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AN EVOLUTIONARY GAME FOR SUSTAINABLE WORKER'S WAGES

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Abstract

In this paper, an evolutionary game was developed between the companies and the workers to understand the dynamics of interaction between them. The evolutionary game was simulated using system dynamics to visualize the evolution of strategies. This model was applied on a case study to predict the effect of wage revision. Thereafter, based on these suggestions, the workers' wages were increased and effect of the increase was in line with predictions of the model. This model can be useful to the companies in deciding the worker's wages so as to reduce attrition and increase worker's effort at job.

Keywords: Social Sustainability, Evolutionary Game Theory (EGT), System Dynamics (SD), Fair Wage.

1. Introduction

Our Common Future (WCED, 1987), or the 'Brundtland Report' as it is commonly known, stated that "In its broadest sense, sustainable development strategy aims at promoting harmony among human beings and between humanity and nature" (WCED, 1987). Thus, it recognized social and environmental perspectives also, in addition to the economic perspective of sustainability. It is easy to understand the economic and environmental dimensions of sustainability. Former refers to the financial aspects of the economic activity, whereas the later in a crude sense refers to the process of replenishing the resources that are being consumed. The social dimension of sustainability is slightly more ambiguous. Few of the topics covered under social sustainability are – "health and social equity, human rights, labor rights, practices and decent working conditions, social responsibility and justice, community development and well-being, product responsibility, community resilience, and cultural competence" (Balaman, 2019).

A company that is socially sustainable should focus on all of these topics. However, among these topics, exploring policies that would best serve the interests of workers is relevant to a wide range of organizations including both the formal and informal sectors; this topic has caused a passionate debate (International Forum on Globalization, 2008; Mair et al., 2019).

Government rules prescribe minimum wages to deal with the problem of exploitation of workers. However, questions have been raised on whether minimum wages protect the workers or not. Fairchild (2004) surveyed a vast body of research and addressed the question whether the poor workers are better off due to the minimum wage. The study of Fairchild lead to the conclusion that the minimum wage does not unambiguously help the poor, and in fact it may do more harm than good (Fairchild, 2004). Hence, it becomes imperative for companies to go further than meeting a legal minimum wage and embrace the concept of fair wages. A fair wage is a wage that is considered "fair" by the employee. The fair wages should be set in such a way that continuation and growth of employment, at a level which is comparable to levels in similar occupations/ activities is ensured (International Labour Organization, 2018)**.** This paper contributes to the debate by proposing a model to check if existing wages leads to a situation of desirable equilibrium, which is in the best interests of both workers and companies. The proposed model can also be used to estimate probabilities of decreasing effort at job and job change by the workers.

2. Material and Methods

Model development is the methodology used in this research. In this paper, a model is developed to understand the behaviour of workers, when their wages are below the fair wage (Bronkhorst, 2020). In their seminal article on research methodology in Operations Management, Mitroff et al. (1974) presented a framework for using system modeling and simulation as a research method. The model development methodology of this paper is inspired by Mitroff et al. (1974).

A combination of Evolutionary Game Theory (EGT) and System Dynamics (SD) is used for developing the model presented in this paper. EGT is better suited for the study of the long-term dynamic interactions among the stakeholders in the organization. SD is used to simulate the models of the evolutionary game which describe the evolutionary process of complex behavioral decision-making (e.g. Wang et al., 2015; Zhu et al., 2020).

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2.1 A Typical Evolutionary Game

An evolutionary game, denoted by G, usually consists of the population set (N), population strategy set (Φ), and population payoff set (P)

$$G = (N, \Phi, P) \quad [1]$$

When G contains n populations, then $N = \{1, 2, . . ., i, . . ., n\}$, where $i \in N$.

The population strategy set, $\Phi = \{S_1, S_2, . . ., S_i , . . ., S_n\}$, where S_i is the strategy set of population i.

The population payoff set, $P = \{P_1, P_2, . . ., P_i , . . ., P_n\}$, where P_i is the payoff of population i.

An Evolutionary Stable Strategy (ESS) is a strategy from which populations will not prefer to switch to other strategies, as there is no benefit in payoff for doing so. And, when the system achieves an ESS at one of its pure strategies, then such ESS is called an evolutionarily stable equilibrium (ESE) state of the system.

2.1.1 A General 2PnS-AEG

The two populations A and B in the general 2PnS-AEG system all have n strategies in their strategy sets. Concretely, the strategy set of population A is Φ_{An} = $\{S_{A,1}, S_{A,2}, . . ., S_{A,n}\}$, and the probability or individual proportion of the individuals in population A choosing strategies $S_{A,1}, S_{A,2}, . . ., S_{A,n}$ is $x_{A,1}, x_{A,2}, . . ., x_{A,n}$, respectively, where $x_{A,1} + x_{A,2} + . . . + x_{A,n} = 1$. Similarly, the strategy set of population B is Φ_{Bn} = $\{S_{B,1}, S_{B,2}, . . ., S_{B,n}\}$, with probabilities of $y_{B,1}, y_{B,2}, . . ., y_{B,n}$, where $y_{B,1} + y_{B,2} + . . . + y_{B,n} = 1$. In addition, assume that the expected payoff of the individuals in population A sequentially choosing strategies $S_{A,1}, S_{A,2}, . . ., S_{A,n}$ is $P_{A,1}, P_{A,2}, . . ., P_{A,n}$. Similarly, the expected payoffs of populations B are $P_{B,1}, P_{B,2}, . . ., P_{B,n}$.

$$P_{Ak} = \sum_{i=1}^{n} \boldsymbol{y_{B,i} P_{A,k,i}} \quad [2a]$$

$$P_{Bk} = \sum_{i=1}^{n} \boldsymbol{x_{A,i} P_{B,k,i}} \quad [2b]$$

Where, $P_{A,k,i}$ is the payoff of the individuals in population A when choosing the kth strategy from Φ_{An} while the individuals in populations B choose the ith strategy from Φ_{Bn}; $P_{B,k,i}$ is the payoff of the individuals in population B when choosing the kth strategy from Φ_{Bn} while the individuals in populations A choose the ith strategy from Φ_{An}. Assume that the average expected payoff of populations A and B is P_{A_ave} and P_{B_ave}, respectively, as follows:

$$P_{A\_Ave} = \sum_{k=1}^{n} \boldsymbol{x_{A,k} P_{A,k}} \; ; \qquad \text{Where} \quad \sum_{k=1}^{n} \boldsymbol{x_{A,k}} = 1 \quad [3a]$$

$P_{B\_Ave} = \sum_{k=1}^{n} \boldsymbol{y_{B,k} P_{B,k}}$;   Where $\sum_{k=1}^{n} \boldsymbol{y_{B,k}} = 1$ [3b]

Based on Eqs 2 and 3, the RD model of the general 2PnS-AEG system is described as follows:

$dx_{A,k}/dt = x_{A,k}\,(P_{A,k} - P_{A\_ave})$ [4a]

$dy_{B,k}/\,dt = y_{B,k}\,(P_{B,k} - P_{B\_ave})$ [4b]

$\forall k, \forall t$ where $k = 1, 2, \ldots, n$.

Eqs 4a and 4b show that the growth rate of individual proportion or the probability of choosing a pure strategy by the individuals in a population, in the general 2PnS-AEG model, is proportional to this proportion or probability, as well as the difference between the obtained expected payoff under this pure strategy and the average expected payoff of the population. Thus Eqs 4a and 4b represent the evolution trend of the behavior of the population.

3.3.1 System as differential equation

Let us assume that 'A' is number (e.g. of animals) which increases by a certain fraction every year. This can be represented by the rate equation given below:

$dA/dt = c*A$ [5]

In this example, the rate variable is function of state variables A. The influence of a state (A) on its rate of change (dA/dt) is called feedback. The proportionality coefficient c is called the relative growth rate, in biological systems (from where the EGT originated). However, in technical systems, the inverse of c is often used, and it is called the time coefficient. The key elements of system dynamics are shown in Figure 1.

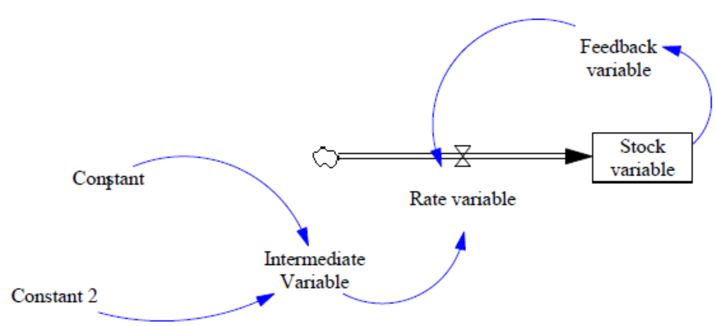

Figure 1. Elements of System Dynamics

3. The Model

3.1. Game Description

In this game between workers and companies, workers focus on basic wages, mobility costs, income rises, and default penalties to decide whether they move away, whereas companies focus on profits, retention costs, mobility loss, and recruitment costs to decide whether they retain workers.

A worker in a company will not be satisfied with his wage, if the worker perceives that he/she is not receiving fair wage. The strategy choices available to the worker would be - to change job (x), to decrease effort at the job (y), or No action (1-x-y). The strategy choices available with the company are – to increase the wages (i), or to not to increase the wages (1-i). The payoffs corresponding to these strategy choices are shown in the Table 2.

The constants in the model are shown in Table 1. The payoff table can be understood with the help of the following description:

Situation 1: The company doesn't intend to increase the wages and workers do not plan to change jobs or reduce their efforts, company's profit from the worker is P. Workers' income i.e. the basic salary is S.

Situation 2: The Company doesn't intend to increase the wages and workers plan to change job, the company will incur a loss L; workers' income will increase by A1 compared with the salary before, and cost to the worker for changing the job is Jc. When the workers move away, the company incurs cost of Rc to recruit new workers.

Situation 3: The Company intends to increase the wages and workers plan to change jobs, the company will incur cost C for increasing the wage of a worker for retention cost. If the worker changes the job, the company will suffer loss L; whereas the worker's cost would be Jc for job change and a penalty Pc (The Company will penalize the employees if they leave the company even after wage increase).

Situation 4: The Company intends to increase the wages and workers do not plan to change jobs, workers' income increases by A2.

It shall be kept in mind the S, A1 and A2 are monetary value of wages and perks of the workers.

In this context, the wage-effort hypothesis (Agell & Lundborg, 1995; Akerlof & Yellen, 1990) can play an important role. According to Adams' formula (Adams, 1963) the perceived value of the labour input will equal the perceived value of the remuneration. According to psychologists, workers who do not receive the fair wage may actually reduce actual effort; whereas increase in wage doesn't result in increase in effort, as in that case workers mentally increase the perceived value of their effort (Akerlof & Yellen, 1990). Ed is the reduction in effort if the worker is not paid fair wages.

Based on the above discussion, a pay-off matrix between workers and companies (see Table 2) is established. The probability that the company intends to increase wages is i ($0 \leq i \leq 1$), while the probability that company does not increase the wage is $1-i$. Similarly, the probability that worker plan to change jobs is x ($0 \leq x \leq 1$), whereas the probability that the worker will decrease the effort is y. And, there is 1-x-y probability that the worker will neither change the job nor reduce the effort at job. The expected revenue when the company increases the wages is P_i and the expected revenue when company does not increase the wages is P_{1-i}, and average expected revenue whether companies intend to increase the wages or not is $P_{Average}$. Similarly, the expected revenue when the worker plans to change jobs is U_x, expected revenue when the worker reduces the effort is U_y, and the expected revenue when worker does not plan to change the job and also doesn't reduce the effort is U_{1-x-y}, and average expected revenue of workers is $U_{Average}$.

Table 1. Constants in the SD Model

Symbol	Description (Rs/ Month)
S	Salary of the worker
A1	Salary increase in the new company
Pc	Penalty to worker for job change after wage increase
Jc	Cost for job change
A2	Salary increase by present company
P	Profit to company due to worker
L	Loss to the company if worker changes job
Rc	Cost of recruiting a new worker
C	Cost to company for increasing worker salary
Ed	Decrease in effort by worker if salary is not increased to the level of fair wage

3.2. Game equation and solution

Based on the payoff matrix, the payoffs can be calculated for each of the strategies of the workers and the company, as shown below:

Worker's payoffs corresponding to strategies x, y and 1-x-y are U_x, U_y and U_{1-x-y}, respectively.

$$U_x = [i * (S + A1 - Jc - Pc) + (1 - i) * (S + A1 - Jc)] \quad [6]$$

$$U_y = [i * (S + A2) + (1 - i) * (S + Ed)] \quad [7]$$

$$U_{1-x-y} = [i * (S + A2) + (1 - i) * (S)] \quad [8]$$

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Similarly, company's payoffs corresponding to strategies i and 1-i are Pi and P_{1-i}, respectively.

$$P_i = [x*(P-L-Rc+Pc)+y*(P-C)+(1-x-y)*(P-C)] \quad [9]$$

$$P_{1-i} = [x*(P-L-Rc)+y*(P-Ed)+(1-x-y)*(P)] \quad [10]$$

The average payoff of the Employee can be calculated as follows:

$$U_{Average} = x*U_x + y*U_y + (1-x-y)*U_{1-x-y} \quad [11]$$

Similarly, the average payoff of the Company can also be calculated –

$$P_{Average} = i*P_i + (1-i)*P_{1-y} \quad [12]$$

Table 2 Payoff Matrix

		Company Strategy			
		Wage Increase (i)		**No Wage Increase (1-i)**	
Employee Strategy		**Company Payoff**	**Employee Payoff**	**Company Payoff**	**Employee Payoff**
Job Change	**x**	P-L-Rc+Pc	S+A1-Jc-Pc	P-L-Rc	S+A1-Jc
Decrease Effort	**y**	P-C	S+A2	P-Ed	S+Ed
No action	**1-x-y**	P-C	S+A2	P	S

In the evolutionary game, the players tend to learn and imitate strategies of higher payoff. The higher payoff strategies have the higher the probability of being chosen.

According to the replicator dynamics, the change rate of x is as follows:

$$F1 = dx/dt = x*(U_x - U_{Average}) \quad [13]$$

$$F2 = dy/dt = y*(U_y - U_{Average}) \quad [14]$$

$$F3 = di/dt = i*(P_i - P_{Average}) \quad [15]$$

It can be tested whether the solutions to the set of replicator equations are evolutionary stable strategy or ESS. The solution is the evolutionary stable strategy (ESS), when the Jacobian matrix's determinant Det (J) >0 and its trace Tr (J) <0, (Friedman, 1991).

The players in the evolutionary game have no benefit in switching to another strategy from ESS.

The Jacobian matrix (J) is:

$$J=\begin{matrix}\frac{\partial F1}{\partial x} & \frac{\partial F1}{\partial y} & \frac{\partial F1}{\partial i}\\ \frac{\partial F2}{\partial x} & \frac{\partial F2}{\partial y} & \frac{\partial F2}{\partial i}\\ \frac{\partial F3}{\partial x} & \frac{\partial F3}{\partial y} & \frac{\partial F3}{\partial i}\end{matrix} \quad [16]$$

3.3. SD Simulation The replicator dynamics of the evolutionary game was simulated using SD, as shown in Figure 2.

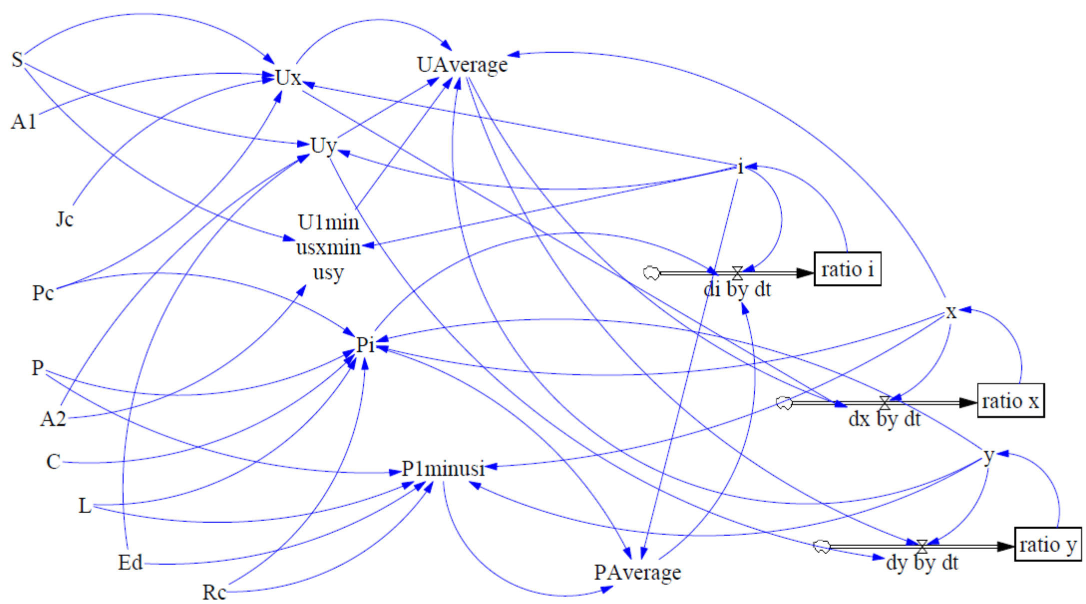


Figure 2. SD Model

4. Results and Analyses

This model was applied on a case study. The company taken as case study is a SME (Small and medium-sized enterprises). This company is a supplier of modules and subsystems to the OEMs and research labs in the aerospace and defence industry. The work of the company is labour intensive and this company has more than 30 unskilled workers.

The officers and engineers of the company sometimes complained that some of the workers are not putting enough effort. The wages were not ideal in this company for the unskilled workers. However, this company was not facing any attrition problem.

Table 3 Value of SD model constants

Symbol	Value in INR /10K	Comments
S	1	Average salary of a worker
A1	0.09	Three point estimate
Pc	0.135	Three point estimate
Jc	0.055	Three point estimate
A2	0.2	Three point estimate
P	0.55	Three point estimate
L	0.3	Three point estimate
Rc	0.02	Three point estimate
C	0.145	Three point estimate
Ed	0.2	Three point estimate (%age of decrease in effort*salary)

The company was planning to revise wages of the workers based on the existing wages in other companies and other market conditions. At this juncture, the company was interested in knowing the effect of increasing or decreasing wages of the workers. According to wage-effort theory (Akerlof & Yellen, 1990), low wages lead to reduction in the efforts of workers, but high wages do not guarantee full effort. Hence, effect of wage revision should be studied keeping in view other aspects as well.

The model developed in this paper was applied to suggest the possible outcomes of the wage change. The constants of the SD model were estimated using PERT three point estimate (PMI, 2017). The final calculated values of constants are divided by 10000, so as to meet computational limitations of Vensim software (version PLE 8.1.0) used for SD modeling, as shown in Table 3.

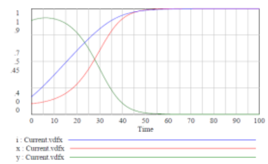
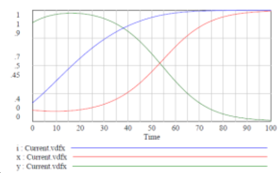
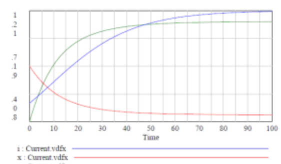
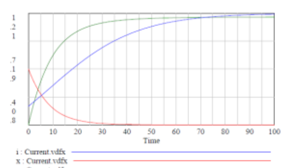
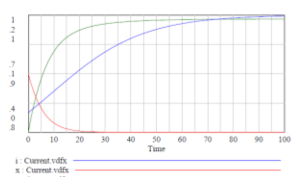
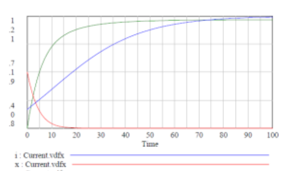
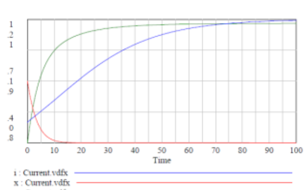
Value of A2	Variation of i, x and y
A2 = -0.3	
A2 = -0.2	
A2 = -0.1	
A2 = 0	
A2 = 0.1	
A2 = 0.2	
A2 = 0.3	

Table 4 Results of Simulation for various proposed values of wage increase in the current company

The initial values of I, x and y were set to 0.5, 0.1 and 0.8; and the SD model was run for various values of wage increase (A2) and results are shown in Table 4.

It can be observed from the Table 4 that increase in wages will have effect on the rate at which more workers start putting maximum effort, as slope of the line corresponding to y changes with increase in the value of A2; Whereas, decrease in wages will have more destabilizing effect. As the there is more decrease in wages (A2<0), the y reduces and the x increases, indicating reducing probability that workers will put in their maximum effort and increasing probability that they will change the job.

Based on these suggestions, the company increased the wages by around 10%, and it was observed that the number of workers who were putting full effort increased after this wage revision. However, it was not possible to reduce the wages and see the effect on workers, as it would have had adverse effect on the business of the company.

5. Conclusions

The evolutionary game theoretic model and simulation of the model using system dynamics were useful in enhancing the understanding of interactions between companies and workers vis-à-vis wages. The application of the model on the case study provided necessary (but not sufficient) support to the fact that increase in wages will lead to workers to put their maximum effort at a faster rate. However, effect of wage reduction could not be observed in practice, as it was not possible to implement it in the company.

The model presented in this paper has a few shortcomings also. The first shortcoming is that worker's wages are not linked to their performance at job. Second, the model is quantitative and based only on the tangible aspects. It may be useful to complement this study with a qualitative study focusing on intangible aspects as well. Authors are planning to work in the direction of attending these two shortcomings in the future research.

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