Supply Chain Design and the Cash Cycle Effect

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Abstract

A model of competition between the two elemental supply chain strategies, Make-To-Order (MTO) and Make-To-Forecast (MTF), is developed assuming an environment of falling real input prices as is the case in the all-important personal computer industry. It is established that an MTO producer may realize a sustainable advantage in a competitive market of MTF producers provided a) input prices are not increasing on average at a high rate, hence MTO does not gain from the cash-cycle effect, b) consumers trade off favorably the consumption delay and higher production cost associated with MTO production against high product variety resulting from customizability and c) MTO market share does not exceed a critical level. There is little research on supply contracts for semiconductor-like products that face a long term negative price trend. We utilize a general descriptive model of semiconductor contract price and investigate the effect of supply contracts on MTO–MTF competition during periods of normal volatility and after supply disruption.

Classification: Production, Manufacturing, and Logistics

Keywords: Supply Chain Managemenent, Risk Management, Make to order, Make to forecast, Personal Computer Supply Chain.

1 Introduction

Supply Chain (SC) design can have a crucial impact in company performance both during normal operation and after major supply disruptions. We examine a strategic supply chain design choice, selecting the method for satisfying customer demand. In particular, we differentiate between two elemental strategies, Make-To-Forecast (MTF) and Make-To-Order (MTO). Under the MTF strategy production takes place in batches of large size, capitalizing on economies of scale in manufacturing, procurement, and delivery. Finished goods have to be inventoried and immediately delivered as orders arrive. As demand is unknown when choosing production volume, the risk of supply not matching demand is always present. By contrast, according to the MTO strategy production takes place only after a customer (or a downstream operation) requests a final (or intermediate) product.

Fisher (1997) has explained why the objective of supply chain management is not just cost-effective production and logistics, but also efficient hedging against demand uncertainty. His analysis suggests that cost efficient supply chain designs like MTF are better suited to stable demand patterns that lead to few forecast errors. Furthermore, market responsive strategies, like MTO, are better suited to unpredictable demand patterns. Cachon and Terwiesch (2003) observe that MTO avoids completely supply / demand mismatch costs which are inevitable for MTF. Mismatch costs increase with demand unpredictability and the cost of unrealized demand. Importantly, PC producers realize the bulk of their profits from innovative products that have both the aforementioned characteristics.

MTO has been researched as a mass customization strategy, because it can achieve the low costs of mass production and the high product variety of custom made goods. Not all mass-customized products, however, require MTO production. Gilmore and Pine's (1997) adaptive strategy, for example selling mass-produced chairs that can adjust with levers in many dimensions, achieves mass customization but does not eliminate supply / demand mismatch costs. Zipkin (2001) compares mass customization to mass production and observes three customization disadvantages: a) configuration elicitation cost, b) excess production cost, and c) product delivery delay that leads to inferior customer service quality. All of these factors are incorporated in our model as they apply to MTO production, but we focus mainly in elicitation cost which is assumed to increase with sales volume (market share). The other two factors are not as pronounced in the PC industry, our focus in this paper. Delivery delay is not as salient in the mind of many PC consumers, in particular businesses buying PCs. And, PC design being modular, production costs do not increase exorbitantly with customization.

Many mass customization strategies can be successfully implemented by following the principle of delayed differentiation, as advanced by Lee and Billington (1995) and Feitzinger and Lee (1997). Product variety increases and production costs are low if final product configuration occurs at the very last link in the supply chain before consumption. Swaminathan and Tayour (1998) describe how this strategy can be implemented by mass producing plain vanilla boxes that take their final form when combined with in-stock components according to customer demand. Delayed differentiation will be considered a MTF strategy if it does not eliminate supply / demand mismatch costs. Interestingly, if applied to PC production it would face a cash-cycle disadvantage when the plain vanilla box has high semiconductor content.

Figure 1 depicts the production flow diagrams of MTO and MTF producers juxtaposed, clarifying the fundamental difference between the two approaches. According to the MTF system the cash-to-cash cycle, starting when cash outflows required for production begin and ending when cash returns to the producer after product sale, is positive. By contrast, as can be seen in Figure 1, MTO cash-to-cash cycle is negative. One can also speak of "negative" inventories under the MTO system, given that they are financed by customers. Importantly, the MTO system may or may not utilize just-in-time deliveries. For instance in the PC industry, finished good delivery does not occur as soon as possible. Prevailing market standards and not a firm sales contract determine PC delivery leadtime.

Curry and Kenney (1999) estimate that most of Dell Computer Corporation's deliveries take place about three weeks after a customer places an order, while component purchase, production, and transportation take less than one week. Compare this to MTF practice in the PC industry where inventory turn periods are long, due to manufacturing lot sizes being large. Curry and Kenney (1999) report a 4 to 6 week inventory turn period for MTF PC producers. Hence, when a PC sale occurs MTF production inputs have been bought about a

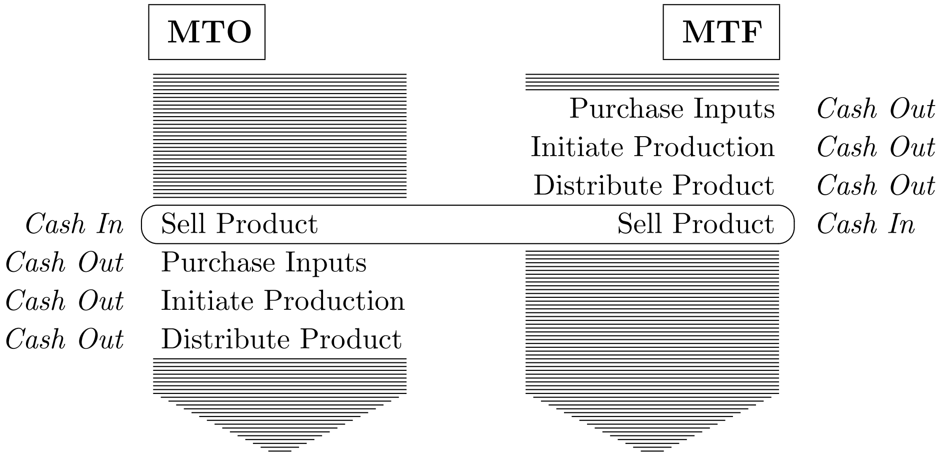

Figure 1: Juxtaposed Production Flow Diagrams. MTO cash cycle (to the left) is negative, MTF cash cycle (to the right) is positive.

month in advance, whereas MTO inputs are about to be bought. As a result, the downward trend in component prices translates to a cost advantage for MTO producers, the cash cycle effect.

The PC industry is a rare testbed for supply chain theories. Contrary to the norm of companies in the same industry, leading PC producers follow radically different supply chain policies, placing them in direct competition. Moreover, most producers do not offer differentiated products (Apple Inc. is recognized as the rare exception). Hence, production cost, operations strategy, and supply chain design become the leading drivers of company performance. In fact, the two leading producers today Dell and HP-Compaq have similar name recognition and market share but vary mainly on supply chain design strategy. We model competition of supply chains by following assumptions that are representative of the PC industry environment and operation. This choice leads to a loss of generality in our model on the one hand, but on the other to insights on competition when supply chain strategy is the most important source of comparative advantage. Typically, supply chain and operations strategy is but a component of business strategy, the effect of which is hard to separate outside the interdependent bundle that includes marketing, financial, and human resources strategies, as well as relations to the business environment and research-and-development.

In most industries and under normal operation, supply chains need to mediate between volatile supply and volatile demand. Thus, managing supply and demand risk is an integral part of supply chain management procedures. In the PC industry input price volatility is characterized by relatively smooth changes, due to contracts with suppliers in US dollars (absence of foreign exchange risk). In contrast, severe supply disruptions come as consequence of extreme and rare events and fall outside the usual pattern of price variation. Unpredictability makes them difficult to manage without carefully laid out business continuity plans. Examples of such events include severe weather, natural disasters, terrorist acts, or political instability that disrupts international commerce. These events even though most efficiently addressed using emergency response plans well thought out in advance, sometimes come so abruptly that can only be dealt with by means of improvisation.

Consider two important recent examples of severe supply disruptions. First, examine the effect a natural disaster in an area with high concentration in semiconductor manufacturing had to PC producers. Papadakis and Ziemba (2001) report that after the 1999 earthquake in Taiwan an immediate increase in global computer memory (DRAM) prices followed, with the spot price of this major PC component going up five times in one week and the contract price (what major producers pay) by an extraordinary 25% in a week. Importantly, this sudden input price increase affected the stock price of MTO producers, while MTF producers were left unscathed.

Next look into a terrorist act induced disruption to international commerce and cross-country supply chains. Andrea and Smith (2002) cite significant disruptions and prolonged idling in MTO (just-in-time) automotive factories operating in Michigan after the terrorist attacks on September 11, 2001 in the US and the ensued closing of the US-Canada border. Many automotive factories in Michigan have Canadian suppliers which make daily deliveries to keep their just-in-time supply chains with no stock-outs and minimal inventories. During the closing of the borders that followed September 11 and the subsequent period of prolonged customs delays, factories had to shut down on both sides of the border.

From the two previous examples it is clear that MTO supply chains face two important disruption risks, which MTF supply chains are by their design not as exposed to. First, as price tends to be fixed at time of sale and production inputs are bought after closing a sale, if prices go up between sale and production time, then MTO manufacturers may be forced to produce and deliver products at a loss. And second, as MTO producers receive raw material – in a just-in-time fashion – right before production starts, if a major disruption cuts off the flow of raw material, then production needs to shut down leaving capital and human resources idle. By design MTF producers do not face the input cost risk, product price is determined after inputs are bought. In addition, only after prolonged disruptions of raw material flow and depletion of regular as well as safety inventories are MTF producers forced to shut down production.

The two supply disruption risks do not pose the same burden to MTO producers of all industries. It is not surprising that the input cost disruption mode had an adverse effect on MTO supply chains for PCs and the production idling disruption mode affected MTO supply chains for automobiles. Production components for automobiles (e.g., engines, transmissions) tend to be unique to the product and processes of each auto manufacturer (client). Whereas components for PCs (e.g., memories, hard drives) are available not only through long-term contracts, but also at any given time through the spot market or stand-by suppliers. Hence, PC supply disruption is likely to lead not to production shut down, but to inordinate prices for components. The opposite is true for automobile supply chains, where often inputs are not available in a spot market. This study develops a general framework for the comparison between MTO and MTF, but focuses more on aspects that relate mainly to the computer industry: pronounced MTO cash-flow risk after supply disruptions and volatile but decreasing in trend input prices, leading to cash cycle advantage for MTO.

PC economics is characterized by rapid technological depreciation in inputs, which in turn results in rapid depreciation of final products. Curry and Kenney (1999) estimate that roughly half the cost of a PC is attributed to semiconductor components, which exhibit rapid decreases in quality-adjusted price over time. The remaining PC cost is ascribed to mature technology components with relatively steady prices over time. Grimm (1998) estimates that prices of representative semiconductor components, memory chips, declined by 37% per year between 1975 and 1985 and 20% per year between 1985 and 1996, when adjusted for improved technical capabilities of more recent technology models.

This peculiarity in the production economics of PCs appears to have a significant impact on the way PC production systems and their supply chains are designed and operated. Curry and Kenney (1999) show empirically that MTO producer profits are positively related to the decline in PC component prices, the faster input price declines the higher MTO profitability. By contrast the MTF production system requires high inventory levels and for it a declining trend in input price results in fast depreciating final goods inventory and low profitability. This differential performance in the prevailing input price environment leaves room for MTO producers to offer price discounts, when increased market share is desired. Indeed, industry analysts like Spooner (2004) report that Dell Computer Corporation, the pioneer of the MTO strategy in the PC industry, achieved control of the highest market share in the global PC market (18.6%) in 2004.

Stochastic variation around the declining price trend may result in periods when semiconductor prices go up. When prices go up smoothly, MTO supply chain managers have various means of recourse. Marketing may emphasize the need of cheaper components in a PC configuration compensating for lower quantities of the one whose price is increasing. In addition, smooth price changes are easily forecasted, thus pricing at time of sale can be managed by MTO producers with little difficulty. We show that periods when one semiconductor component cost increases are actually very likely. As, though, there are many semiconductor components to a PC, whose price varies independently, periods for which the total cost of semiconductor inputs increases are rare. Consequently, betting on declining total input cost for PCs by following the MTO strategy, is not too risky.

The model we introduce in this study advances the understanding of MTO design by including three important features. First, it examines the cash-cycle effect and its impact when component prices exhibit a declining trend. Second, it considers contract prices that do protect producers in the short term, but are renegotiated over time. By employing a contract price model that describes many current supply contracts in practice, our analysis sheds light to the effect price shocks have on major producers. And third, our analysis examines both the efficiency and the perceived fragility of MTO supply chains. Clearly, these conditions are not germane to PC industry only, but find application in all industries using semiconductor components. In addition, other industries depending on a commodity that may follow a pattern of declining price for long periods of time, say oil or gold between 1981–97, may also gain insights from our analysis.

The remainder of this paper is organized in four sections. Section 2 proposes a stochastic model for the evolution of semiconductor prices. This section is divided in three parts. One describing spot market price, as it can be estimated by supply chain practitioners. A second describing our descriptive contract price model. And, a third examining the behavior of a bundle comprised by many semiconductor inputs with largely independent stochastic dynamics. In section 3, the main model of competition between MTF and MTO producers is developed. Throughout section 3 we assume many MTF producers compete against each other and one MTO monopolist. Next, in section 4, the relative impact of decaying impulse disruption in semiconductor input prices is estimated for the two types of PC producers. In this section, the regular spot price model is extended to incorporate the impact of price shocks. In addition, in section 4 we examine the effect of supply price shocks on MTO market value volatility and the impact of disruption risk management on MTO-MTF competition. Finally, section 5 concludes with a discussion of results and their implications.

2 Semiconductor Input Price: Behavior and Model

The basic model for the cost of a single semiconductor input is developed in this section. This stochastic model captures the current behavior of semiconductor input prices, that exhibit a pattern of steady decline. We consider a price model that is general and likely to be used by supply chain practitioners, ARIMA$(0,1,\infty)$ or causal ARIMA $(p,1,q)$ (see for instance, Brockwell and Davis, 1991, pp. 273–329). Various PC inputs (e.g., hard drives, processors, memories, optical disks) may be described by this rich model. Naturally, each component requires separate estimation as prices of inputs follow largely independent stochastic dynamics induced by technological innovation in different industries. In addition, the relation of spot price to a descriptive contract price model is examined. In our model contract price is renegotiated from time to time. We show that the semiconductor bundle price declines very predictably and the risk of bundle price going up is very small.

The long term behavior of semiconductor inputs has been researched extensively by eco-

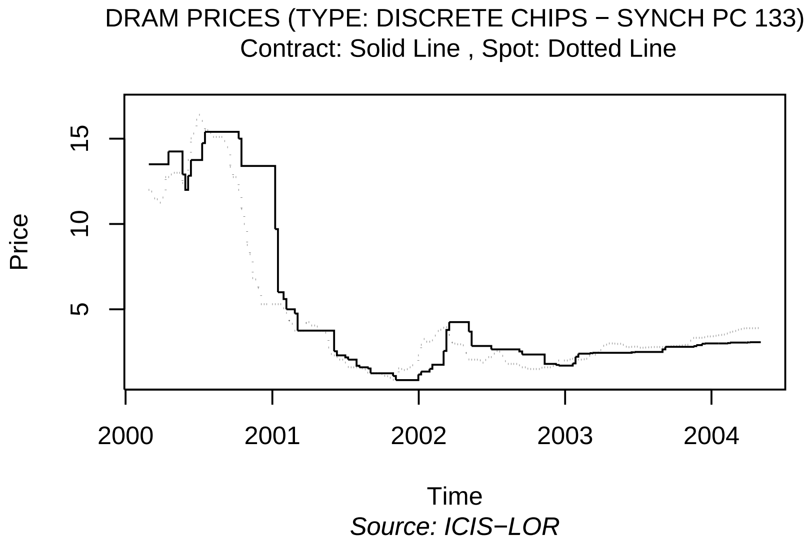

Figure 2: Actual prices for a representative DRAM product. Both Contract and Spot prices appear on the graph. Note the general pattern of price decline and the lack of stationarity.

nomic researchers mainly due to their potential impact on national income accounts. Aizcorbe (2002) has observed a yearly 24.4% decline in computer processors (CPUs) when matched for similar capabilities. In addition, it was estimated that unadjusted prices fall relatively slowly, by 0.5% annually. Grimm's (1998) analysis of real semiconductor prices, that is prices compensated for quality improvements due to technological innovation, suggests an exponential price decline over time, at about 20% per year.

The two macroeconomic studies above utilize aggregate prices, on quarterly and yearly basis respectively. Studies useful for supply chain management and input price forecasting are likely to use monthly or weekly samples of semiconductor prices. Figure 2 shows actual weekly spot and contract prices for a DRAM product. The long-term downward trend is clear. In addition, it is evident that these series are not stationary, thus differencing is required. Generally, spot price first-order differences exhibit fairly high low order autocorrelation.

A shorter sampling period, will obviously result in a focus on different dynamics. In addition, we expect that supply chain practitioners would estimate ARIMA models using a much shorter history. The infinite moving average terms do not pose insurmountable difficulties. ARIMA(0,1,∞) models are estimated in practice as ARIMA(p,1,q) models with only (p+1+q) terms. The rule of thumb for the minimum series size of an ARIMA study is 50 observations. Chatfield (1996) expects that less that 50 observations make ARIMA estimation less reliable than simpler methods like double exponential smoothing. Hence, supply chain practitioners interested in predicting prices for the weeks or months to come, would use a year's or two worth of data for weekly sampling rate. Clearly, technology progress induced 5-year cycles would look as components of the trend in a time series of 2 year length.

2.1 Semiconductor Component Spot Price

We expect that the following stochastic model captures the essential properties of a semiconductor input's price in the estimation window of about 2 years and for forecasting a few or several weeks ahead. Typically, semiconductor price logarithm would be a more appropriate model whereby prices are always positive. In our case, given the shorter price history, the easier to fit linear trend will suffice. Ours is a discrete time model. To clarify expressions we will not use time, *t*, as subscript, as is customary, but *t* will be enclosed in parentheses as argument.

Notation 1 *Discrete Time as Argument*

$\phi(t;\xi)$ is the instance at time $t \in \mathbf{Z}$

Definition 2.1 *State Space Model for Semiconductor Spot Price: ARIMA(0,1,∞)*

$$c_k(t) = c_k(t-1) + d_k(t) \tag{1}$$

$$d_k(t) - \bar{d}_k = \sum_{\tau=-\infty}^{t} \alpha_k(\tau)\epsilon_k(\tau) \tag{2}$$

Where:

$c_k(t)$ is the cost per PC unit of semiconductor input k for week t.

$k \in K$ type of semiconductor input. Set K comprises all possible semiconductor inputs to a PC.

t is the time index taking value zero at the beginning of the estimation window.

$d_k(t)$ is local price trend (1st order difference) for semiconductor input of type k with finite variance $\sigma^2_{dk} < \infty$.

$\bar{d}_k < 0$ is global (average) price trend for input k. It is negative as prices decline.

$\alpha_k(\tau) : \sum_{\tau=-\infty}^{t} |\alpha_k(\tau)| < \infty$ are the ARIMA model terms for input k.

$\epsilon_k(t)$ is white noise with 0 mean and finite variance.

This representation is very general. In practice, one expects low order autocorrelation to be high and this would pose additional requirements on $\{a_k(t)\}$. An immediate consequence of low order autocorrelation is predictability of the spot price in the short term. The results that follow require only that semiconductor input price trends are negative.

2.2 Semiconductor Component Contract Price

A study of the computer industry press, for instance Serant and Ojo (2001), reveals the semiconductor contract price is renegotiated over time. We develop a model that describes at least three types of observed contractual relationships between major producers and semiconductor suppliers. First, computer manufacturers tend to renege on long term contracts prescribing constant prices when spot price declines substantially. This practice is fairly prevalent but very surprising, due to fact that it is rarely challenged in court by suppliers. Second, very often one observes informal contracts whereby prices are adjusted downwards either voluntarily by suppliers or by mutual consent according to spot price declines. And third, one observes supply contracts under which contract price is adjusted periodically according to a long term forecast of price trajectory.

The fundamental difference between contract and spot price is that the former may remain constant for many periods. This is captured in our model by the thinning process $\{Y(t)\}$ that counts the times contract price is renegotiated/updated.

Definition 2.2 *Semiconductor Contract Price Model for Producer P (Thinned Spot Price)*

$$c_{Pk}(t) = c_{Pk}(t-1) + \frac{\Delta Y_{Pk}(t)}{\mu_{Pk}} d_k(t) \tag{3}$$

$\{Y_{Pk}(t)\}$ is a stochastic process with $P(\Delta Y_{Pk}(t) = 1) = \mu_{Pk}$ and $P(\Delta Y_{Pk}(t) > 1) \simeq 0$.

Contract renegotiation times $\{t_{RPk} : \Delta Y_{Pk}(t) = \Delta Y_{Pk}(t + t_{RPk}) = 1, \forall \tau \in (t, t + t_{RPk})\ \Delta Y_{Pk}(\tau) = 0\}$ follow a general distribution with $E\{t_{RPk}\} = \mu_{Pk}^{-1}$ and $V\{t_{RPk}\} < \infty$

P index showing type of producer: f for MTF and o for MTO.

$d_k(t)$ and $\{Y_{Pk}(t)\}$ are assumed independent

Clearly, if the increments of the thinning process $\{Y(t)\}$ are independent, then it is a Poisson process. If the variance of the renegotiation times is very low, then the contract price model becomes equivalent to periodic price renegotiation. Commonly, supplier contracts for industrial inputs minimize certification and setup expenses and last for many years with prices renegotiated every few months. This renegotiation is rarely periodic, but renegotiation in successive periods appears also to be unlikely. Hence, renegotiation times fall between the two aforementioned extremes, but appears to be closer to periodic renegotiation.

Definition 2.3 *MTF and MTO supply contracts for input k are dependent in the following way:*

$$E\{\Delta Y_{fk}\Delta Y_{ok}\} = \mu_{fok} \in [0,1] \tag{4}$$

Independence of spot price decline and renegotiation is in large part a modeling assumption. Considering models of dependence between $d_k(t)$ and $\{Y_{Pk}(t)\}$ would be interesting but is left outside the scope of this study. The following useful results are easily obtained.

Proposition 2.1 *Central Moments of* $\{c_{Pk}(t) - c_{Pk}(t-1)\}$ *are given as*

$$E\{c_{Pk}(t) - c_{Pk}(t-1)\} = \bar{d}_k \quad , \quad V\{c_{Pk}(t) - c_{Pk}(t-1)\} = \mu_{Pk}^{-1}(\sigma_{dk}^2 + (1-\mu_{Pk})\bar{d}_k^2) \tag{5}$$

Proof: For the first part:

$$\begin{aligned} E\{c_{Pk}(t) - c_{Pk}(t-1)\} &= E\{\frac{\Delta Y_{Pk}(t)}{\mu_{Pk}} d_k(t)\} \\ &= \frac{\mu_{Pk}}{\mu_{Pk}}\bar{d}_k(t) = \bar{d}_k(t) \end{aligned} \tag{6}$$

For the second part:

$$\begin{aligned} V\{c_{Pk}(t) - c_{Pk}(t-1)\} &= E\{\frac{\Delta Y_{Pk}(t)}{\mu_{Pk}} d_k(t)\}^2 - \bar{d}_k^2 \\ &= \mu_{Pk}^{-2} E\{\Delta Y_{Pk}^2(t)\}(\sigma_{dk}^2 + \bar{d}_k^2) - \bar{d}_k^2 \\ &= \mu_{Pk}^{-1}(\sigma_{dk}^2 + \bar{d}_k^2) - \bar{d}_k^2 \quad \blacksquare \end{aligned} \tag{7}$$

Note, that, as $0 < \mu_{Pk} < 1$, contract price difference variance is higher than σ_{dk}^2, the variance of the spot price difference.

It is important to establish that, even though contract prices for each individual semiconductor input k have a negative average trend in our model, at any time at least one semiconductor input price is highly likely to trend upwards, as is observed in practice.

Proposition 2.2

$$\forall t, \lim_{|K| \to \infty} P\left(\bigcap_{k \in K} \{c_{Pk}(t) - c_{Pk}(t-1) < 0\}\right) = 0$$

Proof: Let $\bar{P} < 1$ be $\bar{P} := \max_{k \in K}\{P(c_{Pk}(t) - c_{Pk}(t-1) < 0)\}$. Then using that c_{Pk} are mutually independent,

$$P\left(\bigcap_{k \in K} \{c_{Pk}(t) - c_{Pk}(t-1) < 0\}\right) = \prod_{k \in K} P(c_{Pk}(t) - c_{Pk}(t-1) < 0) \leq \bar{P}^{|K|} \tag{8}$$

Clearly, $\lim_{|K| \to \infty} \bar{P}^{|K|} = 0$. ■

This result implies that PC producers need to avoid renegotiating all their semiconductor supply contracts at the same time because at least one such input is bound to go up during renegotiation. Spot price autocorrelation for each individual product though makes it easy for PC producers to identify which inputs to renegotiate. Not renegotiating semiconductors at all though is a very costly alternative as the semiconductor bundle moves very predictably to lower and lower prices for same technological capabilities.

2.3 Total Semiconductor Bundle Cost

Definition 2.4 *Total Semiconductor Cost Per PC Unit*

$$C_P(t) := \sum_{k \in K} c_{Pk}(t) \tag{9}$$

Proposition 2.3

$$\lim_{|K| \to \infty} P(C_P(t) - C_P(t-1) < 0) = 1 \tag{10}$$

Proof: Recall that for all k $d_k(t)$ and $\Delta Y_{Pk}(t)$ are independent. Hence, from Central Limit Theorem,

$$C_P(t) - C_P(t-1) \sim N\left(\sum_{k\in K} \bar{d}_k, \sum_{k\in K} \mu_{Pk}^{-1}\sigma_{dk}^2\right)$$

Let Φ be the cdf of the standard Normal distribution, an increasing function.

$$P(C_P(t) - C_P(t-1) < 0) = \Phi(-\frac{\sum_{k\in K} \bar{d}_k}{\sqrt{\sum_{k\in K} \mu_{Pk}^{-1}\sigma_{dk}^2}})$$

Recall that $\forall k, \bar{d}_k < 0$, hence $0 > \bar{d}_{\max} := \max_K\{\bar{d}_k\}$. Let,also, $\sigma_{\max}^2 := \max_K\{\mu_{Pk}^{-1}\sigma_{dk}^2\}$. Now,

$$P(C_P(t) - C_P(t-1) < 0) \geq \Phi(-\frac{|K|\bar{d}_{\max}}{\sqrt{|K|\sigma_{\max}^2}}) = \Phi(\sqrt{|K|}\frac{|\bar{d}_{\max}|}{\sigma_{\max}}) \tag{11}$$

Finally,

$$\lim_{|K|\to\infty} \Phi(\sqrt{|K|}\frac{|\bar{d}_{\max}|}{\sigma_{\max}}) = 1 \quad \blacksquare \tag{12}$$

A PC does not have very many semiconductor components with distinct stochastic dynamics. In practice one expects $|K|$ to be between 4–5 depending on PC type. For this high, but not exorbitantly high, $|K|$ value the calculation of the probability of decreasing total semiconductor price requires a detailed analysis. Nonetheless, as we have shown one can expect the probability of decreasing total semiconductor price to be high.

Barring side payments, the ergodic average of spot and contract prices should be equal over the life of the contract t_{RPk}: $\int_0^{t_{RPk}} c_{Pk}(t)dt = \int_0^{t_{RPk}} c_k(t)dt$. As t_{RPk} lengthens production is smoother, not influenced by transient spot price movements, and hence production plans are easier to implement on budget. When t_{RPk} is exceedingly long, price signals are distorted and producers do not use the optimal quantity of input. PC producer contracts for semiconductors must at least be preferable to the instantaneous spot price of the semiconductor bundle, which as we have shown is very predictable (in the absence of supply disruptions). Of course, contract and spot prices are comparable only if quantity discounts, major producers always qualify for, apply to both.

It is easy to show that if each input k begins trading at the same price for both producer types, then at every period after initial trading both producers face the same expected cost.

Proposition 2.4 *Under mild assumptions expected cost for both producers is equal to expected spot input cost:*

$$\begin{aligned} &\forall k \ c_{ok}(t_{k0}) = c_{fk}(t_{k0}) = c_k(t_{k0}) \implies \\ &\forall t > \max_K\{t_{k0}\} \ E\{C_o(t)\} = E\{C_f(t)\} = \bar{C}(t) \end{aligned} \tag{13}$$

Proof:

$$\begin{aligned} \forall t > t_{k0} \quad E\{c_{Pk}(t)\} &= c_{Pk}(t_{k0}) + \sum_{\tau=t_{k0}+1}^{t} E\{c_{Pk}(\tau) - c_{Pk}(\tau-1)\} \\ &= c_{Pk}(t_{k0}) + (t - t_{k0})\bar{d}_k \\ &= E\{c_k(t)\} \end{aligned} \tag{14}$$

Thus, $E\{c_{Pk}(t)\}$ is given independent of type P. Now,

$$\forall t > \max_K\{t_{k0}\} \quad \bar{C}(t) := E\{C_P(t)\} = \sum_{k\in K} E\{c_{Pk}(t)\} = \sum_{k\in K} E\{c_k(t)\} \tag{15}$$

Which again is independent of type P. ■

This important result makes clear that in current practice $\bar{C}(t)$ can be seen either as expected contract cost or as expected spot cost. In the next section we will use $\bar{C}(t)$ also as the contract cost of semiconductors in a competitive market comprised of many MTF PC producers. Industry contract cost would equal individual contract cost if all MTF producers renegotiate their contracts in step, a strong assumption. Alternatively, $\bar{C}(t)$ may be seen as the expected contract cost for semiconductors faced by a potential contester contemplating entry to this market of MTF producers and using the same SC strategy. Under free entry, contester PC price equals PC cost and contester price determines industry PC price. In this framework, industry price is also determined by instantaneous expected spot cost, $\bar{C}(t)$. It is helpful to use the following notation for the average per time unit decline in total semiconductor cost. Note, that it does not depend of producer type P.

Definition 2.5 *Average Semiconductor Price Decline Rate*

$$\bar{d} := \bar{C}(t) - \bar{C}(t-1) = \sum_K \bar{d}_k \tag{16}$$

Having established a model for the behavior of semiconductor prices we proceed with an investigation of its impact on the competition between MTO and MTF supply chains. We consider two cases. Firstly, we examine typical price variation, as has been described in this section. Secondly, we examine the effect of an out-of-pattern price increase due to a severe supply disruption.

3 MTO and MTF Competition in the PC Market

The main model of competition under normal operation is developed in this section. Three factors are shown to have an impact on the comparative advantage of MTO over MTF: a) cash cycle savings in capital costs from delaying purchase of steady price inputs; b) cash-cycle savings from purchases of declining on average semiconductor products; and c) how consumers tradeoff consumption delay and usually higher production costs, associated with lot size of one, against increased product fitness to customer needs through customization. Note that depending on industry conditions these factors may lead to a competitive disadvantage of MTO over MTF (i.e., have a negative net effect).

We assume competition takes place between one MTO monopolist and many MTF producers. In addition, we assume free entry for MTF producers. MTF producers compete within and between their supply chain type, as is the case in practice today. In practice the MTO strategy has more than one followers, but is not as highly contested as MTF. An oligopoly for the MTF strategy would better reflect PC industry realities. Monopolistic competition, however, provides sufficient insights and simplifies derivations.

MTF producers operate under an efficient lot size regime, so that their production lot size minimizes manufacturing, transportation, and input acquisition costs. Optimal lot sizes are large reflecting increasing returns to scale in these cost categories. The industry-wide production cost, however, may be considered linear to production volume due to competition of MTF producers within their category and free entry. An individual MTF producer having found its optimal production volume does not vary it in response to market demand. But, due to free entry, if more units are demanded, then a new MTF producer enters the market operating at the same optimal volume. It is well known that a linear industry supply curve results when input costs are independent of industry size (see, for instance, Nicholson (1992)). And the latter is an appropriate assumption in current practice. Let the MTF industry expenditure function be as follows.

Definition 3.1 *MTF per unit input cost*

$$\mathbf{C}_f\,(t) = \left(F + C_f(t - T_f)\right)\delta + m_f \tag{17}$$

Where:

$F \geq 0$ is the share of fixed-price (standard technology) input costs per product, not depending on time.

$C_f(t) \geq 0$ is the total cost for semiconductor components per product for MTF, which varies with time according to (9).

$T_f \geq 0$ is the cash cycle period for MTF producers.

$\delta > 1$ discount factor reflecting inventory cost for T_f periods.

$m_f \geq 0$ is the generalized manufacturing cost per product for MTF producers including transportation and overhead.

The inventory holding cost rate for T_f periods will be $(\delta - 1)$ per dollar of inventory value. Next, consider MTO producers.

We assume that MTO and MTF producers offer a PC that contains the exact same components. At price P_o MTO producers may capture q customers from the MTF group:

$$P_o = P_f + D(q) \tag{18}$$

MTF and MTO products are not interchangeable, even if they have the same components. MTF products are ready to consume at time of sale and therefore more desirable, whereas MTO products necessitate a consumption delay (about a month long). On the other hand, MTF products come in generic configurations and MTO products are individualized. Thus, MTO products gain the consumer on the latter count. As a result, the sign of the difference between producer prices in (18) is indeterminate. Two general assumptions about D, however, may be safely posited. First, the higher D is, the more the profitability of MTO producers.

And second, the more units MTO sells, the more likely it is that sales to consumers with generic preferences will be attempted. Therefore, D may be assumed to be decreasing with q at a decreasing rate, i.e.: $D' \leq 0$ and $D'' < 0$. We will also assume D' is continuous, i.e.: $|D''| < \infty$ and $D'(0) = 0$.

With MTO lot size being one, expenditure is linear with volume, as follows.

Definition 3.2 *MTO per unit input cost*

$$\mathbf{C}_o\,(t) = F + C_o(t) + m_o \tag{19}$$

The parameter m_o is the MTO generalized manufacturing cost. One part of it, pure manufacturing cost, is clearly higher than the respective MTF cost due to MTO not realizing economies of scale. Another part, supply demand mismatch cost, may be lower for MTO. Overall the difference between m_o and m_f has indeterminate sign.

We may now define MTO expected per unit profit from the production of q units, as their comparative advantage, $\Pi(q,t)$. Notation is simplified if we use $\pi = \Pi/q$ for average or per unit profit for MTO.

Proposition 3.1 *Comparative MTO advantage per unit produced*

$$\pi(q,t) = (F + C_f(t - T_f))\delta - (F + C_o(t)) + D_T(q) \tag{20}$$

Proof: Using (18), MTO per unit profit may be calculated as:

$$\begin{aligned} \pi(q,t) &= P_o(q,t) - \mathbf{C}_o \\ &= (F + C_f(t - T_f))\,\delta + m_f + D(q) - (F + C_o(t) + m_o) \end{aligned} \tag{21}$$

If the total price difference includes manufacturing costs in a way that

$$D_T\,(q) = D\,(q) + m_f - m_o \tag{22}$$

then (20) follows. ■

From (20) it is clear that MTO producers make available PCs to market at every period. Each period they compete with a different set of MTF producers that purchased inputs T_f periods earlier.

Proposition 3.2 *Expected MTO comparative advantage per unit produced is given as:*

$$\bar{\pi}(q,t) = (F + \bar{C}(t))(\delta - 1) - T_f \bar{d}\delta + D_T(q) \tag{23}$$

Proof: From (20):

$$\bar{\pi}(q,t) = \left[F + \bar{C}(t - T_f)\right]\delta - \left[F + \bar{C}(t)\right] + D_T(q) \implies \tag{24}$$

$$\bar{\pi}(q,t) = \left(F + \bar{C}(t) - T_f \bar{d}\right)\delta - \left(F + \bar{C}(t)\right) + D_T(q) \quad \blacksquare \tag{25}$$

The MTO monopolist will enter the market, $q > 0$, if expected profit is positive. At the very least $\bar{\pi}(0,t) > 0$, as $\forall q \in \Re^+ \bar{\pi}(0,t) > \bar{\pi}(q,t)$. Volume will be set at the level that maximizes profits.

Proposition 3.3 *MTO enters market iff production volume is within a critical range*

$$\exists q^* := \arg\max_{q \in \Re^+}\{\bar{\pi}(q,t)q\} \Leftrightarrow q^* \in (0, \hat{q}) \textit{ and } \bar{\pi}(0,t) > 0$$

$$\textit{where} \quad \hat{q} = [D_T]^{-1}(-(F + \bar{C}(t)(\delta - 1) + \delta T_f \bar{d})$$

Proof: Second Statement Necessary

From the first order condition:

$$(F + \bar{C}(t))(\delta - 1) - T_f \bar{d}\delta + D_T(q^*) + q^* D'_T(q^*) = 0 \implies \tag{26}$$

$$(F + \bar{C}(t))(\delta - 1) - T_f \bar{d}\delta + D_T(q^*) = -q^* D'_T(q^*) > 0 \tag{27}$$

Note that the second order condition is satisfied $\forall q : 2D'_T(q) + qD''_T < 0$. Hence, q^* indeed maximizes. Now, (27) $\implies$ $0 < \bar{\pi}(q^*, t) < \bar{\pi}(0,t)$ and, as $\bar{\pi}(q,t)$ is decreasing in q, $q^* > 0$. Also, using that $D_T(q)$ is decreasing,

$$(27) \implies -D_T(\hat{q}) + D_T(q^*) > 0 \implies D_T(q^*) > D_T(\hat{q}) \implies q^* < \hat{q}$$

Which completes the necessary part. Now, for the sufficient part let $g : \Re^+ \mapsto \Re$ be:

$$g(q) = (F + \bar{C}(t))(\delta - 1) - T_f \bar{d}\delta + D_T(q) + qD'_T(q) \tag{28}$$

Obviously, g is continuous as D_T and D'_T are. But,

$$g(0) = (F + \bar{C}(t))(\delta - 1) - T_f \bar{d}\delta + D_T(0) = \bar{\pi}(0,t) > 0 \tag{29}$$

Thus,

$$g(\hat{q}) = \hat{q} D_T'(\hat{q}) < 0 \implies \exists q^* \in (0, \hat{q}) : g(q^*) = 0 \tag{30}$$

Of course, this q^* satisfies both first and second order conditions and maximizes expected profits. ■

Equation (23) makes clear that there are three components to the value MTO extracts: a) the first depends on inventory cost efficiencies inherent to the MTO strategy, b) the second is a function of savings realized by MTO due to declining prices in semiconductor inputs , and c) the third depends on the relative difference in desirability of MTO versus MTF products and on the relative difference in manufacturing costs. Recall that $\bar{d} \leq 0$ and the third factor in (23) is nonnegative. Interestingly, MTO's advantage remains nonnegative even if $\bar{d}$ is slightly positive. As long as the first term in (23) exceeds the other two terms.

4 Relative Impact of Supply Disruptions

We examine the impact safety inventory of components has in the ability of PC producers to mitigate the effect of a supply disruption. MTO producers require no inventory in our model and thus neither safety inventory. Naturally, no inventories will lead to higher variability in customer response, but this appears to have little effect in the PC industry. MTF producers have many reasons to keep safety inventory. Typically, safety inventories of components are required to deal with variability in inward deliveries, which is pronounced in the case of overseas sourcing. We proceed by extending the semiconductor price model to incorporate the effect of disruptions. Having developed the price disruption model we examine the impact of disruptions on MTO comparative advantage. In particular, we show that disruptions may increase MTO market value risk.

Extraordinary events, like natural disasters or political instability, may result in abrupt increases of semiconductor prices that take various forms. Here, a model of abrupt price change is considered, whereby the disruption occurs immediately after the event of interest and then decays with time. We extend the semiconductor-component price model in (9) in a mean preserving manner to include the effect of sudden, out-of-pattern price disruptions.

We assume disruptions occur at the beginning of each period and are attenuated by a factor that varies with time. This model is qualitatively different than the normal variation model, because at times low order autocorrelation is lost due to price shocks, $w_k(t)$. According to our model price shocks decay at rate that is constant (depending only on input type). This modeling assumption facilitates derivations without impacting our results. We begin with MTO producers.

Definition 4.1 *Extended Semiconductor Price Model for MTO*

$$C_o^W(t) = C_o(t) + \sum_{k \in K} \Delta Y_{ok}(t) w_k(t)/\mu_{ok} \quad \text{with} \tag{31}$$

$$w_k(t) = \sum_{\tau=-\infty}^{t} X_k(\tau)(\eta_k(\tau) - \bar{\eta}_k(\tau))\beta_k^{t-\tau} \tag{32}$$

where:

$\{\sum X_k(t)\}$ is a Poisson process with $P(X_k(t) = 1) = \lambda_k$ and $P(X_k(t) > 1) \simeq 0$.

$\eta_k(t)$ i.i.d. random variables determining disruption magnitude for input k with $E\{\eta_k\} = \bar{\eta}_k$ and variance $V\{\eta\} < \infty$.

$0 < \beta_k < 1$ is the price shock attenuation factor for input k.

$\{Y_{ok}(t)\}$ is the thinning process determining times of price renegotiation for input k and producer o as before.

Y_{ok}, X_k, η_k are mutually independent.

This combination of usual and out-of-pattern volatility sidesteps the requirement for a detailed state space specification of $C_o(t)$. Had this existed and been linear, the behavior of the system after disruption would be straightforward to obtain. We expect, though, that determining the detailed state space equations for the semiconductor price is time-consuming and cumbersome, hence, outside the usual scope of price forecasting studies employed by purchasing departments. Moreover, there is no guaranty that the specification of the state space model would be linear. Thus, reaction to a high magnitude price deviation may not be similar to the one for a low magnitude price deviation.

The first-order-like decay assumed in (31) as a model for disruption-induced price is very realistic. The serious supply disruptions we study tend to arrive unexpectedly, cause input prices to obtain a maximum deviation from normal levels very fast, and then slowly decay towards regular levels without overshooting the initial deviation. Market participants make their decisions after disruptions in ways that reinforce this pattern.

Suppliers of industrial inputs respond to shortages but slowly, as production schedules are not easy to vary in the short term. By the time production schedules can change the cause of the disruption is clarified and the right escalation of production is easy to determine. Thus, overproduction and 2nd order correction of the price is avoided. Companies consuming industrial inputs also operate under slow changing production schedules. Thus, price spikes are very high in the beginning, but as time progresses demand of industrial inputs adjusts and at the same time price regresses to normal levels. Finally, intermediaries immediately recognize the value of inventories of goods in short supply and hoard them, offering them only to the highest bidder. As time goes by prices adjust downwards. With the cause of the disruption being clear this adjustment is not so fast that prices go below normal levels. In summary, transparency of the phenomenon causing the disruption and slow adjustments tend to lead to first-order-like disruption decay.

We expect that MTO producers face an input price as in (31), but MTF producers have more opportunities to mitigate the effect of a disruption. If the price of a semiconductor input is up for renegotiation between an MTF producer and its supplier, then safety inventory may be used in order for MTF to delay this renegotiation for a while. MTF producers may use a portion of their safety inventory of semiconductor inputs in order not to replenish it at the peak of after-disruption price. Instead they replenish T_L periods later at a new price without production idling.

This policy is to happen only in exceptional circumstances and safety inventories are not envisioned here to normally have a hedging function. MTF producers need to keep as a matter of course safety inventory. And the cost of maintaining safety inventory is part of usual MTF manufacturing cost. When the price of semiconductor inputs is due for renegotiation, MTF producers are not as hard-pressed to accept supplier prices. Suppliers, knowing MTF producers use their safety inventories, may offer MTF producers better prices in exchange for later deliveries. The overall effect is expected to be captured by MTF prices being not as sensitive to price shocks. The proposed semiconductor price model after disruption for MTF producers is given by the following.

Definition 4.2 *Extended Semiconductor Price Model For MTF*

$$C_f^W(t) = C_f(t) + \sum_{k\in K} \Delta Y_{fk}(t) w_k(t) \beta_k^{T_{Lk}} / \mu_{fk} \tag{33}$$

$$\text{with } w_k(t)\beta_k^{T_{Lk}} = \sum_{\tau=-\infty}^{t} X_k(\tau)(\eta_k(\tau) - \bar{\eta}_k)\beta_k^{t+T_{Lk}-\tau} \tag{34}$$

Where T_{Lk}, the possible delivery delay in the event of a disruption, is not expected to be very long, most likely less than T_f, the inventory cycle period. As T_{Lk} and λ_k are small the probability of consecutive disruptions is also small. When this is not true, this postponement policy is of questionable value.

The new semiconductor price model will lead to different calculations of MTO's comparative advantage. The extension to our price model is mean preserving, due the following corollary.

Corollary 4.1

$$E\{w_k(t)\} = 0 \tag{35}$$

Proposition 4.1 w_k *Autocovariance is given as*

$$\forall t_1, t_2 \in \Re^+ : t_1 \leq t_2 \quad E\{w_k(t_1) w_k(t_2)\} = \lambda_k V\{\eta\} \frac{\beta_k^{t_2-t_1}}{1-\beta_k^2} \tag{36}$$

Proof: Due to independence of $X_k(t)$ and $\eta_k(t)$ at different times:

$$\begin{aligned} E\{w_k(t_1) w_k(t_2)\} &= \sum_{\tau=-\infty}^{t_1} E\{X_k^2(\tau)(\eta_k(\tau) - \bar{\eta}_k(\tau))^2 \beta_k^{(t_1-\tau)+(t_2-\tau)}\} \\ &= \sum_{\tau=-\infty}^{t_1} E\{X_k(\tau)\} V\{\eta\} \beta_k^{2(t_1-\tau)+(t_2-t_1)} \quad \blacksquare \end{aligned}$$

Corollary 4.2 w_k *Variance is given as*

$$V\{w_k\} = \lambda_k V\{\eta\}(1-\beta_k^2)^{-1} \tag{37}$$

Proposition 4.2 *MTO advantage per unit produced under extended price model is:*

$$\pi^W = \pi + \delta \sum_{k\in K} \Delta Y_{fk}(t) w_k(t - T_f) \beta_k^{T_{Lk}} / \mu_{fk} - \sum_{k\in K} \Delta Y_{ok}(t) w_k(t) / \mu_{ok} \tag{38}$$

Proof: Similarly to (20) we obtain MTO comparative advantage per unit for the extended model:

$$\begin{aligned}\pi^W &= (F + C_f^W(t - T_f))\delta - (F + C_o^W(t)) + D_T \\ &= \pi + \left(C_f^W(t - T_f) - C_f(t - T_f)\right)\delta - \left(C_o^W(t) - C_o(t)\right) \quad \blacksquare\end{aligned}$$

Corollary 4.3 *Expected MTO advantage per unit produced remains the same after extension:* $\bar{\pi}^W = \bar{\pi}$

Even though expected MTO comparative advantage is the same in both models, its variance increases.

Proposition 4.3

$$V\{\pi^W\} = V\{\pi\} + \sum_{k\in K} V\{w_k\}\left(\frac{\delta^2\beta_k^{2T_{Lk}}}{\mu_{fk}} + \frac{1}{\mu_{ok}} - 2\delta\beta^{T_{Lk}+T_f}\frac{\mu_{fok}}{\mu_{fk}\mu_{ok}}\right) \tag{39}$$

Proof: The first term in the right part of (38) is uncorrelated to the other two, hence:

$$\begin{aligned}V\{\pi^W\} &= V\{\pi\} + E\left\{\sum_{k\in K}\frac{\delta^2\beta_k^{2T_{Lk}}}{\mu_{fk}^2}\Delta Y_{fk}^2(t - T_f)w_k^2(t - T_f)\right. \\ &\quad \left. + \frac{1}{\mu_{ok}^2}\Delta Y_{ok}^2(t)w_k^2(t) - 2\frac{\delta}{\mu_{fk}\mu_{ok}}\Delta Y_{fk}(t - T_f)w_k(t - T_f)\Delta Y_{ok}(t)w_k(t)\right\} \qquad (40) \\ &= V\{\pi\} + \sum_{k\in K}\frac{\delta^2\beta_k^{2T_{Lk}}}{\mu_{fk}^2}E\{\Delta Y_{fk}\}V\{w_k\} \\ &\quad + \frac{1}{\mu_{ok}^2}E\{\Delta Y_{ok}\}V\{w_k\} - 2\frac{\delta\beta_k^{T_{Lk}}}{\mu_{fk}\mu_{ok}}E\{\Delta Y_{fk}\Delta Y_{ok}\}V\{w_k\}\beta_k^{T_f} \quad \blacksquare \qquad (41)\end{aligned}$$

Naturally, MTO market valuation will depend on its expected net return, $\bar{\pi}^W q$, and its risk, $V\{\pi^W\}q^2$. And MTO valuation decreases the higher this risk is. Equation (39) is an important result clarifying the decision framework for MTO's risk management policies and its interaction with MTF policies.

Corollary 4.4 *Perfect Disruption Smoothing For MTF*

$$\forall k\ \beta_k^{T_{Lk}} \to 0 \implies V\{\pi^W\} - V\{\pi\} = \sum_{k\in K} V\{w_k\}/\mu_{ok} \tag{42}$$

In this case, supply disruption risk is MTO strategy specific. Hence, it has a more important role in the competition between MTO and MTF. Equation (42) suggests, that a way for MTO to mitigate disruption risk is to renegotiate supply contracts as often as possible, $\mu_{ok} = 1$. Of course, buying from the spot price only has to take into account regular, without disruption, performance. Currently, the PC component spot market is easy to predict in the short term, but appears to be thin. As a result spot price behavior may change if large quantity volumes are negotiated.

Interestingly, if MTF producers cannot smooth out supply disruptions at all, $T_{Lk} = 0$, then MTO requires a totally different supply contract policy. To show this it is convenient to assume that $\beta_k^{T_f} \to 1$, i.e. disruption duration is much longer than the cash cycle. If MTO renegotiates contracts exactly at the same time MTFs do, then $\mu_{fk} = \mu_{ok} = \mu_{fok}$. In which case, the extra volatility from disruption nearly disappears:

Corollary 4.5 *Extra volatility due to disruption nearly disappears when: a)there is no disruption smoothing for MTF, and b) MTO contract renegotiation is in step with MTF. Provided c) disruption duration is long.*

$$\begin{aligned} & T_{Lk} = 0, \mu_{fk} = \mu_{ok} = \mu_{fok} \textit{ when } \beta_k^{T_f} \to 1 \implies \\ & V\{\pi^W\} - V\{\pi\} = \sum_{k \in K} V\{w_k\} \frac{(\delta - 1)^2}{\mu_{ok}} \end{aligned} \tag{43}$$

Note that typically $\delta \to 1$. Hence the extra risk from supply disruption is orders of magnitude lower than the one calculated in (42). In this case, though, MTO needs to follow in-step MTF supply contract renegotiations.

5 Conclusions

The proposed model of competition in a commoditized industry of MTF producers anticipates that entry by a MTO producer depends on three major factors. First, consumers need to take lightly the inherent consumption delay associated with MTO deliveries and think highly of the increased product variety MTO producers can offer. The loss of economies of scale by producing at lot size of one should not be very high. And third, as the MTO producer may buy production inputs with a considerable delay compared to its MTF counterparts, a pattern of declining prices in semiconductor components generates a sizable advantage to MTO, the cash cycle advantage. Equation (23), however, makes clear that no decline in inputs prices and even a slight increase on average still leaves MTO producers with an advantage, due to their inherently lower inventory cost.

In our analysis we have differentiated between regular variation in semiconductor input price and out-of-pattern behavior after disruptions. We show that regular variation fits very well to MTO supply chain strategy mainly because the total semiconductor cost is not likely to increase for long periods. Furthermore, when some semiconductor input cost increases with time for a period, a scenario which we show is common, a number of ways exist for MTO producers to ameliorate the effect of this increase. Hence, it is price shocks and not smooth cost increases that may erode MTO inventory cost advantage.

During disruptions of the global market for semiconductor components, MTO producers have few means of mitigating the cash flow risk they are exposed to. If their MTF competitors are in a position to smooth out the effect of supply disruption to themselves, then price shocks increase MTO market value volatility and, thus, reduce MTO financial performance. Of course, a smoothing out of the effect of input price shocks to MTF producers means that suppliers of semiconductor components have to shoulder the full burden of these shocks. In a highly competitive market for semiconductor components this may not be very likely. It appears, though, that the real victims of semiconductor price shocks are small producers and warehousers, those more likely to purchase low volumes. Thus, price shock smoothing by MTF producers appears not to be contrary to the fundamentals of the PC industry today.

In addition, we have showed that perfect disruption smoothing from MTF producers makes long term supply contracts less valuable to MTO. We have showed, however, that when supply disruptions affect MTF producers also, MTO needs to renegotiate PC inputs in step with MTF. This could possibly cause MTO to favor more long-term contracts. Our analysis depends on supply disruption risk being significant for MTO compared to regular volatility. If this is not the case, then supply disruptions lose their salience with MTO producers. Presently, man-made and natural causes of supply disruptions have increased in frequency and magnitude. It appears that disruption risk is gaining more and more in importance.

References

Andrea D. and B. Smith. 2002. “The Canada-US border an automotive case study.” Center for Automotive Research, Ann Arbor, Michigan.

Aizcorbe A. 2002. “Why Are Semiconductor Prices Falling So Fast? Industry Estimates and Implications for Productivity Measurement.” Finance and Economics Discussion Series 2002-20, Board of Governors of the Federal Reserve System (U.S.)

Brockwell P. J. and R. A. Davis 1991. *Time Series: Theory and Methods (2ed)* .Springer Series in Statistics. Springer-Verlag.

Cachon G. and C. Terwiesch 2003. *Matching Supply with Demand.* McGraw Hill.

Chatfield C. 1996. *The Analysis of Time Series: An Introduction (5ed).* Texts in Statistical Science. Chapman & Hall.

Curry J. and M. Kenney. 1999. “Beating the Clock: Corporate Responses to Rapid Change in the PC Industry.” *California Management Review* 42(1) 8-36.

Feitzinger E. and H.L. Lee. 1997. “Mass Customization at Hewlett-Packard: The Power of Postponement.” *Harvard Business Review* (Jan/Feb) 116-121.

Fisher M. 1997. “What Is the Right Supply Chain for Your Product?” *Harvard Business Review* (Mar/Apr) 105-116.

Grimm, B. 1998. “Price Indexes for Selected Semiconductors, 1974-96.” *Survey of Current Business* 78(2) 8-25.

Lee H. and C. Billington. 1995. “The Evolution of Supply-Chain-Management Models and Practice at Hewlett-Packard.” *Interfaces* 25(5) 42-63.

Nicholson, W. 1992. *Microeconomic Theory: Basic Principles and Extensions, 5e.* Dryden Press, Fort Worth, TX, 447–50.

Papadakis, I. and W. Ziemba. 2001. “Derivative Effects of the 1999 Earthquake in Taiwan to US Personal Computer Manufacturers.” *Mitigation and Financing of Seismic*

Risks: Turkish and International Perspectives, P. Kleindorfer and M. Sertel, eds. Kluwer Academic, Boston.

Serant, C. and B. Ojo. 2001. “OEMs walking away from contracts.” *Electronics Buyers News* April 9 1257.

Spooner J. G. 2004. “Business buying puts Dell back atop PC pile,” *Cnet News.com*, April 15.

Swaminathan J. and S. Tayour. 1998. “Managing Broader Product Lines Through Delayed Differentiation Using Vanilla Boxes.” *Management Science* 44(12) 161-172.