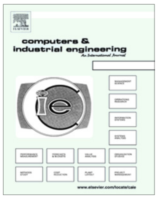
Computers & Industrial Engineering 87 (2015) 394–406

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie



Quantitative analysis of semiconductor supply chain contracts with order flexibility under demand uncertainty: A case study

Konstanze Knoblich [a],*, Cathal Heavey [b], Peter Williams [b]

[a] Infineon Technologies AG, Am Campeon 1-12, Neubiberg, 85579, Germany
[b] Enterprise Research Centre, University of Limerick, Limerick, Ireland

ARTICLE INFO

Article history:
Received 9 December 2014
Received in revised form 30 April 2015
Accepted 3 May 2015
Available online 29 May 2015

Keywords:
Supply chain management
Supply chain contracts
Forecast error
Semiconductor industry

ABSTRACT

The evidence base for the configuration of rolling horizon flexibility (RHF) contracts (a type of quantity flexibility contract) used in the semiconductor industry to coordinate production and demand remains meagre, more art than science. Informed by the characteristics of actual clauses and demand behaviors drawn from a company's experience, a discrete-event simulation model is developed to represent the company's supply chain. It comprises of three parties: a customer, a supplier (semiconductor manufacturer), and a capacity provider. Through analysis of customer forecasted demand the paper characterizes forecast demand as being under, over or unbiased. Models of these forecasted demands drives both long and short term planning. In long term planning, which is given twelve months before an order is delivered, capacity at the capacity provider is booked. Short term planning is also driven by this forecast which, within a binding period, is governed by an RHF contract. Results from the model report inventory levels, and delivery compliance, namely Delivery Performance (DP) and Delivery Reliability (DR), measures widely used in this sector. It is concluded from this work that on the balance of performance measures RHF contracts with asymmetrical flexibility bounds are substantially better than those with symmetrical boundaries, and that this conclusion is robust with regard to both over-planning and under-planning behaviors. This robustness is a critical attribute with respect to the endemic medium-term vacillation between both states experienced in practice in this sector.

1. Introduction

The semiconductor industry is one of the most productive but alsoone of the most volatile industries (Tan & Mathews, 2010). The permanent progress in innovation, reduction of the product life cycle time and growing competition from Asia raise a lot of challenges for this advanced technology industry, especially with regard to responding to uncertain emergent demand realization. To stay competitive semiconductor manufacturers must provide their customers with a high level of order flexibility in order to support them in adapting to their emergent markets, such as is manifested in economic up and down turns at medium and long-term levels. The lead-time from firm order commitment to actual delivery adds to the complexity of responding, and this is dependent on the degree of customization of the product,being in practice a constant within a product class and with a strict regime of compliance. Rolling-horizon flexibility (RHF) contracts are seen as a means to coordinate demand and supply under such conditions, whereby early indications of anticipated future demands are transmitted from customer to manufacturer, providing some forewarning to facilitate the planning of capacity and material supply commitments.

The supply chain modeled consists of three parties: a customer, a supplier (semiconductor manufacturer), and a capacity provider. The paper first studies and characterizes customer demand received by the supplier into three types of forecasted demand: over-planning, under-planning or unbiased forecasted demand. The paper proposes an approach to model these three types of forecasted demand, with this approach validated against customers within the case study company. Under the contract, customers send order forecasts twelve months in advance to support long term capacity planning, which is used to purchase capacity from the capacity provider. The capacity provider is assumed to have infinite capacity to be mobilized as capacity is booked twelve months prior to delivery of the order, an assumption used within the case study company. To support short term planning, the supplier provides the customer with the flexibility to adjust order quantities within the order lead time and within a binding period

---

* Corresponding author.
E-mail addresses: konstanze.knoblich@infineon.com (K. Knoblich), cathal.heavey@ul.ie (C. Heavey), peter.williams@ul.ie (P. Williams).

http://dx.doi.org/10.1016/j.cie.2015.05.004

customer demand is governed using a RHF contract. Within the binding period in the RHF contract the quantity flexibility clause defines the upper and lower boundaries (in percentages) within which the customer is allowed to update their forecasted demand quantity, as per Tsay (1995), Lee, Padmanabhan, and Whang (1997) and Wang and Tsao (2006).

The motivation for this paper is to evaluate the RHF contract to understand better how to set the quantity flexibility clauses in order to minimize inventory and maximize Delivery Performance (DP) and Delivery Reliability (DR), performance measures used by the supplier.

The remainder of the article is organized as follows. Section 2 provides an overview of relevant literature. Section 3 presents in more detail the case study company, focusing on supply chain contract clauses and forecast accuracy, which gives the industrial context to this work. Section 4 presents the simulation model used in this paper with Section 5 presenting results. Finally, conclusions and future research are presented.

2. Literature review

A supply chain contract is a coordination mechanism in decentralized supply chains to motivate the supply chain partners to behave like an integrated supply chain and to benefit therefore from improved operational performance (Wang, 2002). Supply chain contracts have been studied extensively in the context of conventional supply chains.

However, there are several unique characteristics that make semiconductor supply chains differ from supply chains generally studied within the literature: semiconductor supply chains have long cycle times; they are capital intensive with long investment cycles; to keep unit cost low, utilization of capital equipment needs to be very high; products must be moved with a high velocity performance and low flow factors; products tend to have short product life-cycles, especially with greater application-specificity and higher variety product families; demand is highly volatile as Original Equipment Manufacturer (OEM) customers adapt to emergent demand, and forecasting can have low accuracy especially due to heavy over and under planning bias (Katircioglu & Gallego, 2011).

Supply chain contracts in general are reviewed comprehensively by Cachon (2003) and Lariviere (1999) with focus on specifying contract design parameters to achieve better supply chain coordination under different circumstances. Cachon (2003) provides a comprehensive study of prices and volumes for different contract types and, among others, the quantity flexibility contract is analyzed under conditions which coordinate a supply chain.

A detailed analysis of quantity flexibility contracts is carried out by Tsay (1999), who propose the quantity flexibility contract as a method for material and information flow coordination in a supply chain with rolling horizon planning. They investigate the incentives for which a customer and seller would participate in a quantity flexibility contract, that is, would a customer be willing to commit to a certain order quantity for a lower price, and would the seller derive benefits from certainty of sales.

Bassok and Anupindi (2008) analyzed an open loop feedback control based heuristic algorithm for the contract and demonstrated that the order process variability decreases significantly as flexibility is decreased. They also provide insights on deciding how much flexibility is sufficient from a customer's perspective and how it effects customer satisfaction. They suggest that for tighter flexibility bounds, the seller could give a discount.

Walsh, Williams, and Heavey (2008) simulated two types of a RHF contracts. They modeled a supply chain consisting of an Original Equipment Manufacturer (OEM) and a contract manufacturer (CM). One contract type had constant flexibility boundaries and the other had decreasing flexibility boundaries over the contract horizon. They concluded that measured by fill rate, bullwhip effect and inventory level, both contracts have favorable performance outcomes for both the OEM and the CM parties. Regarding the design parameters of the quantity flexibility contract, the upper and the lower boundaries of the flexibility profile were assumed stationary and symmetric (in percentages), following Bassok and Anupindi (2008).

Wang (2008) added delivery lead-time flexibility to order quantity flexibility, and concluded that lead time flexibility allows the customer to improve their service level and reduce their shortage cost when the penalty cost per shortage is relatively high. Furthermore they note that service level should be maintained at least at a certain level to keep customers loyal.

Kim (2011) analyzed a quantity flexibility contract between a customer and a supplier, and demonstrated the supplier's trade-off between the customer service level and the inventory risk. Whereas for the customer, the benefit keeps increasing and then remains constant as the flexibility rate increases. In general the author stated that in a decentralized system, the quantity flexibility contract can provide an effective coordination mechanism for the supply chain.

The notion of flexibility on order lead time is extended in various ways. For example, Das and Abdel-Malek (2003) propose a model with a minimum delivery lead time for the supplier to ship orders. When the customer requests a faster delivery, then a price penalty is imposed. In Wang (2008)'s model a regular lead time is set at 7 days, and an option is included to change a regular order into a "hot" order so as to reduce the lead time at an extra cost. Chan and Chan (2006) studied the relationship between flexibility in both delivery quantity and due date and outcomes in terms of cost fill rate. The flexibility range of delivery due dates is determined through a coordination mechanism between supplier and retailer.

The focus of this work is on the order flexibility in terms of quantity and in the context of different customer forecast demand behavior (unbiased, over and under planning) and production and delivery lead times. This work is not intended to derive optimal ordering and inventory policies given that the implementation of the contract for optimal policies associated with quantity flexibility would be extremely complex and unattractive for implementation (Bassok & Anupindi, 2008). In the model we use production and delivery lead times as observed in the case study company which depends on the product type.

While in Kim (2011), the customer demand signal was modeled as a stochastic process without any bias,experience recorded in the case company indicates substantial periods of demand signal bias with over- and under-ordering. Thusin the present work the demand signal is subject to forecast error,which is explicitly modeled with an over or under planning bias to reflect reality. The simulation experiments in this article use a stochastic process to generate initial customer demand, according to Walsh (2009) but extends this by an additional stochastic process for the weekly demand forecast updates in order to model forecast error more explicitly. This is achieved by modeling forecast variability changes over the forecasted horizon, where the forecast error decreases as the delivery date approaches, in order to simulate realistic customer demand behaviors received by the supplier (i.e. case study company).

Cyclicity is a constant concern in the semiconductor industry sector, especially at a periodicity above individual contract duration: Tan and Mathews (2010) (Fig. 5) through a fourier analysis show that there is a dominant repetitiveness period in the order of 0.5 cycles per year with significant shorter cyclics. They note that this industry is characterized by more volatility than most