ABSTRACT

The research focuses on the moderating influence of macroeconomic factors on the total supply chain cost performance of inventory management and purchasing contracting decisions. Based on archival DRAM market data, system dynamics simulation will be applied to guide managerial decision-making.

KEYWORDS: Purchasing strategy; System dynamics simulation; Macroeconomic factors; Inventory management; DRAM market dynamics

INTRODUCTION

Purchasing decisions are multifaceted with many parameters. These decisions substantially impact the organization’s financial performance (Monczka, Handfield, Giunipero, & Patterson, 2011; Smeltzer & Ogden, 2002). The buyers’ decisions directly affect costs of good sold (COGS) and therefore profitability (Herbon, Moalem, Shnaiderman, & Templeman, 2012). COGS in most organizations are generally above 50 percent of the total revenues (Inderfurth, Kelle, & Kleber, 2013); hence, investigating potential opportunities for cost and profitability improvement is crucial.

The semiconductor industry provides an example of a complex supply market. Specifically the dynamic random access memory (DRAM) market is characterized by high price fluctuations with frequent new product introductions and complex product cannibalization effects. DRAMs provide a specific research context to assess cost implications of buying decisions. The high market volatility and complexity of this market necessitate analytical support tools to guide procurement professionals in their decision-making and provide some generalizability to other highly volatile industries. However, scholarly analytical approaches neglect critical aspects and focus only on specific facets of supply chain (SC) decisions. To date, the literature is limited regarding the moderating effects of macroeconomic factors and the impact of a dynamic business environment on total cost performance (Herbon et al., 2012). The extant research emphasis appears incomplete with regard to supply chain focus, functional emphasis, and the level of analysis. Concerning supply chain focus, research has emphasized downstream issues (distribution channels) (Raghunathan & Yeh, 2001; Smaros, Lehtonen, Appelqvist, & Holmström, 2003; Waller, Johnson, & Davis, 1999), but the upstream supply channel has been neglected. Concerning functional emphasis, research has analyzed many of the operational aspects with the objective of minimizing transportation and/or inventory costs (Cachon, 2001; Polat & Arditi,
2005; Yao & Dresner, 2008). Analytical research in this area typically focuses on warehouse facility locations but rarely on purchasing decision-making. Finally, concerning the level of analysis, the analytical supply chain research has focused mainly on micro-organizational aspects (e.g., dispatching rules or scheduling) (Tako & Robinson, 2012; Zee & Vorst, 2005) with minimal attention paid to macroeconomic aspects (Canbolat, Gupta, Matera, & Chelst, 2008; Wadhwa, Saxena, & Chan, 2008; Wouters, Anderson, & Wynstra, 2005). The macroeconomic perspectives pertain to economic growth, inflation rates, political-economic factors, or supply chain disruption risks that may have larger total cost implications.

There are some attempts to integrate environmental risks for enhanced decision-making in procurement (Mendelson & Tunca, 2007). Nonetheless, the sourcing decisions are highly context-dependent and it would be expected that divergent contextual influences could result in completely different outcomes. For example, when sourcing memory chips, buyers need to cope with divergent trends such as price and currency fluctuations. A buyer in Europe might not benefit from a small price reduction on the Asian spot market (calculated in US dollars) when the “home” currency Euro is declining at a steeper rate, overshadowing the price development (Carter & Vickery, 1988). One critical concern within purchasing is the selection mechanism for choosing suppliers (Mendelson & Tunca, 2007). Different modeling approaches for supplier selection decisions have been published in the literature, but all have limitations (Degraeve, Labro, & Roodhooft, 2000). Typically, researchers focus on a few variables of interest and rely on assumptions (that may be unrealistic) to make the model tractable (Griffies, Bell, & Closs, 2012). So far, research is inconclusive in regard to an appropriate analytical approach that applies to all supplier selection scenarios. Degraeve, Labro, & Roodhooft (2000) highlight the difficulty of finding a theoretically sound basis that enables an effective comparison for the different approaches available for supplier selection. Typically, key environmental factors impacting supplier selection decisions are neglected. Even the literature reviews or taxonomies leave large gaps for future research (De Boer, Labro, & Morlacchi, 2001; Degraeve et al., 2000; Ho, Xu, & Dey, 2010; ReVelle, Eiselt, & Daskin, 2008).

Most academic modeling approaches include unrealistic assumptions like the focal firm’s transactions not impacting the price levels at the spot market (Inderfurth et al., 2013). In reality, this assumption might be difficult to hold, as spot market exchanges are characterized by frequent transactions, which can quickly impact spot pricing levels (Fu, Lee, & Teo, 2010; Mendelson & Tunca, 2007). There is a need to combine the strategic use of spot markets by purchasing and also inventory management policies to investigate the specific influence of macro level environmental factors. Further investigation could enhance the understanding of this complex decision-making phenomenon. The decisions impact each other and should be investigated holistically to identify interdependencies and potential detrimental effects. Hence, the overarching purpose of this research is to better understand these interdependencies and interactions to ultimately understand how decision-making for purchasing professionals might be enhanced in these volatile markets. The specific research question is:

What is the moderating influence of macroeconomic factors such as technological obsolescence rate and currency exchange rate fluctuations on the total SC cost performance of inventory management and purchasing contracting decisions?

The research question will be addressed by system dynamics simulation modeling. This paper will proceed with a literature review, the research purpose and question, the conceptual and
hypotheses development, as well as the methodology section. It concludes with theoretical and managerial implications.

LITERATURE REVIEW

Figure 1 illustrates contract and spot market developments in the dynamic DRAM market. In addition to market fluctuations, divergent economic growth rates might impact inflation rates (and indirectly prices) to varying degrees. Therefore, analytical models could provide support in determining an appropriate inventory management policy for the mid-term time horizon.

![Figure 1: DRAM spot and contract price variations](image)

**Spot Buying and the DRAM market**

In more stable markets, purchasing operations typically include a strategic supplier selection phase followed by a long-term purchasing contract. In the DRAM market, products can be purchased either with contracts or on the spot market (Seifert, Thonemann, & Hausman, 2004), and many buyers utilize a mix of both (Fu et al., 2010). Therefore, purchasing professionals are continuously debating what quantities to contract from suppliers and what quantities to buy flexibly from the spot market (Mendelson & Tunca, 2007). In this decision-making, they have to consider the inventory levels as well as the expected impact of macroeconomic factors on costs. The issue arises of how to make the most appropriate decision for a specific situation. Research is lagging practice in comparing and contrasting different approaches and quantifying performance or cost implications of the decisions.

**Analytical Research Related to Purchasing Decision-Making**

Many researchers consider some aspects of the sourcing decision such as purchase price, purchasing transaction costs, transportation cost (Costantino, Dotoli, Falagario, Fanti, & Iacobellis, 2009) but tend to neglect quality, risks, or macroeconomic parameters. Hence, the model applicability for practitioners varies significantly. For example, typical modeling objectives are to minimize the average procurement, inventory holding, and shortage costs (Sheopuri, Janakiraman, & Seshadri, 2010; Silbermayr & Minner, 2014). However, the analytical modeling approaches typically simplify the problem to achieve tractability (Griffis et al., 2012). For instance, Keskin et al. (2010) consider procurement, inventory replenishment, holding, and backorder costs. However, they do not consider risks, quality, transportation, or
Purchasing decision-making has been studied with a focus on spot buying (Inderfurth et al., 2013; Ni, Chu, Wu, Sculli, & Shi, 2012; Xing, Wang, & Liu, 2012), perishable items (Rijpkema, Rossi, & Vorst, 2014), supply chain flexibility aspects (Wadhwa et al., 2008), or supply chain returns (Keskin et al., 2010; Ni et al., 2012; S. J. Wu & Closs, 2009). Other researchers have studied procurement auctions and bidding mechanisms (Gallien & Wein, 2005) or quantity discounts and its impact on inventory coordination (Shin & Benton, 2004). A separate research stream has focused on inventory management decision-making. Polat & Arditi (2005) conducted a comparison between lean, just-in-time (JIT) purchasing and a just-in-case (JIC) approach regarding inventory costs. Melo et al. (2009, p. 401) stressed that prior research has analyzed distribution systems “without considering the supply chain as a whole.” They noted that many relevant tactical and operational SCM decisions (incl. procurement) would need more research attention, and an integrated approach with location decision-making (Melo, Nickel, & Saldanha-da-Gama, 2009). Nevertheless, many current research studies have considerably simplified the supply chain network structure under investigation.

Optimization Models of Purchasing Questions

Optimization studies are based on assumptions or constraints, which possibly limit the practical relevance of the findings (Griffis et al., 2012; Mentzer, 1989). But practitioners seek solid and rigorous decision-making solutions. Wrong decisions could have significant financial impact particularly in the semiconductor industry (Fu et al., 2010). For example, massive DRAM price drops repeatedly impacted the bottom line of both suppliers and customers. Many organizations went out of business (e.g., Qimonda in Germany) or were forced to merge with former competitors. This highly volatile environment is impacting both suppliers and customers. Even price decline phases can be detrimental to the profitability of customers (not just suppliers), which is atypical in other industries. Recently, DELL suffered a $470 million gross profit decline due to DRAM price effects impacting its inventory value (Fu et al., 2010; Song, Yang, Bensoussan, & Zhang, 2014), clearly indicating the need to consider purchasing and inventory management concurrently along with macroeconomic factors such as obsolescence rates (technological innovation rates and corresponding product cannibalization effects).

Use of Simulation for Purchasing Questions

In contrast to optimization and heuristic modeling approaches, the use of simulation is capable of including a larger number of factors in the solution. Therefore, simulation has been used successfully in supply chain settings. For example, Shockley & Fetter (2015) analyzed distribution and transportation productivity gains through consolidation. In a multi-agent approach, researchers studied purchasing task complexity and purchasing department structures (de Boer, Ebben, & Pop Sitar, 2003). Various researchers have emphasized that procurement risks need to be considered in more depth and that the analytical models need to be extended in future research (Canbolat, Gupta, Matera, & Chelst, 2008). Globalization has added another dimension of complexity. The environment of international sourcing is characterized by changing external factors, mostly beyond the buyer’s control. Examples are natural disasters, geopolitical disruptions, demand unpredictability, fluctuations in currencies and prices, technology failures, or pandemic outbreaks (e.g., SARS in Asia in 2003; swine flu
virus in Europe). Natural disasters can happen both in developed and less developed countries. However, the recovery time (resilience level) is a significant differentiator; there will be a higher impact in countries with poor building codes or fragile, non-redundant communication networks or transportation systems (Canbolat et al., 2008). Figure 2 illustrates a number of impact factors causing the high complexity of the DRAM purchasing situation.

![Figure 2: Complexity of DRAM purchasing environment](image)

Generally, a wider perspective on the complex purchasing decision is necessary to avoid unrealistic assumptions. In addition to the distribution channel (downstream) perspective that has been emphasized by analytical research so far, the supply side (upstream) should receive more scholarly attention. Moreover, researchers should consider both micro- and macro-level factors and apply a more encompassing approach to ensure practical relevance.

**RESEARCH SETTING**

Applying systems dynamics simulation will enable the investigation of the interactive effect of purchasing strategies and inventory policies with macroeconomic factors on total SC cost performance. In an experimental design, a variety of scenarios are simulated to compare the total cost implications. Several essential assumptions are made in the research model:

- First, only one product (DRAM) is procured and no substitution is considered (e.g., no substitution of two 1GB chips for one 2GB chip).
- Second, it is assumed that the demand of the focal firm will be fully satisfied by spot market and/or contract purchases (thus, no DRAM scarcity scenario).
- Third, the entire one-product inventory is evaluated weekly and the difference between purchase price and market value is determined to calculate a positive or negative contribution to total SC costs.
- Fourth, it is assumed that the obsolescence rate impacts (in a continuous long-term trend) both the contract as well as the spot market prices.

**Rational for Applying Simulation**

The research question involves purchasing, inventory management, and external macro-economic perspectives. Such a problem would be too complex and dynamic to be solved with optimization or metaheuristic techniques (de Boer et al., 2003). Thus, this research will apply a simulation approach. The key advantage is the possibility to control the conditions of the model; with the simulation model, various scenarios can be investigated such as different inventory management policies or purchasing strategies in different market environments, for example.
Several different simulation techniques such as multi-agent, discrete-event, or systems dynamics have been developed, each with specific pros and cons. Multi-agent system simulation is well suited to address problems with multiple problem-solving entities and to deal with distributed and concurrent problem solving (Li, Ji, Sun, & Lee, 2009; Swaminathan, Smith, & Sadeh, 1998; Zee & Vorst, 2005). However, the purchasing decision-making in this research is not distributed to various agents but rather a central question, so that the specific strengths of multi-agent systems would not be utilized in this case. Another simulation option could be a discrete-event (DE) simulation set-up or the use of system dynamics (SD), which could cope with the recurrent nature of the phenomenon.

CONCEPTUAL MODEL AND HYPOTHESES DEVELOPMENT

Figure 3 depicts the conceptual model in a causal loop diagram, as derived from the prior literature review. The research will focus on two main supply chain decisions, namely the inventory management and the purchasing contracting decisions. The cost-implications of both are highly context dependent, so that no direct effect will be measured. In contrast, the moderating influence of three different environmental factors on the relationship between the two decisions and the resulting total SC costs will be analyzed. Conventional wisdom indicates that reducing the levels of inventory in the supply pipeline should usually result in reduced total costs; however, some researchers have highlighted that in certain environments, holding more inventory results in lower costs (Polat & Arditi, 2005). One example could be an environment with substantially increasing product prices or with significant detrimental cost effects on imported materials due to currency devaluations. The DRAM semiconductor market demonstrates many of these implications.

In the purchasing literature, research has differentiated between long-term contracting and the use of spot markets (Fu et al., 2010; Mendelson & Tunca, 2007), but has not considered the moderating effects of macro-level factors on total costs, which is addressed in the current model. Figure 4 depicts the underlying conceptual model for this research paper. The inventory management policies and the purchasing strategies will be explained along with the corresponding hypotheses in the paragraphs following the model.
Inventory Management Policy

Contractual inventory quantities from the entire supply pipeline are considered, including finished goods inventory at the supplier, intermediate warehousing or buffering, in-transit pipeline inventory, and incoming inventory at the focal firm. Assuming the purchase of non-perishable items with industry-typical but non-excessive obsolescence or theft risks, high inflation rates (in the supplier’s country) can overcompensate usual inventory carrying costs (including warehousing costs). Polat & Arditi (2005) observed that high inflation rates could be the most important reason for companies to maintain high inventory levels in countries experiencing high inflation rates. Furthermore, it is assumed that the buying company has access to capital from its home market (and/or outside the country of supply) because inflation and interest rates are typically correlated and thus most likely higher in the supplier’s country with high inflation. Moreover, high inflation rates influence the inventory values as well, as they result in higher component evaluations for products that have been purchased (and paid) in the past.

The technological change rate in the market is another critical aspect of inventory management policy. A new product generation will usually have a detrimental effect on the value of prior product generations (known as the cannibalization effect) (Fu et al., 2010; Seifert et al., 2004). In this regard, it is critical to differentiate between price developments (spot market or contracts) and product value development. The latter relates to customer value for the end product and new generations usually show better performance (speed, size, storage capability, energy consumption, etc.) and thus higher value. In contrast, however, the former relates to supply and demand mechanisms. Consequently, there are surprising price developments during the final transition period between old and new product generations. For example, when phasing out old DDR2-products, at one time only two or three global suppliers (manufacturers, not dealers) might remain in the market. Possibly, they might achieve some windfall profits as temporarily the old product becomes scarce.

Obsolescence

Technological turbulence refers to the degree to which technology changes over time within an industry and the degree to which those changes affect the industry (Jaworski & Kohli, 1993). Accordingly, the semiconductor market is characterized by noticeable dynamism due to rapid technological innovation cycles influencing component pricing. While dynamism relates to a high rate of change, turbulence is characterized by dynamism plus unpredictability. DRAM market developments are difficult to predict in a short-term horizon, even though they follow...
long-term cyclical trends. In dynamic markets, the risk of product obsolescence is significant. Due to short product life cycles, products in inventory can become out-of-fashion quickly and then only sold at a discount (Hayes & Wheelwright, 1979). Therefore, a rapid succession of new products results in a cannibalization effect on prior product generations (Seifert et al., 2004). In general, declining market prices affect the financial value of current inventory positions that have been purchased in the past (at higher product prices). Accordingly:

**H1a:** Low inventory levels (low safety stock levels) will lead to lower total SC costs in markets with high technological obsolescence rates.

**Currency Devaluation**

In 2014, the value of the Russian ruble fell drastically and, consequently, the component purchase prices in US$ for Russian goods declined by 50%. Another exchange rate example is the Euro (€), which fell by about 25 percent within nine to ten months. Generally, currency devaluation in the supplier’s market causes a decline of the inventoried goods values that have been paid already (Carter & Vickery, 1988; Kouvelis, 1999). Hence, it is more cost effective to keep inventory levels as low as possible when operating in a devaluation environment. Accordingly, it is hypothesized:

**H2a:** Low inventory levels (low safety stock levels) will lead to lower total SC costs when the supply market is experiencing high currency devaluation rates.

**Stockouts**

Operational supply chain improvement efforts are frequently directed at minimizing inventory levels so that inventory management costs (incl. obsolescence and devaluation risks) are kept low. However, lower inventory will typically result in lower service rates. The probability for product unavailability (stockouts) and the total SC costs could increase because the focal firm could be harmed by tangible and/or intangible losses (Wan & Evers, 2011). The penalty for impact of the stockouts varies from market to market and from customer to customer. There are primarily four different outcomes of a stock out (Coyle, Langley, Novack, & Gibson, 2009):

1) The customer waits until the product is available.
2) The customer back-orders the product.
3) The company loses current revenue.
4) The company loses a customer and future revenue.

One possibility is that the customers (internal or external) accept the stockout situation and simply wait until the product is available again. If future customer order decisions were not negatively affected, then the penalty for this occurrence would be relatively low. However, should the customer permanently defect to a competitor, then the stockout costs would be high due to lost future revenue and profit potential. The probability of stockouts is related to inventory levels because the higher the inventory levels, the higher the service level achievable (Closs, Nyaga, & Voss, 2010). Even unforeseen events (supply chain disruptions) can be compensated with available inventory (Marquez & Blanchar, 2004). In contrast, a low inventory level will expose the organization to SC risks which could result in higher total SC costs due to relatively higher stockout costs (Gu, Zhang, & Li, 2015). Therefore:

**H3a:** Low inventory levels (low safety stock levels) will lead to higher total SC costs when the stockout costs are high.
Purchasing Contracting Strategy

The purchasing decision determines the general type of relationship to be pursued with suppliers (e.g., arm’s length versus partnering/alliance) and the specific contractual conditions (e.g., long-term or short-term contracts) (Rijpkema et al., 2014). Research has analyzed the implications and benefits of long-term contracting versus spot market procurement (Inderfurth et al., 2013; D. J. Wu & Kleindorfer, 2005). Spot markets provide companies the opportunity to better cope with demand and supply fluctuations (Fu et al., 2010; Song et al., 2014) and to respond flexibly to unexpected demand increases or inadequate capacity reservations. Spot prices are usually highly volatile (Xing et al., 2012) and have been considered as random changes in prior research (Inderfurth et al., 2013), so that their use causes a financial risk. The use of spot markets offers both an opportunity for lower costs and a threat of higher costs (Kirche & Srivastava, 2010; Xing et al., 2012). Spot markets are responsive to economical developments (Fu et al., 2010) so that a period of high inflation will result in quick price adaptation on spot markets; in contrast, the long-term contract pricing is typically more stable and slower in adaptation to economic trends.

Obsolescence

A dynamic environment with a high rate of technological change requires suppliers to invest continuously in R&D and production capability (Slater, Mohr, & Sengupta, 2014); this capability development follows a learning curve, initially limiting manufacturing capacity (when innovative technology is newly introduced to the market). Therefore, in markets with high technological dynamism, innovative products could be sparse in the beginning before manufacturing capacities have been increased to fully meet new product demand. Some examples could be semiconductors for new gaming consoles (Song et al., 2014), or scratch-resistant, hardened glass for Apple’s iPad (Isaacson, 2012). Spot markets would respond quickly to potential capacity shortages in contrast to long-term contracts, where pricing is typically less responsive (Fu et al., 2010). Spot markets can become illiquid and offer insufficient quantities for market participants at times (Mendelson & Tunca, 2007). The relational view theory (Dyer & Singh, 1998) would indicate that the buyer should benefit from being a preferred customer (customer of choice) in a long-term contracting relationship. Thus, the buying company could expect to receive preferential allocation of the scarce innovative product and suffer less than competitors that rely exclusively on spot markets. Furthermore, in periods of scarcity such as during the transition period between old and new product generation, the spot market prices are usually higher than the contract prices, leading to:

**H1b**: Contracting (in contrast to spot market use) will lead to lower total SC costs in markets with high technological obsolescence rates.

Currency Devaluation

In dynamic market environments, customers’ needs are particularly difficult to predict; consequently, organizations face uncertainty regarding the best long-term technology and market paths to follow (Calantone, Garcia, & Dröge, 2003). In unstable market environments, spot markets adapt more quickly. Companies can quickly take advantage of declining market prices (Carter & Vickery, 1988). Two currency effects could cause softening product prices. These are either a foreign currency decline (supply market) or a home country currency increase (sales market) (Angelini, Dieppe, & Pierluigi, 2015). It is thus hypothesized:

**H2b**: Spot market use (in contrast to contracting) will lead to lower total SC costs when the supply market is experiencing high currency devaluation rates.
Stockouts

The use of spot markets is an instrument to enhance flexibility (Inderfurth et al., 2013). The purpose for the organization is to better and more quickly adapt to environmental changes (Ni et al., 2012; Xing et al., 2012). Administrative procedures and routines are already proactively established to handle unforeseen events by taking advantage of the spot market. Therefore, even unexpected problems (e.g., supply chain disruptions) can be countered more effectively, and potentially detrimental effects can be compensated for more easily. By regularly using the spot market, the organization achieves a more effective level of responsiveness and adaptability to external changes. Accordingly, it appears that:

**H3b:** Spot market use (in contrast to contracting) will lead to lower total SC costs when the stockout costs are high.

Total SC Costs

The dependent variable, total SC costs, is based on the accumulation of many individual cost elements. The term refers to all of the costs incurred in importing finished goods, semi-finished goods, raw materials and/or components from one country into the country of destination (typically the buyer’s country). Total SC cost combined with the total cost of ownership (TCO, which includes pre-transaction, transaction and post transaction costs) will provide complete transparency of the cost of moving products from one country to another (Ellram & Tate, forthcoming). Total SC cost requires an analysis of the boundary spanning activities, as does TCO (Wouters et al., 2005). In the literature, many different elements of total SC costs have been identified. Table 1 lists the main elements of that construct.

Table 1: Main elements of total SC costs (adapted from Ellram & Tate, forthcoming)

<table>
<thead>
<tr>
<th>Purchase price</th>
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<tbody>
<tr>
<td>Handling and transportation costs, including fuel surcharges</td>
</tr>
<tr>
<td>Expediting costs (incl. fees for fast shops or overnight shipments/airfreight)</td>
</tr>
<tr>
<td><strong>Inventory carrying costs</strong></td>
</tr>
<tr>
<td><strong>Inventory obsolescence costs</strong></td>
</tr>
<tr>
<td>Duties and taxes</td>
</tr>
<tr>
<td><strong>Insurance fees</strong></td>
</tr>
<tr>
<td><strong>Procurement administrative costs</strong></td>
</tr>
<tr>
<td>Supplier and or specific product qualification costs</td>
</tr>
<tr>
<td><strong>Currency conversion and currency hedging costs</strong></td>
</tr>
<tr>
<td>Supplier monitoring and developing efforts</td>
</tr>
<tr>
<td>Quality-related costs such as assurance efforts, defect prevention, appraisal, and rejection costs including product rework and damage costs</td>
</tr>
<tr>
<td><strong>Customer service penalties (incl. the financial value of compensation measures)</strong></td>
</tr>
<tr>
<td>Risk and compliance measures</td>
</tr>
<tr>
<td><strong>Service recovery or backordering costs (shortage costs) to keep the customer after significant supply chain delays (e.g., free trial products to bridge the waiting period)</strong></td>
</tr>
<tr>
<td>Additional indirect costs (e.g., watchtower for complex supply chain operations or financial risk monitoring of suppliers)</td>
</tr>
</tbody>
</table>
METHODOLOGY

Simulation has been referred to as the art and science of designing a model that acts in the same way as a real system (Elam, Anderson, Lamphere, & Wilkins, 2011; Law & Kelton, 2000; Polat & Arditi, 2005). Some of the key advantages of this modeling method are the ability to analyze complex systems without making limiting assumptions, to fully control the system, and to incorporate random occurrences for input analysis (Evers & Wan, 2012). Simulation is highly flexible and, in contrast to optimization methods, can cope with a relatively large number of variables and parameters, so that real systems can be mirrored as close as possible. Thereby, the scenarios replicate the procurement phenomenon in a more realistic and relevant way. For example, well-validated models are capable of simulating the stochastic and dynamic behavior of environmental variables such as demand variations (Longo & Mirabelli, 2008) and serve as a context for testing (Tongarlak, Ankenman, Nelson, Borne, & Wolfe, 2010).

For this model, the number of different purchasing scenarios is high, so that the use of optimization techniques would be infeasible; however, a simulation model can cope with the number of different purchasing strategies or inventory management policies and environmental factors either separately or in interaction with each other. Dynamic simulation represents causal events and their consequences (actions) within one system. In this purchasing and inventory management context, either the use of discrete-event (DE) or systems dynamics (SD) simulation approaches appears as a viable option. In their recent literature review, Tako & Robinson (2012) identified common domains of both DE and SD applications in the logistics and supply chain context. The authors underline that SD is frequently used for inventory planning and management decisions while DE is applied to analyze replenishment control policies and supply chain optimization. The authors conclude that simulation is relatively seldom used to analyze supplier selection or other purchasing issues. Both DE and SD simulation techniques will be assessed concerning the usefulness to address the research question of this paper.

Discrete Event Simulation

In discrete-event simulation, conditions and variables are changing at specified (discrete) points in time due to specific events. Thereby, sensitivity analysis can be conducted without the necessity of changing parameters in a real-life setting. Procurement-related decision-making was simulated in different contexts from varying research perspectives. Examples include the integrated sourcing and inventory decisions (Keskin et al., 2010), a procurement transaction cost analysis (Costantino et al., 2009), the most effective sourcing strategies for perishable product supply chains (Rijpkema et al., 2014), or the mitigation of procurement risks due to volatile commodity pricing with a hedging strategy (Ni et al., 2012). Tang and colleagues (2004) have developed an enterprise simulator to support e-solutions-based procurement in a B2B context. Others have applied regression analysis, optimization, and simulation modeling of a production-distribution network to assess the cost effectiveness of allocation strategies under uncertainty (Ahire, Gorman, Dwiggins, & Mudry, 2007). Overall, however, DE provides no option to simulate recursive flows and is therefore not optimal for addressing the research question.

Systems Dynamics Simulation

Originating with Forrester who introduced a systems perspective, the SD approach has been developed separately from the DE technique (Forrester, 1961). SD is particularly capable of simulating complex systems with multiple, interrelated parameters and variables as well as
nonlinear process flows. Hence, the SD method is well suited for addressing this research question where different rates are interconnected in causal relationships that are characterized by various feedback loops (Sterman, 2000). SD has been applied primarily on a “larger” supply chain network context and considerably less for a specific function such as purchasing. For example, SD has been applied to validate a SC network configuration by measuring inventory and backorder levels (Kristianto, Gunasekaran, Helo, & Sandhu, 2012).

Nonetheless, one of the rare purchasing simulation studies has focused on different contraction options using an SD simulation approach (Marquez & Blanchar, 2004). However, the authors emphasized contracting strategies and neglected the spot market as a potential complementary alternative strategy for purchasing to deal with demand uncertainty. Overall, SD is chosen as the best-suited simulation technique to address the research question of this project. Archival data will be used from industry records to obtain empirical distributions and to represent the stochastic nature of the demand. Furthermore, sensitivity analysis will be performed to assess the impact of purchasing or inventory policy changes. Critical will be the use of actual DRAM demand data from one organization to use for model verification and validation.

**Experimental Design**

As depicted in the previous section in Figure 4, two main factors are included in the experimental design, inventory management policy and purchasing strategy. For the former, two levels are considered (safety stock levels of one and six weeks). For the latter, five levels with a varying mix between spot market and contracting are considered. The experiment will focus on the interaction effects between those two main factors and three environmental variables (technological obsolescence rate, currency devaluation risk, and stockout costs). There are only two different levels of technological obsolescence rate but three levels for the other two potential moderators represented in the experiment. The dependent variable is total SC cost as the only performance outcome to be measured. The purchasing performance will be captured sufficiently with this single item because cost includes the qualitative dimension as well.

The experiment to be tested with simulation follows a $2 \times 5 \times 2^* 3^* 3$ design with 180 cells. The research project follows prior studies with similar experimental design (e.g., S. J. Wu & Closs, 2009). However, there are four critical assumptions inherent in the modeling set-up:

- Only one product is procured, no substitution considered (e.g., no substitution of two 1GB chips for one 2GB chip)
- Entire demand of the focal firm will be fully satisfied by spot market and/or contract purchases (no DRAM scarcity)
- Entire DRAM inventory is evaluated weekly and the difference between purchase price and market value is determined to calculate a positive or negative contribution to total SC costs
- Obsolescence rate impacts spot (short-term) and contract (mid-term) price levels

**Replications**

The number of statistically necessary replications, the compulsory warm-up duration until steady stage has been reached, and the adequate replication duration will be calculated by using the guidelines of prior simulation research models (Law & Kelton, 2000; Rabinovich & Evers, 2003; Sargent, 2000; Tongarlak et al., 2010; Wan & Evers, 2011; S. J. Wu & Closs, 2009). The number of replications will be determined so that the means of the dependent variables are estimated within a five percent level of precision across all replications (Rabinovich and Evers,
2003, p. 220). The warm-up period estimation procedures of Welch will be followed, as suggested by Rabinovich & Evers (2003). Some researchers recommend a high number of replications (e.g., 100 times) to enable the calculations of means and standard deviations for the collected statistics, so that statistical confidence intervals can be calculated and statistical hypothesis testing could be performed (Elam et al., 2011).

**Model Verification and Validation**

In simulation modeling, the verification and validation steps are critical to ensure a high degree of validity and reliability of findings. Various researchers have outlined these essential sub steps to be performed thoroughly to prove the methodological rigor (Elam et al., 2011; Polat & Arditi, 2005; Sargent, 2000; S. J. Wu & Closs, 2009). Model verification is concerned with controlling the internal calculations of the simulation to detect potential internal errors. The outcome of the code should be verifiable so that potential programming errors can be detected. Model validation is focusing on how representative the simulation results are of the real world – whether the simulation represent the actual phenomenon (real-life process) accurately. Thus, a model might be verified but still not valid due to unrealistic parameter selections or assumptions, for instance.

**IMPLICATIONS**

**Theoretical Implications**

There are three main theoretical contributions. First, the current paper addresses the interdependencies between various influence factors that have not been addressed together in the literature yet. Specifically, macro-level contextual factors that moderate purchasing decisions’ influence on total SC costs. For example, purchasing strategies and inventory management policies are jointly analyzed with market plus exchange rate fluctuations to achieve a holistic understanding. This enables to gain deeper insights of this complex phenomenon and to contribute to the current body of knowledge.

Second, this paper is extending the application of simulation methods to the purchasing field. Only a few researchers have applied simulation for purchasing phenomena. However, the system dynamics approach is a powerful methodology to deal with feedback loops. In this way, the recursive impact on spot markets, the connectedness between various market participants’ actions and the price-determination mechanism are highlighted. Likewise, the various factors that are affected by and, in turn, affect the GDP growth rate, are represented in the larger, extended model. Current research has relied on a more sequential conceptualization excluding recursive flows.

Third, obsolescence effects have received limited attention. In this research study, the obsolescence rates (cannibalization effects) and their impact on inventory values and market prices are considered. This is a theoretical contribution as the existing conceptualizations are complemented and completed. The purchasing decision, including spot market and contracting options, is complex in markets with high technological dynamism. Consequently, incorporating obsolescence in the analytical modeling approach enhances the understanding.

**Managerial Implications**

Purchasing professionals can use the results of this research to reflect upon their inventory management and purchasing contracting practices. They can verify the relevance for their
particular business environment. The total SC costs implications of these environmental forces have been described in detail to enable practitioners to adjust their procurement strategies and decision-making. For example, the traditional approach of inventory minimization policy could be revisited in light of the results of this research project; the conventional wisdom might not hold in all instances. Therefore, a new trade-off decision has surfaced for procurement managers. Relevant parameters for operational, tactical, and strategic supply management decision-making have been depicted with this research. The simulation model, once validated, could be applied by practitioners to conduct sensitivity analysis for critical procurement decisions. By addressing what-if questions, the financial implications of critical decisions can be evaluated beforehand, avoiding costly (or fatal) managerial mistakes.

LIMITATIONS AND FUTURE RESEARCH

The complex purchasing decision is influenced by a variety of factors, which have not yet been fully captured. Therefore, a number of additional macro-environmental factors such as political stability, regulatory environments, etc. could be added to the model in the future. Environmental factors have been considered as moderators, but their direct effect could also be studied. For instance, a simulation model could investigate the direct effects of the three second-level constructs micro-context, macro-context, and logistics (transportation)-context on total SC costs. Furthermore, a better integration of global sourcing research with the transportation and location optimization research should be attempted. For instance, transportation modes (air, sea, rail, street) could be compared in different scenarios of varying environmental impacts. An interesting phenomenon to be studied would be the interaction effect among transportation-related and contextual factors and the corresponding implications on total SC costs.

The public opinion impact on sourcing decisions (e.g., running sweatshops in Asia) has not yet been analytically addressed; the data collection and parameterization appears difficult in this context. Some researchers have studied the impact of market or supplier capacity constraints on purchasing decisions; this research stream could be extended by considering macro-level factors in a global context (Canbolat et al., 2008). Research has also not addressed the phenomenon of technological change and its influence on procurement decision-making in sufficient analytical detail. Moreover, the specific inventory obsolescence risk due to internal cannibalization and the related strategic decision-making of new product introductions and corresponding sourcing decisions would be another fruitful avenue of future research (Zsidisin, Ellram, Carter, & Cavinato, 2004). Analytical modeling research has tended to neglect the implications of “soft” cross-cultural aspects including language barriers and intercultural human or communication effects (e.g., handling of negative, detrimental facts/updates to avoid losing face in some Asian countries) when addressing global sourcing or supply chain phenomena; this would be particularly relevant for the individual or team level of analysis. Future research could extend the application of sophisticated simulation modeling with the other analytical techniques such as optimization and/or metaheuristics, so that the methodological tool set can be extended.

Finally, product substitution options are an additional avenue for further research. In this research project, the DRAM market has been a very specific context. However, a system dynamics simulation approach could address similar research questions in different settings. Overall, opportunity for extending this research on purchasing decision-making appears plentiful to further enhance the body of knowledge.
REFERENCES


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