# Information Technology and The Vertical Organization of Industry

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## Abstract

A model has been developed to study the interdependence between a firm's choice of information technology and degree of integration, and the structure of its industry.

Advances in information technology might provide incentives for a firm to specialize or focus on its core competence. However, the success of its specialization strategy depends on the extent of industry-level specialization, which is, in turn, the result of the behavior of individual firms and their adoption of information technology favoring specialization.

Electronic markets and industries have been chosen as an application domain, as they would not even exist without information technology. Furthermore, they are very dynamic emerging industries with rapidly changing structures.

# 1 Research Problem: Information Technology and Industry Structure Evolution

The literature suggests that over time industry structure evolves from industry-level integration to industry-level specialization (i.e., Chandler 1990, Arora et al. 1997/98). Initially, firms and industries tend to be integrated.[1] At an early stage of an industry, the option to "make or buy" items unique to that industry is most likely reduced to "make", because a "buy" alternative may simply not exist. For one, suppliers may not exist. For another, too few suppliers could use their market power to make inputs prohibitively expensive or refuse to sell inputs at all. Theses coordination problems are known as the small numbers bargaining problem and market foreclosure respectively (e.g., Whinston 1990, Ordover 1990). In 1913, Ford was nearly 100% vertically integrated, producing almost all of its inputs. Over time, firms and industries appear to become more specialized.[2] Today, automakers typically provide only 30%-40% of a car's value added (Womack et al. 1990, 33-35). A similar observation has been made for digital interactive services such as consumer online services (Schlueter-Langdon 1999). The only providers that survived the early 1990s infancy stage were highly vertically integrated (e.g., America Online, CompuServe and Germany's BTX/T-Online). The ones that failed—even before the Web became popular—were far less integrated (e.g., Delphi, eWorld and Europe Online).

Across industries, firms have to understand the dynamics of industry evolution to make appropriate decisions on the scope of business activities—the degree of integration—and choice of technology to support these activities. This is particularly important for entrants. Once a market and strategic position have been identified, decisions on the scope of activities and choice of technology become the foundation and skeleton of any financial business plan. This must be done before moving on to specify implementation issues, such as a business process design and marketing planning.

This paper aims to investigate the dynamics of industry structure evolution by analyzing the impact of information technology and selected market structure variables on the success of specialization strategies. Specifically, we try to analyze how the performance of specialized firms is effected by its choice of information technology and the degree of industry-level integration.[3]

[1] Perry describes a firm as vertically integrated if "it encompasses two single-output production processes in which either (1) the entire output of the "upstream" process is employed as part or all of the quantity of one intermediate input into the "downstream" process, or (2) the entire quantity of one intermediate input into the "downstream" process is obtained from part or all of the output of the "upstream" process" (1989, 185). This notion of vertical integration rules out the case in which some of the output of the upstream process is employed as some of the input in the downstream process. "Vertical integration also means the ownership and complete control over neighboring stages of production or distribution" (Perry 1989, 186).

[2] Specialization, it should be noted, should not be confused with size; automakers, for example, are becoming more specialized as they outsource manufacturing and assembly to suppliers while at the same time becoming bigger by merging with competitors.

[3] "The vertical organization of industry is an important topic that has not received its due attention. There has been a great deal of work on vertical ownership but not on [the competitive characteristics of "open" and "closed" forms of industry organization and their welfare implications]" (Farrell et al. 1998, 170-171). The authors define "open" as a "regime when firms add one stage of value and put the results back in the market, rather than controlling a longer segment of the value chain" (150). This definition is compatible with the one for industry-level specialization as used here.

This decision problem is very obvious in the area of digital interactive services, such as Web portals (i.e., Yahoo!) and electronic commerce providers (i.e., Amazon). These emerging industries would not even exist without new digital information technology (IT), such as the Internet and Web protocols (i.e., TCP/IP, HTTP, HTML, URL) and related software applications (i.e., NCSA Mosaic Web browser and HTTPd server).

From the perspective of an entrant such as a start-up, specialization is a preferable choice for several reasons. First, integrated entry is usually very expensive, and, if not achieved through a single merger or acquisition, but rather many small steps it can be also very time-consuming. Second, an integrated entrant would be exposed to competition along many processes, while a specialized entrant could focus on a smaller set of activities. In the area of online and Web services, only Microsoft's MSN (Microsoft Network) tried to compete head on with America Online. Others chose to focus on specific areas only (i.e., Yahoo!'s directory and search, GeoCities' online communities of interest and chat, Uunet's Internet access service).

The trend toward industry-level specialization or open structures is facilitated by technological progress and specifically by the emergence of standards. Many industry studies suggest that the emergence of standards or modular design coincidences with an increase in the number of specialized producers.[4] Once equipment can be broken into components, production processes can be separated and reorganized to better facilitate the division of labor. Instead of building cars by making and assembling all its pieces in one place, today, parts (disks) are manufactured worldwide and assembled into components (disk brake), which are build into systems (axle complete with suspension and brakes), which in turn are finally assembled into a car. As companies wish to focus on those sets of components and related skills that they consider to be their core competence, ownership may be divided as well (Pralahad and Hamel 1990).[5] Thus firms become more specialized and the industry as a whole opens up. As the division of labor implies trade between specialized agents, benefits of specialization for any agent also depend on the efficiency of trade or market transactions between agents. Research has revealed that IT, in particular, has the potential to significantly lower transaction cost, making market coordination less costly than hierarchy (Malone 1987, Table 1, 485), thereby providing further incentives for specialization.

While specialization appears to be a viable strategy in a highly specialized industry and vertical integration an appropriate strategy in a highly integrated industry, choices become less obvious for situations in between. There are several complications.

Firstly, specialization is only a choice if it is technologically possible, which may not be obvious. Information technology presents itself as a steady stream of promising product announcements every day. Only time and trials reveal which one has the potential to emerge as a standard. Although the Web protocols (HTTP, HTML, URL) have already been invented in 1990 it took more than five years for them to evolve as popular standards (www.w3.org;

[4] An overview of recent case studies is provided by Arora et al. (1997/98). The example of the computer industry is discussed in Farrell et al. (1998, 144-145).

[5] According to a Harbour & Associates study, Detroit's Big Three have significantly reduced in-house production. Ford and Chrysler, for example, have even outsourced the production of brakes entirely ("Make It of Buy It?" 1996).

www.merit.edu).

Secondly, specialization should potentially be more successful—profitable—than vertical integration. Success could depend on the potential cost advantages from specialization over vertical integration, such as lower fixed and variable production cost, as well as lower transaction cost between specialized agents. Just as with standards, only time and trials typically reveal the profit impact of new software applications. Many Web start-ups, for example, remain unprofitable despite being in business for a couple of years already.

Thirdly, it may take others to release the cost savings potential of specialization, or, in other words, it depends on industry-level conditions. This is obvious in a situation where all incumbents are vertically integrated. Without suppliers, a firm cannot specialize. The firm would have to create its own suppliers and competitive markets for inputs, which appears to be quite challenging for a single firm. If two firms would simultaneously decide to break up vertically into two firms each, then they could immediately create two competing suppliers. Therefore, from the perspective of an individual firm, its decision to adopt technology to specialize depends on the behavior of other firms. In other words, individual decisions depend on industry-level conditions, which, in turn, are the result of the collective behavior of firms.

Fourthly, as new information technology is introduced continuously, the viable degree of specialization is also constantly shifting. While an industry's history may reveal a clear path toward specialization its extension into the future is difficult to predict. In order to make better decisions it would be helpful to understand the dynamics of industry evolution.

# 2 The Model

## 2.1 Research Question and Hypotheses

In order to analyze the dynamics of IT-enabled industry structure evolution we investigate the choice of specialization strategies. Specifically, we ask what strategy should an entrant adopt with regards to choice of information technology and degree of integration?
The subject of our analysis is, therefore, a specialized firm.[6] The dependent variable is the specialized firm's profit. Among the four independent variables are two firm-level variables and two industry structure variables. The firm-level variables include (1) choice of information technology and (2) degree of integration. The industry structure variables are (3) number of firms in the industry and (4) the degree of industry-level integration.

In order to keep the research problem simple, values for each of the aforementioned variables have been simplified.

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[6] The objective is not to optimize the performance of the entire production system—global performance—which may not maximize each firm's performance—local performance. In Farrell et al.'s model, for example, specialization throughout the supply chain or "open" interaction leads to the socially optimal outcome because it minimizes costs (1998). As a firm's profit is not only determined by cost the socially efficient choice does not need to be the most profitable. In their model and specifically in the case of Bertrand competition, cost heterogeneity drives industry profits, which in turn provides firms with a joint incentive to create a structure that maximizes cost heterogeneity and not necessarily minimizes cost.

*Choice of Information Technology*. Only two information technology alternatives are distinguished: “old” versus “new”. “Old” information technology is understood as monolithic, proprietary platforms or dedicated, standalone systems with very high fixed cost and low variable cost. “New” information systems are considered modular and compatible with moderate fixed and variable cost. In the area of digital interactive services information systems have evolved from proprietary client-server systems, such as the America Online information system, to open and compatible component technology, such as the Web protocols, browser and server. The arrival of the latter made it possible for many firms to enter digital interactive services markets such as Yahoo!, Excite and Lycos.

*Degree of Integration*. Firms can either be specialized on one stage of a production system or integrated across two stages. Integration is limited to 100% integration. In other words, if a firm is integrated across two sequential production stages it produces only and all the inputs it needs for its downstream stage.

*Number of Firms and Industry-level Integration*. There are only two industry scenarios: (1) a closed or integrated industry with few but mostly integrated firms (I*i*) and (2) an open or specialized industry with many and mostly specialized firms (I*s*).

This selection of variables and range of values creates a matrix of four different situations/settings as depicted in Table 1.

| **Industry/Supply Chain Structure Scenario** | **IT Options** | |
|---|---|---|
| | “**Old**” IT | “**New**” IT |
| **Integrated and Few Firms** (***Ii***; most firms are integrated, few suppliers) | H1: Being integrated is more successful (profitable) than specialization. | |
| **Specialized and Many Firms** (***Is***; most firms are specialized, many suppliers) | | H2: Being specialized is more successful than integration. |

**Table 1: Overview of Settings and Research Hypotheses**

For now, two settings have been chosen with one hypothesis each: H1 for the scenario of industry-level integration and “old” IT. H2 for industry-level specialization and availability of “new” IT.
Having specified the research problem and stated the research hypotheses, the following section will denote how the characteristics of the research problem have been modeled in order to test the research hypotheses.

## 2.2 Supply Chain Modeling and Simulation

Two models could be found that address the dynamics of industry evolution (Arora et al. 1997/98, Farrell et al. 1998). Both models investigate the process of vertical integration and disintegration. They differ in that Arora et al. “explicitly investigates the dynamics of industry structure evolution in a competitive market setting, albeit with boundedly rational firms” (Arora et al. 1997/98, 3), while Farrell et al. consider strategic interaction (Bertrand and Cournot competition).
In order to investigate the dynamics of an entire industry with multiple business segments, the

use of simulation experiments is viewed as a promising approach.[7]

## 2.3 Conceptual Model

In order to model the research problem of an optimal entry strategy, the following key components need to be incorporated: (1) an industry, (2) firms, and (3) a supply chain. Also, the following issues have to be addressed: How to recognize or differentiate (1) the structure of a firm, (2) states of IT, and (3) industry-level feedback.

In the model, an industry is conceptualized as being composed of firms, with similar firms representing a business segment, such as manufacturers and retailers. Firms are composed of at least one business process, which, in turn, is comprised of production and cost functions. A supply chain defines the order of the main business processes or, in other words, the successive stages of value-added.

Combining different processes creates firms with different structures. A firm with one process is considered specialized, while a firm composed of a combination of processes is referred to as an integrated one. Different states of IT are reflected in the shape of cost functions ($C_{FIX}$, $c_{VAR}$), which are embedded in a business process.

The industry-level feedback mechanism is achieved by coordinating the interaction of firms along the value chain through markets. Therefore, each firm is at the same time a buyer of inputs and a seller of outputs.

In order to identify viable entry strategies, the success of different types of firms at the same stage in the supply chain has to be studied. The performance of an individual firm within a supply chain configuration is measured by its profits, which are derived by subtracting cost of inputs and production from revenues made by selling output to the firm’s most downstream market. Due to market coordination of production activities, the performance of each firm, as well as system performance, is the result of the collective behavior of many agents, as opposed to more traditional approaches—in particular, neoclassic economic models that follow a top-down design with aggregate demand and supply functions representing an economic system.

## 2.4 Complex Adaptive System Architecture

### *2.4.1 Multi-Agent System and Enterprise Integration Modeling*

The conceptual model has been implemented as a multi-agent system (MAS). Its design process has benefited from the application of a formal multi-agent framework of coordination in enterprise integration developed by Sikora and Shaw (1996) and from Holland’s complex adaptive system (CAS) modeling methods (1995, 10–40).

The architecture of the MAS model shares characteristics of enterprise integration models,[8] such as multiple level abstraction in representing organizational structures, communication

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[7] Chaturvedi and Mehta, for example, suggest to use agent-based simulation models as “that for an even moderately complex economic model, there is very little hope of actually solving the problem” (1999, 60). See also Rust (1996).

[8] Lin, Tan, and Shaw provide a brief overview of selected, more recent enterprise integration models (1996, 3-4).

between participants via message-passing, and agent adaptability as well as properties of CAS models, such as flows and aggregation.

Furthermore, the MAS modeling process and, in particular, the implementation of the model have benefited from two CAS simulations: Lin's supply chain network application (1996) and the Anasazi village formation simulator (Kohler and Carr 1996). Lin's model supports the evaluation of approaches for improving order fulfillment performance in supply chain networks in manufacturing. Kohler and Carr's model is utilized in the analysis of the Anasazi village formation, a prehistoric settlement system in Southwest North America.[9] Both models have been among the first applications using the Swarm toolkit.[10]

### *2.4.2 Building Blocks, Flows, and Aggregation*

Figure 1 provides a high-level overview of the architecture of the MAS model. It represents a production system or supply chain which can be broken down into three stages of processes which contribute to the transformation of two types of raw materials into one final good.

[9] While Lin's simulator resembles complicated process chains, albeit with linear interaction, the Anasazi village application features simple processes but adaptive behavior instead of linear interaction. This complication can produce non-linear outcomes, which in turn could allow for the study of emergent behavior such as settlement formation. In the Anasazi village simulator, the smallest unit of analysis or core agent is not a business unit/process but a household. It requires inputs (e.g., food, space for living and farming), generates output (corn), can grow (birth of children) and shrink (death of household member), and engages in trade with other households. The Anasazi village implementation has been a valuable case example, because it features a primitive exchange mechanism. Lin's supply chain network application, in particular, provided insights into the implementation of multiple layer abstractions utilizing Swarm's nested inherent hierarchy property.

[10] Swarm is a general purpose, multi-agent simulation software platform developed at the Santa Fe Institute. It is particularly well-suited for the study of complex adaptive systems, since it allows discrete event simulation of [economic] interactions between heterogeneous agents (firms, markets) and a collective environment (an industry), as well as between agents themselves (Minar et al. 1996a, 1996b; Hiebeler 1994).

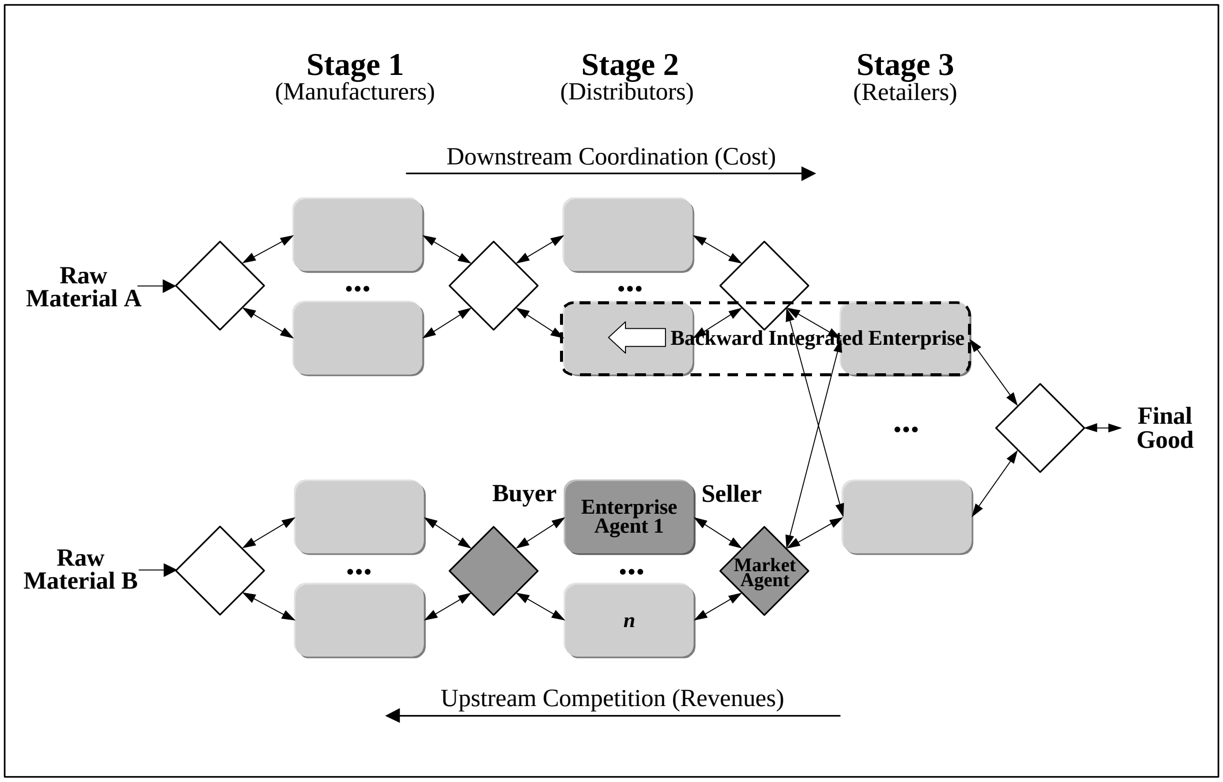



**Figure 1: Architecture of the Simulation Model**

The final stage of processing requires two intermediate goods, each produced in separate process strings. These joint process strings are in turn composed of a two-stage sequence of processes each. This convergent supply chain design is compatible with the high-level abstraction of a generic value chain for digital interactive services as described in Schlueter and Shaw (1997).

The supply chain stages are implemented as process agents, each of which is assigned to one firm or enterprise agent. Enterprise agents of the same stage represent a business segment. Integration of an enterprise agent into the next stage upstream is achieved by also assigning a process agent of that stage to the same enterprise agent. If input requirements of the enterprise agent's core process can be provided entirely by its upstream process agent, then this configuration is considered 100% vertically integrated. Please note that firms can currently only be integrated backwardly; although a 100% backward integrated retailer-type firm (stage three) would be no different from a 100% forward integrated stage-two-type firm. Any degree of integration below 100% would make a difference, however.

Enterprise agents interact with each other through market agents. Because each enterprise agent is a seller of its output and, at the same time, a buyer of inputs required to produce the output in the first place, market agents facilitate two flows throughout the system: the flow of goods downstream and revenues upstream.[11] Some of the revenues made from the sale of the final good downstream are passed on to enterprise agents upstream as a reward or return for their contribution to the final value added. The share of revenues distributed upstream depends

[11] Flows are one of Holland's essential characteristics of a complex adaptive system (1995, 23-27, 38).

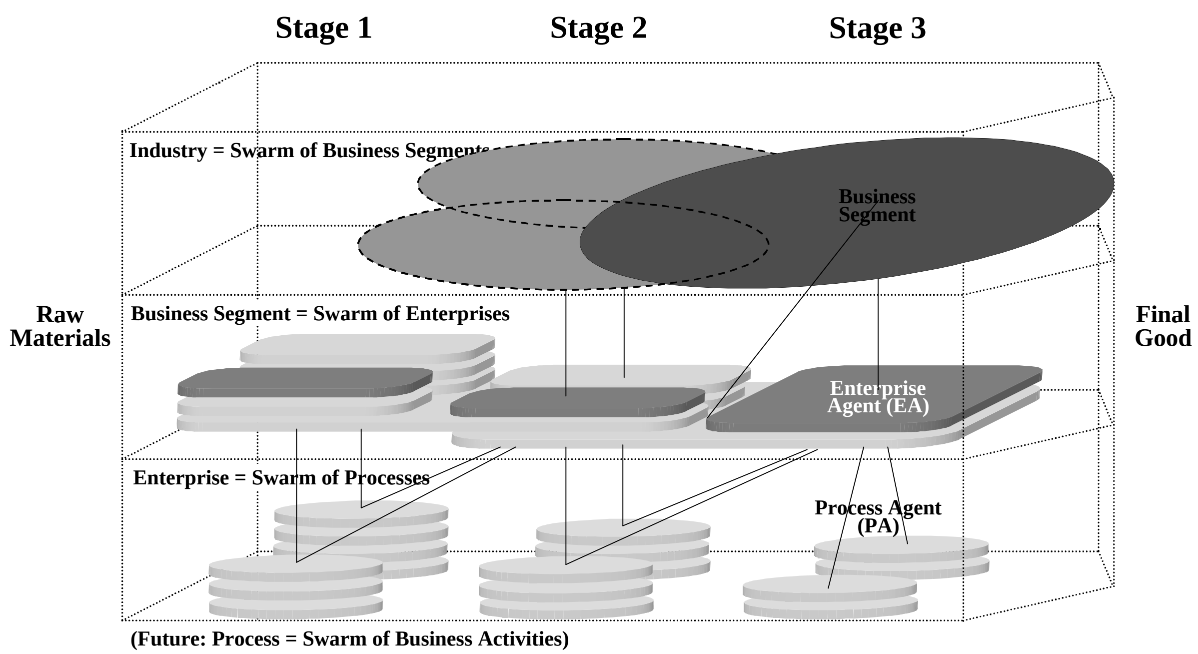
on conditions with local markets such as the number of buyers and sellers. This decentralized credit-passing scheme provides performance incentives throughout the entire system (i.e., Holland 1995, 42 and 53-60). Backward integration reduces an enterprise agent's dependence on upstream market conditions. As illustrated in Figure 1, 100% backward integration would allow bypassing of an upstream market altogether.

Figure 1 also reveals an important design method called building blocks (Holland 1995, 34-37; actual building blocks can be perceived as agents in the context of multi-agent systems). The method refers to the decomposition of a complex scene into few, distinct categories of components and relationships. Building blocks can be reused and combined to create relevant, perpetually novel scenes. With decomposition and repeated use of building blocks, novelty arises through combination. Even with only a few sets of categories of components or building blocks and rules for combining them, an exponentially large number of different configurations can be assembled.

The challenge with building blocks is the decomposition of a complex scene into as few and most relevant categories of components and rules for combining them—also referred to as dependencies—as possible. If this can be achieved, building blocks provide great scalability and efficiency with reconfiguration.

Building blocks become even more powerful when applied to aggregation or tiered designs. Aggregation "concerns the emergence of complex large-scale behaviors from the aggregate interactions of less complex agents" (Holland 1995, 11).[12] It is considered a basic characteristic of all complex adaptive systems. Figure 2 illustrates how aggregation has been achieved through the nested hierarchies (i.e., enterprise = swarm of processes) and multiple-layer design (i.e., industry, business segments and enterprises) of the multi-agent system: Different low-level process agents are combined to form enterprise agents. Similar enterprise agents aggregate to create different business segments, which in turn represent an industry.

[12] Aggregation corresponds to the concept of sub-agents in Sikora and Shaw's multi-agent system framework (1996, 1998).




*Source: Adapted from Schlueter, C., and M. J. Shaw. 1998. An Organizational Ecosystems Simulator Applied to Electronic Commerce. Proceedings of CIST/INFORMS April 1998 Conference held in Montreal, Canada.*

**Figure 2: Building Blocks and Aggregation**

This design allows for patterns of high-level events to derive from the settings of low-level building blocks. A change in conditions of process agents, such as an increase in scale economies, trickles up through higher layers to create some aggregate outcome that can be observed at the top layer, such as an increase in industry concentration. In other words, higher-level events, such as changes in industry structures, emerge from lower-level conditions and dynamics of interaction.

Having introduced the three types of agents—enterprise, process and market agents—and high-level relationships, the following paragraph takes a look inside each agent and its dependencies.

### *2.4.3 Agent Functions and Dependencies*

Figure 3—a detail of Figure 1 (agents marked in gray)—reveals how tasks have been distributed throughout the system. Each agent carries a distinct functional component: $F_{EA}$ = {Adaptation}, $F_{PA}$ = {Production}, and $F_{MA}$ = {Clearing}.

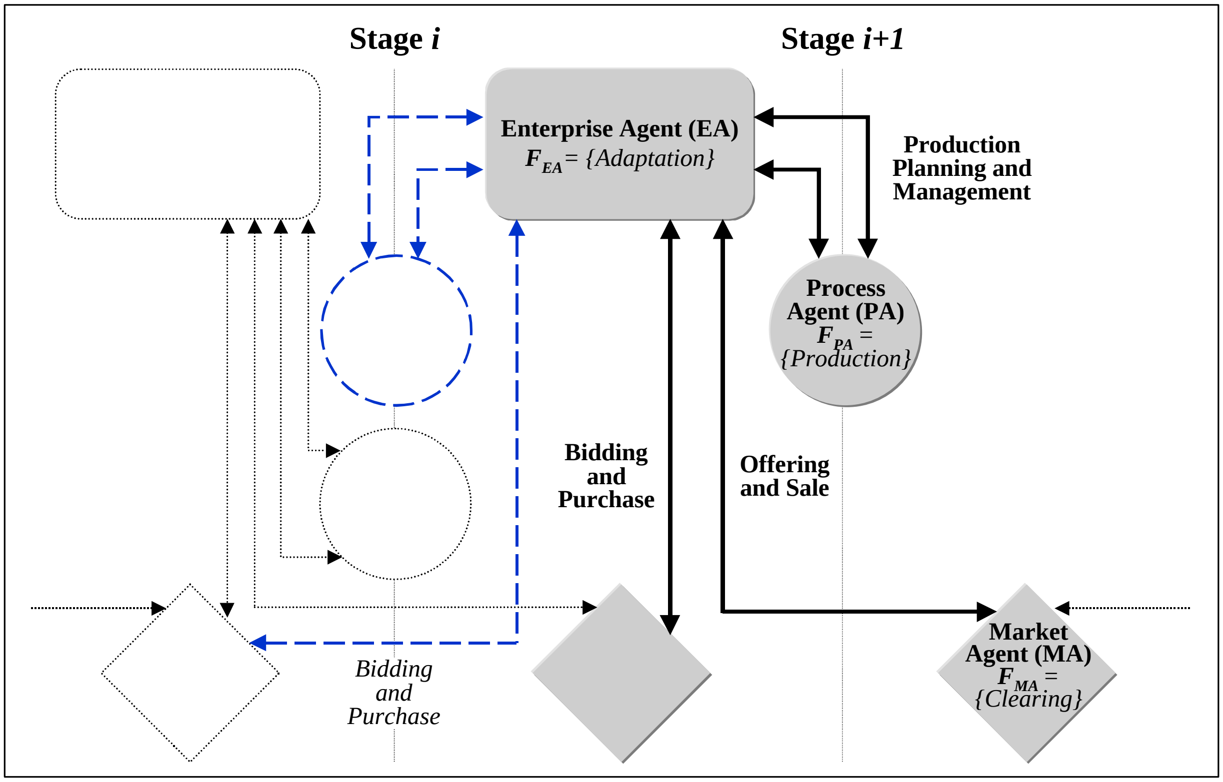



**Figure 3: Building Blocks and Interdependencies**

Agents or their embedded functional components are linked with each other through dependencies. In this multi-agent system, four different links are sufficient to create a multi-stage supply chain. If one wishes to turn the selected enterprise agent into a backward integrated firm with production capabilities also in stage 1, then this could be achieved with the current set of components:  One process agent and three interdependencies would have to be added as indicated with dotted lines in Figure 3.

The following three paragraphs will explain each of the embedded functions or methods.

*Enterprise Agent Activities and Functions*

Enterprises are composed of at least one process agent. They plan and manage production, which is executed by their process agents. Enterprise agents buy non-labor process inputs and fund production of their process agent(s). Purchasing overhead and SG&A (Selling, General & Administration) charges are currently not considered. There is no inventory build-up of either inputs or output; excess supplies and unsold goods are completely written off within one value creation cycle. (This is a very reasonable assumption as direct supplies and the final products in DIS markets are usually services, such as an online newspaper.)

In the case of integrated firms, the enterprise agent is comprised of at least two process agents, internal sourcing is maximized to fully utilize the pre-assigned in-house share (called *InHouseShare* in the software code).

Figure 4 illustrates how the *InHouseShare* variable can be utilized to “dial-in” a particular coordination mechanism.

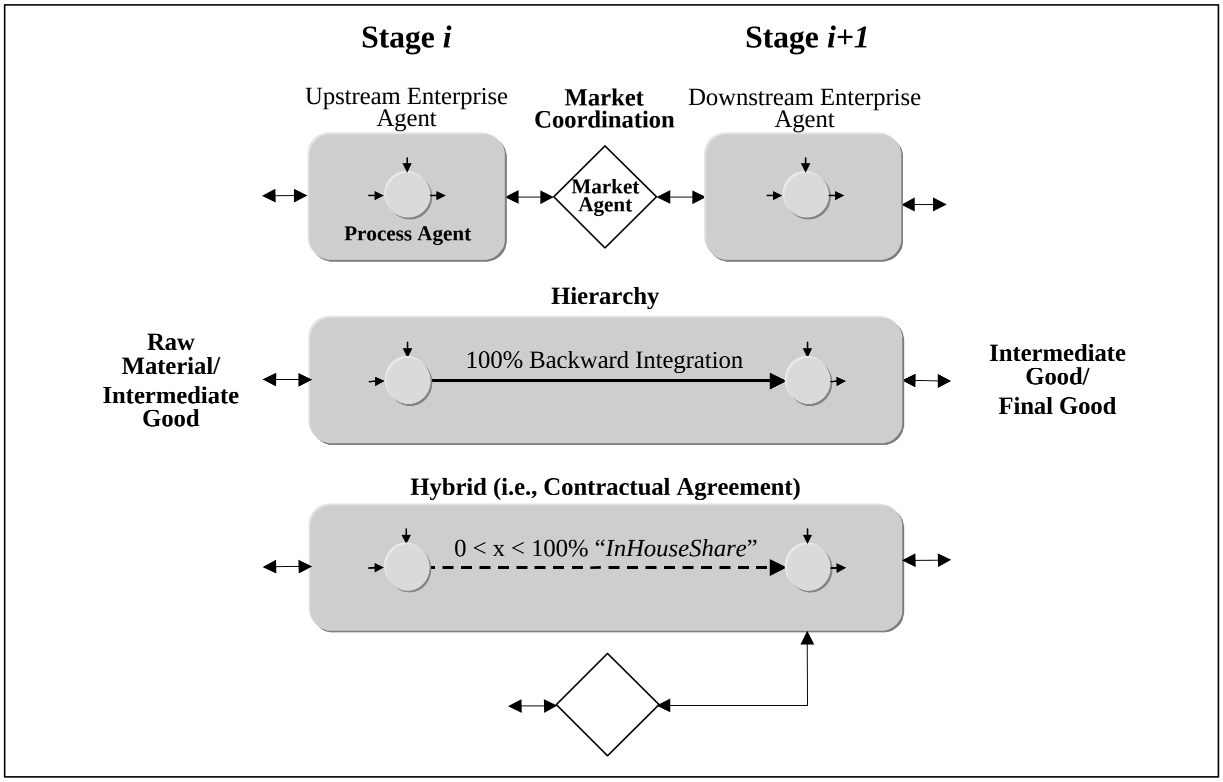



**Figure 4: Enterprise Agent—Flexibility of Coordination Mechanism}**

As the *InHouseShare* can vary between ≥ 0% and ≤ 100%, the entire spectrum of coordination alternatives between the two extremes of hierarchy and market can be implemented (Coase 1937, Williamson 1975). A hybrid configuration, for example, could be chosen to capture the impact of a contractual agreement.

The total enterprise agent costs are given by:

$$C_E = \sum_{k=1}^{n_P} C_{P_k} + C_{EP_k} \qquad \text{(E-1)}$$

| | |
|---|---|
| $k$ | Number of enterprise processes |
| $n_P$ | Most upstream process of the enterprise |
| $C_{Pi}$ | Process cost function |
| $C_{EPi}$ | Cost of process inputs |

The costs of inputs for each process are given by:

$$C_{EP}(t_i) = dp_{aP}(t_i)\, p_{aP}(t_{i-1})\;\; a_P(t_i)\, x_1 + dp_{bP}(t_i)\, p_{bP}(t_{i-1})\;\; b_P(t_i)\, x_2 \;+\; p_{gP}\, x_3$$

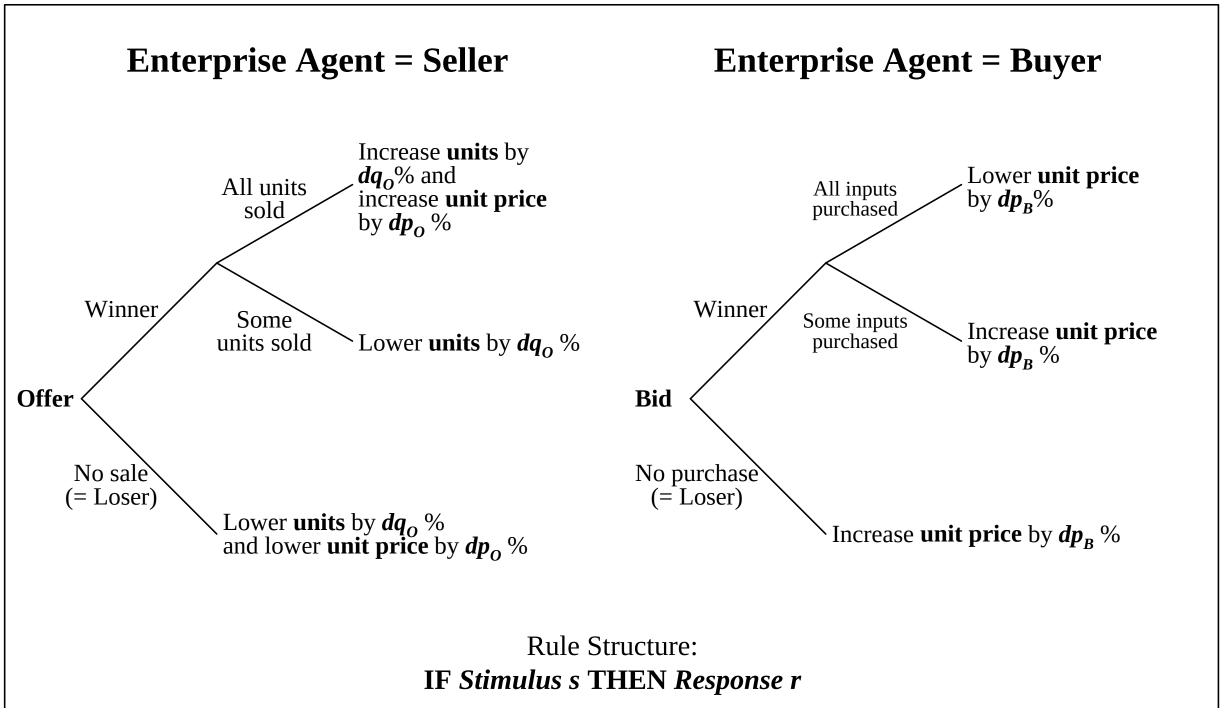
(E-2)

| | |
|---|---|
| $t_i$ | Time step $i$ |
| $p_{aP}(t_{i-1})$ | Unit price of process input α |
| $dp_{aP}(t_i)$ | Unit price change of process input α |

$p_{bP}\ (t_{i-1})$ Unit price of process input β

$dp_{bP}\ (t_i)$ Unit price change of process input β

Decisions on market interaction (offer price and quantity, bid price) are made on an enterprise level and based on distributed (every firm), primitive “learning” (“IF stimulus s THEN response r” rules) and production requirements (bid quantity). Figure 5 depicts the decision trees which underlie the adaptation rules (rules reflect bounded rationality).




*Source: Adapted from Schlueter, C., and M. J. Shaw. 1998. An Organizational Ecosystems Simulator Applied to Electronic Commerce. Proceedings of CIST/INFORMS April 1998 Conference held in Montreal, Canada.*

**Figure 5: Enterprise Agent—Decision Trees for Market Adaptation**

Decision-making is based on rules, which determine the adaptive behavior of an enterprise agent. As sellers, enterprise agents make offers and have to decide on price and quantity; as buyers of inputs, they submit bids and make a decision on bid price. Decisions are made simultaneously; no firm commits to its offer and bid prior to its competitors.

*Process Agent Activities and Functions*

For each core process, it is assumed that two inputs are needed to produce one unit of output [$Q_P = f(x_1, x_2)$]. The relationship between inputs is such that output is limited by the most scarce input [$f(x_1, x_2) = \min\{a_P x_1, b_P x_2\}$—a Leontief case, as opposed to a Cobb-Douglas function with substitutive factors].

The effect of input expansion on the amount of output is assumed to be one with constant returns to scale; thus, cost functions are linear, “which is often a reasonable assumption to make about technological structures” (Varian 1984, 18):

$$Q_P\,(x_1, x_2, x_3) = a_P\, x_1 + b_P\, x_2 + g_P\, x_3 \qquad \text{(E-3)}$$

$x_1$ In-system or direct input type 1
$x_2$ Direct input type 2
$x_3$ Out-of-system input or in-direct input
$a_P$ *InSystemNeed0* (name of variable used in the software code)
$b_P$ *InSystemNeed1*
$g_P$ *OutSystemNeed*

Each core process exhibits fixed and variable cost:

$$C_P\,(Q_P) = C_{FIX} + c_{VAR}\, Q_P \qquad \text{(E-4)}$$

$C_{FIX}$ Process fixed cost (*FixCost*; i.e., depreciation and amortization)
$c_{VAR}$ Variable cost of process value added (*CashNeed*; i.e., production set up, talent management)

*Market Agent Activities and Functions*
Each of the stages of the supply chain is linked with a market agent. As market agents communicate with enterprises only and as enterprises might be 100% backwardly integrated across several stages some market agents might be idle during simulation runs.

The most upstream market of the entire supply chain system is called the raw materials market, the most downstream market is called the final good market and markets in between are also referred to as intermediate good markets.

A market agent matches buyers’ bids and sellers’ offers, applying a pre-specified mechanism. Figure 6 depicts market and enterprise interaction.

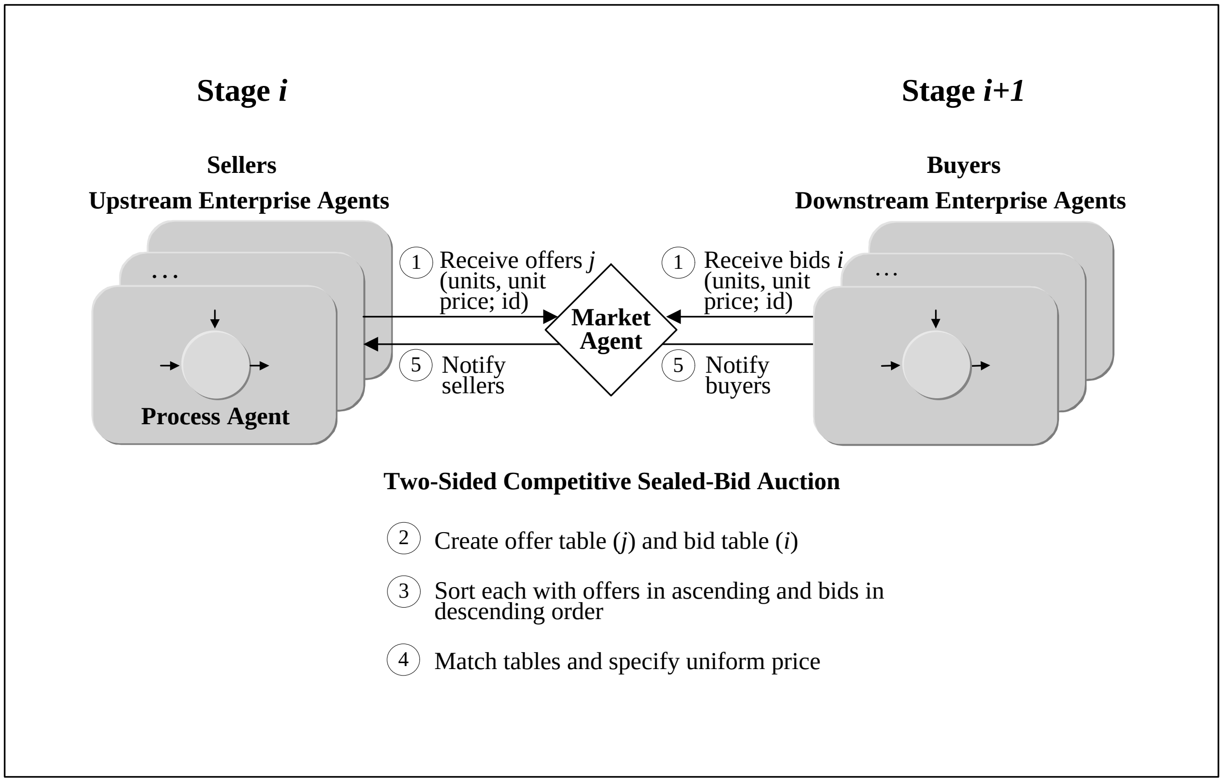



**Figure 6: Market and Enterprise Agent Interaction**

Currently, a two-sided competitive sealed-bid auction mechanism has been implemented. Kambil and van Heck provide an overview of different auction models and implications (1996). Competitive markets in general have proven to create highly efficient results in allocating scarce resources. The mechanism chosen resembles a stock market. The marketplace agent collects offers and bids (units, unit price) from enterprise agents and sorts them into two separate tables (offer-table and bid-table), with offers in ascending order and bids in descending order. Then a second column is created for each table, accumulating unit volume for each price position such that any offer table field shows the maximum of what gets offered at same row price, while any bid table field shows the maximum of what will be bought at same row price. Finally, a uniform price is set to be the lowest accepted bid, maximizing exchange revenue (not transactions).

The clearing mechanism can be formally described as:

$$\text{Uniform\_Price} = \max_{\forall i}\left\{ p_{B_i} \,\middle|\, p_{B_i} \cdot \min\left[ u_{B_i}, \max_{\forall j}\left( u_{O_j} \,\middle|\, p_{O_j} \leq p_{B_i} \right)\right]\right\} \tag{E-5}$$

$p_{B_i}$ Bid unit price

$u_{B_i}$ Bid units

$p_{O_j}$ Offer unit price

$u_{O_j}$ Offer units

Since all successful buyers pay the same market-clearing price, this institution is considered to create an impression of fairness (Kambil and van Heck 1996).

## 3 Implementation

Swarm proved to be a very appropriate tool to build simulation applications for the analysis of supply chains.[13]

In order to investigate emergent industry structures, a new simulation application had to be developed and built. Non of the available Swarm-based simulators provided the functionality required for organizational analysis, such as vertical integration and market coordination. The resulting simulator is not just another application, but rather a new tool kit designed to facilitate organizational analysis. It is a library of reusable supply chain modeling components that enable rapid development of customized decision support tools. It features a few relevant, yet simple building blocks (components/agents and rules/dependencies) that can be arranged to quickly create complex scenarios without losing flexibility and ease of modifications. The system is called ORECOS (ORganizational ECOsystems Simulator) (Schlueter and Shaw 1998). It takes advantages of key concepts in object-oriented development, such as inheritance and polymorphism, to increase scalability and flexibility for adaptation and change.

Instances of enterprise types are actual agents employed in simulation runs.
In order to run a particular application, six input files are currently required, which shape a specific experimental setting based on ORECOS system functionality: SuperSettings.data (defines number of vertically related steps in the supply chain structure and relations), MarketFile.data (specifies location of markets in step structure), EPTypes.data (defines different types of enterprise agents), EPInstances.data (specifies enterprise agent instances within enterprise agent type parameters), CPTypes.data (defines different types of core process agents), and CPTypesVar.data (specifies randomization of enterprise adaptation). The system architecture has been implemented and the system code written by Peter Bruhn, Christoph Schlueter and Gek Woo Tan.[14]

The functionality of the ORECOS system has been validated through a staged testing of its components (Schlueter-Langdon 1999).

## 4 Experimental Design

The goal of the simulation experiments is to facilitate the identification of successful entry strategies for emerging DIS industries. Two settings with different industry-level concentration and process cost conditions have been created to reflect conditions in emerging online information markets. Because of the choice of abstraction in the conceptual model and

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[13] Lin et al. provide a brief overview of how to use Swarm as a simulation platform (1999, 18-19) and how to apply it to implement a (hierarchical) supply chain network model (20-23). Lin also provides a mapping of supply chain and Swarm properties (21).

[14] A first version of the software code is available in Bruhn (1997, Appendix). First simulation experiments and results have been published in Schlueter and Shaw (1998).

implementation limitations, simulation experiments will only share modest similarities with online information markets.

Because the model is designed to investigate conditions in intermediate good markets or the inner-workings of the production system only, complications for input and output of the system have not been considered. Therefore, in both settings, demand for the final good is increasing linear and supply of raw materials is unlimited.

A simulation experiment advances in time steps. For both scenarios, one time step has been chosen to represent a one-month time period. Each simulation experiment or run is conducted over 24 time steps or two years.[15] At each time step, firms adapt to market conditions as explained in paragraph 2.3.2 (Agent Functions and Dependencies) and illustrated in Figure 5 (Enterprise Agent: Decision Trees for Market Adaptation). This decision process is randomized in that values of unit and price change are drawn from a normal distribution with a constant variance (e.g., a 5% change is implemented as ì = 5 with ó = 1).

Figure 7 illustrates how the two settings differ in terms of structural conditions in intermediate good markets.

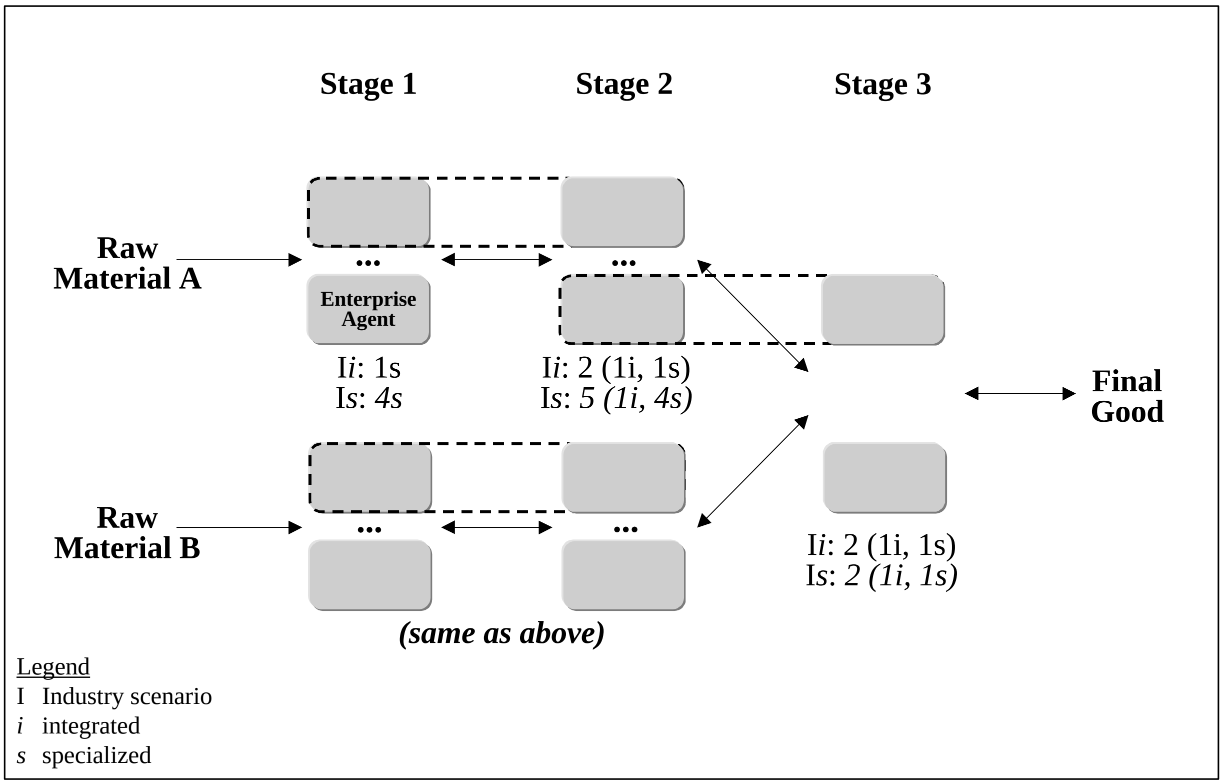


**Figure 7: Two Industry Scenarios—Number of Firms and Industry-level Integration (I*i*) versus Industry-level Specialization (I*s*)**

The scenario of industry-level integration (I*i*) is two firms at stage 1, four firms at stage 2—one backward integrated and one specialized enterprise for each input string, and two firms at

[15] Two years may already be too long a time period considering that the DIS industry is still in its early phase of the product life cycle, which is usually characterized by rapid product innovation and change of share distribution (i.e., Klepper 1996).

stage 3 (one backward integrated firm and a specialized one). Twelve firms have been added to create the settings for the second scenario of industry-level specialization (I*s*). While conditions at stage 3 remain the same, specialized firms have been added to stages 1 and 2.

Because all integrated firms have been chosen to be 100% backward integrated, the condition in intermediate good markets for scenario I*i*, for example, is characterized by a constellation of one seller facing two buyers between stages 1 and 2 and two sellers facing one buyer between stages 2 and 3. 14 and 26 process agents are required in order to implement the scenarios I*i* and I*s* respectively (see Appendix, Table A1).

Assumptions about cost functions are based specifically on observations of the market for online information services and electronic publishing. Internet/Web technology has significantly altered cost structures. In particular, modularity and compatibility have changed scale and scope economies in IT implementations. In the simulator, economies of scale and scope can be created on a process level through different combinations of fixed and variable cost ($C_{FIX}$, $c_{VAR}$).

Scope advantages exist when one firm can produce multiple products more cheaply than single firms can produce each product separately.[16] The actual values for selected parameters of production functions and cost functions do reflect relative differences, however, in order to keep the simulation simple, at the expense of true resemblance of electronic publishing markets.

With "old" IT cost function values reflect the assumption that integrated firms enjoy a clear cost advantage. Fixed cost and variable cost parameters of specialized firms are 25% higher than those of integrated firms.

Furthermore, it is assumed that a scope advantage of 10% remains between integrated firms using "old" IT and specialized firms using "new" IT.

Further details and values for all variables are provided and explained in Schlueter-Langdon (1999, 152-157; see Appendix Tables A2 and A3).

For each of the two scenarios (I*i* and I*s*) many runs have been executed. For each run, the cost functions have been altered to reflect choices of IT ("old" vs. "new"). In order to test the success of a specialized entry for both scenarios, profits of the most downstream (stage 3) firms (R*i* vs. R*s*) have been measured and compared.[17] In a scenario of industry-level specialization (20 firms in the industry) and availability of "new" IT, for example, the firm R*s* can be interpreted as an entrant that is using "new" IT to compete with the incumbent R*i*. In this scenario, rival R*i* may still use "old" IT (such as a proprietary platform with high fixed cost and low variable cost) or already "new" IT.

[16] Scope economies provide an integration incentive if the production of more than two goods, firstly, depends on the same proprietary know-how base, and, secondly, requires the same specialized indivisible assets as input (i.e., Teece 1980).

[17] If losses are incurred and if cumulative losses exceed cash account balance, then a firm would drop out of the simulation run, or, in other words, exit.

## 5 Simulation Results and Discussion

A multi-step approach has been devised to start and maintain simulation runs (or steady state). In order to create a "living" system in compliance with the specifications outlined in Section 4 (Experimental Design), the following features have been added sequentially: First, a linear system (no enterprise adaptation to market results) has been configured with every enterprise agent producing output profitably. Second, adaptation and growth have been introduced.

In the setting of industry-level integration and "old" IT (upper left quadrant of Table 1) and with enterprise decisions on units of output only (no price adjustments; either a unit increase of 5% or a decrease of 5% (ì = 5 with ó = 1, normal distribution), the most downstream specialized firm (3*s*) did not survive a run of 24 time steps. A 5% increase in unit output per time step would translate into an annual unit growth rate of about 80%. Given fallen DIS prices, the growth rate in the simulation corresponds well with growth in DIS markets (Schlueter-Langdon 1999, Figure 2D-4, 25). Because volatility appeared to be too high and the rule-based adaptation mechanism not smooth enough, further experiments have been conducted with a reduced rate of change of units of output and prices. A rate of +/- 2.5% has been chosen. A 2.5% increase in unit output per time step would translate into an annual unit growth rate of approximately 34% which is approximately half of the compound annual growth rate of Internet host growth for the four years from end of 1994 to end of 1998 (Schlueter-Langdon 1999, Figure 2D-3, 25).

In the setting of industry-level specialization, when enterprise decisions are based on change of units of output and unit price—price of input(s) (bids) and output (offers)—and specialized firms use "new" IT and integrated firms employ "old" IT, the specialized firm (3*s*) tends to be more profitable than its integrated rival. Despite lower process cost resulting from scope advantages through integration, specialization appears to be at least as successful, if not more, than integration in the scenario of industry-level specialization.

Figure 8 depicts the aggregated results of a series of ten randomly selected runs for the third stage firms (D9s4-0 to D9s4-9; each for 24 time steps and for the first 12 time steps; 3*i* = integrated third stage firm, 3*s* = specialized third stage firm; Figure A1 in the Appendix shows the results of a single, random run).[18]

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[18] All variables and initial conditions were the same across all runs, except for the seed used to generate the random numbers within a run. All initial conditions and the value of the seeds used to generate the random numbers have been recorded, so that any particular simulation run can be recreated.

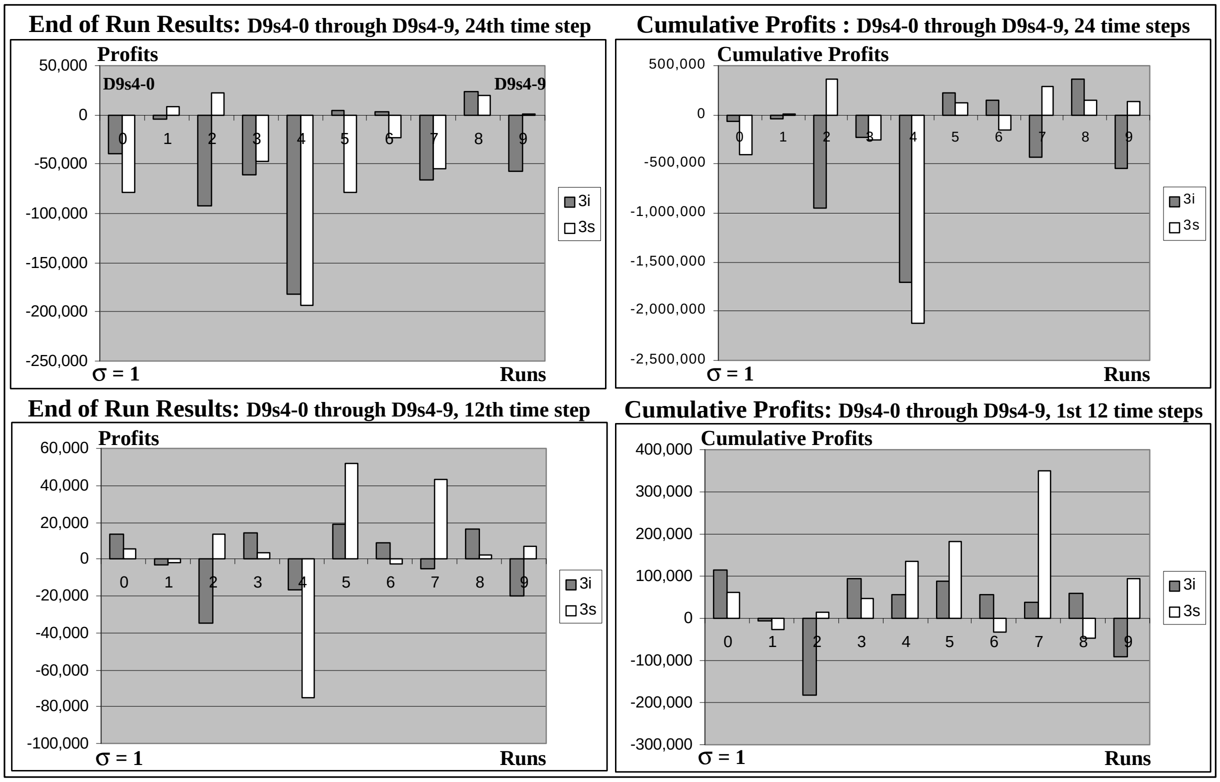


**Figure 8: Summary of Results**

After 24 time steps, the specialized firm is profitable in four out of ten runs versus three out of ten for its integrated rival (upper left diagram in Figure 8). Because 24 time steps, or the equivalent of two years, may be too long a time period for the infancy stage of a product life cycle, results after 12 time steps of the same runs have also been considered. After the first 12 time steps, the specialized firm is profitable in seven out of ten runs and the integrated one in five out of ten (lower left diagram in Figure 8). While both firms have been profitable in the same run four out of ten times and unprofitable in two out of ten cases at time step 12, the values deteriorate to one and four out of ten respectively at time step 24. These results suggest that, in this scenario, the industry itself may become less attractive over time. These suppositions are confirmed by the development of cumulative profits. Over 24 time steps, the specialized enterprise agent is profitable in six out of ten runs versus three out of ten for its integrated rival (upper right diagram in Figure 8). After 12 time steps, both firms show cumulative profits in seven out of ten runs, however, the total net cumulative results (profits) for the specialized firm exceed the one of its integrated competitor by approximately 245%; lower right diagram in Figure 8. Also, cumulative results appear to support the conclusion drawn from point-in-time results that the industry, in this scenario, is becoming less attractive over time. While both firms show cumulative profits in the same run in five out of ten cases and losses in only one run after 12 time steps, these values change to two out of ten and three out of ten after 24 time steps. Even total net cumulative results, which have been profits after 12 time steps, turn into big losses after 24 time steps. Nonetheless, losses of the specialized enterprise agent are still more than 40% lower than those of its integrated rival.

Statistical analysis reveals only week evidence that the performance of the 3*s*-firm is better than that of its integrated rival 3*i*. Assuming that observations are values of random normal variables, a t test for paired samples is applied (as 3*s* and 3*i* interact through the same markets;

observations are not independent). For $\alpha = 0.05$ and $H2_0$ (profits/losses are the same) and $H2_A$ (3*s* is more successful), $t_{12}$ (= 1.236; cumulative results for the first 12 time steps) and $t_{24}$ (= 0.747; cumulative results after 24 time steps) are less than $t_C$ (= 1.812; t distribution, 10 degrees of freedom, single-sided test) (Bleymüller and Gehlert 1988, 124). Therefore, $H2_0$ cannot be rejected. In other words, the test suggests that financial results of 3*i* and 3*s* do not differ. Given that there is a bias toward 3i success, because 3i enjoys production cost advantages as shown in Table 4-7, specialization or specialized entry appears to be a viable strategy in this particular industry scenario.
For $\alpha = 0.2$ and the same $H2_0$ and $H2_A$, $t_{12} > t_C$ (= 0.879; t distribution, 10 degrees of freedom, single-sided test) (Bleymüller and Gehlert 1988, 124). Therefore, $H2_A$ is accepted. In other words, with a type-1 error of $\alpha = 0.2$, financial results of 3*s* are better than the ones of its integrated rival. For $\alpha = 0.25$, $t_{24} > t_C$ (= 0.7).

The simulation results conform well with the observation and analysis of DIS markets (Schlueter-Langdon 1999). In DIS markets, the largest and most successful firms have been initially highly vertically integrated. America Online, for example, has built strong vertically integrated competencies, which have been advantageous in becoming and remaining the product innovation leader. Major acquisitions and alliances have facilitated internalization of these competencies such as the purchase of ANS for $35 million in November 1994. Less integrated rivals, such as Delphi, fell behind the integrated leaders, while others, such as Europe Online, failed outright.
With the emergence of the Web standards and popularity of Web software application and information systems many new firms have entered digital interactive services (Schlueter-Langdon 1999, Figure 2D-7, 29). At the same time service offerings have been expanded beyond online information and electronic publishing markets into other vertical markets such as financial services (i.e., E*Trade brokerage, Bank24 retail banking), travel services (i.e., MS-Expedia and Travelocity travel stores) and many other consumer goods categories (i.e., Amazon book retailer, CDNow music CD retailer).

# Appendix

| **Categories of Firms** (Enterprise Agent Supertypes and Types) | | **Firm Structure** | | | | | **Supply Chain Structure** (Number of firms per scenario and per type) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Main process | Backward integration into ... (%) | | | | Industry-level integration | | Industry-level specialization | |
| | | | $p_{11}$ | $p_{21}$ | $p_{12}$ | $p_{22}$ | EAIs | PAIs | EAIs | PAIs |
| Manufacturer A | | $p_{11}$ | | | | | 1 | 1 | 4 | 4 |
| Manufacturer B | | $p_{21}$ | | | | | 1 | 1 | 4 | 4 |
| Distributor A | DA*i* | $p_{12}$ | 100 | | | | 1 | 2 | 1 | 2 |
| | DA*s* | | | | | | 1 | 1 | 4 | 4 |
| Distributor B | DB*i* | $p_{22}$ | | 100 | | | 1 | 2 | 1 | 2 |
| | DB*s* | | | | | | 1 | 1 | 4 | 4 |
| Retailer | R*i* | $p_{13}$, $p_{23}$ | | | 100 | 100 | 1 | 4 | 1 | 4 |
| | R*s* | | | | | | 1 | 2 | 1 | 2 |
| Total Number of Enterprise and Process Agent Instances | | | | | | | 8 | 14 | 20 | 26 |

**Table A1: Supply Chain and Firm Structures**

Legend

| | |
|---|---|
| $p_{xy}$ | Process type, string *x* and stage *y* (current implementation: 2 strings and 3 stages) |
| *i* | Integrated firm |
| *s* | Specialized/focused firm |
| EAI | Enterprise agent instance (actual enterprise agent) |
| PAI | Process agent instance |

| **Coefficient** | **Production Processes** | | | | | |
|---|---|---|---|---|---|---|
| | $p_{11}$ | $p_{12}$ | $p_{13}$ | $P_{21}$ | $P_{22}$ | $P_{23}$ |
| $a_P$ | 1 | 2 | 2 | 1 | 2 | 2 |

**Table A2: Values for Production Functions—Example**

| **State of IT** | | **Process Cost** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $p_{11}$ | | $p_{12}$ | | $p_{13}$ | | $P_{21}$ | | $P_{22}$ | | $P_{23}$ | |
| | | $C_{FIX}$ | $c_{VAR}$ | | | | | | | | | | |
| "Old" | DA*i* | 9 | 2.25 | 13.5 | 1.8 | | | | | | | | |
| | DB*i* | | | | | | | 27 | 1.8 | 18 | 1.8 | | |
| | R*i* | | | 13.5 | 1.8 | 18 | 1.8 | | | 18 | 1.8 | 18 | 1.8 |
| | DA*s* | | | 16.88 | 2.25 | | | | | | | | |
| | DB*s* | | | | | | | | | 22.5 | 2.25 | | |
| | R*s* | | | | | 22.5 | 2.25 | | | | | 22.5 | 2.25 |
| "New" | DA*s* | | | 15 | 2 | | | | | | | | |
| | DB*s* | | | | | | | | | 20 | 2 | | |
| | R*s* | | | | | 20 | 2 | | | | | 20 | 2 |

**Table A3: Cost Function Values—Example**

Legend

| | |
|---|---|
| D | Distributors (2$^{nd}$ stage firms) |
| R | Retailers (3$^{rd}$ stage firms) |
| A, B | Raw material types |

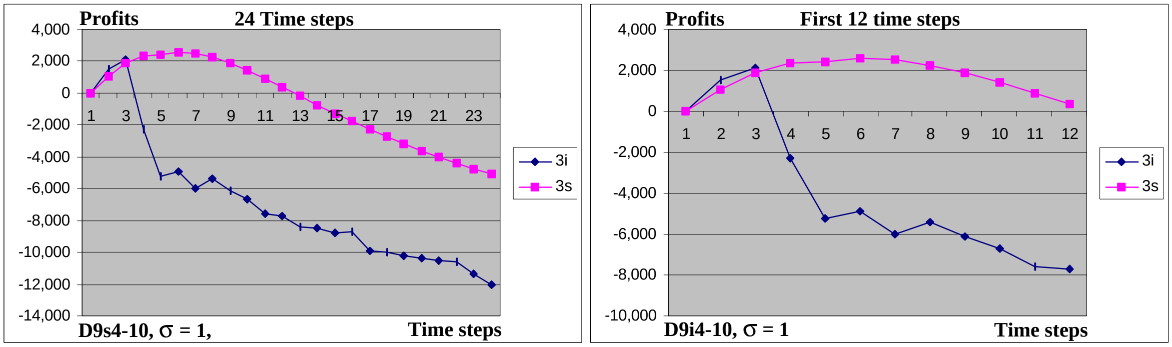


**Figure A1: One Run—Industry-level Specialization, 3rd Stage, Specialized Firm 3*s* versus Integrated Firm (3*i*)**

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