Proceedings of the 2012 Winter Simulation Conference
C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, eds.

AN EVALUATION OF AN OPTION CONTRACT IN SEMICONDUCTOR SUPPLY CHAINS

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ABSTRACT

The purpose of this paper is to evaluate an option contract within a semiconductor supply chain consisting of one semiconductor manufacturer and one customer. In an option contract the customer pays an upfront fee (option price) for an option to purchase product. A simulation model is used to compare the performance of an option contract against a standard supply contract used in a semiconductor supply chain in terms of delivery performance and costs for the supply chain partners.

1 INTRODUCTION

Extreme variability in capacity utilization is an established characteristic of the semiconductor industry. Important factors in this volatility are, at one level economic cycles leading to amplified fluctuations in end-product demand, at another the incessant progress in innovation and consequent shortening of product life cycles to the degree that they are measured in months. Also mass customization of end-products resulting in highly variable day-to-day fluctuations in the demand for individual products. Consequently, semiconductor manufacturing customers request and expect high levels of order flexibility and short order lead-times to align with changing market demands and contexts. This creates major challenges for semiconductor manufacturers due to substantially longer physical production cycle times when compared to the requested order lead times.

Sharing of forecast information between buyer and seller is necessary in this industry, but it alone is not sufficient to manage effectively this demand volatility. Game-playing is common: customers inflate their demand forecasts to ensure the semiconductor manufacturer builds enough capacity, while the manufacturer plans conservatively to avoid overcapacity and to stay cost competitive. This behavior can result in tight supply and allocation difficulties for the manufacturer, and also downtime and lost revenue for customers.

The use of options in supply chains is gaining increased attention: the customer pays an upfront fee (option price) for an option to purchase a product, which gives the customer the right but not the obligation to execute and therefore buy the product. Options contracts are claimed in the literature to enhance supply chain flexibility through exercising the right to change order quantities. Upfront payments compensate supply-side manufacturers for costs where a customer does not exercise its option to buy. Options are generally tied to a contract and cannot be traded between supply chain members. This kind of option is called “nested option” (Wang and Zhang 2011).

The research question that arises from this discussion is as follows: Are options contracts a useful addition to improving performance of a semiconductor supply chain? In this paper we report on an evaluation of a nested option contract in a semiconductor supply chain consisting of one semiconductor manufacturer and one customer, in an environment of highly variable constant demand.

The structure of the paper is as follows. In section 2, the literature on option contracts is reviewed. Section 3, presents a description of the simulation models used in the experimentation. Results are presented in section 4, and section 5 concludes with a discussion and suggestions for further work.

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2 LITERATURE REVIEW

Supply chain contracts in general are reviewed comprehensively by Cachon (2003) and Lariviere (1999) with focus on which contract design achieves supply chain coordination. Cachon (2003) provide a complete study of prices and volumes for different contract types and, among others, the quantity flexibility contract is analysed under conditions which coordinate a supply chain. Donohue (2000) models a manufacturer's supply-side flexibility in a two-stage supply chain by giving the supplier two production modes, normal and fast. The fast mode allows the customer to order additional parts to take advantage of updated demand forecasts. The objective is efficient conditions for channel coordination. The performance measure is total profit. Cachon and Lariviere (2001) model flexibility through options in a two-stage buyer-supplier contract where the buyer makes a firm commitment and buys additional options with the supplier installing capacity accordingly. After demand is realized, the buyer has the right to exercise their options. The contract is studied under forced and voluntary compliance regimes and the performance is measured for individual supply chain participants and the whole supply chain. .

Cheng, Ettl, Lin, and Yao (2002)'s variant of an option contract focuses on the optimal order decision of the buyer and the optimal pricing decision of the supplier. Barnes-Schuster, Bassok, and Anupindi (2002) use options to find a better order distribution along the periods of contract validity in a two-stage two-period supply chain under correlated demand. Again, the customer initially places firm orders for two periods and buys additional options; after observing demand in the first period, the buyer can increase from their initial demand quantity for the second period by exercising their options. Their performance focus is cost: before and during the first period, the supplier produces at a regular cost, and from the beginning of the second period but after the options are exercised, the supplier produces at an extra cost. Options are shown to improve channel performance, and an appropriate price for channel coordination is derived. van Delft and Vial (2004) provide an extended implementation of this model using stochastic programming including numerical performance estimation from various contractual parameters like costs and revenue.

Erkoc and Wu (2005) model capacity reservation contracts with deductible reservation fees and exogenous wholesale prices: the customer buys capacity reservations and pays the reservation fee offered by the supplier who then decides how much capacity to build. After demand uncertainty is resolved in time, the customer exercises all or part of the reserved capacity. Within this context, the authors investigate individual rationality and channel coordination. They also consider different compliance regimes and partial information updates. The supply chain profit is a function of the wholesale price the supplier's production costs and the capacity level. The authors stated that the supply chain profit of a capacity reservation contract with a fully deductible reservation fee is suboptimal unless the customer's reservation quantity is equal to the supplier's capacity.

In a single-period, two-stage supply chain, Wang and Tsao (2006) introduce a bidirectional option contract: the buyer has the possibility to adjust the initial order both downwards and upwards. If the buyer exercises his options as call options, then he pays a unit exercise price for each exercised option whereas he can get back a corresponding full or partial refund if he exercises the options as put options. Outcomes were evaluated from the buyers' perspective and optimal policies were developed for the buyer. Wang and Liu (2007) develop an option-based contract model to study channel coordination and risk sharing in a decentralized retailer-led supply chain: the option contract has an option price and exercise price, and the retailer has to pay the option price for each unit reserved above the initial order quantity, and for each called option the retailer has to pay the exercise price. They found that two conditions are necessary for a successful coordination: firstly to maintain a negative correlation between exercise price and option price, and secondly that the firm commitment must be lower than the optimal production quantity of a corresponding centralized system. Under these conditions they conclude that the option-based contract model performs better in terms of profit than the traditional price-only contract model.

Gomez-Padilla and Mishina (2009) study an option contract in a two-stage retail supply chain with one retailer and either one or multiple suppliers. The suppliers and retailer's benefits are measured by their own revenues diminished by their individual costs. The authors showed that an option contract in a supply chain consists of one retailer and one supplier will increase the benefit for all supply chain partners as well as for the chain. Variation in demand is modeled as exogenous.

Knoblich, Ehm, Heavey, and Williams (2011) study contracts with Rolling Horizontal Flexibility (RHF) and cancellation clauses, which are commonly found in the semiconductor sector, among other sectors. They report that in practice, a key component of variation causing concern to practitioners lies in the form of forecast error, rather than exogenous demand variation alone. The analysis in Knoblich, Ehm, Heavey, and Williams (2011) is extended here to include option contracts. The analysis presented here differs substantially from Gomez-Padilla and Mishina (2009)'s model in that forecast error is explicitly modeled.

3 MODEL DESCRIPTION

This paper evaluates an options contract in a semiconductor supply chain against a typically used contract (denoted the standard contract) used in this sector. The standard contracts operates as follows (see Section 3.1):

1. The *Buyer* forecasts demand L_c periods before the delivery date. This forecast is subject to a forecast error;
2. Based on this forecast the *Seller* reserves capacity;
3. The standard contract contains two operational clauses: RHF clause and a cancellation clause.

The options contract operates as follows (see Section 3.2):

1. The *Buyer* forecasts demand L_c periods before the delivery date. This forecast is subject to a forecast error;
2. The *Buyer* purchases options based on this forecast for delivery window o;
3. Based on these options the *Seller* reserves production capacity;
4. The *Buyer* can exercise his options with full flexibility within the delivery window o;
5. The *Seller* makes available in the spot market any non-exercised options;
6. If the *Buyer* cannot satisfy demand through exercising his options, product can be purchased from the spot market.

The buyer's forecast is modeled using a gamma distribution. The standard gamma is a continuous distribution with two parameters that provide good control of the shape of the distribution. The reasons for choosing this distribution are that it is positively skewed and allows high values of coefficient of variation. The density function of the gamma distribution is generated according to the following formula:

$$f(x) = \frac{\beta^{-\alpha} x^{\alpha-1} e^{-\frac{x}{\beta}}}{\Gamma(\alpha)}$$

with the mean μ and the variance σ of the Γ distribution given by $\mu = \alpha\beta$ and $\sigma^2 = \alpha\beta^2$ with the shape parameter α and the inverse scale parameter β.

Forecast error is modeled using a normal distribution with mean value μ and variance σ^2. A mean of $\mu = 0$ is used to model an unbiased buyer or a shifted normal ($\mu \neq 0$) for a buyer that over or under forecasts. To illustrate further, Figure 1 plots forecast error for a sample run from the simulation model against a data from a real buyer. This buyer is unbiased in forecasting in that the buyer equally over and under estimates forecasts.

3.1 Standard Model

In the standard contract model, the buyer provides his weekly rolling demand forecast for time period T, L_c periods before the first scheduled delivery date DD in planning period T. The supplier will source

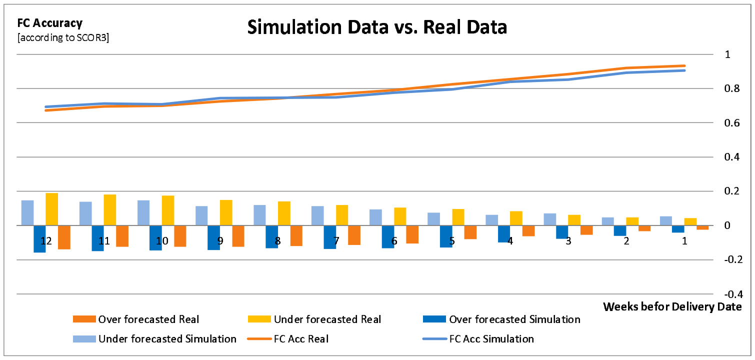

Figure 1: Demand signal compared against real data.

capacity accordingly to the buyer's demand forecast in order to meet the monthly aggregated demand for period T. The standard contract used in this paper consists of two supply chain operational contract clauses. The RHF clause gives the buyer the right to change his initial demand forecast quantity within the rolling horizon flexibility boundaries. This clause can be expressed as follows:

$$(1-y_{tj}^{L})D_j^{t-1} \leq D_j^t \leq (1+y_{tj}^{U})D_j^{t-1} \text{ when } t \leq j$$
$$D_t^t = D_t \text{ otherwise}$$

where D_j^t is the buyers demanded quantity for period j forecasted in period t. y_{tj}^{L} and y_{tj}^{U} are the lower and upper flexibility bounds for period j at period t. This equation gives the customer the right to adjust his demand according to his latest demand information until $t = j$. When $t = j$, the demand is the final requested demand and is indicated as $D_t^t = D_t$. The second clause relates to cancellation. Specifically, the buyer can cancel his forecasted demand by a percentage p within a specified time period, defined as $[i_a^p, i_b^p]$ over T, where i_a^p, i_b^p define the start and the end of the period where p percentage of an order can be canceled without penalty. For the experiments presented in this paper, the parameters p for the cancellation clauses is set to 0. This is justified as the cancellation clause only extends the lower flexibility boundary. the same effect can be achieved by decreasing the lower flexibility boundary. All customer orders which are below the lower boundary, can be viewed as cancellations for which the customer has to pay a cancellation fee of 100% of the product price.

3.2 Options Model

In the option contract model, the buyer decides how much options $D(j)$ he wants to buy for the delivery window o, L_c periods before the first scheduled delivery date DD in delivery window o. The supplier will reserve capacity equal to the amount of options purchased in order to meet aggregated demand for delivery window o. For each option the customer has to pay the option price p_o and for each exercised option the exercise price p_e. If the customer does not exercise all purchased options for a certain delivery window o, the option price serves as a compensation fee for the seller who will incur production cost for these options. The non exercised options are transferred to the spot market. In the case where the buyer's demand exceed his options, he can buy additional products on the spot market for price p_s assuming that the spot market has available products.

When $p_e = 0$, p_o can be seen as the "wholesaler" price and the contract between customer and supplier as a fixed commitment contract. When $p_o = 0$, which is the case for the standard contract, the contract can be seen as wholesaler contract with a non binding forecast. When $p_e > 0$ and $p_o > 0$ the contract can be thought as an option contract with an option price of p_o and an execution price of p_e. In the experiments described in this paper the option price is set at one third the standard product price (p_{std})

where $p_{std} = p_o + p_e$. The spot price includes the standard product price p_{std} plus the average price decline p_d and average inventory costs, i, per period t, with $p_s = p_{std} + p_d + i$.

4 SIMULATION RESULTS

The method of supply chain modeling is widely used to analyze what outcomes would be from a given set of supply chain operating conditions. Simulation modeling has developed this process and the use of discrete event has given economical insight into the expectations of the supply chain performance when simulating different operational conditions. The development of the presented discrete event simulation model is based on two main models. The first model, which is stochastic, models the customer demand signal which is subject to a forecast error and the second (deterministic) models the flexibility commitments of the contracts. The objective of the experimentation is to compare a typical contract (denoted the standard contact) against an option contract in a supply chain that representative of a semiconductor supply chain where there is not only the uncertainty of exogenous demand but also forecast errors which as documented in Knoblich, Ehm, Heavey, and Williams (2011) are extremely high in this sector.

The performance measures used in the experimentations are the delivery performance (DP), the delivery reliability (DR) and the supply chain profit (see Equation 3). DP is a volume weighted demand fulfillment measurement which compares the customers final requested demand, D_t, with the quantity of delivered products (Billings), B (see Equation 1). DR is the comparison of the order stipulated in the contract , D_c, with the quantity of delivered products (Billings), B, i..e, in the case of the RHF clause if $D_c \geq y^U_{t-1,t}$ then $D^l_c = y^U_{t-1,t}$ (see Equation 2).

$$DP = \frac{\sum |D_t - B|}{\sum D_t + B} \tag{1}$$

$$DR = \frac{\sum |D_c - B|}{\sum D_c + B} \tag{2}$$

$$Supply\,Chain\,Profit = Billings - (Costs_{Seller} + Costs_{Buyer}) \tag{3}$$

Before presenting a results comparing an option contract with a standard contract, results that explore the performance of the option contract as a function of the delivery window, o, and forecast error are given.

4.1 Option Model: Delivery Window and Forecast Error

For the options contract, different delivery window lengths were considered across different categories of forecast errors: neutral, under-forecasting and over-forecasting. The simulated delivery window lengths evaluated are $o = \{1, ..., 13\}$. Forecast error is modeled using the normal distribution, as described in Section 3, with $\sigma = 20$.

Figure 2 (left hand side) presents results showing the forecast accuracy, and the performance of the option contract measured using billings, B, and delivery performance, DP. The delivery reliability is not considered due to the fact that the full amount of pieces, for which the buyer purchased options, are preproduced by the supplier. Therefore a delivery reliability, DR of 100% is assumed. Figure 2 (right hand side) presents results where the normal distributed used to model forecast error has a shifted mean of 0.75. This represents where the buyer has a tendency to under forecasting, i.e. $D^t_{j-1} < D^t_j$. First, in both cases DP decreases as o increases. It is not obvious why this is the case, however, it could be the result of the greater granularity of option allocation with lower values of o. In Figure 2 for both cases Billings (Contract) increase as o increase. This probable results from the fact that as o increases the buyer has greater flexibility, due to a larger delivery window, i to exercise purchased options. The results also show that the Billings (Contract) are greater for the under forecasting ($\mu = 0.75$) customer and Billings (Spot) are lower than for the neutral ($\mu = 0$) forecasting buyer. This is because a buyer that under forecasts will have more options to exercise than what will be required.

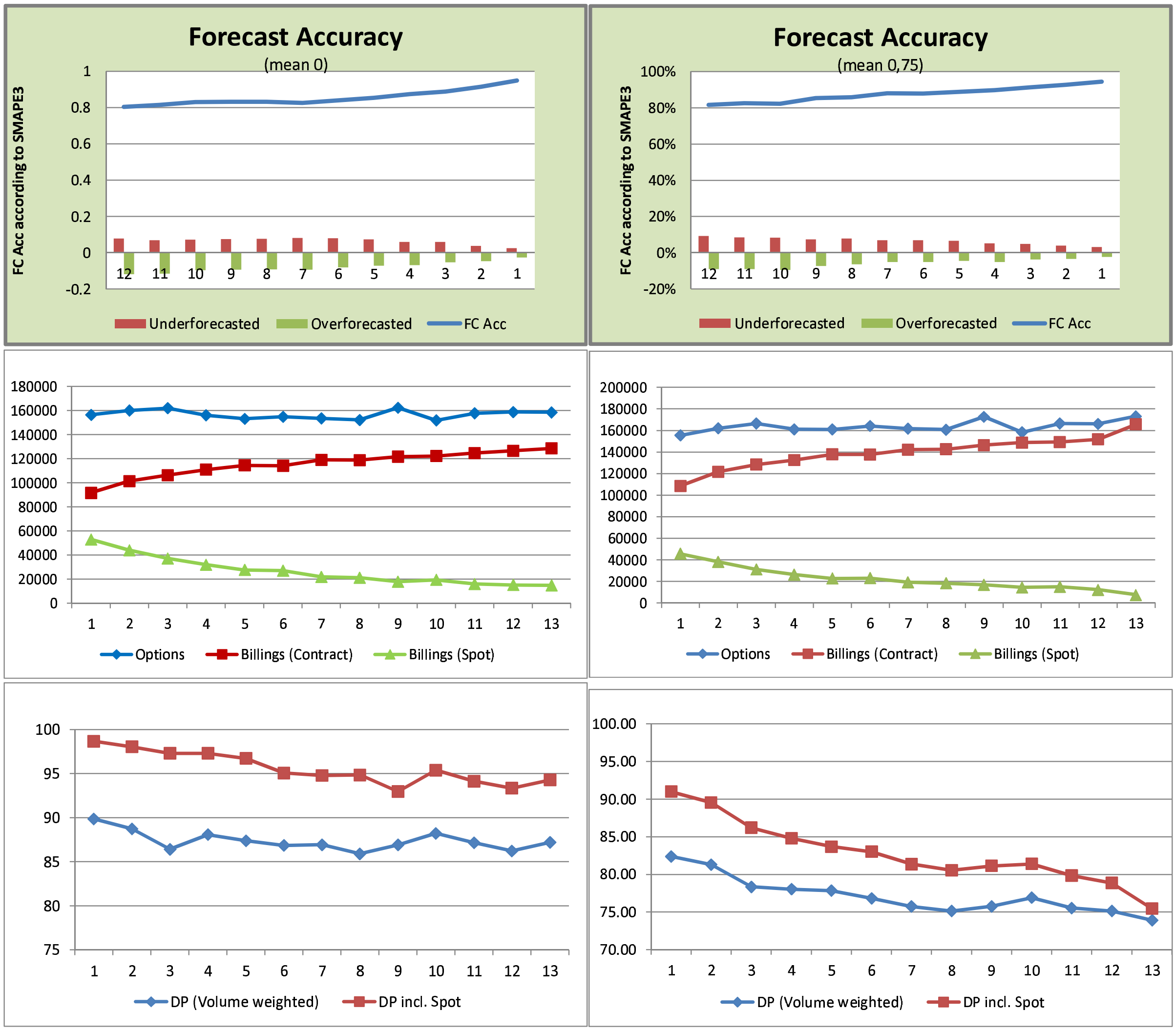

Figure 2: Results for $o = \{1, \ldots, 13\}$ for a neutral forecasting buyer (left side) and under forecasting buyer (right hand side).

Figure 3 shows the forecast error with $\mu = -0.75$ (left hand side) and $\mu = -1.5$ which results in over forecasting ($D^t_{j-1} > D^t_j$). First, in both cases DP increases as o increases. This can be explained by the greater flexibility of option allocation in terms of delivery date and the fact that the over planed options assure that the supplier builds more than sufficient capacity and therefore generates available supply on the spot market. The results also show that the Billings (Contract) are greater for lower over planning ($\mu = -0.75$) customer and Billings (Spot) are higher than for the higher ($\mu = -1.5$) over forecasting buyer.

Comparing Figures 2 and 3 it can be seen that DP is higher for the over forecasting cases. This is explained by the fact that over forecasting is based on a negative forecast error which means that the buyer is reducing his initial forecast quantity over the planning horizon. This behavior leads to over planed forecasts ($D^t_{j-1} > D^t_j$), which results in over production on the suppliers side and therefore assure the

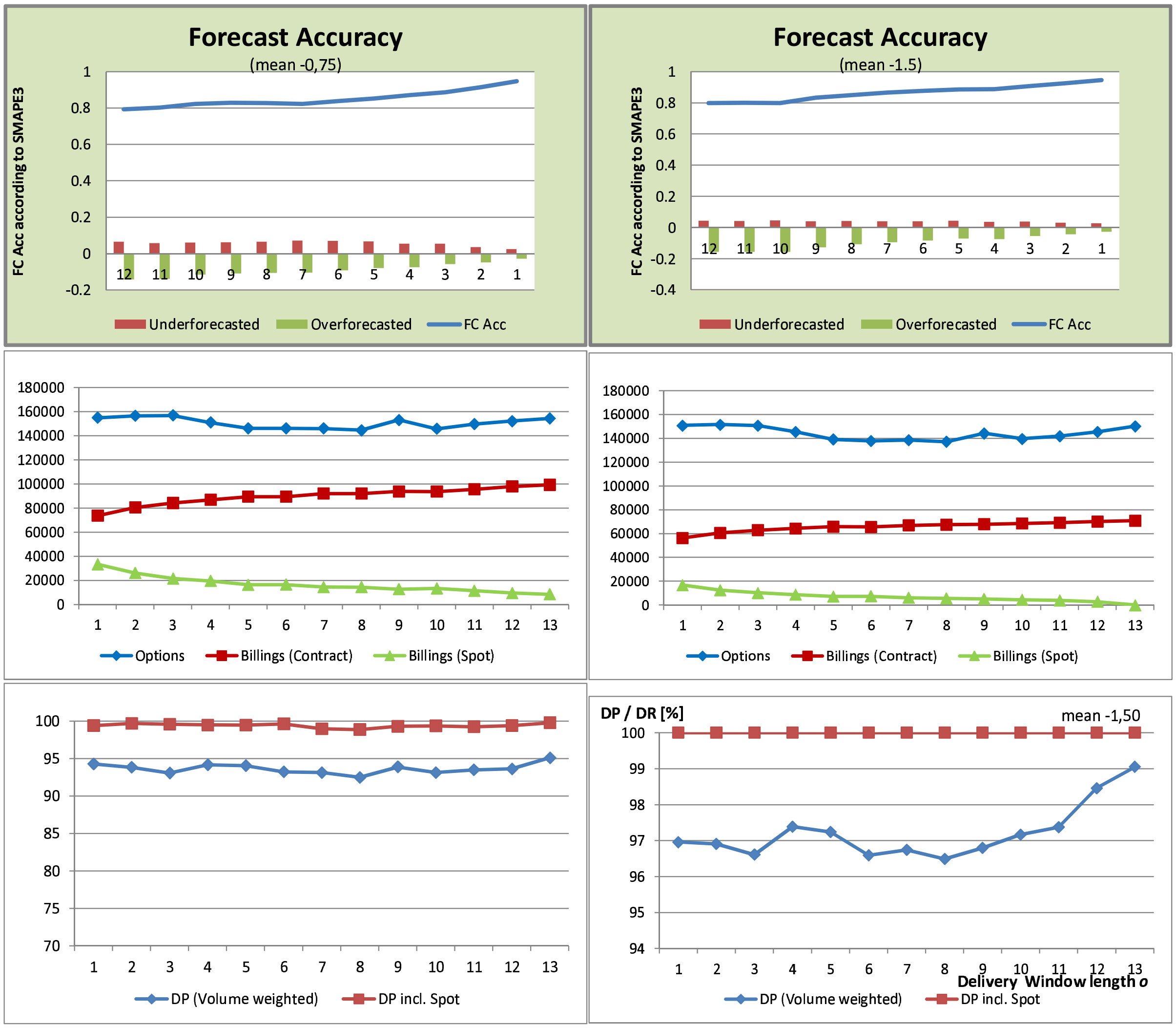

Figure 3: Results for $o = \{1, \ldots, 13\}$ for two categories of over forecasting buyers (left hand side ($\mu = -0.75$)) and (right hand side ($\mu = -1.5$).

buyer high product availability on the contract as well as on the spot market. Therefore a high DP on the contract market is achieved and a even higher DP by considering the spot market too. In the case of under forecasting, the buyer increases his initial forecast quantity over the planning horizon ($D^t_{j-1} < D^t_j$) and exercise therefore all his options before the end of each delivery window, which leads to a decreasing DP as o increases . The buyer purchases additional products on the spot market for the remaining time of the delivery window in order to fulfill his market requests. This explains the fact, that for the under forecasting cases ($\mu > 0$) compared to over forecasting cases ($\mu < 0$) more options are exercised and therefore more billings on contract and spot market are generated.

4.2 Evaluation of Option Contract

This section further evaluates an option contract by comparing it with a standard contract typically used in semiconductor supply chains. The performance of the standard contract with a RHF clause is highly dependent on the upper and lower flexibility bounds (y^U_{jt}, y^L_{jt}) used (Walsh, Williams, and Heavey 2008).

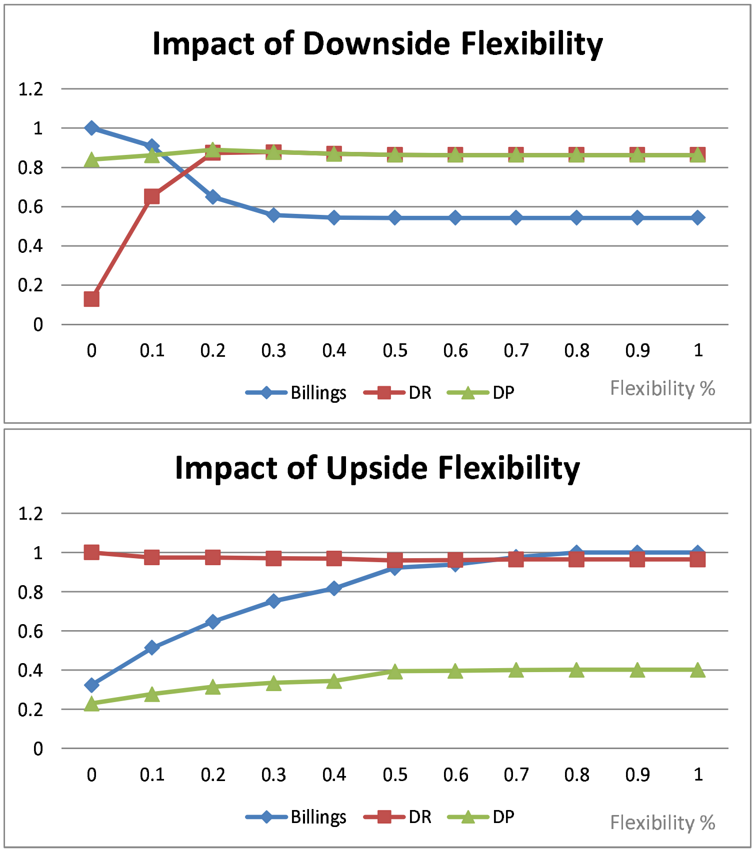

Figure 4: Impact of Downside and Upside Flexibility on Delivery Performance (DP), Delivery Reliability (DR), and Billings.

Therefore results on experiments to establish the most appropriate values for (y_{jt}^U, y_{jt}^L) are presented to facilitate a fair comparison of the standard contract with the option contract.

The simulated upside and downside flexibility rates were y_{jt}^U and y_{jt}^L are equal to $\{0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$. First a contract with unlimited upside flexibility and different downside flexibilities was simulated. Then a contract with unlimited downside flexibility and different upside flexibilities was evaluated. Figure 4 shows that the DP increases within growing downside flexibility boundary, whereas the DR remains quite constant. This is explained by the fact that within no-downside flexibility, the customer has no possibility to adjust their demand downward and therefore on average receives more pieces than actually ordered. For this experiments the following upside and downside flexibility boundaries were used:

$$(y_{jt}^U = 0.5, y_{jt}^L = 0.15) \text{ when } j-4 \leq t \leq j$$
$$(y_{jt}^U = unlimited, y_{jt}^L = 0.15) \text{ when } j-8 \leq t \leq j-5$$
$$(y_{jt}^U = unlimited, y_{jt}^L = 0.15) \text{ when } j-16 \leq t \leq j-9$$

In comparing the contracts, standard and option, both were simulated with the same demand signal parameters, which are β=50 and β=20 for the gamma distribution and a sigma of 20 for the normal distribution in order to generate the forecast error. A neutral forecast error $\mu = 0$ was used. . The option price (p_o) is 1/3 of the product price (p_{std}). The spot market price (p_s) is 133% of the product price. This is made up of a price decline at 23% of the product price, plus an allowance of 10% of the product price for additional fees to cover aspects like spot market administration, inventory management and so forth,

Table 1: Comparison of options contract with standard contract.

			Options Contract					
		Standard Contract	$o = 2$	$o = 4$	$o = 6$	$o = 8$	$o = 10$	$o = 12$
Maximal DP		89,56	98,05	97,31	95,08	94,84	95,41	93,34
average Billings		94264	145712	142874	141339	140152	141756	141,867
Customer costs	Cancellation fees	720	–	–	–	–	–	–
	unused option fees	–	17580	13554	12190	10073	8850	9665
	costs on spot market	–	14,565	10561	8955	7041	6430	5003
Supplier costs	Inventory costs	56	609	542	596	613	588	597
SC Profit		93488	112958	118217	119598	122425	131675	126602
Profit compared to Standard contract			17,24%	20,92%	21,83%	23,64%	29,00%	26,16%

i.e. the price charged on spot market is 33% above the basic product price. Cancellation fees are 100% of the product price.

Results comparing an option contract, with different delivery windows, and a standard contract are shown in table1. Results are presented showing the Maximal DP attained, the average billings, (B), customer costs, supplier costs and the overall supply chain profit. These preliminary results show that the option contract to increase profits for the supply chain as a whole, whilst improving the supply chains service delivery. Table 1 shows that there is a trade-off between profit and supply chain service when selecting the delivery window. Costs on spot market are the surcharge on the product price which the customer has to pay on the spot market.

5 CONCLUSIONS

This paper evaluated the use of option contracts in semiconductor supply chains, supply chains, that as well as experiencing volatile demand due to exogenous demand also have high forecast errors. Past work was reviewed on option contacts used in supply chains. Then simulation models, consisting of one buyer and one seller, were presented to model a standard contract typically used in semiconductor supply chains and an option contract. For the option contract, different delivery window lengths were considered with the used demand signal affected by a forecast error with differently biased buyers (under planning, over planning). Preliminary results evaluating the standard contract against the option contract was presented. These results show that the option contract shows the potential to increase the overall profit of the supply chain whilst substantially improving supply chain service delivery. However, further more detailed experimentation analysis is required to fully understand the potential of option contracts in semiconductor supply chains.

By a simulation approach it was possible to see that an option contract will increase the profit for the chain and the delivery performance for an unbiased customer demand signal.

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