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VALUE CHAIN MANAGEMENT: AN ILLUSTRATION USING VARIABILITY MAPPING AND DECISION FRONTIER ANALYSIS

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ABSTRACT

We address uncertainty and confusion in value chain management through the use of recently developed phase plane and decision frontier analysis. The new methodology enables the distinction between the concept of local, self-inflicted, uncertainty and the concept of global, state of the world, uncertainty through phase plane mapping. We utilise the solution to a set of stochastic differential equations to encapsulate attitudes to uncertainty, opportunity and risk. One source of information on and targets for variability is through the method of dynamic acquisition which assists in generating expert forecasts. The forecast errors can be monitored to provide an innovative facility for mapping changes in variability which should enhance research and understanding of the mechanisms occurring in value chains. The method also addresses the need for improved network relationships as well as supporting enhanced agility.

Keywords Value Chain, Uncertainty Mapping, Risk and Opportunity, Phase Plane and Decision Frontier Analysis

1 INTRODUCTION

Work in the Value Chain Forum has led to customer demand being defined in terms of performance, contract cost, through life cost and timeliness (McGuffog et al., 1999; McGuffog, 2011) while highlighting the need to encapsulate attitudes to uncertainty such as seeing opportunity or risk. Faisal et al. (2006) map supply chains on the two dimensions of risk and challenge by using customer sensitivity and risk alleviation competency derived from brain-storming exercises or other sources. Zairi et al. (2010) emphasise the importance of relationship building with regard to the needs of customers. They also highlight the need for increased agility. Christopher (2004) outlines methodology for creating resilient supply chains while Tang (2006) reviews articles addressing supply chain risk. In this brief paper we describe a way of monitoring localised as well as globalised risk making use of phase plane mapping through monitoring the progress of projection or forecasting errors. The method supports the relationships formed in the value chain since it is adopts a network approach through the prioritisation of edge over node (Pearson, 2008b) as well as addressing customer satisfaction through the incorporation of goodwill costs at every modelling stage (Pearson, 2007). The method also uses profiling as well as fulfilling the requirements of agility (Pearson et al., 2010).

2 A SIMPLE VALUE CHAIN: THE STOCHASTIC MODEL AND PROBLEM FORMULATION

A simple value chain is modelled by a contractor (dual operator) making an agreement with a customer (primal operator) to complete a project in a number of stages monitored within a certain agreed time scale. The customer defines the demand (*D*) for services and products at each stage of the project while the contractor determines the way in which these services are supplied (Q), including a safety margin ($k\sigma_e$) to ensure customer satisfaction and successful completion on time in the risky environment.

The collaborative objective (assuming normally distributed forecasting errors) is to maximize

$E\{Profit\}$ = $E\{$*Contribution from captured demand -Costs of overage - Costs of underage*$\}$

$$= \mu_1(c_{p_1} + c_{p_2}) - E[(Q-D)^+]\,(c_{o_1} + c_{u_2}) \; - E[(D-Q)^+]\,(c_{u_1} + c_{o_2} + c_p)$$

$$= \mu_1(c_{p_1} + c_{p_2}) - \{(k\Phi(k) + \phi(k))(c_{o_1} + c_{u_2}) + (\phi(k) - k(1-\Phi(k))(c_{u_1} + c_{o_2} + c_p)\}\sigma_e \qquad (1)$$

subject to: $E(Q) = E(D) - k\sigma_e$ (or $\mu - k\sigma_e = 0$) (Newsvendor Constraint) (2)

where $^+$ indicates the value of the variable when it is positive and zero otherwise (Pearson, 2003). Also $\mu_1 = E(D)$, $\mu_2 = E(Q)$, $\mu = \mu_2 - \mu_1$ and $\phi(k)$, $\Phi(k)$ are the normal distribution density and cumulative distribution functions, respectively, for safety factor, k. The customer and contractor agree to complete certain stages of the project perhaps with the assistance of a Gantt chart. Probability distributions may be associated with the completion of the stages (perhaps by using PERT or other methods). The outcome may lead to certain targets not being met, which results in a series of forecasting errors generated at each stage of the project. σ_e is the standard deviation of these jointly calculated forecasting errors. The contributions to profit of the customer (downstream operator) and contractor (upstream operator) are c_{p_1} and c_{p_2}, respectively, and $c_p = c_{p_1} + c_{p_2}$. The contribution to profit for the contractor is the (nominal) payment associated with completing that stage minus the contractual costs of completing it. The contribution to profit for the customer is calculated in terms of the measurable increase in satisfaction gained from successful completion of that stage. The overage and underage costs of the customer are c_{o_1} and c_{u_1}, respectively, while for the contractor they are c_{o_2} and c_{u_2}. An interesting feature of the problem and the way it is formulated is that the customer's (primal) overage is the same as the contractor's (dual) underage. The associated costs, however, are not necessarily the same. For instance, the customer may put a certain value on a disappointment, such as the failure to deliver on time, which differs from that of the contractor. In this context the contractor may face a financial penalty as drawn up in the contractual agreement, while the customer faces the disappointment (and possible financial loss) when the project defaults at that stage.

2.1 THE MIX (OVERAGE/UNDERAGE) SOLUTION

The mix solution tracks the way in which partners across decision frontiers synchronize their efforts to reach optimality (Pearson, 2008a). In this context the decision frontier is at the tie which exists between the customer and the contractor. The solution (Appendix 1) is described by the equation

$$\Phi(k) + \frac{\partial \sigma_e}{\partial \mu}\phi(k) = Const \left\{ = \frac{c_{u_1} + c_{o_2} + c_p/2}{c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p} \right\} \qquad (3)$$

We see that the constant in equation (3) depends on the project costs and contribution to profit (where $c_p = c_{p_1} + c_{p_2}$) defined in Section 1.1. The LHS of Eqn. (3) has an additional term to the classical fixed variability solution which measures the rate at which error variability changes with respect to the 'mix' variable μ. This assists in the identification of the optimal (maximum profit) solution in conditions of increased uncertainty.

2.2 THE GLOBAL (VOLUME) SOLUTION

In contrast to the local (mix) variable, μ, the global variable, η, is formulated as the sum of expected demand and supply ($\eta = \mu_1 + \mu_2$), which assists in the monitoring of change in the global market place. The global ('volume of the total expected demand and supply output') solution is described by the equation (Appendix 1):

$$\phi(k)\frac{\partial \sigma_e}{\partial \eta} = Const = \left\{ \frac{c_p}{2(c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p)} \right\} \qquad (4)$$

We see that the constant again depends on the costs and contribution to profit defined in section 1.1. The LHS has a single term which measures the rate at which the error variability changes with respect to the 'global' variable, η. This also assists in the identification of the optimal (maximum profit) solution. The two equations (3) and (4) form a dynamic system of stochastic differential equations which trace the optimal solution in circumstances where variability changes and uncertainty increases or decreases over time and with relation to differing contractual and marketing strategies.

3 PHASE PLANES: AN ILLUSTRATION

We use an example drawn from a large engineering project to illustrate the methodology. A city council (customer and primal operator) approaches a contractor (dual operator) to install a single route tram system in a city. The operators agree that the tram system will be installed in 16 two-monthly stages (32 months in all) with monitoring taking place at each stage. Figure 1 shows the plot of quantity, forecast demand and actual demand against project stage, each stage representing two months in time. The quantities are not specified as these may represent specific materials, man-hours of labour or financial investment, referred to here as "Value Units".

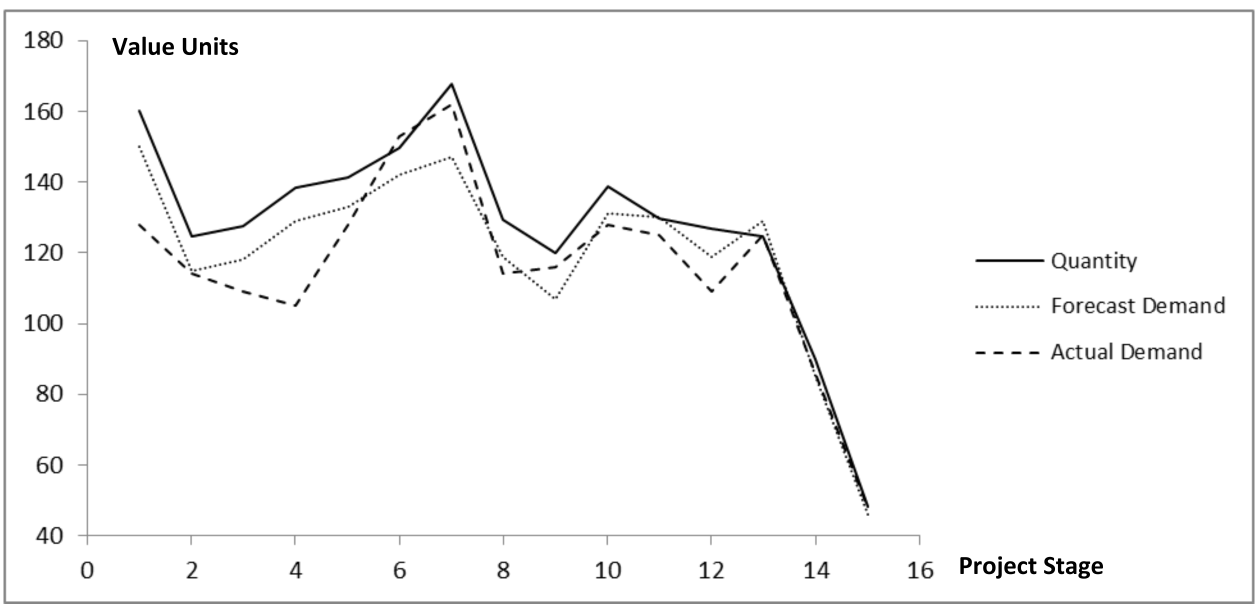

Figure 1 Plot of Quantity, Forecast Demand and Actual Demand against Project Stage

Information about historical plots as well as projections involving future events and plans can be incorporated into the forecast which then acts as a profile which can be adapted dynamically during the project development stages (Pearson, 2006).

3.1 LOCAL (MIX) PHASE PLANE

The local phase plane maps the progress of the contractual agreement entered into by the operators during the stages of the project. If the mutually agreed targets are exactly achieved within the risk environment then both operators will be satisfied and the target solution will be achieved (see Figure 2). If the path described by the mix plot drifts outside of the area of capability (that is, when there is higher overage or underage than planned) but still remains within the boundary set by the isovalue line (so that, for instance, the contractor fails to meet one of the targets within the time schedule for that stage but still meets the overall contribution to profit target by improvements in other areas) then the two parties may not be over concerned. If, however, the path drifts outside of the boundary described by the profit isovalue line due to high uncertainty and failures in forecasting then there may be a need to implement penalties or renegotiate the contractual agreement.

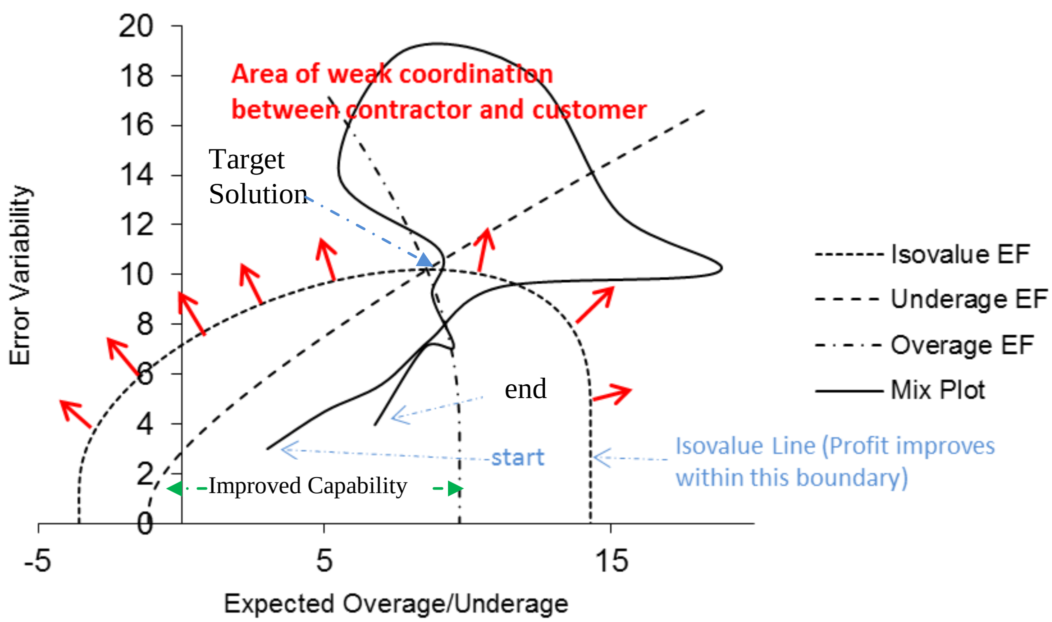

Figure 2 Local (Mix) Phase Plane

Figure 2 illustrates this during the central period of the contract (months 10 to 24). The Figure shows the three efficient frontiers (EF) associated with improvement in profit (isovalue line, Appendix 2), improvement in underage and improvement in overage associated with the risky environment. If the mix plot moves to the wrong side any of the efficient frontiers then the path is moving into a suboptimal position with regard to that requirement mapped in the uncertain environment. This leads to a risk of a failure of coordination and requires adjustment. In our example we see that the project operates efficiently at the beginning and the end of its life cycle, but does not do so during the central period as the path strays into the area of weak coordination so that the profit margins are compromised. The area where the profit improves on the agreed initial target lies within the profit isovalue line. The area where the targets for underage (e.g. insufficient tram rail laid at this stage of the project) and overage (e.g. excess of tram rail laid on unsuitably prepared ground, or exceeding the agreed time scale) lie outside of the underage and overage efficient frontiers and so the progress of the project would be no longer capable with respect to these targets. In our example the central phase of the project reveals a tendency to failures in both of these targets (as well as the profit target) so that there is instability in the chain of operation. To get a more complete picture, however, we should also refer to the global phase plane in Figure 3.

3.2 GLOBAL PHASE PLANE

Figure 3 illustrates the progress of the project in the context of the global risk environment. After several months the contractors discovered problems in meeting the targets agreed at the beginning. Part of the difficulty was the amount of infrastructure work which had to be carried out before laying the tram lines. This led to delays and increased expense. Another factor was the increased uncertainty due to a recession which meant that access to finance was restricted. The efficient frontier determined by reference to Eqn. (4) was crossed by the path in the global phase plane leading to concern about the viability of continuing with the project. As a result the terms of the contract needed to be renegotiated and the schedule changed.

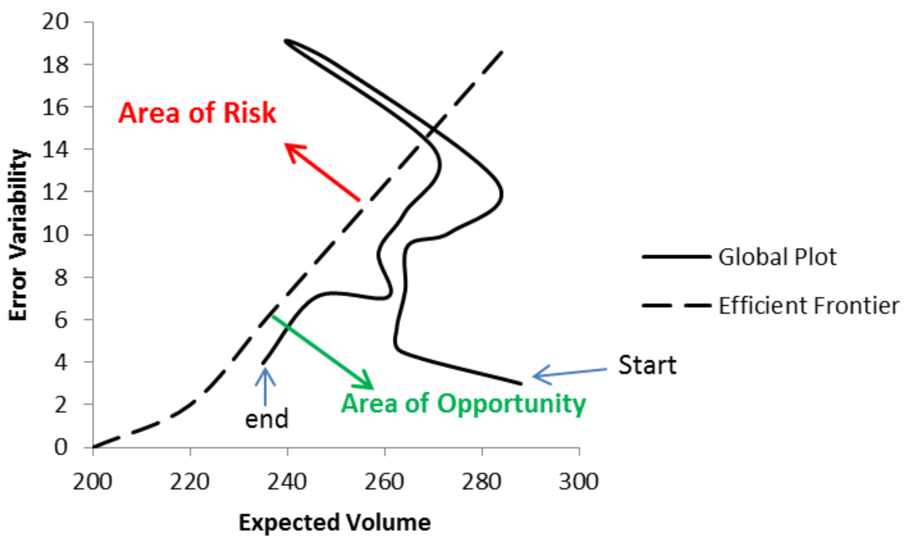

Figure 3 Global Phase Plane

4 DISCUSSION

The method of dynamic acquisition (McGuffog, 2011) establishes trade-offs within and between objectives and serves as input from experts leading to target performance measures and efficient frontiers as well as forecasts required by the proposed methodology. Subsequent observation of outcomes over a number of projects provides a measure of forecast accuracy and hence forecast errors. Following on from the definition of the demand of a customer in terms of performance, contract cost, through life cost and timeliness (McGuffog et al., 1999), the new methodology outlined here deals with performance and contract cost by phase plane analysis, since each phase plane has associated efficient frontiers which assist in the achievement of these measures. Through life cost and timeliness can be dealt with dynamically through an extension to the phase plane methodology which allows for the incorporation of dynamic pricing. Demand itself may be insufficiently clear and may need to be adjusted via trade-offs encapsulated within the efficient frontiers. T. McGuffog (2011) describes the “cost of confusion” and illustrates how ‘the probabilities of falling below the best estimates for cost and time are much less than those for exceeding them’. This characteristic is revealed by the much smaller area occupied by improved capability in Figure 2 than the complementary area outside of it.

The concept of local, self-inflicted, uncertainty caused by lack of cooperation across a decision frontier is reflected in the local ('mix') phase plane of Figure 2. The three efficient frontiers, then, in the local phase plane are determined by endogenous variables such as customer satisfaction, unacceptable wastage and basic contractual agreements between operators linked in the value chain. The concept of global, state of the world, uncertainty is mapped in the global chart of Figure 3. The efficient frontier in the global phase plane, therefore, is determined according to exogenous variables, such as market variability in prices, consumer confidence, weather and economic climate. The attitudes to uncertainty, opportunity and risk correspond to this division and are reflected in the performance measure targets set by the stochastic differential equations, capability plots and control zones illustrated in Pearson (2008b). The methodology, then, establishes three efficient frontiers in the local phase plane to identify where optimal profit is made subject to constraints associated with customer goodwill and satisfaction, unacceptable wastage and basic contractual agreements between operators in the value chain. A fourth efficient frontier is that associated with optimising profit in conditions of uncertainty in the global market place. Furthermore the phase planes are significantly uncorrelated (Pearson, 2008b) which allows distinct patterns to be identified. The methodology involving interpretation of each project/product life-cycle associated with each customer/project profile (Pearson, 2010) therefore uncovers patterns in the data (e.g. underlying push and pull strategies) which may offer assistance for future decision policy.

Discussion on the sort of contractual arrangement entered into across appropriate decision frontiers assists in identifying appropriate associated efficient frontiers and enables the monitoring of the decision process. The adoption of a limited cooperation approach to value chain networks, therefore, has significant advantages. The main advantage is the likelihood of increased profit and efficiency while also maintaining customer satisfaction and loyalty (Pearson, 2006). The main disadvantage is the danger that knowledge acquired in a particular business will not be maintained within that business, but passed on instead to an operator further up (or down) the value chain. Sensitivity of knowledge and knowledge transfer may need careful consideration when maintaining relationships between retailers and logistics partners or intermediaries. Quantifying such things as customer goodwill and satisfaction, as well as improved profit and reduced costs and improvements from the employment of feedback mechanisms as well as the considerations outlined above would satisfy many of the requirements of modern value chain management as set out by Zairi et al. (2010).

5. CONCLUSION

The methodology which makes use of variability mapping, phase planes and decision frontier analysis has already been applied in the newsvendor problem and supply chain networks (Pearson, 2003, 2006, 2007, 2008a, 2008b, 2010). This new approach brings rigorous tools for measuring and monitoring coordinated project management between networked operators in both a local and global environment of uncertainty. The methods are especially applicable to value chain management where they can be employed to monitor progress in projects open to uncertainty leading to risk but also opportunity. The need to distinguish between risk and opportunity in a scientific way can lead to improved value chain management and auditing as well as better opportunity discernment. The methodology is currently being further developed in order to incorporate dynamic pricing with the ability to identify optimality due to price changes in the value chain incorporating variability mapping and phase plane analysis.

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APPENDIX A

Two-Echelon Proof: Changing Variability (Pearson, 2003). The primal-dual objective function makes use of the primal-dual transformation. We consider the mix variable, which is the difference between the dual (Q) and primal (D) variables. We define X=Q-D and forecast values $\hat{X} = \hat{Q} - \hat{D}$. We let σ_e be the standard deviation of $e = e_2 - e_1$, where e_1 and e_2 are the primal and dual forecasting error terms, respectively. Then $\hat{X} - X + k\sigma_e \sim N(k\sigma_e, \sigma_e{}^2)$, and $E(X) = \mu = \mu_2 - \mu_1$. e will have a univariate normal distribution with mean zero. A similar result follows for the global variable, η. The primal dual transformation is: $\mu = \mu_2 - \mu_1$ and $\eta = \mu_2 + \mu_1$, so that $\mu_1 = (\eta - \mu)/2$, $\mu_2 = (\eta + \mu)/2$, and $\partial\mu_1/\partial\mu = -1/2$, $\partial\mu_2/\partial\mu = +1/2$, $\partial\mu_1/\partial\eta = +1/2$ and $\partial\mu_2/\partial\eta = +1/2$. We are then able to find the maximum value of the objective function (1) subject to the constraint (2) by applying a Lagrange multiplier with decision variables μ, η and k. We have

$$L = \mu_1 c_p - \{(\phi(k) - k(1-\Phi(k)))c_p + (k\Phi(k) + \phi(k))(c_{o_1} + c_{u_2}) + (\phi(k) - k(1-\Phi(k)))(c_{u_1} + c_{o_2})\}\sigma_e - \lambda(\mu - k\sigma_e).$$

So that $\dfrac{\partial L}{\partial k} = -\sigma_e\{\Phi(k)(c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p) - (c_{u_1} + c_{o_2} + c_p)\} + \lambda\sigma_e = 0$,

and $\lambda = \Phi(k)(c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p) - (c_{u_1} + c_{o_2} + c_p)$. Also

$$\frac{\partial L}{\partial \mu} = -\frac{1}{2}c_p - \sigma_e^{\mu}\left\{(\phi(k) + k\Phi(k))(c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p) - k(c_{u_1} + c_{o_2} + c_p)\right\} - \lambda(1 - k\sigma_e^{\mu}) = 0,$$

Where $\sigma_e^{\mu} = \partial\sigma_e / \partial\mu$ so that

$$\lambda = -\frac{1}{2}c_p - \sigma_e^{\mu}[\phi(k)(c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p)] = \Phi(k)(c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p) - (c_{u_1} + c_{o_2} + c_p).$$

Equation (3) follows. Furthermore

$$\frac{\partial L}{\partial \eta} = \frac{1}{2}c_p - \sigma_e^{\eta}\left\{(\phi(k) + k\Phi(k))(c_{o_1} + c_{u_2} + c_{u_1} + c_{o_2} + c_p) - k(c_{u_1} + c_{o_2} + c_p)\right\} + \lambda k\sigma_e^{\eta} = 0,$$

where $\sigma_e^{\eta} = \partial\sigma_e / \partial\eta$, which leads to equation (4).

The Hessian determinant is negative definite for $\sigma_e^{\mu\mu}\sigma_e^{\eta\eta} - (\sigma_e^{\mu\eta})^2 > 0$. If there were no clear maximum, then the structure of the Hessian would need to be investigated. It could be that the profit increases without limit as the global output increases. This would happen if σ_e^{η} <0, for instance.

APPENDIX B

Equation of Isovalue Line (Pearson, 2003). This is derived by substituting the optimal values for the overage (o_v) and underage (u_n) into Eqn. 1:

E(Profit)

$$= \mu_1 c_p - \{(\phi(k) - k(1-\Phi(k)))c_p + (k\Phi(k) + \phi(k))(c_{o_1} + c_{u_2}) + (\phi(k) - k(1-\Phi(k)))(c_{u_1} + c_{o_2})\}\sigma_e$$

$$= \mu_1 c_p - \{(\phi(k) - k(1-\Phi(k)))(c_{u_1} + c_{o_2} + c_p) + (k\Phi(k) + \phi(k))(c_{o_1} + c_{u_2})\}\sigma_e$$

$$= \mu_1 c_p - \{(c_{u_1} + c_{o_2} + c_p)u_n + (c_{o_1} + c_{u_2})o_v\}$$

And so $\mu_1 c_p - E(profit) = \{(c_{u_1} + c_{o_2} + c_p)u_n + (c_{o_1} + c_{u_2})o_v\}$ (App B.1)

On the isovalue line the LHS of Equations (1) and (App B.1) are constant. Setting $k = +\infty$ in Eqn. (1),

$$\mu_1 c_p - E(\mathit{profit})$$
$$= \{(\phi(k) - k(1-\Phi(k)))c_p + (k\Phi(k) + \phi(k))(c_{o_1} + c_{u_2}) + (\phi(k) - k(1-\Phi(k)))(c_{u_1} + c_{o_2})\}\sigma_e$$
$$= k\sigma_e\{(\phi(k)/k - (1-\Phi(k)))c_p + (\Phi(k) + \phi(k)/k)(c_{o_1} + c_{u_2}) + (\phi(k)/k - (1-\Phi(k)))(c_{u_1} + c_{o_2})\}$$
$$= \mu\{(\phi(k)/k - (1-\Phi(k)))c_p + (\Phi(k) + \phi(k)/k)(c_{o_1} + c_{u_2}) + (\phi(k)/k - (1-\Phi(k)))(c_{u_1} + c_{o_2})\}$$
$$= \mu(c_{u_1} + c_{o_2}) \qquad \text{(App B.2)}$$

Equating the RHS of (App B.1) and (App B.2) gives $\mu = [o_v + ((c_{u_1} + c_{o_2} + c_p)/(c_{o_1} + c_{u_2}))u_n]$. The second result follows by setting $k = -\infty$ in Eqn. (1).

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