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Single Or Multiple Sourcing: A Mathematical Approach To Decision Making

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ABSTRACT: *There is often a tussle between choosing a right sourcing strategy which says, whether the buyer should go for single sourcing or multiple sourcing. In this paper we introduces quality as a parameter apart from other parameter such as economies of scale and specific knowledge or learning effect on sourcing strategy selection by taking into account the small number of interaction involving buyer and competing suppliers, formulated mathematically using Berndt Wood Model (Translog cost function). The objective is to find whether the difference function between the cost of production in single sourcing and Multiple (dual) sourcing is decreasing or increasing, when quality as parameter is introduced. Using the concept of maximization and minimization of a function, it is achieved, considering certain assumptions. Here the results indicates that in the long run multiple sourcing is definitely the better option, which able to cater quality as well as supplier opportunism and cost. This further established by the numerical illustration.*

KEYWORDS ***-****Strategic sourcing; product quality; translog cost function; game theory; minimization and maximization;*

I. INTRODUCTION

When an organization or company decides to outsource, it looks for benefits like, increased cost savings, value for money, better service levels, access to best practices and greater Innovation [1]. Selection of right strategy for sourcing is a bit complex issue. Whether the buyer or an organization goes for single sourcing or multiple sourcing since each has its once benefits and drawback. If a buyer goes for single sourcing it provide benefits like preferential treatment, discounts. Historically the single sourcing contracts are the lengthy engagements [1],[2]. This locking into lengthy engagement with the single supplier would lead to opportunistic behaviour from supplier which may lead to rising of prices. Also there will be always a risk associated with single supplier that if the supply fails then there may be a whole supply chain failure. Buyer can also opt for multi-sourcing strategy where more than one supplier is involved, discounts; preferential treatment may not be as favourable as with single sourcing supplier but it may insure the buyer from supplier opportunism. In present scenario, economies of scale are the important factor. Buyers exploit this factor by purchasing in bulk from the supplier. Although this buyer and supplier both try to maintain good relationship, results in win-win situation. However single sourcing strategy practice is not much evident [3]. Single sourcing strategy produces more reliability, good relationship, reduces operational cost but at the same time switching cost creates vulnerability.

Multi-sourcing strategy includes multiple suppliers. This exposes the buyer with various risk. One of biggest risk is the governance which is quite insignificant in single sourcing. Performance of one vendor can significantly affect the performance of other vendor. There may be chaos when service levels are not met and things go wrong. More the suppliers, more is the complexity. There is the estimation provided by the analysts that cost of managing single sourcing provider deals which range from 3% to 10% of the total cost of the deal which can go far as 15% to 40% in a multiple sourcing arrangement. However engagement with multiple suppliers will make the buyer to come across with many different sets of skills, machinery and equipments which in turn provide confidence in buyer for various potential businesses and power of sourcing various product or services to the customer [4].

There have several papers that attempts to address the issue of single versus multiple sourcing. Transactional Cost Analysis (TCA) is one of the approach to address this issue and has been reflected in several papers [5],[6]. These paper supports single sourcing strategy due to its value creation potential. However, TCA approach itself is a subjective approach and questions arises on its formalization. In addition to the same, traditional TCA consideration is in the issue to make or buy decisions, tangential consideration of optimal number of suppliers, assumes dyadic interaction and thus implicitly focuses on single sourcing strategy. To examine the TCA arguments, it is extrapolated to examine the small number of interaction impact on buyer and competing suppliers, which is quite not evident.

To overcome these limitations, Khai Sheang lee, et al [2], adopts game theoretic approach to examine the merits of a single versus multiple sourcing strategy. They incorporated the effect of economies of scale and specific knowledge in their model and investigated. However there is a factor product quality, which is unobserved factor that is assumed to be either constant or uncorrelated [7]. The factor product quality is introduced in this paper and examined the impact of this on sourcing decision.

II. LITERATURE REVIEW

The Literature review is divided into three sections. Section A: Review of strategic sourcing issues, decisions models and other classification over the period 1997-2010. Section B: Brief description about sourcing decisions and impact on quality of product. Section C: research paper highlights the factors which impact strategic sourcing decisions and supported facts which motivates our approach to look into the impact of quality into the buyer strategic sourcing decision.There has been focused review work on strategic sourcing. Focused 225 published research contributions over a period of 14 years (1997-2010) were assessed. Five major areas of research emerged based on the analysis of papers selected. These areas include strategic sourcing related issues, supplier selection, evaluation methods and decision tools, purchasing methods, buyer supplier relationships and e-procurement. Contribution from focus area Strategic sourcing issues, Supplier selection, evaluation methods and decision models, purchasing method Buyer-seller relationships are 36.4%, 12%, 21% and 9% respectively. Further classification such as Supply chain strategies, Supplier selection criteria, Decision support tools, Single vs Multiple sourcing, Supply base reduction, Supplier Switching and Structure supplier relationships are 7.6%, 8%, 4%, 3.6%,0.4%,0.9% and 7.1% respectively. Further classified into focus area and type of research was done [11]. Cross-sectional analysis is as follows:

Table 1: Cross-sectional Analysis of Focus area and Type of Research

Focus Area Type	Strategic Sourcing issues	Supplier selection evaluation methods and decisions tools	Purchasing Methods	Buyer supplier relationship	e-procurement	Total in %
Analytical	8.0%	7.1%	8.9%	0.9%	7.6%	32%
Best Practices	0.4%	0.9%	1.8%		2.2%	5%
Conceptual	9.3%	0.4%	3.6%	1.3%	2.7%	17%
Emperical	18.2%	2.2%	6.2%	6.2%	9.3%	42%
Review	0.9%	1.3%	0.4%			3%
Total in %	37%	12%	21%	8%	22%	

However further classification is done on the Strategic sourcing decision making tools. Cross section analysis is as follows:

Table 2: Cross-sectional analysis of Method and Tools for Analysis

Focus Area Type	Strategic Sourcing issues	Supplier selection evaluation methods and decisions tools	Purchasing Methods	Buyer supplier relationship	e-procurement	Total in %
Analytical	8.0%	7.1%	8.9%	0.9%	7.6%	32%
Best Practices	0.4%	0.9%	1.8%		2.2%	5%
Conceptual	9.3%	0.4%	3.6%	1.3%	2.7%	17%
Emperical	18.2%	2.2%	6.2%	6.2%	9.3%	42%
Review	0.9%	1.3%	0.4%			3%
Total in %	37%	12%	21%	8%	22%	

(Source: Uma Kausik and B Mahadevan, [11])

The tools category analysis includes Markov decision process, simulation, game theory and queuing theory. However in the absence of % bifurcation of others, optimality is considered among the distribution such that 12.5% of contribution of each tools aggregates to represent 'Others'. Thorough the review analysis there is no-where the author has propagated the hybrid approach based on Transactional Cost Analysis using game theory mathematical models to strategic sourcing decisions. However the author suggested more hybrid approach is required to cater solution to strategic sourcing decision issues. Hence Khai Sheang Lee, et.al [2], can be revisited for strategic sourcing decision issues.Switching cost and Complexity in market place can be relook by Buyer supplier relationship restructuring. It is evident in these cases incumbent supplier were engaged to reduce cost and maintained compromising the quality of product and services provided [8].

However, outsourcing has led to considerable benefits such as cost reduction but also increase attention towards product quality issues when outsourced. For example massive pet food recalls in both US and Canada in 2007 and product recall in China, 2008 (baby formula of Sanlu was found to contain mealmine, originated from contaminated milk supply outsourced to local farmers). A serious hazard of outsourcing is exposed. Hence a negative impact of product quality is observed when outsourced [9]. So outsourcing do reduces cost however quality is also compromised. Although the author later in his study that the gap in product quality can be filled through contract enforcement, however the specifically not mentioned about the governance and monitoring cost arises when multiple suppliers are involved, which is itself is the additional cost. Also is not clearly indicated that whether product quality as a parameter, with economies of scale and learning effect will help the buyer in strategic sourcing decision making.

In case of Sourcing in food supply chain is always is really complex. Consumers are demanding year round availability product in retail outlets. Author highlights the complexities such sourcing from different regions, shelf life of product (decay of quality of product should be less, long sustainability), minimising cost, providing fresh high quality product to the consumers with less waste requires effective sourcing strategy. Despite of optimization in fresh food supply chain, existing strategic sourcing strategy are ineffective. However decision makers have to achieve a trade-off between the logistics cost drivers and product quality cost [10]. Hence product quality is a differentiator in strategic sourcing decisions. Sourcing strategies may also leads to product quality recalls. Product recalls are due to serious quality failure and have significant negative impact on firm performance. Offshore outsourcing has a greater impact on product recalls. Author suggest outsourcing to the smaller supplier base may lead to fewer recalls. However if there is high level of outsourcing then higher is the recalls. It has been also found that there is negative curvilinear relationship between outsourcing and firm performance. Measure were used to developed the relationship are market share and financial performance [12]. However the author relationship between outsourcing and low quality performance. TCE (Transactional Cost Economics) concept, hypothesis are laid, analysed using negative binomial regression techniques. TCE suggests that uncertainty, bounded rationality and opportunistic behaviour creates transaction costs. The prime objective is to minimize such costs [13].

Our research work takes care about the impact of quality on the strategic sourcing decision of the firm. The product quality was always treated as the unobserved factor or uncorrelated with the included variables in the demand function. In many cases this assumption is incorrect, in result the conventional cost function estimated does not provide accurate representations of the structure of production. One of the reason product quality is included, since quality characteristics are the strategic variables which the firm can use to pursue profit maximization [7]. With multiplier supplier procurement strategy there is always a competition between the suppliers which curbs suppliers opportunism [7]. Buyer will have an opportunity to receive lower prices and shipping costs. Supplier will be responsible to maintain the necessary technology, expertise and forecasting abilities, cost , quality and delivery competencies [14]. However dealing with multiple suppliers is likely to require longer time in negotiation which in turn may delays or disturb production schedules [15].Long term partnership is the strategy taken by many winning companies with suppliers to achieve the same benefits provided through the multiple sourcing strategy, in turn reducing the supplier base. Xerox reduces its supplier base from five thousand in 1981 to several hundred by 1985. Reducing with huge numbers helps them to form effective partnerships with those who are willing to produce high quality, low cost components [16].

Reducing the supplier list has become the priority for many firms; some have even considered single sourcing would be a choice. The concept of single sourcing has evolved with growing popularity of JIT (Just in time) concept [17]. There was a survey study which indicates the benefits of single sourcing. It includes higher quality at lower total cost to the buyer and higher supplier-buyer cooperation [19]. Other benefits such as monitoring cost will be less and more consistency of product can be achieved [18]. Greater reliability, increased machine throughput and reduced number of failures and repairs are further more benefits provided by the single source stated by the Engineers of Machine design [15]. In Multiple sourcing strategy, concept of splitting orders in a context of cost minimization or economics. Researchers have assessed the benefits of order splitting in economic context, total cost for ordering, purchasing prices and inventory holding and stock out penalties are minimized. In this case using numerical search technique researchers claim that dual sourcing is often better than single sourcing [20]. Analyst from Industry suggested firms to adopt multisourcing supplier strategy, pointing out advantages of major cost savings and operational and strategic risk reduction [22],[23]. Multi-sourcing supplier strategy allows firms to tap into unique resources of diverse supplier relationships and gaining complementary competitive advantages [24],[21]. The concept of few strategic partner may prevent the firm from discovering new business opportunities and new markets to deliver product or service. Such misses have the potential to lose large service offerings [25].

Organization should employ a relatively small number of suppliers (atleast two) which may reduces operational risk and increase completion [26]. Multi-sourcing suppliers' selection is particularly interesting when candidate suppliers provide similar services [23].Some Researchers said when a market has been segmented, a marketer may choose to serve one or more of the segments. Thus, if the market was divided between those firms more likely to use single sourcing, some marketers would choose the latter because they view the division of business among numerous suppliers to be detrimental to enduring buyer-seller relationships, while other marketers would choose former because to be as profitable as being the single source. Uncertainty of a specific buying and selling situation might explain when multiple sourcing might be preferred over single sourcing [27].However the main argument that supports a multiple sourcing strategy lies in the need to maintain control over supplier's opportunism. Constant monitoring of supplier's production prevent supplier's opportunistic behaviour [28]. This knowledge would ensure the sharing of production efficiency gains. However this assumption may not always true. Monitoring is more costly. Splitting of demand among the supplier's have its own disadvantage for buyer. Buyer may able to leverage less efficiency gains due to economies of scale unlike in single sourcing strategy. It is also not evident that reduction in efficiency gains is justifiable in terms of benefits that are derived from controlling supplier opportunism. However, it concluded that neither of the strategies was equivocally the best [3]. To understand the opportunistic behaviours by parties interactions, Khai Sheang lee, et al, [2],uses the game theoretic approach, which is also proposed by Moorthy, [29] as most suitable approach. Khai Sheang lee, et al, [2] recognizes the importance of specific assets in buyer-seller relationship as emphasizes in TCA, they incorporated the concept of economies of scale and impact of acquiring specific knowledge, explicitly examine the opportunistic behaviours of the interacting parties uses all in game theoretic analysis of sourcing strategies. The author did not include product quality, put as limitation in the analysis, however he propagated that product quality is the important factor and may bring some different results. This is taken care in our study along with other factors included in the equation.

III. GAPS AND OBJECTIVE

In this competitive market cost savings, long term supplier buyer relationship for dependability for sustenance in the market cannot be the only factor, product quality is the potential game changer which need to be considered when the buyer decide for sourcing partner. Through the focused literature review propagate significant gap which is a consolidated approach such as along with economies of scale and acquiring specific knowledge effect , product quality is the factor is ignored or either put into limitations with other limitations such as reputation effect, penalties, equal technology, same learning rate and collusions [2], [7], when decision were taken by buyer to outsource strategy (either Single Sourcing or Multiple Sourcing) and also supplier opportunism which may happen in the long term supplier-buyer relationship.Our objective is to put product quality into the cost equations which by earlier authors considered as limitations and see the effect of rise in product quality along economies of scale and acquired specific knowledge effect mathematically, using the concept of maximization and minimization of function, which will help to take buyer, constructive decision to either go for single sourcing or multiple sourcing.

IV. PROBLEM FORMULATION

This model is the adaptation of Khai Sheang Lee, et al,[2], model, which is a two stage sequential game, which is repeated over two periods. In first stage buyer has to decide between sourcing from a single supplier or from multiple (dual) supplier. In this case the concept of economies of scale is incorporated. The supplier who is having the bulk demand will benefits the economies of scale, hence the average cost of production will become less. However in the second stage, given the buyer's sourcing decision, the supplier(s) responds by determining the optimal price to charge. This game structure is then repeated in another period, in order to capture the effect of specific knowledge acquired over time, provided economies of scale factor is present.

The model used as follows:

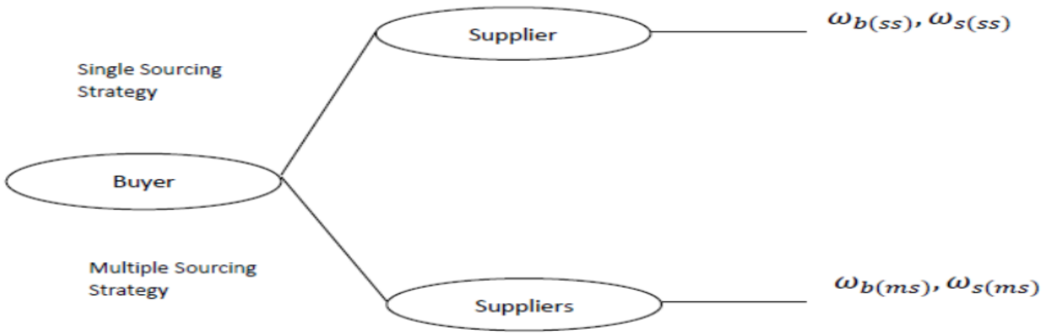

Figure 1. Game theoretic model of sourcing strategy [2].

$\omega_{b(ss)}$ and $\omega_{b(ms)}$ refer to as buyer's payoffs under a single source and a multiple source strategy, respectively. Similarly, $\omega_{s(ss)}$ and $\omega_{s(ms)}$ refer to the supplier's payoffs under a single source and a multiple source strategy, respectively. Now Nash equilibrium is derived for the game in terms of the buyers optimal sourcing strategy and suppliers optimal prices [30].[2]. Hence the profit function can be defined as the difference between the buyer payoff and supplier pay off for both single sourcing and multiple sourcing. This can also be taken can by studying the cost function of the supplier in single sourcing and multiple sourcing strategy. If the cost function is showing higher value hence the profit margin for the supplier in single sourcing or multiple sourcing is less which in turn less room for the buyer to negotiate with supplier on cost and quality both.

Incorporated the effect of economies of scale in the model. The effect of economies of scale is defined as the decline in average cost (per unit of product) with increase in production volume per unit of time. It is assumed, no capacity constraints to production. Hence with increase in quantity, due to economies of scale, the cost of production per unit of product reduces. For instance in single sourcing strategy, unit transportation cost may be reduced as a result of shipping a larger volume at one time to a pre-planned schedule [2]. In Single sourcing focused on a particular buyer item, this facilitates an increased in familiarity with the items, their location and destination and handling procedures of materials [17]. There will be minimum setup cost of machines, contracts and services [31].Incorporated the effect of acquiring specific knowledge. It is modelled as an efficiency gain, in turn reduces cost. Considering an incumbent suppliers, hence the specific knowledge is acquired during production. The effect of specific knowledge(or learning) is defined as the decline in unit cost with increase in cumulative uninterrupted production [31]. The effect of specific knowledge depend on accumulated production volume across all periods of time, since the production begins [2]. Incorporated the effect of Quality (product quality). With an increase in specific knowledge the product will also increase [2]. Economist routinely ignore the possibility of endogenous product quality in cost function. In the presence of price regulation, one should expect even greater variation in product quality, since quality characteristics are the only strategic variable that the firms can use for profit maximization [7]. Braeutigam and Pauly, [32] they explores the implication of endogenous product quality in the estimation of cost function. They argue that one should consider quality to be the standard case in cost function estimation. Failure to account of quality will result in biased cost function estimates. Hence product quality is the important factor and shall be considered in the demand and cost function which in result help the firm to choose right sourcing strategy which will take care cost, quality and on time delivery.

Variable were defined as

P : *Price of the unit at which the bid happened*

P_Q : *Price of the Q units in demand;* $P_Q = Q * P$

P_d : *Price of the* q_d *defective unit produced;* $P_d = q_d * P$

q_d : *defective unit produced*

P_L : *Price of the Average direct labour hours for producing Q unit;* $P_L = Q * \overline{Y_Q} * P_l$

P_l : *Price of the labour effort per hour*

$P_{\alpha Q}$: *Price of the* αQ *unit in demand;* $P_{\alpha Q} = \alpha Q * (P - \varepsilon)$

$P_{(1-\alpha)Q}$: *Price of the* $(1-\alpha)Q$ *units in demand;* $P_{(1-\alpha)Q} = (1-\alpha)Q * P$

$q_{d'}$: *defective unit produced by second vendor*

$P_{L^{\cdot}}$: *Price of Average labour hours for producing* αQ *unit*; $P_{L^{\cdot}} = \alpha Q * \overline{Y_{\alpha Q}} * P_{l^{\cdot}}$

$P_{L^{\cdot\cdot}}$: *Price of Average labour hours for producing* $(1-\alpha)Q$ *unit*; $P_{L^{\cdot\cdot}} = (1-\alpha)Q * \overline{Y_{(1-\alpha)Q}} * P_{l^{\cdot\cdot}}$

$\bar{Y}_Q$: *Average labour hours for producing* Q *units*; $\bar{Y}_Q = (K * \frac{1}{1+\log_2 b} Q^{1+\log_2 b})/Q$

K : *no. of direct labour hour for producing first unit*

$\overline{Y_{\alpha Q}}$: *Average labour hours for producing* αQ *units*; $\overline{Y_{\alpha Q}} = \dfrac{K_{\alpha Q} * \frac{1}{1+\log_2 b} \alpha Q^{1+\log_2 b}}{\alpha Q}$

$K_{\alpha Q}$: *Average number of labour hours for producing first unit for* αQ *unit*

$\overline{Y_{(1-\alpha)Q}}$: *Average labour hours for producing* $(1-\alpha)Q$ *units*; $\overline{Y_{(1-\alpha)Q}}$

$$= \frac{K_{(1-\alpha)Q} * \frac{1}{1+\log_2 b}(1-\alpha)Q^{1+\log_2 b}}{(1-\alpha)Q}$$

$K_{(1-\alpha)Q}$: *Average number of labour hours for producing first unit for* $(1-\alpha)Q$ *unit*

ϵ_s : *Error term associated with the cost function of Single sourcing*

ϵ_{m1} : *Error term associated with the cost function of Multiple (dual) sourcing, Vendor 1*

ϵ_{m2} : *Error term associated with the cost function of Multiple (dual) sourcing, Vendor 2*

Our Modified Translog Cost function 2nd order Taylor approximation and also inline with Berndt Wood Cost function Model and Cobb Douglas Cost function model defined as

$$\log C = b_0 + b_1 \log I + \textstyle\sum_i b_i \log P_i + \frac{1}{2}\sum_j b_{jj} \log P_j{}^2 + \sum_{ij} b_{ij} \log P_i \log P_j + \epsilon_{s/m_{1/2}} \quad (1)$$

Where as

C : *Output need to predicted on the bases of Input cost associted with input parameter*

P_i : *Prices or cost associated with the Input parameter*

$\epsilon_{s/m_{1/2}}$: *error term associated with cost function either of single sourcing or multiple sourcing*

I : *Quantity or Unit size or unit or productivity*

For Single sourcing

Cost function for single sourcing

$$C = C(Q, P_Q, P_d, P_L) \quad (2)$$

Then using Trans log cost function we have the equation

We derived the modified translog cost function by using 2nd order Taylor approximation such that when Partially differentiated w.r.t q_d

$$\frac{\partial \log C}{\partial q_d} = 0 \quad (3)$$

we get the following value of q_d as:

$$q_d = \frac{1}{p} \exp\left[-(b_d + b_{Qd} \log P_Q + b_{dL} \log P_L)/b_{dd}\right] \quad (4)$$

And also

$$\frac{\partial^2 \log C}{\partial q_d^2} > 0 \quad (5)$$

However the value of the above equation came negative which shows the cost will increase in the duration of time, hence profits will come down.

For Multiple (Dual) Sourcing

The cost equation is defined as

$$C1 = C(\alpha Q, P_{\alpha Q}, P_{d^{\cdot}}, P_{L^{\cdot}}) \quad (6)$$

$$C2 = C\left((1-\alpha)Q, P_{(1-\alpha)Q}, P_{d^{\cdot\cdot}}, P_{L^{\cdot\cdot}}\right) \quad (7)$$

And assuming

$$\frac{q_d}{\alpha Q} + \frac{q_{d^{\cdot}}}{(1-\alpha)Q} < 1 \quad (8)$$

The modified translog cost function for C1 and C2 is derived using 2nd order Taylor approximation such that when partially differentiatedthe cost function we w.r.t q_d

$$\frac{\partial\,(\log C1 + \log C2)}{\partial q_d} = 0 \quad (9)$$

And also using binomial expansion

$$\left(\frac{q_d}{\alpha Q}\right)^2 \left(b_{d^{\cdot}} + b_{d^{\cdot\cdot}d^{\cdot\cdot}}\left(\log P_{(1-\alpha)Q} + 1\right) + b_{(1-\alpha)Qd^{\cdot\cdot}} \log P_{(1-\alpha)Q} + b_{d^{\cdot\cdot}d^{\cdot\cdot}} \log P_{L^{\cdot\cdot}} + \frac{\alpha Q^2}{2}(P-\epsilon)^2\right) + \left(\frac{q_d}{\alpha Q}\right)\left(b_{d^{\cdot\cdot}} + b_{d^{\cdot\cdot}d^{\cdot\cdot}} \log P_{(1-\alpha)Q} + b_{(1-\alpha)Qd^{\cdot}} \log P_{(1-\alpha)Q} + b_{d^{\cdot\cdot}l^{\cdot}} \log P_{L^{\cdot\cdot}} - 2P_{\alpha Q}\right) - \left(b_{d^{\cdot}} + b_{\alpha Qd^{\cdot}} \log P_{\alpha Q} + b_{d^{\cdot}L^{\cdot}} \log P_{L^{\cdot}} - \frac{3}{2}\right) = 0 \quad (10)$$

And also

$$\frac{\partial^2(\log C1 + \log C2)}{\partial {q_d}^2} > 0 \quad (11)$$

Hence in dual sourcing the cost of production or service is less w.r.t time which leads to more profit to the supplier.

V. DATA COLLECTION METHODOLOGY

The sourcing is done in two way. Beneficiary organization takes services from Single vendor and also multiple (dual) vendor. The data is collected from both the six small Indian IT companies of size (200-300 person) and beneficiary organization (large organization-Multinational Company) which provide Infrastructure help desk and support services to the beneficiary IT organization. In the first scenario where single vendor is providing both help desk (first level support) and also bug fixing support (second level) to the beneficiary organization. In second scenario where multiple vendor, in our case dual vendor where vendor 1 is providing the help desk support (first level resolution) and vendor 2 is providing the technical support such development, enhancements and bug fixes support (second level resolution). The beneficiary IT organization and six other IT organization follows ISO 20K process, ISO 9001:2008 and CMMI practices. The parameter like productivity ,total actual effort, Effort per tickets/incidents, cost per tickets, rework effort, rework cost, actual cost of total tickets, ticket size were studied. Due to confidentiality purpose the data is masked through parametric scaling and also the organization names cannot be shared due to confidentiality. Total 250 projects were studied for computation of cost function for single sourcing and 228 projects were studied for computation of cost function for multiple sourcing (dual). These projects are collected in small chunks for the organization as the process follows are same as mention above and after collection the concerned parameters for study are normalized. Box and whisker method is used for outliering.Productivity is taken as the parameter to implement box and whisker tool for performance outliering. In total 25% of the data is ouliered.Cost function hold great importance in the literature of microeconomics. It has been used in the past number of applications such as in transportation economics. Different types of cost function were generated based on the research questions under consideration. A large number of studies on Cobb Douglas and translog types of cost functions. As mentioned by Braeutigam [33] cost functions can be used to address a number of issues such as to determine the impact of factor price on the total cost, economies of scale, economies of scope, effect of technology on the cost structure.In our study cost function very is much important to understand the relationship between the total actual cost, total effort, productivity, quality, economics of scale and learning effect on single sourcing and on Multiple sourcing (dual). Comparison between their cost function and effect on economics of scale, quality and learning effect on cost function. In IT there is no proper data structure available nor collected to compare the cost function of outsourcing technique to take decision using the economies of scale, learning effect and operation parameter (productivity, quality). Therefore a novel technique is developed using translog cost function with a small modification.

VI. DATA ANALYSIS AND NUMERICAL EXAMPLE DEMONSTRATION

Analysis is done in two stages. First stage the data is collected for the parameters which we have considered in our model from different companies. Normalized and arranged in tabulated form and used regression analysis approach for the same. Single sourcing cost function approach is analyzed separately. The analysis is done using MS excel Data analysis package. For single sourcing, we have the Regression analysis table attached.

Coefficient used in Translog Cost Function for Single Sourcing	*Coefficient details*	*Coefficients value*	*P-value*	*Significant/Insignificant*
b_0	Constant	1.13738283	0.23976061	*Insignificant*
b_Q	Bid total quantity cost	0.291594445	0.00008681	*Significant*
b_d	Rework cost	0.325143774	0.02349255	*Significant*
b_L	Average hours cost for unit	0.75960688	0.00027693	*Significant*
b_{QQ}	Square of bid total quantity cost	0.131261283	0.0226997	*Significant*
b_{dd}	Square of Rework cost	0.101235331	0.01311761	*Significant*
b_{LL}	Square of Averge hour cost for unit	0.011803467	0.0084303	*Significant*
b_{Qd}	Product of bid total quantity cost and Rework Cost	0.045427578	0.01246258	*Significant*
b_{QL}	Product of bid total quantity cost and Rework Cost	0.09600201	0.51193875	*Insignificant*
b_{dL}	Product of Rework cost and Average hours cost for u	-0.006442073	0.237172135	*Insignificant*
b_1	Quantity or Unit Size	0.735623582	0.01453466	*Significant*

Figure 2: Single Sourcing Cost function regression coefficient table

The Adjusted R^2 is coming as .67 and standard error of .37. Total observations are taken for analysis is 180 projects. The calculated F statistic is coming as 38.64 and significant. Hence predicted actual cost can be computed by dropping the insignificant parameters from the cost equation.Similar approach is used to compute values for Multiple (dual) sourcing. Regression analysis table is attached for the cost function for Vendor 1 and Vendor 2.

Coefficient used in Translog Cost Function for Multiple Sourcing (Vendor 1)	*Coefficient details*	*Coefficients*	*P-value*	*Significant/Insignificant*
b_2	Constant	1.1390276	0.2468482	*Insignificant*
$b_{\alpha Q}$	% Shared Bid total quantity cost	0.1964918	0.0068858	*Significant*
$b_{d'}$	Rework cost	0.0986865	0.0663872	*Significant*
$b_{L'}$	Average hours cost for unit	0.8242172	1.127E-05	*Significant*
$b_{\alpha Q \alpha Q}$	Square of % Shared bid total quantity cost	0.0487546	0.0018877	*Significant*
$b_{d'd'}$	Square of Rework cost	0.1144375	0.0106905	*Significant*
$b_{L'L'}$	Square of Averge hour cost for unit	0.0076791	0.0652838	*Insignificant*
$b_{\alpha Q d'}$	Product of % Shared bid total quantity cost and Rework Cost	0.2211018	0.0542455	*Significant*
$b_{\alpha Q L'}$	Product of % Shared bid total quantity cost and Average Cost	0.0416022	0.7335983	*Insignificant*
b_4	% Shared Quantity or Unit Size	0.5356236	0.0570645	*Significant*
$b_{d'L'}$	Product of Rework cost and Average hours cost for unit)	0.0057991	0.3423315	*Insignificant*

Figure 3: Multiple (dual) Sourcing Cost function regression coefficient table for Vendor 1

The Adjusted R^2 is coming as .62 and standard error of .39. Total observations are taken for analysis is 120 projects. The calculated F statistic is coming as 20.45 and significant. Hence predicted actual cost can be computed by dropping the insignificant parameters from the cost equation.

Coefficient used in Translog Cost Function for Multiple Sourcing (Vendor 2)	*Coefficient details*	*Coefficients*	*P-value*	*Significant/Insignificant*
b_3	Constant	-0.0474966	0.7986872	*Insignificant*
$b_{(1-\alpha)Q}$	% Shared Bid total quantity cost	0.0982032	0.0002546	*Significant*
$b_{d''}$	Rework cost	0.078797	0.0490042	*Significant*
$b_{L''}$	Average hours cost for unit	0.0177021	0.288892	*Insignificant*
$b_{(1-\alpha)Q(1-\alpha)Q}$	Square of % Shared bid total quantity cost	0.1217683	0.0001471	*Significant*
$b_{d''d''}$	Square of Rework cost	0.032224	0.0106905	*Significant*
$b_{L''L''}$	Square of Averge hour cost for unit	0.2521179	0.0652838	*Insignificant*
$b_{(1-\alpha)Qd''}$	Product of % Shared bid total quantity cost and Rework Cost	0.0272128	0.0590213	*Significant*
$b_{(1-\alpha)QL''}$	Product of % Shared bid total quantity cost and Average Cost	0.2948868	0.0155647	*Significant*
b_5	% Shared Quantity or Unit Size	0.3356236	0.2098975	*Insignificant*
$b_{d''L''}$	Product of Rework cost and Average hours cost for unit)	0.0018369	0.7748966	*Insignificant*

Figure 4: Multiple (dual) Sourcing Cost function regression coefficient table for Vendor 2

The Adjusted R^2 is coming as .68 and standard error of .38. Total observations are taken for analysis is 120 projects. The calculated F statistic is coming as 13.62 and significant. Hence predicted actual cost can be computed by dropping the insignificant parameters from the cost equation.Validation of Cost function model for both Single sourcing and Multiple (dual) sourcing is done through the data set which not used while performing regression analysis.

Hypothesis	**Definition of Hypothesis**	**Definition of Hypothesis**	**Definition of Hypothesis**
H_0 :	Actual Cost for the Service provider/Vendor in Single sourcing = Predicted cost using cost function	Actual Cost for the Service provider/Vendor in Multiple (Dual) sourcing Vendor 1 = Predicted cost using cost function	Actual Cost for the Service provider/Vendor in Multiple (Dual) sourcing Vendor 2 = Predicted cost using cost function
H_a :	Actual Cost for the Service provider/Vendor in Single sourcing ≠ Predicted cost using cost function	Actual Cost for the Service provider/Vendor in Single sourcing ≠ Predicted cost using cost function	Actual Cost for the Service provider/Vendor in Single sourcing ≠ Predicted cost using cost function
Chisquare value	101.52	87.50	49.59
Degree of Fredom	19	18	9
Chisquare Tabulated Value at 0.05	30.14	28.86	15.5
Inference	Significant	Significant	Significant

Figure 5: Validation of Cost function model for both Single sourcing and Multiple (dual) Sourcing-Comparison

This Numerical analysis as an example, just to show the capability of the Cost function and to help the user to take decision on strategy. These prices are hypothetical due to confidentiality the actual price cannot be disclosed. Hence the hypothetical prices were taken to do the numerical analysis to validate the model.

Single sourcing	**Dual Sourcing (Vendor 1)**	**Dual Sourcing (Vendor 2)**
$P = 90\ dollars$	$P = 90\ dollars$	$P = 100\ dollars$
$P_l = 70\ dollars$	$P_{l'} = 70\ dollars$	$P_{l''} = 70\ dollars$
$\alpha = 80\%$	$\alpha = approx\ 80\%$	$1 - \alpha = approx\ 20\%$
$b = 80\%$	$b = 80\%$	$b = 80\%$
$P_{q_d} = 900\ dollars$	$P_{q_d} = 900\ dollars$	$P_{q_{d'}} = 200\ dollars$
$q_d = 10$	$q_d = 10$	$q_{d'} = 2$
$K = 1.5\ hours\ for\ 1st\ tickets$	$K = 1.5\ hours\ for\ 1st\ tickets$	$K = 1.5\ hours\ for\ 1st\ tickets$
$P_L = 9001.13\ dollars$	$P_{L'} = 7405.93\ dollars$	$P_{L''} = 3516.06\ dollars$
$Q = 400\ tickets$	$\alpha Q = 300\ tickets$	$(1 - \alpha)Q = 100\ tickets$
$P_Q = 36000\ dollars$	$P_{\alpha Q} = 27000\ dollars$	$P_{(1-\alpha)Q} = 10000\ dollars$
Using Cost function equation Actual cost achieved for Single Sourcing	**Using Cost function equation Actual cost achieved for Multiple (Dual) Sourcing (Vendor 1 + Vendor 2)**	
Actual Cost = 14371.66 dollars	**Actual Cost = 12778.74 dollars**	

Figure 6: Comparison between Actual cost incurred by service provider in Single sourcing and Multiple (dual) Sourcing

Since we can see distinct difference in the actual cost which will also instigate the buyer to negotiate with the multiple sourcing vendors on bid amount easily.

VII. CONCLUSION

We can conclude from the above that Multiple sourcing is the better option for the buyer in terms of cost for bid and negotiations. We can clearly see from the above that the quality is better in single sourcing however the cost has to paid for the same. From the above equations (3) we can see that quality function is negative exponential in nature. However for multiple (dual) sourcing, the quality function equation (9) is a quadratic function which can be interpreted as upto its vertex the defect generation will decrease then again it will tends to increase. Which is certainly a trade off between cost and quality. So from above analysis it can be recommend and multiple (dual) sourcing approach for a buyer is good option to go in order to get better cost benefits and appropriate quality. There are several limitations in our analysis. We have not considered reputation effect which may punish vendors who behave opportunistically. We have also assumed that the vendors/service providers possess the same technology and learn at a same rate. However service providers if they learn at different rate then result may vary. The issue of collusion between the service providers are omitted. Governance and monitoring cost is supposed to be similar in both Single and multiple (dual) sourcing.

This similar concept we tried in the IT industry which leads to further limitations such as data collection different sources and normalizing leads to certain error. Team size working on tickets, skills, processes, role ratio are same. As per the organization information the data has been scaled up in order to maintain the confidentiality and % of scaling is not shared. We have tried with the used IT sector data specifically from Infrastructure Management System (Help desk support, enhancement, tickets resolution) hence if the same model may be used in other sector the result may vary.

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