Incentive Compatible Green Procurement Using Scoring Rules

Deepak Bagchi[1], Shantanu Biswas[1], Y. Narahari[2], N. Viswanadham[2], P. Suresh[1], S. V. Subrahmanya[1]

Abstract— **In this paper, we address the issue of selection of suppliers in order to ensure that the procurement process in a manufacturing or service supply chain is green in the sense of minimizing carbon emissions. We assume that at the root level, we have an orchestrator who wishes to put together a green supply network consisting of multi-tier suppliers. The suppliers are strategic and may not reveal their carbon emissions truthfully. In such a setting, we use an incentive design approach based on proper scoring rules to elicit truthful emission reports from the suppliers. Since our approach makes it optimal for the suppliers to report their carbon emissions truthfully, the overall multi-tier supply network that results minimizes the overall amount of carbon emissions of the procurement process.**

I. INTRODUCTION

Procurement is one of the three important processes in any supply chain. In the context of a manufacturing supply chain, the procurement process involves selection of tier 1 suppliers to manufacture sub-assemblies and the logistics providers to transport them to the manufacturing site. The tier 1 suppliers in turn select tier 2 ones and transporters who in turn select tier 3 suppliers and the process repeats until the raw material suppliers. In some cases it is the manufacturer follows multi-tier procurement policy and selects not only the tier suppliers but also the suppliers in other tiers. Some auto companies for example select the steel for all the suppliers. They also collect the material from the suppliers instead of asking them to deliver. This is called factory gate pricing. The logistics processes are called inbound logistics players. Supply hubs constitute a best practice where the 3PLs maintain the inventory for the suppliers at the manufacturer site.

In the context of a service supply chain, we have a similar situation. First we select tier 1 service providers to supply level 1 services. The tier 1 service providers may select their own tier 2 suppliers for the tier 2 services, and so on.

Green procurement is the selection and acquisition of products and services that minimize negative environmental impacts over their life cycle of manufacturing, transportation, use and recycling, or disposal. Simply put, green procurement involves adding environmental aspects to price and performance criteria when making procurement decisions. Suppliers who satisfy green partner environmental quality standards and pass an audit process in ISO14000, OHSAS18000. They should follow reuse or recycle and remanufacturing, the 3Rs, in procurement process.

[2]Y. Narahari and N. Viswanadham are with Game Theory Lab, Dept. of Computer Science and Automation, Indian Institute of Science, Bangalore, India.

[1]Deepak Bagchi, Shantanu Biswas, P. Suresh and S. V. Subrahmanya are with E-Comm Research Lab, Education & Research, Infosys Limited, Bangalore, India.

The procurement process involves selection of supplier groups for each component in all the tiers. This is a very important step particularly in the green supply chains. Once the suppliers groups are formed, the next step involves identifying the suppliers for a particular order and telling them how much to deliver to whom and when. This is the coordination problem. The final step is the execution where the coordinator ensures that the deliveries happen as per the plan. The same is true for each logistics players. In this paper, we are concerned with the first step in the procurement process i.e. the identifying the supplier groups for various components or services. In particular, we wish to include green considerations in this process through a mechanism design approach to take into account the strategic nature of the suppliers.

A. Motivating Example

Consider a fourth party logistics provider (4PL) who is routinely required to orchestrate and coordinate all the logistics requirements of a global company. Typically the 4PL provider would select a group of 3 PLs for various logistics tasks and each 3 PL may summon the services of different logistics providers to undertake the transportation and other logistics tasks. If the 4PL provider wishes to minimize the total amount of carbon emissions, then it has to select the 3PL providers appropriately. Similarly, each 3PL provider will have to select the logistics providers at the next lower level appropriately. Since the players involved here (3PL and other logistics providers) are all strategic, they may not report the carbon emissions truthfully. However, since carbon auditing reports will eventually reveal the exact amount of carbon emissions, it would be interesting to investigate whether we can design incentive mechanisms that would make the suppliers reveal the carbon emissions truthfully in the first place. In this paper, we propose an approach based on proper scoring rules to solve this problem.

B. Contributions and Outline

In this paper, the overall goal is to design a green procurement process by minimizing the total amount of emissions when the suppliers in the multi-tier supplier network are strategic. We assume that at the root level, we have an orchestrator who wishes to put together a green supply network consisting of multi-tier suppliers. The suppliers may not reveal their carbon emissions truthfully and we propose a novel approach based on proper scoring rules to induce truth revelation by all the suppliers.

In Section 2, we present relevant work on green procurement and also some preliminaries on scoring rules. In Section

3, we present a scoring rule based model for solving the problem. In particular, we describe the scoring rules to be used and the incentive design to induce truth revelation. In Section 4, we first start with a simple stylized case study and next discuss a more realistic setting for which we provide experimental results. We conclude the paper in Section 5.

II. Literature Review

The goal of sustainable procurement is to pursue sustainable development objectives through the purchasing and supply process [1]. Sustainable procurement involves balancing environmental, social and economic objectives. A large global enterprise that produces a product (or provides a service) functions as an orchestrator [2]. Any orchestrator minimizing the environmental impact of its activities needs to choose its suppliers based on the trade-off between costs and respective emissions. The orchestrator has to coordinate closely with its suppliers in order to achieve the required level of emissions. To accurately calculate its carbon footprint, the orchestrator wants its strategic suppliers to truthfully report their carbon emissions.

It is important for the orchestrator to develop processes that can evaluate the information provided by the suppliers and provide some guarantees to its accuracy. This is particularly important in cases where the required information is an imprecise probabilistic estimate and cost is involved in the information generation. The providers of such information are rational self-interested agents and may have an incentive to misreport their estimates or to allocate less costly resources to information generation (and increase the estimate errors) [3]. Therefore an information buyer (such as a supply chain orchestrator) must present the providers with incentives for committing required resources to generating their estimates and to truthfully report the estimates. The truthful elicitation of information from self interested agents has been the subject of much attention in the literature. Scoring rules have been used to design payment mechanisms that incentivise agents to report private probabilistic predictions truthfully and to the best of their forecasting abilities [4], [5], [6]. Mechanisms using these rules reward accurate estimates or forecasts by making payments to agents based on the difference between the predictions and the actual outcomes (observed at some later stage).

Also scoring rules that are strictly proper can be employed by a mechanism designer to ascertain that agents accurately declare their privately calculated distributions, reflecting their confidence in their own forecast. Without such a mechanism in place, agents may either lie about their estimates to secure higher returns or not bother to provide the most accurate estimates.

Scoring rules have been the focus of much attention in the areas of meteorology [7], in evaluating predictors [8], in the prediction markets [9], and in fair division of rewards among agents performing a task [10]. Much of the literature of strictly proper scoring rules concerns four rules namely quadratic, spherical, logarithmic and a parametric family of rules known as the power rule family or k-power scoring rules [11]. In the context of error estimates the Gaussian distributions has been extensively used [12] and we can derive the scoring rules for these distributions.

TABLE I
NOTATION

N	Number of players, $1, 2, \ldots, n$
m_i	Actual number of carbon emission unit for i^{th} child
$\hat{m_i}$	Reported number of carbon emission unit for i^{th} child
e_i	Relative error of prediction for i^{th} child
σ_i	Standard deviation of probability distribution for i^{th} child
$\hat{\theta_i}$	Bid submitted by i^{th} child
θ_i	True Bid of i^{th} child
c_i	Cost incurred by the i^{th} child while reporting carbon emission
u_i	Utility expected by the i^{th} child if it joins the network
B	Green Budget
S_i	Score for i^{th} child
R_i	Incentive Payment to i^{th} child

III. Model

We consider a large scale enterprise that has a pool of suppliers to procure material for its products / services. The company is motivated to truthfully capture the amount of carbon emission for its product or services and also wants to select the suppliers such that the overall carbon emissions are minimized. The problem becomes a challenging one as the supply chain partners, being autonomous, may exhibit strategic behavior and report a different value from the true values.

We consider that the orchestrator take a decentralized approach where each supplier collects activity data, converts it into emissions data and then reports this data to the orchestrator. This approach helps in removing the discrepancies between the calculation method of different suppliers and also each supplier can report their emissions to external authorities if required. We make following assumptions for the orchestrator:

- The orchestrator has a set of task that need to done in order to achieve a service or product. The task may have further subtask.
- Each task or subtask has a pool of suppliers. These suppliers can have further pool of sub-suppliers.
- Each suppliers has knowledge of capturing and calculating carbon emissions.
- The orchestrator has green budget B to be used as an incentive to elicit true and accurate values of carbon emissions from the suppliers.
- The orchestrator divides the work into task and subtasks. Each of the task and subtasks has to be done.
- The suppliers will incur cost and effort to calculate the amount of carbon emissions.
- The supplier selection in this paper is based on only carbon emission. We assume that other quality parameters have been use to form the initial pool of suppliers.

The orchestrator does the green supplier selection in two steps:

- The orchestrator first uses the green budget to elicit the true values of carbon emissions and builds up a

tree similar to shown in figure 1. This step is called as Information elicitation step.
- After the tree has been build, the orchestrator then build his supply chain network from this tree by minimizing the overall carbon emissions.

A. Information Elicitation step

In this paper we model the carbon emission reporting as a tree where the orchestrator is the root node [13]. As shown in figure 1, the orchestrator has task to be done. Each task may further gets divided into subtasks. Each task or subtask has a pool of suppliers to do the job. This pool is considered to be large. From this pool, the orchestrator would like to get the suppliers, who report truthful and accurate carbon emissions. To elicit this information, the orchestrator uses the budget B as an incentive.

In the beginning each parent node that has a pool of suppliers, promises an incentive to all suppliers in the pool for truthfully and accurately reporting their carbon emissions. Depending on their own costs and efforts, we may get a small subset of suppliers from the pool who accepts to report their carbon emissions. As shown in figure 1, the $Task112$ gets 2 suppliers who are willing to report their carbon emissions based on the incentive provided by the node $Task112$.

Similarly each suppliers may either do the job on its own or it may delegate the job to its own set of sub-suppliers. The suppliers who does the job on its own will calculate its own carbon emission units. The suppliers who delegates the job will offer part of the incentive they receive from the their parent to get the carbon emission values from their pool of sub-suppliers. Based on the cost and incentive the tree can keep growing to a multi-level supplier tree network. The process stops when there is no node which wants to further delegate the job to its child. In the tree thus formed,only the leaf nodes does the job. The role of intermediate nodes is to aggregate the carbon emission calculated by its child nodes. We assume that total carbon emission for a node is either their own emissions, if they are leaf or the aggregation of carbon emissions of their child nodes i.e. they are not adding any carbon emission from their process. For simplicity we assume no node can have more than one parent, i.e. the process discussed above will always form a tree.

1) Reporting the carbon emission: Under the setting discussed in above section, the only source of information about carbon emission is the leaf nodes, because parent nodes are only responsible for aggregating information received from their children. The carbon emissions calculated by the leaf nodes can vary from time of forming the tree to the time of actual supply has been made. This could be due to lot of factors, one such factor may be non availability of the raw material at the time of making or delivering the product, that was assumed to be available at the time of formation of the tree. This could make a significant difference to the amount of carbon emissions. Here we have will two values of carbon emission: reported value when the tree is built and the actual values when the job would be finished. The orchestrator would like to have the reported carbon emissions

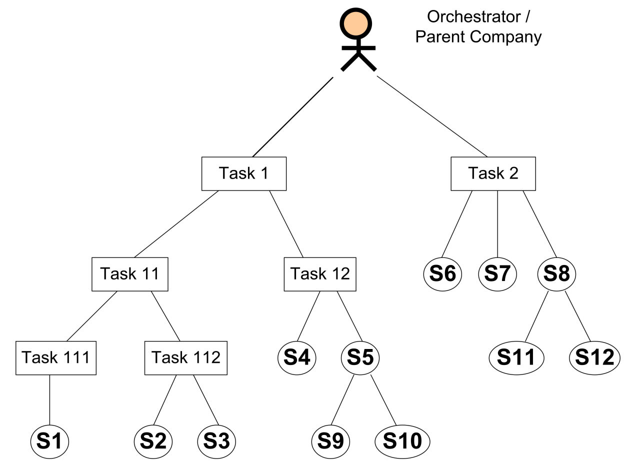

Fig. 1. Tree model for Dynamic Supply Chain

to be as close as possible to the carbon emissions at the time when actual job is finished.

We consider that each leaf node will have relative error probability distribution for the carbon emission they calculate. The relative error for the i_{th} child of a parent is given by equation 1.

$$e_i = \frac{m_i - \hat{m}_i}{\hat{m}_i} \tag{1}$$

We consider the relative error probability distribution to be a normal distribution $\mathbb{N}(\mu, \sigma^2)$, for all the leaf node. The relative error probability distribution comes from historical data over a period of time and will converge to zero hence $\mu = 0$ for all leaf nodes. The standard deviation of this normal distribution reflects how confident a supplier is $\hat{m}$ value. Here absolute standard deviations of e_i will be $\sigma_i \times m_i$.

The reporting of carbon emissions is as follows: The reporting starts from the leaf nodes. Each leaf node i reports the tuple $\hat{\theta}_i = \{\hat{m}_i, \sigma_i\}$ to its parent where $\hat{m}_i$ is its carbon emission and σ_i is the standard deviation of the normal distribution representing the relative error of calculating the carbon emissions. Each leaf node reports its observation to its parent, then the parent appropriately aggregates all the reports from its children to a single report which becomes its observation. Then this parent also reports back to its parent. Finally the root node receives reports from its first level children and aggregates them to the quantity of carbon emission. The aggregation at the parent is a simple weighted average of the bid of all its child nodes. Our objective is to make this final result as accurate as possible to the actual carbon emissions at the time finishing the whole process.

2) Reward Mechanism: The root node or the orchestrator uses the green budget B as an incentive or reward. The reward has to be done in a way that honest reporting results in more reward than dishonest reporting. Reward is distributed in a top-down manner starting from the root node [13]. We consider that the accurate value of the bid reported by the i^{th} child of a parent node is given by $\theta_i = \{m_i, \sigma_i\}$.

In order to reward suppliers for accurate reporting of their bids, we design a payment mechanism which employs scoring rules. The parents first uses a scoring rule to score the children based on the relative error between reported and the actual values. The green budget B is then distributed by the parent according to the scores of respective children. The scoring rule is required to be chosen in a way that the suppliers can maximize their incentive if they have $\hat{\theta}_i$ as close as possible to θ_i.

Proper Scoring Rules are belief elicitation techniques designed to provide an agent the incentives to report her beliefs in a thoughtful and truthful manner [4]. In this paper we use, the Continuous Ranked Probability Score (CRPS) given by Geniting and Raftery [6]. The score of the i^{th} child of a parent with relative error e_i is given by equation 2.

$$CRPS_i = \sigma_i\big[(\frac{1}{\sqrt{\pi}} - 2\varphi_i(\frac{e_i}{\sigma_i}) - \frac{e_i}{\sigma_i}(2\Phi_i(\frac{e_i}{\sigma_i}) - 1))\big] \quad (2)$$

Here φ_i and Φ_i denote the probability density and the cumulative distribution function of a standard normal variable e_i respectively.

$$R_i = CRPS_i B \quad (3)$$

Here the $CRPS_i$ value has been normalized between 0 and 1. The CRPS scoring rule used here is a strictly proper scoring rule which means that the suppliers can maximize their incentives by reporting the values closer to the actual values. The proof is given in [6]. After obtaining the scores for the i^{th} child, the parent distributes the incentive using equation 3.

B. Green Procurement under Budget Constraints

The orchestrator has a procurement budget for procuring the required set of services while minimizing the carbon emissions. In other words, the orchestrator has to procure at least the required set while minimizing the carbon emissions under the budget constraints. Therefore the procurement problem becomes a weighted set covering problem with budget constraints. This is a NP-complete problem but the literature on combinatorial procurement auctions suggests many heuristics and approximation solutions to this problem [14] In the stage I, the orchestrator identifies the potential suppliers who can bid for the procurement auction. In stage II, the orchestrator solves the procurement auction problem. Since the suppliers are rational and may behave strategically. Therefore, we can extend this scenario by introducing strategic bidding and a standard VCG (Vickrey-Clarke-Groves) mechanism [15].

IV. Case Study and Simulations

We consider a simple supply chain tree for an event management activity. At the first level we have 3 tasks transport, catering and travels that need to be taken care for the event as shown in figure 2. Initially the orchestrator, offers equal proportion of the green budget B, for each of the 3 subtasks. The task transport and catering, further proposes the equal proportion of this budget to each of its supplier pool. Each supplier i, for the node say catering calculates its cost c_i of reporting carbon emissions and an utility u_i that it expects, if he joins the network. We consider that a supplier i will join the network if $R_i \geq c_i + u_i$. Under this condition, as shown in figure 2, the catering node gets 1 sub-supplier and the travel node gets 2 sub-suppliers. Similarly for the registration task which is further subdivided into 3 subtasks as bags, proceedings and t-shirts, gets 2, 1, 2 sub-suppliers respectively.

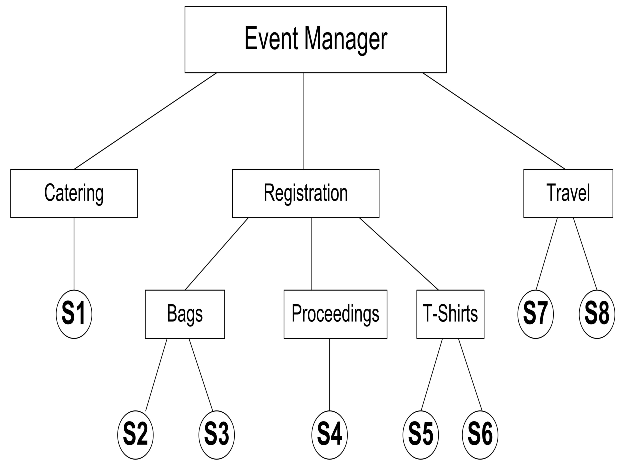

Fig. 2. Tree network for an Event Management Activity

Let us consider the values for the leaf node suppliers from figure 2, as given in below table II. Here we assume that each suppliers has been promised \$100. The incentives each supplier receives is also given in the table. For our illustrative example, the following table gives the list of the potential suppliers and their costs.

TABLE II
Incentive Calculation

Supplier	$\hat{m_i}$	m_i	σ_i	R_i
S1	35	30	0.25	86.46
S2	38	40	0.11	96.69
S3	30	30	0.13	100
S4	10	9	0.5	92.28
S5	10	8	0.15	92.48
S6	10	13	0.17	85.02
S7	20	20	0.11	100
S8	13	10	0.18	87.07

TABLE III
Simple Example

Supplier	p_i	m_i
S1	30	30
S2	25	40
S3	35	30
S4	10	9
S5	30	8
S6	25	13
S7	5	20
S8	10	10

Assume that the total budget available with the orchestrator is \$ 100 for procurement. The least cost procurement for this example gives the following solution:
Selected Suppliers: S1, S2, S4, S6, S7; total procurement cost = \$ 90; total carbon footprint = 112.

But the minimum carbon footprint solution under the budget constraint is given by (See Figure 3:
Selected Suppliers: S1, S2, S4, S5, S8; total procurement cost = $ 100; total carbon footprint = 97.

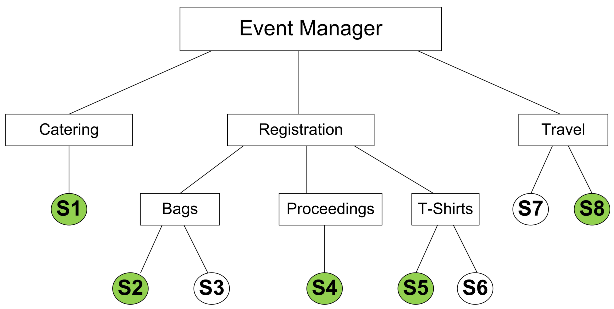

Fig. 3. Minimum Carbon Footprint Solution

A. Simulation Setup

For our experimental analysis we consider that an orchestrator has to do 3 task. Each of the supplier and task has a pool of 5 sub-suppliers. We generate ransom values for c_i and u_i value of supplier i. For example, let us consider one such case for the pool of suppliers available to for a task as given in table IV. The suppliers that may be willing to join the network for an promised incentive of $\$100$ each are $\{2, 3, 5\}$.

TABLE IV
SIMULATION CASE EXAMPLE

Supplier	m_i	c_i
1	25	75
2	30	50
3	85	20
4	10	95
5	42	50

B. Simulation Results

In the figure 4, we have shown the relationship between a supplier σ_i values and corresponding incentives it receives. The simulations has been by keeping the m and $\hat{m}$ values constant and varying the σ values.

We can infer from the plot that as the standard deviation value goes from lower to higher the incentives keeps on deceasing. Hence the suppliers will be motivated to predict there error probabilities as better as possible.In the figure 4, we have shown the relationship between the green budget B and the depth of the tree formed. We can observe from the plot in figure 4 that as the budget is increased, the number of suppliers joining the network generally increases.

REFERENCES

[1] Helen Walker and Wendy Phillips, "Sustainable procurement: emerging issues," *International Journal of Procurement Management*, vol. 2, no. 1, pp. 41–61, 2009.

[2] G. Loveman and J. O'Connell, "Li & fung (trading) ltd.," *Harvard Business School Cases*, 1995.

[3] M. Xue, D. Wang, J. Gao, and K. Brewster, "The advanced regional prediction system (ARPS): Storm-scale numerical weather prediction and data assimilation," *Meteorology and Atmospheric Physics*, vol. 82, no. 1-4, pp. 139–170, 2004.

[4] L. J. Savage, "Elicitation of personal probabilities and expectations," *Journal of the American Statistical Association*, vol. 66, no. 336, pp. 783–801, 1971.

[5] J. E. Matheson and R. L. Winkler, "Scoring rules for continuous probability distributions," *Management Science*, vol. 22, no. 10, pp. 1087–1096, 1976.

[6] T. Gneiting and A. Raftery, "Strictly proper scoring rules, prediction and estimation," *Journal of the American Statistical Association*, vol. 102, pp. 359–378, 2007.

[7] G. Brier, "Verification of forecasts in terms of probability," *Monthly Weather Review*, vol. 78, no. 1, pp. 1–3, 1950.

[8] R. Winkler, "The quantification of judgment: Some methodological suggestions," *Journal of the American Statistical Association*, vol. 62, no. 320, pp. 1105–1120, 1967.

[9] P. Shi, V. Conitzer, and M. Guo, "Prediction mechanisms that do not incentivize undesirable actions," *Proceedings of WINE '09, Berlin*, pp. 89–100, 2009.

[10] A. Carvalho and K. Larson, "A truth serum for sharing rewards," *Proceedings of 10th International Conference on Autonomous Agents and Multi Agent Systems, Taipei, Taiwan*, pp. 635–642, 2011.

[11] Reinhard Selten, "Axiomatic characterization of the quadratic scoring rule," *Experimental Economics*, vol. 1, no. 1, pp. 43–61, 1998.

[12] T. Haavelmo, "The probabitity approach in econometrics," *Econometrica, supplement 12*, vol. 12, Supplement, 1944.

[13] Ratul Ray, Rohith D. Vallam, and Y. Narahari, "Eliciting honest feedback from crowdsourced tree networks using continuous scoring rules," *Proceedings of 12th International Conference on Autonomous Agents and Multi Agent Systems, Minnesota, USA*, vol. To Appear, May, 2013.

[14] Shantanu Biswas and Y. Narahari, "Object oriented modeling and decision support for supply chains," *European Journal of Operational Research*, vol. 153, pp. 704–726, 2004.

[15] Y. Narahari, D. Garg, N. Rama Suri, and H. Prakash, "Game theoretic problems in network economics and mechanism design solutions," *Advanced Information and Knowledge Processing Series*, Springer, 2009.

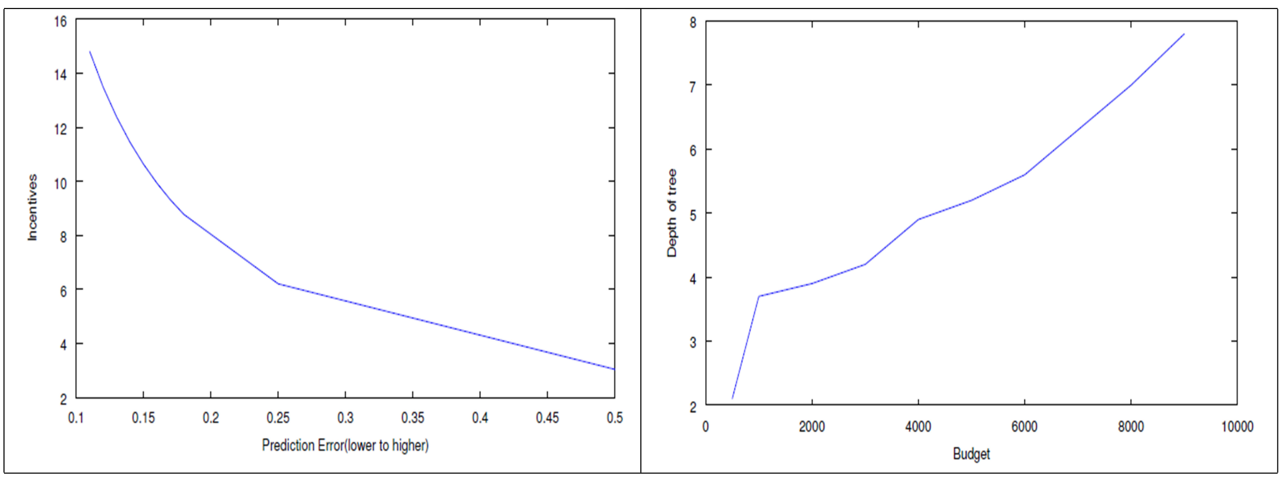

Fig. 4. Simulation Results