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A Software Based Simulation for Cleaner Production: A Game between Manufacturers and Government

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Research Highlights

We devise a generic game model in the field of cleaner production.

Different game scenarios are generated to reflect the variation of strategic actions.

‘Gambit’ software package integrated with Excel spreadsheet is used for the game simulation.

Major factors involved in the game are identified.

A Software Based Simulation for Cleaner Production: A Game between Manufacturers and Government

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Abstract

This paper provides an approach in the field of cleaner production, by showing how game theory could be applied to better understand the possible actions of government and manufacturers in the context of a ‘game’ to achieve more environmentally friendly products. In order to demonstrate the problem situation of cleaner production more visually, the ‘Gambit’ software package is used to simulate the created game model conceived as a “two person non-cooperative” game. With the improvement of cleaner production, different game scenarios have been generated to reflect the variation trend of strategic actions. The application of game theory is shown to provide a useful insight to inform strategic decision making in both government and manufacturers. In addition, the limitation of the game model and the associated analysis has also been discussed, which lays a foundation for further work.

Keywords: Cleaner Production; Decision Making; Game Theory; Game Simulation; Gambit Software Package

1. Introduction

An umbrella term for a range of practices aimed at decreasing the impact of modern industrial production on the environment, cleaner production has been defined as “*the continuous application of an integrated, preventive strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment*” (UNEP, 2006). Cleaner production strategies can be applied to any point in a product’s life cycle in order to mitigate the adverse impact on the environment and human health by decreasing the amount or toxicity of raw materials used in the manufacture or packaging of a product; redesigning products in order to increase their lifecycle, reusability and reparability; reforming the quality of products by which the residual toxicity and waste once products entering the post-consuming stage should have been minimized; changing the patterns of raw materials demand and consumption that reduce the amount and toxicity of waste generated, *etc* (Tchobanoglous & Kreith, 2002; Allen & Rosselot, 2004, Reniers & Amyotte, 2012).

Whilst such strategies can bring economic as well as environmental benefits, for example via energy savings or reductions in the amount of raw materials purchases, or reduction in the costs of waste disposal by reducing the amount and/or toxicity of waste for disposal (Smith, Hargroves, & Desha, 2010), there is little dispute that the state has a role in setting a policy context conducive to cleaner production. For instance, the Chinese government has a stated policy of promoting cleaner production as a route to sustainable development, in which subsidies including tax breaks, equipment upgrading

etc., are offered to enterprises for the implementation of cleaner production (China NDRC, 2006; Dong *et al.*, 2010). As Smith, Hargroves, and Desha also emphasise, a range of policy interventions is needed to promote sustainable production. However, the policies will have to confront with uncertainties during the implementation of cleaner production, due to the conflict of interests between the relevant stakeholders, especially between the government and manufacturers (Dong *et al.*, 2010). Furthermore, whilst environmental policies are essential to achieve sustainable development, they may not be sufficient. Even in the context of the EU, which has put environmental regulations firmly on the policy agenda since the 1970s, many manufacturers still primarily focus on the profit which is the original bottom line for business (Henriques, 2004), while not taking the full lifecycle of products into account, and even do not regard waste materials management as a key business area. In addition, studies have been shown that smaller organizations pay less attention to “waste prevention” or “cleaner process” than larger ones (European Environment Agency, 2003).

In this paper we demonstrate how game theory offers an approach to model the behaviour of industrial organizations under different scenarios. We present a simple ‘cleaner production’ game in which Government and Manufacturers are the principle ‘actors’. The Government role, is seen as promoting environmental protection to create a genuinely sustainable society, whilst safeguarding economic development overall, which can be integrated into the concept of the “Triple Bottom Line” (Elkington, 1997). TBL provides an interpretation of the concept of ‘sustainability’ that, not only focuses

on the economic value, but also on the environmental and social impacts that organisations have it in their power to influence (Elkington, 1997; Savitz & Weber, 2006). For the manufacturers, there are three levels to run a business from bottom to top, which can be described as basic market demand, a sustainable source of raw materials and energy for production, and ‘green’ societal value for environmental protection (Kane, 2010). The traditional basis on which companies operate is governed by the profit motive, hence there has been a tendency to neglect their higher moral responsibility to provide ‘environmentally sound’ and ‘socially responsible’ products having due regard to the Triple Bottom Line (TBL). The manufacturer’s role is to promote their individual firm’s economic stability whilst acting in accordance with policy and norms of behaviour. Thus, there is a large area of common interest between government and manufacturers, which present opportunities and dilemmas to each party in the ‘cleaner production’ game. Moreover, game theory will allow a model taking account of such actions to be tested more thoroughly, as well as provide an approach to determine the possible dominant strategy in the market.

In this paper we first review the existing literature on game theory application to industrial production, and then provide a simple and generic game model based upon the analysis of the problem situation behind the cleaner production game. Moreover, the ‘Gambit’ software tool is used to simulate the created game model followed by a number of set scenarios, in which government and manufacturers’ actions are determined mainly by governmental policy of economic sanction, cost of technological

innovation and expected sales profit, whilst fixing governmental subsidy (tax break) as a constant. Finally, we offer some conclusions on the potential of game theory as a guide to decision makers and suggest further work.

2. Literature review

Game theory has been widely used as a mathematical and logistical approach applied in various research fields, such as economics, marketing, supply chain management, *etc.* It describes the interaction between the ‘players’ who are involved, and as such can be seen as an “interactive decision theory” (Aumann, 2003; Pak & Brieva, 2010; Zhao, Neighbour, Han, McGuire, & Duetz; 2012). In general, the role of game theory in academic research is to help ‘players’ decide their own strategies by predicting the actions of other players based on the expectation of the short term maximized payoff (despite any unintended consequences in the long term) (Zhao, Neighbour, Han, McGuire, & Duetz; 2012).

In the research area of industrial production, game theory has been used for the analysis of market structure, product portfolio management, production process planning and scheduling, as well as selection for choosing appropriate processing technology (Zhou, Jiang, & Huang, 2009; Limaie, 2010; Sadeghi & Zandieh, 2011; Li, Gao, & Li, 2012; He, Ding, & Hua, 2012). With the concept of ‘green’ and ‘low-carbon’ technology gradually entering into product lifecycle management, as a measure against ‘climate change’, studies indicates the traditional production will be upgraded to a more

environmental oriented pattern of production, *i.e.* ‘cleaner production’ (Zhao, Neighbour, Deutz, & McGuire, 2012). In this context, game theory provides a useful insight into pollution control thus improving environmental performances for cleaner production (Jørgensen & Zaccour, 2001; Albiac, Sánchez-Soriano, & Dinar, 2007; Breton, Sokri, & Zaccour, 2008; Chew, Tan, Foo, & Chiu, 2009; Dong *et al.*, 2010). For example, Dong *et al.*, have built a theoretical framework based on game theory to analyze the conflicts between local government and polluting organisation, which also incentivizes cleaner technologies in the Chinese electroplating industry. Policy variables including ‘psychological costs’, ‘environmental benefit evaluation’, ‘reward local government for its implementation’ have been discussed in the game model. However, the analysis of strategic interaction for industrial production using game theory simulation techniques have been rarely reported in the literature, with the exception of those specific to production capacity share and product pricing mechanism (Menniti, Pinnarelli, & Sorrentino, 2008; Renna & Argonet, 2011). In addition, most of these previous studies present game theoretical analysis in an abstract way, based upon mathematical models or frameworks, in the form of equations containing many parameters. The messages derived from such complex analyses can be poorly understood by decision makers. With the development of computer science, computer based game simulation provides a more intuitive environment to help decision makers improve their application of theory and concepts (Chang, Chen, Yang, & Chao, 2009; Lee & Chen, 2009).

This study employs a software package called ‘Gambit’ (McKelvey, McLennan, & Turocy, 2007), to visually demonstrate the possible interactions between government and manufacturer in the context of a ‘cleaner production’ game. With the ‘Gambit’ tool being used for game analysis, the results are easier to apply to aid decision making on the development of cleaner production. This application will not only help policy makers *e.g.* government, better understand the dilemma of cleaner production and the different interactions resulting from game theoretical analysis, but also aid manufacturers identify mitigation strategies to act in accordance with the principles of cleaner production.

3. Game model for cleaner production

At its simplest, a “Two-Person Non-Cooperative” game model is built with two players: Government (G) and Manufacturers (M), respectively. A game is defined as non-cooperative if there is no pre-play communications or agreements, *e.g.* the strategies selected by players cannot be coordinated within such a game situation (Chew, Tan, Foo, & Chiu, 2009; Gale, 2000, p.219). This model starts from the consideration of ‘fiscal measures’ by Government and ‘cost-benefit analysis’ by manufacturers in the process of cleaner production, respectively. Suppose each of them has two available strategies. For government, the strategies are: {R, NR} which indicate whether government should regulate (R) the manufacturing process and the market competition in order to promote cleaner production or not regulate (NR), while keeping the current relationship between supply and market demand. Correspondently, there are two

strategies for manufacturers, which are {CH, NCH}. Action CH means that the manufacturers decide to change (CH) their existing process technology or equipment aiming for better product quality and market expansion, whilst NCH means no change to existing business practices. Table 1 shows the expected payoffs for the two players with different actions.

Insert Table 1 here

In the payoffs matrix, T_B corresponds with the governmental subsidy in a form of Tax Break in order to help manufacturers implement cleaner production; P denotes economic penalties if manufacturers still insist on environmentally unfriendly production, and C represents the cost of technological innovation of manufacturers for cleaner production. E denotes the economic benefit that government would gain in terms of revenue when manufacturers improve production technology, whilst minimizing environmental impact, such as reducing environmental risk and carbon footprint *etc.* S indicates the additional sales that manufacturers may expect from adopting cleaner production instead of the existing method of production. I denotes that the possible loss resulting from environmental impact (such as pollution events). It is assumed in this study, manufacturers cannot predict the actions taken by government at earlier stage of the game or before the game is played, however they may pay more attention to the potential economic benefits when choosing to change or not to change. Meanwhile, government cannot determine whether to regulate the market initially or not, as the actions from the manufacturers could change or not change their existing production

mode. Thus, their actions are triggered simultaneously, which can be seen as static (Geckil & Anderson, 2010).

For any non-cooperative game, the solution is derived from the Nash Equilibrium, by which that each player's chosen strategy is a best response to other player's strategies (Fudenberg & Tirole, 1991; Gibbons, 1992, p.8). How to find out the Nash Equilibrium will be described more detail in the following section.

4. Game simulation

In this section, a simulation software tool 'Gambit' integrated with Excel Spreadsheet is used to express the dilemma and possible game actions between government and manufacturers. Gambit is an open source free software for game theory simulation, through which users are allowed to apply the functions provided for their own requirements. In addition, the game solution is encapsulated in a user friendly interface, in which the functions can be invoked easily by users to simulate the game situation (McKelvey, McLennan, & Turocy, 2007).

According to the above basic game model, the authors here present three possible game scenarios in sequence to select different pairs of strategies. These game scenarios are generated by inserting different numerical values in terms of a logic unit. Especially, the numerical values for each parameter used for Gambit simulation are generated by random number function of Excel 2007. The details of the game scenario analysis are

described in the following sections.

4.1 Game scenario one

Game scenario one illustrates the preliminary stage of the game situation, which reflects the difficulty in developing a cleaner production program. For government, the supervision and regulation of cleaner production is still insufficient with ambiguous policies of sanctions and incentives. Furthermore, any new change may also give rise to an economic risk for the manufacturer. For instance, if the additional sales of environmentally friendly products can not initially cover the total economic cost, manufacturers will be reluctant to implement cleaner production. Thus, once $S - C + T_b < -P$, manufacturers will prefer paying the penalties for environmentally unfriendly production. Selected model parameters for game simulation are presented in Table 2. Here, in order for wider application, all the parameters are expressed in terms of a logic unit. For example, costs may be indicated as 1 unit to represent the real monetary value. The tax break can be provided in terms of ‘Capital allowance’, currently around 22% in UK for plant and machinery (UK HM Revenue & Customs, 2008), and thus it is suggested in this model 22 percent of the technological innovation cost can be saved by upgrading the existing machinery, equipment or tools to promote cleaner production. The factor on revenue and additional sales are set as both random variables, which are generated by the random function of Excel, 10 to 10000 times more than the cost. In this scenario, we assume that additional sales can cover 50% of the cost at most (0.1 to 0.5). Moreover, the fine factor related to economic

sanctions needs to be set at a very low level (0 to 0.2), which is estimated by the equation $S - C + T_b < -P$, as well as the value range of additional sales factor (S), shown in Table 2. Otherwise, if the penalty for manufacturers is set at a higher level, manufacturers would mostly opt to change their production process. Thus, the dominant strategy pair will be (R, NCH) in this scenario.

Insert Table 2 here

Once the model parameters have been determined by Table 2, the Nash Equilibrium is stable and will not vary no matter how many times the game model is run. Thus, a random group of numerical value from the random number of Excel function has been selected to represent the game situation by means of the ‘Gambit’ tool (see Fig.1a). In the Gambit tool, the dominated strategies can be eliminated iteratively by the dominance panel. The strictly dominated action is opposite to dominant strategy, which is defined as “always worse than another, regardless of beliefs at the information set” (McKelvey, McLennan, & Turocy, 2010). In this scenario, CH is the strictly weak strategy for manufacturers which should be eliminated at first (see Fig.1b). When manufacturers determine not to change their current production mode, non-regulation becomes the dominated strategy accordingly. Fig.1c shows the second round of dominated strategy elimination, in which ‘NR’ has been crossed out. The pair of dominant strategy comes out since all the dominated strategies have been eliminated. In scenario one, the result in Fig.1d suggests that government should regulate the manufacturing process by selecting ‘R’, while the manufacturers’ position remains

unchanged ('NCH') due to the insufficient economic sanctions.

Insert Fig.1 here

The remaining strategy pair (R-NCH) represents the unique and stable Nash Equilibrium for this game solution. Moreover, this is a pure strategy game, which is a game with probability of one given to the selected strategy and zero to others (Romp, 1997). For instance, Fig.2 shows the computation result of Nash Equilibrium, from which the probability equals to one when government chooses 'R' and manufacturers choose 'CH'.

Insert Fig.2 here

The traditional method of computing Nash Equilibrium is strongly deterministic. However, the 'Gambit' tool provides a novel approach called 'Quantal Response Equilibrium' (QRE) to search the subset of Nash equilibria. This approach uses imperfect or noisy expectations logic instead of the perfectly rational expectations logic, when searching for the Nash Equilibrium (McKelvey & Palfrey, 1995). Fig.3 demonstrates how the 'QRE' approach is used to search Nash Equilibrium. As the QRE model is a function of probability distribution and the error of choice selection, Lambda (λ) in the figure is related to the level of error in expectation. For $\lambda = 0$, the actions are composed of errors, and for $\lambda \rightarrow \infty$, there is no error. If both players, government and manufacturers, evaluate their expected payoffs in an unbiased way, the probabilities of each strategy being selected should be the same at the beginning of the game, that is

why all the graphs in Fig.3 start at 0.5. As Lambda tends to infinity (∞), the Nash Equilibrium converges to a unique value. For example in this game scenario, the pair of Nash Equilibrium is 'R-NCH', as well as the probability of selecting both strategic actions, equals to one (See Fig.3a and Fig.3d).

Insert Fig.3 here

4.2 Game scenario two

Without efficient governmental regulation for industrial production, society could be exposed to serious environmental impact. If government imposes heavier economic penalties (P) for environmentally unfriendly actions, manufacturers are again obliged to compare the payoff in implementing cleaner production (CH), with that of keeping existing methods (NCH) in order to identify the most beneficial strategy. Game scenario two suggests that if $S - C + T_B > -P$, there is no dominant strategy in the game. Thus, a mixed-strategy game scenario will be generated to find out the corresponding Nash Equilibrium. A mixed-strategy equilibrium, in contrast to pure strategy equilibrium, can be defined as "at least one player involved in the game will place a probability distribution for the alternative strategies" (Romp, 1997). However, each player can only select one specific strategy in a pure strategy game, *e.g.* as in the above game scenario one. Table 3 reflects the parameters selected for game simulation of the second scenario. Suppose that the level of economic penalties (P) for environmentally unfriendly actions is now set to severe, *i.e.* weighted as 10000 times more than cost.

Insert Table 3 here

Fig.4 shows the variation of Nash Equilibria as calculated by the ‘Gambit’ tool, with the sales factor being varied from 0.1 to 1. It can be found that the probability that government chooses non-regulation (NR) while Manufacturers choose change (CH) is nearly 1, about 99%. This pair of strategic selection (NR-CH) approximates closely to the dominant strategy selected in game scenario three, which will be demonstrated in the following section. Moreover, this selection is strongly determined by governmental sanction. Only if the penalty is high enough, will manufacturers consider changing their current industrial process by upgrading the existing equipment or technology for cleaner production.

Insert Fig.4 here

4.3 Game scenario three

With “green consumerism” gaining increasing influence on the market, so well cleaner production mature correspondingly, and thus manufacturers will increasingly seek to benefit from business opportunities connected with sales of ‘environmentally friendly products’. Once the additional sales completely cover the total cost adopting cleaner production methods ($S > C$), government will no longer need to take actions to regulate the process, manufacturers opting to develop cleaner production voluntarily. This game scenario suggests the dominant strategy is that government chooses ‘NR’, and manufacturers choose ‘CH’, which is the optimal result among the three game situations.

Table 4 summarizes the conversion factors to determine the model parameters.

Insert Table 4 here

As long as 'additional sales' (S) is above cost (C), 'NR-CH' (Non-regulation for Government, Change for Manufacturers) is the unique Nash Equilibrium of this game scenario no matter how the factors change. Fig.5 shows the possible maximum and minimum payoffs of strategies of 'R-CH' and 'NR-CH' with both revenue and sales factors being varied from 10 to 10000.

Insert Fig.5 here

As long as the equality $S > C$ is satisfied, the Nash Equilibrium will not be changed in this scenario. Fig.6 shows a random group of numerical values being selected to simulate the game situation by Gambit tool (assuming 10 for both revenue and sales factors in this example). Like the analysis of game scenario one, the dominated strategy and its corresponding payoff should be eliminated. Thus, Figure 6.b shows no matter government choose regulation or non-regulation, 'NCH' is the weak strategy for manufacturers which should be eliminated at first. When the action of 'NCH' has been eliminated in the first round, 'R' is the dominated strategy for government in the second turn whilst 'CH' is selected by manufacturers (see Fig.6c). Once all the dominated strategies have been eliminated, Fig.6d suggests that the dominant strategy is that 'NR' selected by government and 'CH' by manufacturers. This result also suggests a pure strategy pair with the probability of one being calculated for both strategy 'NR' and 'CH', respectively (see Fig.7).

Insert Fig.6 here

As an analogy to the first game scenario, 'QRE' approach can be also applied to this scenario in order to search the unique Nash equilibrium. Fig.7 reflects that the strategic action pair 'NR-CH' is the unique and stable solution of Nash Equilibrium found by the 'Gambit' tool.

Insert Fig.7 here

In contrast, the 'QRE' curves shown in Fig.8, which present the steady trend of rising or declining probability, have fluctuated at first and then stabilized. For example, when government chooses the action of 'R', the probability firstly ascends from 0.5 to above 0.6 and then regresses, finally falling down to 0 (See Fig.8a). This phenomenon results from the principle of maximum benefits followed by different actions of Government, 'R' and 'NR' respectively. From the payoff matrix in the game scenario three, it can be seen from Fig.6 that government can gain the maximum benefit while choosing 'R' to the extent of 3321.95 logic unit. That is why the probability of 'R' has shown an upward tendency from 0.5 to 0.6 in Fig.8a. However, when taking the possible actions of manufacturers into account, *e.g.* 'CH' being selected, the individual rational behaviour reminds government to re-consider the payoffs. By contrast, government can gain more benefit as 0.25 logic unit followed by selecting 'NR'. Thus, the probability to choose 'R' has fallen back to 0.5, and then gradually reduced to 0.

Insert Fig.8 here

4.4 Analysis of game interaction

According to the above game simulation, it is concluded that the strategic actions that government and manufacturers will take mainly resulted from the following factors, economic penalty (P), technological innovation cost (C) and additional sales (S). Fig.9 illustrates the interaction between influencing factors and the strategic actions.

Insert Fig.9 here

It is clear that the economic penalty (P) set by governmental policy needs to be high enough to compel manufacturers to change their current production mode actively, thus to implement cleaner production as well as provide ‘environmentally friendly’ products. The technological innovation cost (C) should be in accordance with the basic standards or principles of cleaner production, to ensure that new products are associated with reduced environmental risk and carbon footprint, and are sustainable. For food and those materials with which people will have direct contact, the criteria of production should be much stricter. The potential economic benefit on the part of manufacturers is determined by the additional sales profit (S), which will also give rise to increasing governmental revenue. Moreover, the profit accruing from additional sales is strongly determined by consumer behaviour, and attitudes to ‘environmentally sound products’, public acceptance, automatically determining the actions of manufacturers, i.e., whether to ‘Change’ or ‘Not change’.

5. Conclusion and further study

Game Theory offers an effective approach to formulating a dominant strategy designed to improve performance across the three dimensions of the Triple Bottom Line (Economic, Society and Environment). This study has applied game theory to better understand the dilemmas that can exist between government and manufacturers, as well as provide insightful perspectives on the potential problems in the context of cleaner production. With the model parameters being assigned different numerical values in terms of a logic unit, three game scenarios have been developed sequentially which reflect the possible changes in the actions of government and manufacturers that could accompany the implementation of cleaner production. The game model mainly depends upon the variation of the following three important factors, such as innovation cost (C), economic penalty (P) and additional sales of ‘environmentally friendly products’ (S). Although government will seek to regulate the process in the initial stage of cleaner production, due to insufficient penalties, as well as any possible change giving rise to additional economic risk for manufacturers, *i.e.* additional sales cannot cover the innovation cost, the result in game scenario one suggests the dominant strategy is that government chooses regulation (R) while manufacturers do not change (NCH) the existing production mode (‘R-NCH’). With further development of cleaner production, it is assumed in game scenario two that government attaches more and more importance to efficiency of regulation and supervision, and thus the penalties have been increased accordingly. The game has been evolved as a two person mix-strategy game without any dominant strategy. However, as long as the penalties are set high enough, manufacturers

should opt to change their production technology to be more ‘green’, and government will gradually adjust the regulatory policy. Once cleaner production has been implemented and the ‘environmentally sound products’ have become the mainstream of market, government no longer needs to intervene strongly, because manufacturers are then willing to promote cleaner production to gain increased profits, additional sales covering the total of technological innovation, equipment upgrading *etc.* Thus, the dominant strategy ultimately becomes non-regulation for government and change for manufacturers (‘NR-CH’). This approach using game theory assists decision making, and informs government and manufacturers on how to promote cleaner production.

However, there are still some limitations involved in the game model and simulation. First of all, the manufacturers are considered one entity, regardless of the scale, quantity and quality of productions, economic benefit and selected strategies, *etc.* Secondly, in order to simplify the analysis of game simulation, the factor of tax break has been fixed, and consequently the selection of strategic choice will be influenced. Moreover, the interactions between the different organisations, enterprises and customers have been omitted. Further study will focus on the underlying mathematical modelling for the game representing the complexity between government, manufacturers and other stakeholders, as well as the development of game simulation in different scenarios. Moreover, it is expected the game model can be fully quantified for further application by means of integration with case studies.

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Table 1

Payoffs matrix between Government (G) and Manufacturers (M)

G \ M	M	CH	NCH
	R	$E - T_B, T_B - C + S$	$P - I, -P$
	NR	$E, -C + S$	$-I, 0$

Table 2

Model parameters of game scenario one

Parameters	Conversion factors	Note
Cost (C)	1 unit	
Tax Break (T_B)	$\text{Cost} \times 22\%$	Rand is a function which the random number from 0 to 1 will be selected.
Economic Benefit (E)	$\text{Cost} \times \text{Rand} \times \text{Revenue factor}$	
Additional Sales (S)	$\text{Cost} \times \text{Rand} \times \text{Sales factor}$	Revenue factor is between 10 to 10000
Economic Sanction (P)	$\text{Cost} \times \text{Rand} \times \text{Fine factor}$	Sales factor is between 0.1 to 0.5
Environmental Loss (I)	$\text{Cost} \times \text{Rand} \times \text{Loss factor}$	Fine factor is between 0 to 0.2
		Environmental loss factor is 10000

Table 3

Model parameters of game scenario two

Parameters	Conversion factors	Note
Cost (C)	1 unit	
Tax Break (T_B)	$\text{Cost} \times 22\%$	Rand is a function which the random number from 0 to 1 will be selected.
Economic Benefit (E)	$\text{Cost} \times \text{Rand} \times \text{Revenue factor}$	
Additional Sales (S)	$\text{Cost} \times \text{Rand} \times \text{Sales factor}$	Revenue factor is between 10 to 10000 Sales factor is between 0.1 to 1
Economic Sanction (P)	$\text{Cost} \times \text{Rand} \times \text{Fine factor}$	Fine factor is 10000
Environmental Loss (I)	$\text{Cost} \times \text{Rand} \times \text{Loss factor}$	Environmental loss factor is 10000

Table 4
Model parameters of game scenario three

Parameters	Conversion factors	Note
Cost (C)	1 unit	
Tax Break (T_B)	$\text{Cost} \times 22\%$	Rand is a function which the random number from 0 to 1 will be selected.
Economic Benefit (E)	$\text{Cost} \times \text{Rand} \times \text{Revenue factor}$	
Additional Sales (S)	$\text{Cost} \times (1 + \text{Rand} \times \text{Sales factor})$	Revenue factor is between 10 to 10000 Sales factor is between 10 to 10000
Economic Sanction (P)	$\text{Cost} \times \text{Rand} \times \text{Fine factor}$	Fine factor is 10000
Environmental Loss (I)	$\text{Cost} \times \text{Rand} \times \text{Loss factor}$	Environmental loss factor is 10000

Figure Captions

Fig.1. Gambit simulation for game scenario one

Fig.2. Computation result of Nash Equilibrium in game scenario one

Fig.3. Quantal response equilibrium approach for game scenario one

Fig.4. Nash equilibria of game scenario two

Fig.5. Maximum and minimum payoffs with different factors

Fig.6. Gambit simulation for game scenario three

Fig.7. Computation result of Nash Equilibrium in game scenario three

Fig.8. Quantal response equilibrium approach for game scenario three

Fig.9. Influencing factors and strategic action

File Edit View Format Tools Help

Hide strategies which are strictly dominated: All strategies shown

		CH	NCH
Government	R	7.17	-0.28
Manufacturers	NR	7.39	-0.50

a

File Edit View Format Tools Help

Hide strategies which are strictly dominated: All strategies shown

		CH	NCH
Government	R	7.17	-0.28
Manufacturers	NR	7.39	-0.50

b

File Edit View Format Tools Help

Hide strategies which are strictly dominated: Eliminated 1 level

		NCH
Government	R	-0.28
Manufacturers	NR	-0.50

c

File Edit View Format Tools Help

Hide strategies which are strictly dominated: Eliminated 2 levels

		NCH
Government	R	-0.28
Manufacturers		

d

Fig.1. Gambit simulation for game scenario one

Fig.2. Computation result of Nash Equilibrium in game scenario one

Fig.3. Quantal response equilibrium approach for game scenario one

Fig.4. Nash equilibria of game scenario two

Fig.5. Maximum and minimum payoffs with different factors

Fig.6. Gambit simulation for game scenario three

Fig.7. Computation result of Nash Equilibrium in game scenario three

Fig.8. Quantal response equilibrium approach for game scenario three

Fig.9. Influencing factors and strategic action