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Horizontal coordinating contracts in the semiconductor industry

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ABSTRACT

Integrated device manufacturers (IDMs) and foundries are two types of manufacturers in the semiconductor industry. IDMs integrate both design and manufacturing functions whereas foundries solely focus on manufacturing. Since foundries often have cost advantage over IDMs due to their specialization and economies of scale, IDMs have incentives to source from foundries for the purpose of avoiding excessive capacity investment risk. As the IDM is also a potential capacity source, the IDM and foundry are in a horizontal setting rather than a purely vertical setting. In the absence of sophisticated contracts, the benchmark contract for the IDM and foundry is a wholesale price contract. We define "coordinating" contracts as those that improve both the IDM's and foundry's expected profits over the benchmark wholesale price contract and also lead to the maximum system profit. This paper examines if there exist coordinating capacity reservation contracts. It is found that wholesale price contracts in the horizontal setting cannot achieve the maximum system profit due to either double marginalization effect, or "misalignment of capacity-usage-priority". In contrast, if the IDM's capacity investment risk is not too low, there always exist coordinating capacity reservation contracts. Furthermore, under coordinating contracts, the IDM's sourcing structure, either sole sourcing from the foundry or dual sourcing, is contingent on the firms' cost structures.

1. Introduction

The cost of establishing a semiconductor fabrication plant (commonly called as wafer fab or fab; see for instance, Geng, Jiang, & Chen, 2009) is extremely high, and equipment technology becomes obsolete quickly as new technologies and demanding product requirements emerge. Therefore, the fabs have to be highly utilized in order to pay back the capital expenditure in a timely manner. In the semiconductor industry, there are three types of firms. Integrated device manufacturers (IDMs) both design and manufacture semiconductor devices. Fabless firms design semiconductor devices, but do not possess any fab. Foundries concentrate only on manufacturing and take orders from IDMs and/or fabless firms.

On the demand side, the customers of such firms are themselves established firms that produce products such as cell phones, personal computers, and automobiles, among others. To gain orders from these customers, the semiconductor manufacturers (i.e., IDMs or foundries) need to be cost-effective, responsive, and flexible in accommodating highly fluctuating and uncertain order quantities. Because of this hard-to-match supply and demand situation, only a small number of IDMs and foundries – typically the larger ones in terms of capacity, such as Intel (IDM), Samsung (IDM) and TSMC (foundry) – are consistently profitable. The rest fare less well on their own and are in need of horizontal coordination to justify the needed investment to reach a competitive level of economies of scale and flexibility. It was estimated that in 2009, IDMs like Texas Instruments, Freescale Semiconductor, STMicroelectronics, and Renesas Electronics outsourced their production to foundries at percentages of 55%, 23%, 20%, and 10–20%, respectively (IC Insights, 2011).

Due to the significant lead times required to add capacity, capacity decisions and related investment outlays are made well ahead of actual demand. Once the capacity is installed, the rest of the production activities are conducted in a make-to-order fashion. When an IDM and a foundry interact in a decentralized fashion, from the IDM's perspective, it is important to secure enough capacity internally and/or externally to meet uncertain demand without incurring excessive costs. Since only the IDM

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has access to the end market, the foundry has to work with the IDM in order to be profitable. On the other hand, the foundry is concerned about over-committing capacity. The IDM has to offer the foundry incentives to induce sufficient capacity commitment.

In the absence of sophisticated contracts, the benchmark contract for the IDM and foundry is a wholesale price contract. In the vertical supply chain setting, a wholesale price contract cannot coordinate the supply chain due to the well known double marginalization effect (Spengler, 1950). The IDM and foundry are not in a vertical supply chain relationship, because the IDM himself can produce the product in addition to the option of sourcing the product from the foundry. Thus, the IDM and foundry are in a horizontal setting. This paper identifies new features of wholesale price contracts in the horizontal setting compared with the vertical setting, and investigates whether wholesale price contracts can achieve the *maximum system profit* (i.e., the maximum sum of the IDM's and foundry's expected profits).

A prevailing type of contract used in the semiconductor industry is capacity reservation contract. According to the structure of reservation contracts, the IDM reserves capacity R from the foundry by paying a reservation fee per unit. The reservation fee is refundable, which means the IDM pays to the foundry a wholesale price deducted by the reservation fee for a unit of product when the purchasing quantity is less than R. When $R = 0$, the IDM always pays the wholesale price. That is, the pathological case of $R = 0$ in reservation contracts involves a single contract parameter, "wholesale price", and is actually a wholesale price contract in the horizontal setting. Hereafter, we refer to wholesale price contracts in the horizontal setting as zero reservation contracts (*ZRCs*). We emphasize two differences between *ZRCs* and traditional wholesale price contracts in the vertical setting. First, under *ZRCs*, the foundry may or may not build capacity, even in some cases with the wholesale price exceeding her cost. That is, even though the IDM is willing to pay the wholesale price, there may be no available supply from the foundry. In contrast, in traditional wholesale price contracts, the buyer can always buy whatever quantity he needs from the supplier for a reasonable wholesale price (e.g., a price that exceeds the supplier's cost). Second, under *ZRCs*, the IDM may himself be a source of supply in addition to the foundry. But under traditional wholesale price contracts in the vertical setting, the buyer solely relies on the supplier. Due to these nuances of wholesale price contracts in the horizontal setting, we refer to them as "*ZRCs*".

We refer to reservation contracts with positive capacity reservation ($R > 0$) as positive reservation contracts (*PRCs*). A *PRC* is coordinating if it satisfies the following three conditions.

(1) *Capacity investment coordination*: The resulting capacity investments are the same as in the centralized system that maximizes the system profit.
(2) *Production coordination*: The production decisions (i.e., the demand allocation decisions) are consistent with those in the centralized system.
(3) *Individual rationality*: The resulting IDM's and foundry's expected profits are both greater than what they can earn under the benchmark wholesale price contract.

Conditions (1) and (2) are required to achieve the maximum system profit. Condition (3) guarantees that the contract is individually rational for both the IDM and foundry. We refer to coordinating *PRCs*, if they exist, as *CPRCs*.

In our paper, we pursue answers to the following questions: (1) What are the centralized capacity investments of the IDM and foundry that maximize the system profit? What are the main factors affecting such capacity investments? (2) Can *ZRCs* maximize the system profit? If not, are the underlying reason(s) the same as in the vertical setting? (3) Under what circumstances do *CPRCs* exist? What is the resulting sourcing structure for the IDM? The answers to these questions will offer us a better understanding of the distinctions between horizontal capacity coordination and traditional vertical supply chain coordination.

This paper is organized as follows. Section 2 reviews the relevant literature. Section 3 introduces the model assumptions and notation. Section 4 derives the centralized capacity investments. Sections 5 and 6 study *ZRCs* and *PRCs*, respectively, to investigate their roles in achieving the maximum system profit when the IDM and foundry interact in a decentralized scheme, and check if there exist *CPRCs*. Section 7 compares the firms' expected profits under *PRCs* with those under *ZRCs* and illustrates the impact of profit margin. Section 8 provides concluding remarks.

2. Literature review

Vertical supply chain coordination has received substantial attention in the operations literature. Various forms of contracts are proposed to align supply chain partners' decisions with those of the centralized system. Among these are buy-back (Pasternack, 1985), revenue-sharing (Cachon & Lariviere, 2005), quantity-flexibility (Tsay, 1999), and sales-rebate contracts (Taylor, 2002). Cachon (2003, Ch. 6) provides a comprehensive review of this literature before 2002. More recently, Tomlin (2003) studies a vertical supply chain with a supplier selling a key component to the manufacturer who processes the component into end product. Tomlin (2003) proves the existence of a class of price-only contracts that arbitrarily allocate the supply chain profit between the supplier and manufacturer. Chick, Mamani, and Simchi-Levi (2008) show that cost-sharing contract can coordinate the vertical influenza vaccine supply chain with yield uncertainty. In contrast to the above papers, we emphasize *horizontal* capacity coordination between an IDM and a foundry using capacity reservation contracts. There are dual capacity sources in meeting end-demand (both the foundry and IDM may build capacity for the *end* product), but without direct access to the market, the foundry serves as a subcontractor to the IDM.

Reservation contracts have been studied as part of vertical supply chain coordination in Erkoc and Wu (2005) and Jin and Wu (2007). Wu, Erkoc, and Karabuk (2005) provide an excellent survey of the reservation contracts literature. Erkoc and Wu (2005) propose two variants of capacity reservation contracts: partially deductible reservation contract whose reservation fee is partially deducted if the reserved capacity from the supplier is used, and cost-sharing contract for which the buyer pays a portion of the capacity cost associated with her reservation. Jin and Wu (2007) consider deductible and take-or-pay reservation contracts for vertical supply chain coordination, and extend the model from one customer to two or more customers. Brown and Lee (1998) study "pay-to-delay" capacity reservation contracts and derive optimal policies for the buyer in the semiconductor industry. Our paper differs from the above work in that the buyer (IDM) decides not only how much capacity to reserve from the supplier (foundry), but also how much of his own capacity to build, thus injecting horizontal coordination concerns.

Another stream of literature combines reservation contracts and the spot market, such as Serel, Dada, and Moskowitz (2001), Wu, Kleindorfer, and Zhang (2002), Spinler, Huchzermeier, and Kleindorfer (2003), Wu and Kleindorfer (2005), Spinler and Huchzermeier (2006), Fu, Lee, and Teo (2010), and Inderfurth, Kelle, and Kleber (2013). In these papers, a buyer can reserve capacity from a supplier in addition to buying from the spot market. In our paper, the IDM can reserve capacity from the foundry in addition to his own capacity if built upfront. However, the supply