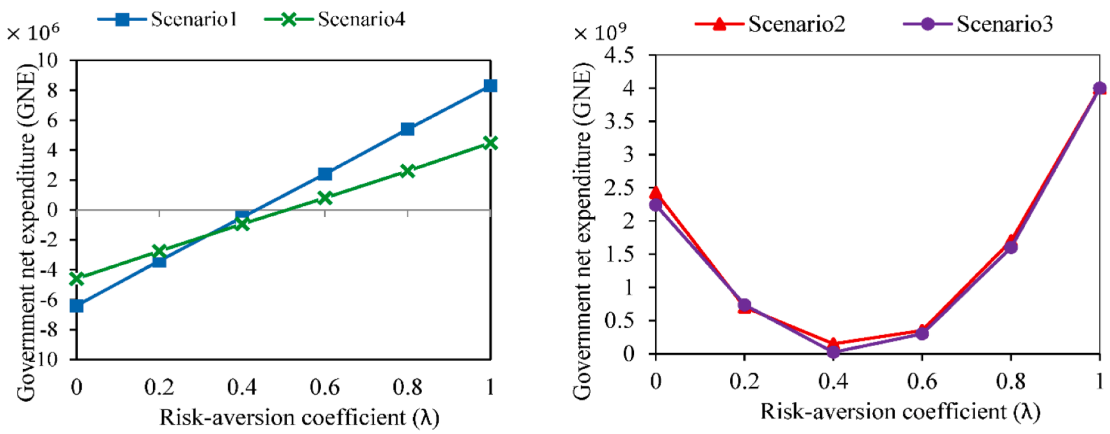

Fig. 4. The impact of risk-aversion coefficient (λ) on GNE under different scenarios.

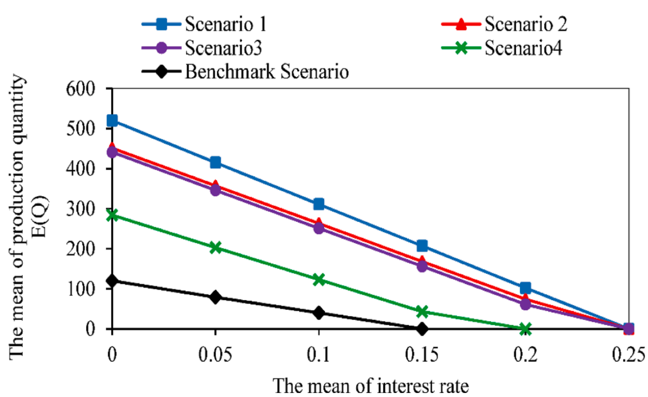

Fig. 5. The impact of interest rate mean ($\bar{r}$) on E(Q) under different scenarios.

is not the most appropriate policy to motivate firms to remain in an industry. Repaying the loan provided at an assigned rate may prevent SMEs from achieving a rational payoff. Since abandoning the market may be more profitable than remaining, the majority of SMEs are going to leave the market.

(d) The length of the recession period may have negative socio-economic consequences; thus, the polices can be compared regarding their corresponding recovery period. From the evolutionary behavior of SMEs in the competitive market, it can be inferred that the imposed policies require different amounts of time to affect the SMEs strategies. According to the numerical example, compelling SMEs to shoulder workforce salaries for a while (Scenario 1) can be an appropriate intervention measure for the government which aims to reach stability in a short period.

(e) If providing the maximum social welfare is essential for the government during the recession, the supportive labor-based policy (Scenario 2) is superior to other policies while it incurs significant government expenditure. However, if the government has some financial constraints, the subsidy on production policy (Scenario 3) can provide a comparable social welfare level with a lower financial burden for the government. Likewise, pressuring SMEs to pay skilled workforce salaries after leaving the market (Scenario 1) is an appropriate measure for a government which is unable or unwilling to undertake huge expenses to support SMEs. However, the government should consider the dissatisfaction level of SMEs leaving the market, because they should incur extra costs during the recession period.

(f) Providing subsidy per unit product is able to increase the production quantity as well as decrease the financial limits, while providing SMEs with loans fail to affects the quantity of production. Hence implementing loans is suitable when the government wants to improve the SMEs' financial potential. Moreover, paying more than 50 percent of skilled workforce salaries by the government will also increase the production quantity as well as diminish the limitations resulted from financial resources.

(g) Providing a moderate direct loan is able to diminish the number of unemployed workers slightly while doing so providing a large amount of direct loan is able to increase the number of unemployment dramatically since, SMEs fail to reach the potential of their production, on the other hand are forced to pay back the loan with a certain repayment rate. It is noteworthy to mention that highly risk-averse SMEs are willing to decrease their

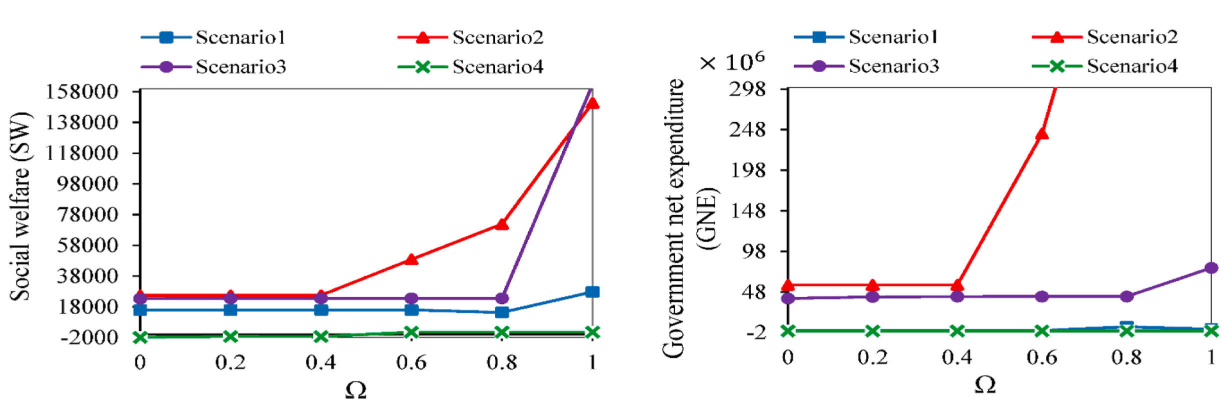

Fig. 6. The impact of Ω on GNE and SW under different scenarios.

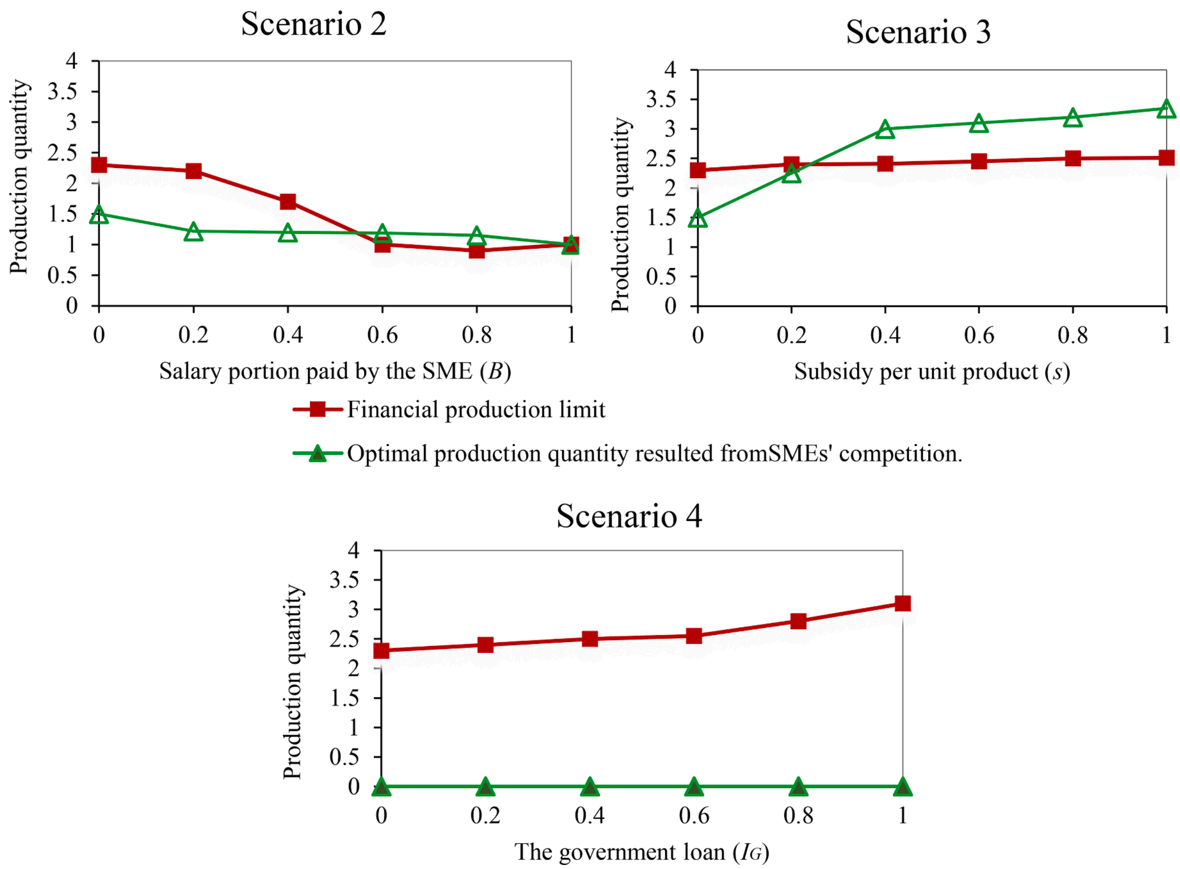

Fig. 7. The impact of Government decision on the quantity product and SMEs and financial potential.

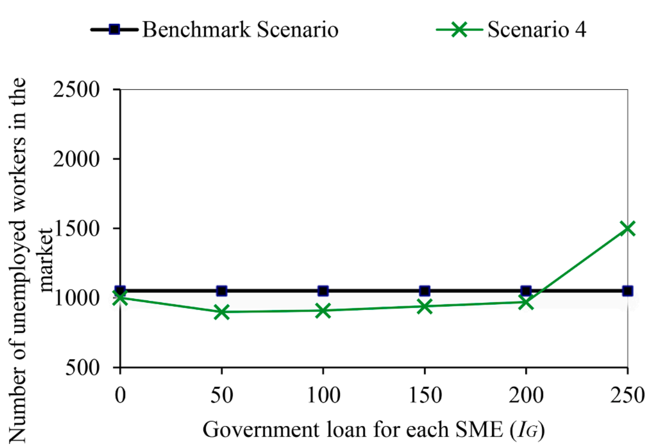

Fig. 8. The impact of Government loan on number of unemployed workers in the market.

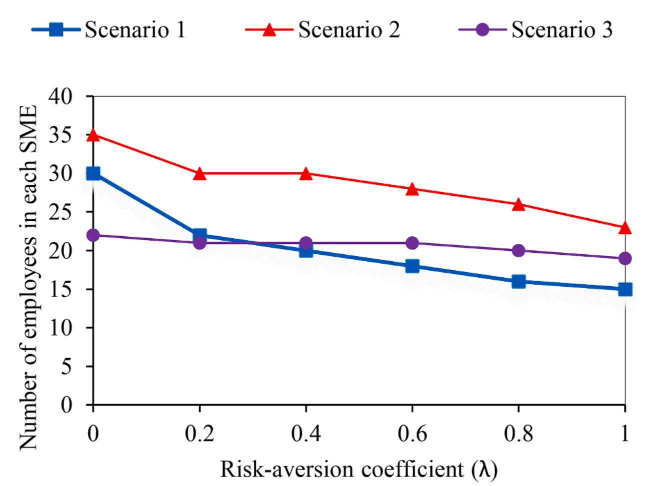

Fig. 9. The impact of risk-aversion coefficient (λ) on the number of employed workers in each SME.

employees under Scenario 1 (pressuring SMEs to pay skilled workforce salaries after leaving the market) compared to other scenarios.

7. Conclusion

This research aims to investigate the best policy for a government to persuade SMEs to remain in the market to minimize the negative outcomes caused by the pandemic. Therefore, four scenarios were conducted according to the government's labor-based or production-based policies. First, the stochastic payoff of each SME was calculated under alternative scenarios. Next, an evolutionary game model was formulated to analyze the behavior of the SME population. Finally, government policies were formulated according to the conditions. It is concluded that labor-based policies succeed in convincing SMEs to remain in the competitive market. The labor-based punitive policy (Scenario 1) incurs extra cost to SMEs that want to leave the market; thus, this policy is suitable when the government aims to reach to market stability in a short period. Production-based policies, such as providing subsidy per unit produced, also succeed in preventing SMEs from leaving the market. Providing a loan for SMEs with a certain repayment rate can reduce payoff of SMEs and may fail to convince SMEs to remain in the market.

Since reluctance to share information is a common decision that is made by many SMEs, real-world implementation of this model is often challenging. In this regards, some obligations or incentives should be applied to enable appropriate information sharing between the SMSs and government. Another limitation is that SMEs and government may encounter many strategies in real-world interactions; therefore, the research is going to face a multi-dimension game, which add the complexity of the model formulation. There are different possible research avenues suggested by the results of the present study. It may prove interesting to consider alternative uncertainty parameters, and alternative intervention policies. Moreover, adding more than two strategies for players could produce illuminating results. Although large-sized enterprises vary with their structure, and thus often have access to alternative strategies to face the crisis, applying this model to large enterprises would also produce new insights. In addition, considering multi-population game as well as considering government as a player who plays directly instead of leading the market can be another interesting field for further research. In his paper, punitive policies were not included; therefore, punitive policies such as different tax policies can be considered in the future researches.

CRediT authorship contribution statement

Ashkan Hafezalkotob: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Validation, Writing – review & editing, Supervision. **Lia Nersesian:** Conceptualization, Methodology, Resources, Software, Formal analysis, Writing – original draft. **Keyvan Fardi:** Methodology, Resources, Software, Investigation, Formal analysis, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cie.2022.108975.

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