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Quantifying the effects of trust in supply chains during promotional periods.

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Abstract: Analytical modelling of supply chains has tended to focus on the material flows whilst neglecting the study of information dissemination through the supply chain. An important factor influencing these flows is the level of trust between supply chain partners. The dimensions of such trust are examined here and a brief review of research aimed at evaluating its importance in this area is undertaken. An optimal control model is then constructed to calculate the cost implications of the prevailing level of trust in a multi-echelon supply chain faced with satisfying a promotion for the end product. The mechanism by which both low and high levels of trust distort demand information as it is transmitted along the supply chain is investigated. A sensitivity analysis reveals that these results are essentially unaffected by the cost structures assumed. Lastly, two methods designed to compensate for low levels of trust are appraised.

QUANTIFYING THE EFFECTS OF TRUST IN SUPPLY CHAINS DURING PROMOTIONAL PERIODS

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1. INTRODUCTION

It is hardly controversial to say that close and amicable relations between supply chain partners tend to improve the performance of the whole supply chain. One facet of this relationship is the level of trust between echelons (businesses) in the chain. In this paper we investigate how differing levels of trust along a chain can affect its performance during a promotional period. During promotions human factors such as bias in information interpretation are of increased importance since information exchange is crucial to the success of the promotion. This investigation was prompted by The Authors' participation in the White Rose Faraday Project on the dynamics of supply chains in the packaging industry. Many participating Industrialists on the project are intuitively aware that greater levels of trust should lead to a better understanding of supply chain issues outside their own operational remit and encourage the dissemination of data normally considered commercially confidential. However, they are unsure of the scale of the potential rewards accruable and are thus unwilling to embark on perhaps unpalatable and time consuming efforts to enhance trust levels. This paper aims to quantify in simple terms the implications of various levels of trust and thus serve as evidence to spur the Industrialists to greater action in this area.

In the next section we decompose the term 'trust' into its most important facets with regard to supply chains. Our aim is to focus on the distortion various levels of (mis)trust have on information exchange. These issues are more acute during promotional periods when the potential for increased profits and losses (unsold stock) is higher.

Section three presents the tools we use to reproduce the rational behaviour of supply chain players. This behaviour is mimicked by a well known method from optimal control the details of which we omit since they can be found in any book on optimal control. In section four we simulate the dynamics of a two echelon supply chain and calculate the cost implications of various levels of trust between the echelons. We then conduct a sensitivity analysis which concludes that these implications are essentially unaffected by the cost assumptions of the model.

Section five then extends these techniques to a four echelon model and investigates how low trust between particular echelons can affect other echelons and the overall cost-effectiveness of the whole chain. We then investigate ways in which low trust can be compensated for through better monitoring of demand information and inventory levels. Section six concludes the paper with recommendations for supply chain practitioners.

2. TRUST IN SUPPLY CHAIN PARTNERSHIPS

Icasati-Johanson (1999) defines trust thus: 'In an exchange relationship, under conditions of risk and interdependence, trust is the belief that a voluntarily accepted duty will prevail ensuring that no party exploits the other's vulnerabilities.' The critical rôle of trust as both a facilitator of inter-firm relationships and a key source of competitive advantage has been highlighted by numerous authors (e.g. Anderson and Weizt, 1989; Dion et al., 1995; Mohr and Spekman, 1994). For instance, Anderson and Weitz (1989) have suggested that relationships enjoying greater levels of trust are more adaptable and will correct any inequalities between supply chain partners over the long term. Crosby et al. propose that trust acts as a deterrent to opportunistic behaviour, thus reducing the perception of risk. Nooteboom et al. (1997) observed that trust made transactions 'cheaper, more agreeable and more flexible' by reducing the need for tight specification and monitoring of contracts. Furthermore, trust in buyer-seller interactions influences satisfaction with profit distribution (Mohr and Spekman, 1994). Conversely, a lack of trust has been linked with partnering failure (Ellram, 1995).

Blois (1999) pointed out that one of the most obvious potential criticisms of trust research was that it treated the concept of trust as a blanket construct. Similarly, Icasati-Johanson (1999) highlighted the need for a multifaceted conceptualisation of trust, whose components may exist at different levels independently of one another. These include integrity, competence, consistency, loyalty and openness (Clark and Payne, 1997). Thus, whilst a buyer may be highly reliable in terms of paying the supplier on time, he may also display low competence at producing accurate forecasts. Moreover, the fact that a buyer behaves in a reliable manner is not necessarily indicative of loyalty or benevolence towards a supplier, although these two components of trust are often related (Icasati-Johanson, 1999).

The next section focuses on the important issue of competence as a component of trust. By modelling the dynamics of production policies for a supply chain we calculate the cost implications of certain levels of trust between the partners as measured by the ascribed accuracy of demand forecasts.

3. MODELLING THE DYNAMICS OF SUPPLY CHAINS

A supply chain is a system of business enterprises (echelons) which link together to satisfy a consumer demand. Supply chains are characterised by the forward flow of materials and goods and the backward flow of information. For many years (Forrester, 1961) supply chain practitioners have been aware of the merits of considering the effect of local policies on the overall supply chain performance. Research in this area has mainly consisted of constructing dynamic models of supply chains and simulating the aggregated flow of goods through them (Towill and Del Vecchio, 1994; Wikner et a.l, 1991). These models have shown how improved informational flows can smooth supply chain dynamics (Evans et al., 1994). However, they have not considered how information might be distorted as it is passed along the supply chain. We suggest that this analytical deficit results from the inability to model the recondite human relationships which form the basis of these information flows. Some work from the discipline of Operational Research as been done on the feedback of information in supply chains. For example, Chen (Chen, 1999) investigated the influence of information delays and demonstrated that it is important for the echelons away from the retailer to have accurate demand information. Lee et al. use a similar model to show how bilateral rather than multilateral information exchange can contribute to the demand amplification effect through progressive demand distortion (Lee et al., 1999). A similar conclusion is reached in (Chen et al., 2000). Our approach can be distinguished from those above in that it focuses on promotional periods when demand information might be valued more highly and simulates the actual dynamics of the supply chain, rather than calculating its summarised distributional attributes.

In this section we first construct a differential equation model of a production-inventory system. The purpose of this is strip away all the details and complexities of an echelon in a supply chain to yield its essential dynamic characteristics-the inventory level and production rate over time. In ignoring the detailed structure of the echelon we are essentially making the plausible assumption that the main variable costs borne by that echelon are connected to these two quantities. The resulting differential equations are therefore simple enough to be amenable to optimal control theory which we use to mimic rational and optimising production managers. The fundamental assumption of rational behaviour can be questioned (Sterman, 1989), but we simply observe that irrational behaviour would tend to degrade decision making whatever the level of trust and thus our results should be considered the best attainable. Furthermore, other authors have shown that rational and optimising behaviour can itself lead to sub-optimal supply chain performance (Lee et al., 1997).

Any model of a production-inventory system must be based on the inventory balance equation (1) which simply expresses the fundamental relationship: the rate of change of the inventory level is the difference between production and demand.

$$\frac{d}{dt}\left(i-\bar{i}\right)=p_c-d(t) \tag{1}$$

Here $i(t)$ is the inventory level, $\bar{i}$ is the desired safety stock level, $p_c(t)$ is the production completion rate and $d(t)$ is the demand rate all at time t. Equation (2) describes the production mechanism by linking the desired (planned) production rate $p_d(t)$ (the control variable) to the actual production rate, $p_c(t)$ by an exponential lag with parameter α, representing the manufacturing time delay, as in (Porter and Taylor, 1972) [towill].

$$\frac{dp_c}{dt}=\alpha\left(p_d-p_c\right) \tag{2}$$

Now suppose that a promotion for the end product is planned and the firm is given or itself generates a forecast $f(t)$ for the promotional demand during that period. Accordingly, production is scheduled to follow this extra demand over the promotional period of H weeks. We make the assumption that the planned production schedule is the same as predicted demand throughout the period. In reality economies of scale in production or a long production leadtime may warrant a different schedule favouring more production at the start (or before) the promotional period. This simplification is simply made to make the problem more transparent and avoid confusion. It does not have an impact on the results of the study since all the costs we are to consider stem from variations about desired levels (of inventory and production) rather than their absolute values. Further, we shall see in section 4 that the results are fairly insensitive to the particular cost structures assumed.

In the likely event that the promotional forecast is inaccurate the production manager is left with either a deficit or surfeit of stocks about a desired level $\bar{i}$. He must therefore make a decision whether or not to change the production schedule. We suppose that costs are incurred doing so and that these increase with the square of the magnitude of the variation. This is plausible since small variations might be accommodated by amending existing production runs. However larger alterations to the schedule may result in expensive downtime, increased setup costs, idle machines etc. We assume that the production manager makes the best decision between changing the schedule and incurring greater inventory costs. This can be simulated by using linear quadratic optimal control (Sage, 1968) through the minimisation of the following cost functional:

$$J = \underbrace{s_1\left[i(T)-\bar{i}(T)\right]^2 + \int_0^H q_1\left(i(s)-\bar{i}(s)\right)^2 ds}_{\text{Inventory cost}} + \underbrace{\int_0^H q_2\left(f(s)-p_c(s)\right)^2 ds}_{\text{Schedule alteration cost}} + \underbrace{\int_0^H r\left\{p_d(s)^2\right\}ds}_{\text{Control cost}} \tag{3}$$

Here, the constants q_2 penalises quadratic variations in the production rate $(p_c(t))$ about its scheduled level $(f(t))$. Similarly, the constants q_1 and s_1 penalise quadratic variations of the inventory level about the desired safety stock level throughout and at the end of the promotional period, respectively. A large inventory deficit may be interpreted as a stockout, depending on the desired safety stock level. Therefore the quadratic nature of this penalty is appropriate. The parameter which classically represents the control cost is chosen to be negligible compared to the other cost components. The solution of an appropriate matrix Riccati equation (Sage, 1968) generates an optimal production plan $(p_d(t))$ over the planning horizon $[0, H]$.

In dynamic representations of supply chains, production-inventory systems such as (1) and (2) are typically cascaded together (Wikner et al., 1991). The demands placed on lower echelons are assumed to be proportional to the production rate in the next higher echelon. So, for example, by appending an index to each quantity (except d) in (1) and (2), we arrive at (4), a model of an N echelon supply chain.

$$\begin{aligned}
\frac{d}{dt}\left(i^1-\bar{i}^1\right) &= p_c^1 - d(t), \frac{dp_c^1}{dt} = \alpha^1\left(p_d^1 - p_c^1\right)\\
\frac{d}{dt}\left(i^2-\bar{i}^2\right) &= p_c^2 - p_c^1, \frac{dp_c^2}{dt} = \alpha^2\left(p_d^2 - p_c^2\right)\\
&\vdots\\
\frac{d}{dt}\left(i^N-\bar{i}^N\right) &= p_c^N - p_c^{N-1}, \frac{dp_c^N}{dt} = \alpha^N\left(p_d^N - p_c^N\right)
\end{aligned} \tag{4}$$

The *ith* echelon may also optimise its production policy in response to a demand forecast $(f^i(t))$. Its cost structure is assumed to be of the same form as that in (3). We shall focus on the differences between the forecasts used by the echelons $(f^i(t)$ and $f^{i+1}(t))$. Suppose that the demand forecasts are passed along the supply chain between adjacent echelons. If each echelon trusted implicitly the accuracy of the forecast given to it, each production schedule in the chain would be identical. This is unlikely to be the case and so we propose to use the 'difference' between two adjacent forecasts as a measure of the trust one echelon has in the competence of the next higher echelon to produce an accurate forecast. This difference can be calculated in a variety of ways, the most general of which, is:

$$\begin{aligned}
T^{i,i+1} &= \exp\left(-\left\|f^i(t)-f^{i+1}(t)\right\|\right)\\
&= \exp\left[-\int_0^H \left|f^i(s)-f^{i+1}(s)\right|ds\right]
\end{aligned} \tag{5}$$

Here, $T^{i,i+1} \in (0,1]$ denotes the level of trust that echelon $i+1$ has in echelon i's forecast: When $T^{i,i+1} = 0$ there is no trust and when $T^{i,i+1} = 1$ there is perfect trust. In fact, the lower bound can be thought of as merely theoretical since it might be supposed that in the complete absence of trust no transaction would take place.

Example 1

We now demonstrate how the optimal control algorithm regulates production in a two echelon supply chain with the following parameterisation.

$$\alpha^1 = 0.9, q_1^1 = 5, s_1^1 = 5, q_2^2 = 5$$
$$\alpha^2 = 0.5, q_1^2 = 2.5, s_1^2 = 2.5, q_2^2 = 10.$$
$$r^1 = r^2 = 0.1$$
$$T^{1,2} = 0.6$$

In this and all following examples we assume that inventory costs increase as one approaches the retail end of the supply chain since each echelon adds value to the product. We also suppose that the cost of altering production schedules increases as we go downstream (away from the retailer) since economies of scale are usually more important at the raw material end of the supply chain and so production runs tend to be longer and more expensive to interrupt. Figure one shows the dynamics of the system for the two cases, when echelon one underestimates demand (case 1) and overestimates demand (case 2).

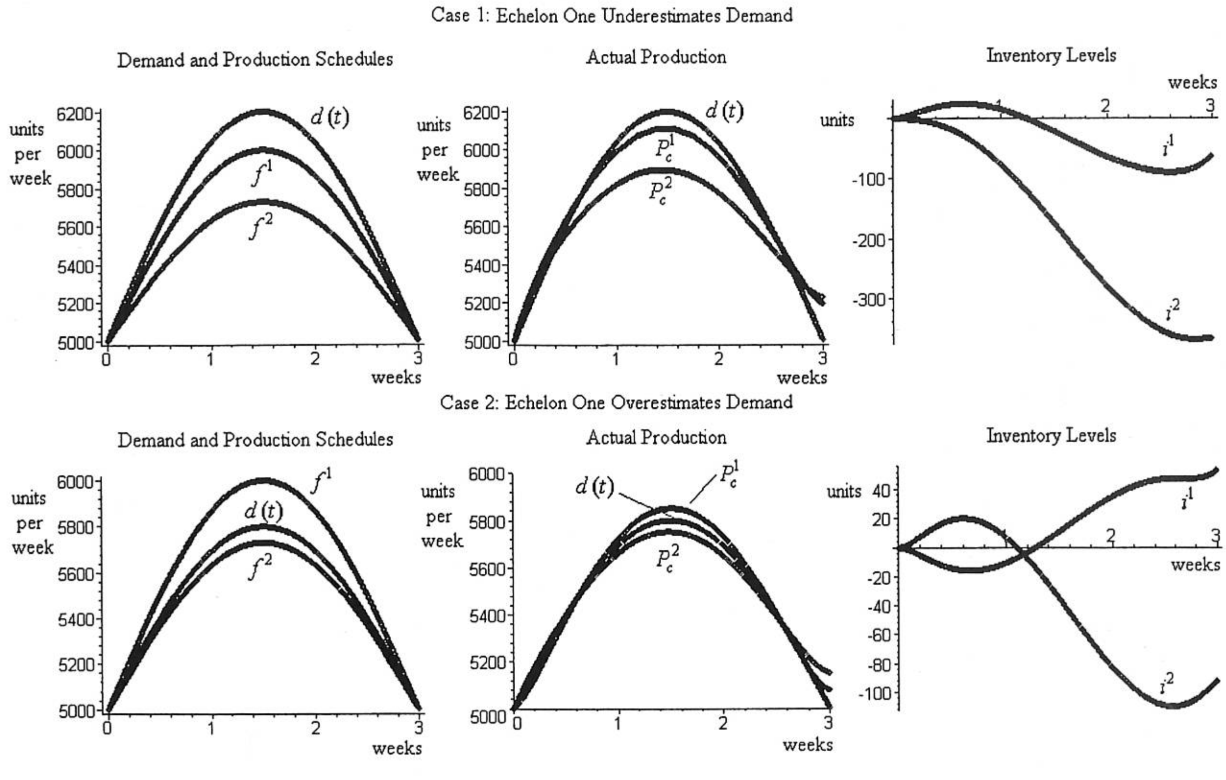

Figure 1. Dynamics of two echelon supply chain

The plots on the left show the demand patterns and production schedules in each echelon. For simplicity we assume the same qualitative shape for each although this analysis is entirely general for the case of differing shapes. The ratio of the peak value of the demand curve to that of f^1 and f^2 is 1.2:1:0.73 and 0.8:1:0.73 in the upper and lower sets of graphs respectively. This means that in each case the maximum forecast error is 20% and echelon two attributes a trust rating of 0.6 to echelon one's forecast. It is entirely possible that with this same level of trust, echelon two's maximum production schedule is $1/0.73 \rightarrow 37\%$ greater than echelon one's. However, in this and subsequent examples we implicitly assume that as one moves away from the retailer end of the supply chain echelons are more and more conservative since they do not want to be left with unsold promotional stock (which may be customised for the promotion and thus unsuited to later sale). So we assume that a given level of trust always decreases the magnitude of the forecast rather than the other way around. The middle graphs show the production rates for each echelon, which we assume were at the steady state value of 5000 units per week before the promotion. Lastly the right hand curves plot the inventory discrepancies about the desired level which, without loss of generality, we take to be zero.

In the first case echelon two is wrong to downgrade f^1 since demand is actually higher. This is why it suffers a large inventory discrepancy (360 units), possibly leading to stockouts (depending on the safety stock level). Conversely, in the second case echelon two is right to downgrade the inflated forecast given to it by echelon one and thus actual production almost exactly follows the production schedule thus incurring a much smaller inventory discrepancy.

4. TRUST AND SUPPLY CHAIN PERFORMANCE

In this section we investigate how variations in the level of trust between echelons affects the cost of the promotion- J in (3). We then carry out a sensitivity analysis on the model and show that the derived cost-trust relationship is relatively insensitive to the cost assumptions.

Figure 2 shows the results of varying the trust level between 0.3 and 1 for various cost structures.

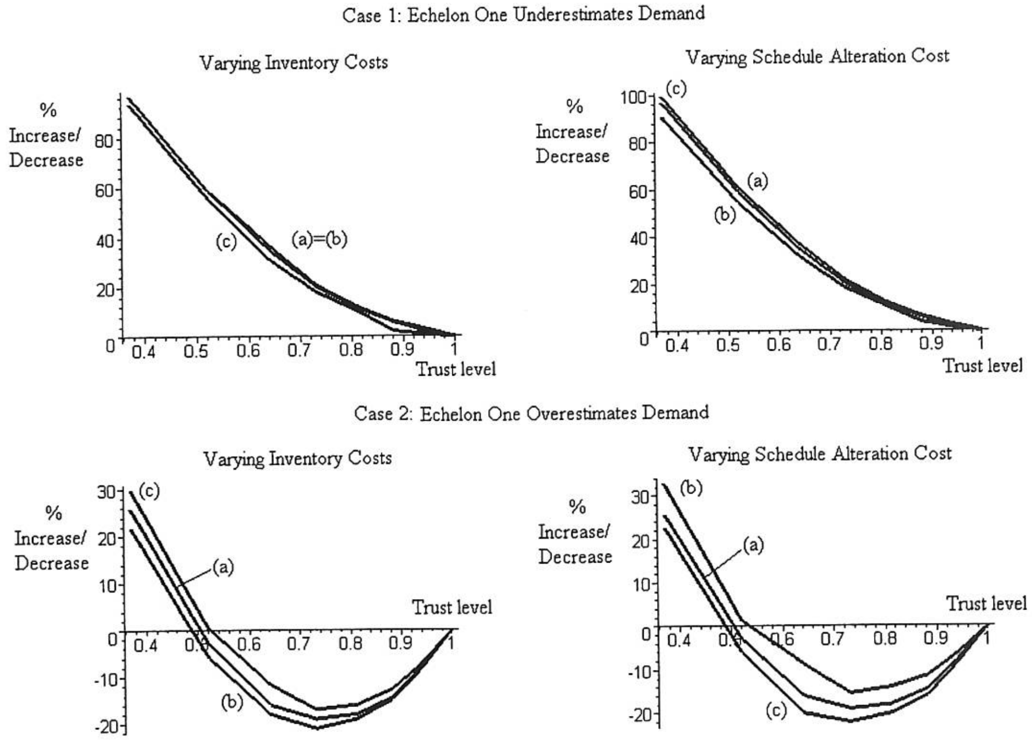

Figure 2. Cost – trust relationship in a two echelon supply chain

Each curve plots the increase/decrease in the total supply chain cost (echelon one + echelon two) as a percentage of the perfect trust (T=1) cost. Plot (a) shows the trust-cost relationship for the system with cost parameters as in example 1. Plots (b) and (c) show the same relationship with the nominated cost parameters doubled and halved, respectively. For example, in the bottom right hand graph (a) plots the trust-cost relationship for the same system as example 1, case two. Plots (b) and (c) plot the same relationship with $q_2^2 = 20$ and $q_2^2 = 5$, respectively.

In both case one and two we see that the trust-cost relationship is relatively unaffected by the particular assumed cost parameters. This is gratifying since it shows that the trust level is one of the dominant determinants of supply chain performance. Furthermore it means that results derived latter can be attributable to the trust characteristics rather than a quirk of the particular cost parameters chosen.

In case one low levels of trust increase the costs incurred by echelon 2 by increasing the discrepancy between the demand passed on to it by echelon 1 and the production schedule planned by echelon 2, thus leading to increased schedule alteration costs and larger inventory depletion than that shown in figure 1.

Case two is slightly more complicated since echelon two's distrust of the forecast given to it by echelon one is now well founded. Consequently its production schedule is closer to the actual demand passed on to it than is echelon one's, which incurs a large schedule alteration cost.

We conclude that during a promotion, if the echelon providing the demand forecast (usually the retailer) tends to underestimate demand then it is most cost effective for lower echelons to trust implicitly this forecast. Conversely, if he tends to overestimate demand then they would be better off being more circumspect and downgrading the accuracy of the forecast. Although these results are intuitively obvious, they are helpful in validating this approach in this simple case where the results can be predicted with a little thought. In the following, however, we simulate longer supply chains whose dynamics engender results which are not so intuitively accessible.

Example 2

Consider a four echelon supply chain with cost parameters as shown in Table 1 below.

Echelon	Time delay	Inventory cost	Schedule cost	Control cost
	α	$q_1 = s_1$	q_2	r
1	0.9	10	1	0.1
2	0.5	5	2.5	0.1
3	0.4	2.5	5	0.1
4	0.3	1	10	0.1

Consider a scenario in which there is perfect trust between each echelon and echelon 1 underestimates demand as in case 1, example 1. We propose to investigate the cost ramifications, for each echelon and the supply chain as a whole, of varying the trust level between isolated pairs of echelons. The purpose of this study is to gauge the importance of trust as one move down the supply chain. Figure 3 shows the cost variation (about the perfect cost scenario) for each echelon below that where the trust is being varied (C^2, C^3, C^4) and the total supply chain cost variation (C).

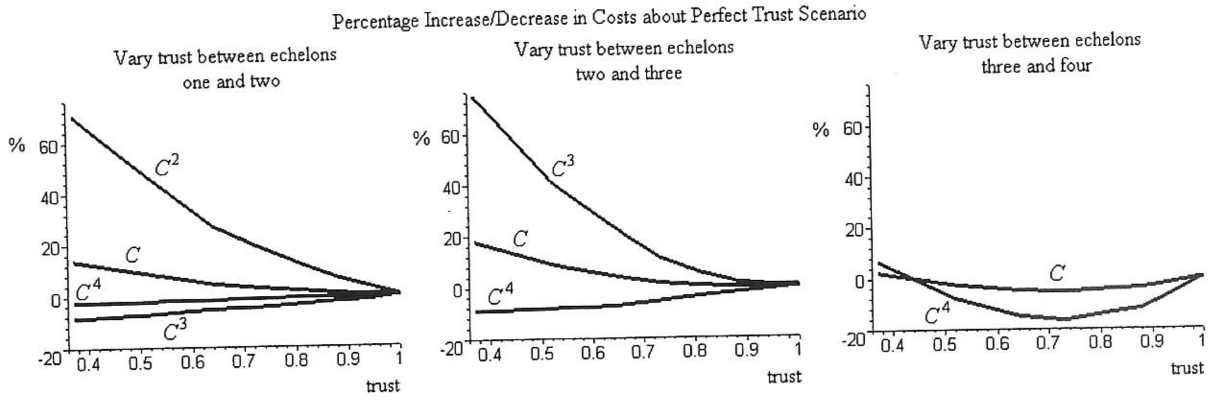

Figure 3. Varying trust down the supply chain.

A number of observations and conclusions can be drawn from these results: Firstly, the main cost of mistrust is borne by that echelon which mistrusts. Secondly, echelons lower down the supply chain may even benefit slightly from this mistrust (as shown in the left hand graph for echelons 3 and 4). The reason for this is that they receive the same forecast as that used by the echelon 2 and then schedule their production to follow it. However increased mistrust on the part of echelon two lowers its production schedule and consequently the actual demand transmitted to them by echelon 2 is lower and thus closer to this forecast. In effect, echelon 2 has incurred extra inventory depletion costs to the benefit of echelons 2 and 3. It should be noted, however that these benefits are small and greatly outweighed by the cost increases to the supply chain as a whole. The right hand graph shows that far down the supply chain, blind trust is not the best policy. The slight decrease in costs borne by echelon 4 at lower levels of trust can be explained thus: By the time the transmitted demand signal reaches echelon 4, it has been sufficiently distorted, even in this case of perfect trust elsewhere in the chain, to be quite different from the forecast given to it (which, in the case of perfect trust is the same as that used by all other echelons) and thus some costs are incurred to reconcile these two signals. It is intuitively obvious that as one proceeds along a supply chain away from the retailer a forecast must become less and less accurate and thus should be treated with increasing circumspection.

To conclude we make the following points:

- During a promotion, if the retailer tends to underestimate demand then it is most efficient for other echelons to trust implicitly his forecasts.
- On the other hand, if demand tends to be overestimated, it is better to treat the forecast with caution.
- Further along the supply chain these effects become less influential since demand distortion occurs along the chain even in the event of perfect trust. Thus trust is less important in echelons further down the supply chain.

5. COMPENSATING FOR MISTRUST

We have seen how mistrust can be costly for supply chains when the level of demand during a promotion is underestimated. Methods to compensate for this mistrust and mitigate this cost disadvantage should therefore be pursued. In this section we evaluate two intuitively attractive methods designed with this in mind. Consider again the standard four echelon supply chain featured in example two this time with the following trust characteristics:

$$T^{1,2} = 0.8, T^{2,3} = 0.7, T^{3,4} = 0.6$$

i.e. moderate levels of trust. We would like to find out if these levels of trust at the top of the chain can be compensated for lower down. It might be supposed that feeding back the demand forecast directly from echelon 1 to lower echelons would reduce costs by eliminating some of the demand distortion created by the lack of trust. Table 2 shows the results of doing so.

Policy	C^3	C^4	C
Feedback f^1 to echelon 3	-14.05	+20.1	+0.91
Feedback f^1 to echelon 4	-	+14	+3.71
Feedback f^1 to echelons 3 and 4	-14.05	+22	+1.41

Table 2. Percentage cost changes resulting from demand forecast feedback

As one can see overall cost savings are elusive using this method. The reason is that transmitted demand is not fed back in the same way as the forecasts. Mistrust at the start of the chain distorts the actual production of echelon 2 and thus the demand signal transmitted to echelon 3 and, in turn, echelon 4. But these latter are now planning to follow the original production plan of echelon 1 and thus the required schedule alterations or inventory discrepancies will increase.

However, we now show that the careful monitoring of inventory levels and transmitted demand can reduce the cost disadvantages shown above. Suppose that half way through the promotion each echelon reviews its production policy and noticing the discrepancy between forecast and actual demand and the concomitant increased inventory depletion, decides to switch its production schedule to the original forecast given to it. Table three show the cost savings of such an action. Figure 4 shows the resulting production rates and inventory levels of each echelon.

	C^1	C^2	C^3	C^4	C
Cost savings	73%	65%	58%	44%	55%

Table 3. Cost savings from late adoption of original demand forecast

One can see that without demand monitoring the cumulative effects of mistrust lead to large inventory discrepancies lower down the supply chain. These are reduced with demand monitoring since echelons 3 and 4 up their production to follow the original forecasts. It should be noted that this one-off rescheduling of production may itself have a cost implication which should be calculated before proceeding. The costs incurred by echelons 1 and 2 are also substantially reduced but their actual production rates look to be very similar to those without monitoring. The reason for the cost reduction is that before the difference between the scheduled production and actual production has been reduced by the one-off correction. In effect, what has happened is that better use of information in the supply chain has lead to an increase in trust between echelons. The action of monitoring production rates, demand and inventory levels has highlighted the error of discounting the forecast and this may, in future promotions, increase the prevailing trust in the supply chain.

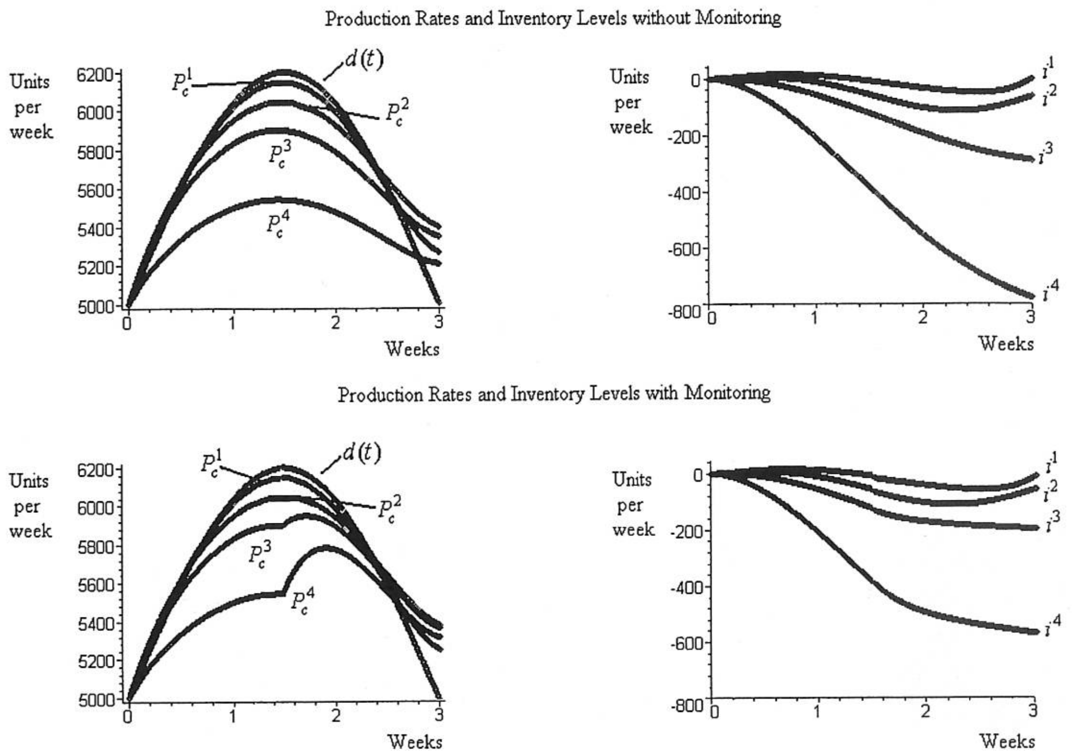

Figure 4. The dynamics of a 4 echelon supply chain with and without demand monitoring

6. CONCLUSIONS

This paper has shown how low levels of trust between supply chain partners can have cost implications for the whole supply chain. An optimal control tool was employed to mimic the rational actions of inventory managers and calculate the costs of various production strategies during a promotion. The credence given to demand forecast by echelons in the supply chain was used as a measure of trust between adjacent echelons.

In the event that actual demand is higher than anticipated, it was found that mistrust in the supply chain can increase costs considerably. However, when demand is overestimated it more efficient to treat the forecast with some caution. In longer supply chains the issue of trust becomes less important further away from the retailer since each echelon distorts the demand signal and thus forecasts become increasingly inadequate.

Two methods to compensate for low trust were investigated. It was found that feeding back the demand forecast to lower echelons did not produce cost benefits since the respective demand signals were distorted by the low trust between echelons. Monitoring production rates, demand and inventory levels with a view to amending production schedules during the promotional period secured cost savings for all echelons in the supply chain.

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