Agent-Based Modelling Incorporating Qualitative and Quantitative Methods: A Case Study Investigating the Impact of E-commerce upon the Value Chain.

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Abstract

This paper investigates the question of how new e-commerce technology is changing the organisational structure of value chains. The research presented in this paper illustrates a new methodology that unites qualitative and quantitative approaches, by undertaking a detailed case study within a major international organisation. The focus is upon exploring those issues identified as interesting and important by a small stakeholder group working in the company and actively participating in the research.

The qualitative investigation involves an interpretive study of interview data collected during a fieldwork phase. The context of the case study is a business transformation programme to develop Internet-based e-commerce that is designed to link customers to an electronic mall, thereby improving information flow, customer service, and internal efficiency. The qualitative research aims to capture the attitudes, perceptions and behavioural patterns observed in customers and other trading partners. The quantitative approach is embodied in an agent-based simulation model, which produces numerical outputs that are compared with statistical data gathered during the fieldwork. The objective is to develop an explanatory model that can be used to improve stakeholders' understandings of the workings of the value chain.

Simulation experiments are carried out to investigate a number of projected system scenarios, and to test hypotheses about the impact of e-commerce drawn from the literature and from the findings of other e-commerce case studies. The main findings of this research relate to the anticipated role of intermediaries in the value chain, and to the identification of key drivers and inhibitors to customer take-up of e-commerce. The paper argues that a multi-methodology approach is appropriate to simulation-based projects. It identifies stakeholder participation as being particularly useful because it enables strong validation procedures to be carried out.

1. Background

The value chain model describes how the different stages of business operations are organised, including all processes involved in designing, manufacturing, and distributing products from the initial blueprints to the final delivery to the end user. Each step in the chain adds value to the overall operation. Traditionally, the value chain perspective views a company as a chain of activities. Porter (1985) distinguishes between value chains, describing activities internal to one company, and value systems, describing several organisations, each carrying out different processes and linking them with its trading partners. However, many researchers also use the former to discuss chains involving interorganisational processes. It is widely accepted that extensive value chains often suffer from problems with information flow - some of the links are not as good as others in providing necessary information – and it is proposed that development of new information and communications technology (ICT), has the potential to improve the networking aspects of the value chain. This includes design, procurement, distribution, marketing, inventory and customer relationship management, for example.

We propose that value chains and interorganisational systems (IOS) are an appropriate area for the application of ABSS techniques, and that models developed will be able to improve our understandings of value chain issues. The systems we are exploring involve many heterogeneous actors, have dense interactions amongst them, and are structured with decentralised communication processes – exactly the type of systems typically developed by researchers in this field. Examples of previous work carried out to model aspects of the value chain, which include the closely related issues of supply, distribution, and intermediation, are (Parunak and Vanderbok 1998; Moss, Edmonds et al. 2000; Fioretti 2001). The work presented in this paper similarly models the value chain and also considers the impact of new ICT by virtue of being closely tied to an investigative case study. A combination of qualitative and quantitative methods is used in parallel with the modelling exercise. The line of reasoning taken in this project is that relying on quantitative data collection alone could be limiting in terms of understanding the attitudes and behaviours of social actors, and that qualitative techniques producing primary data much richer in context could be more insightful in this regard.

Broadening our literature survey to consider the impact of technology upon markets, our first objective is to put the impact of e-commerce into its historical context and identify parallels in the history of technological change. The tendency, perhaps, of many commentators is to overemphasise the importance of electronic commerce (EC) while it is still in its infancy, and to miss the fact that its value comes from how well it can be integrated with existing business systems and processes, and with those of partner organisations. The risk has been amply demonstrated by the underperformance of many new electronic marketplaces, the failure of many dot-com companies, and highly speculative investment behaviour. Recent work (Timmers 1999; Turban, Lee et al. 1999; Berryman, Harrington et al. 2000) has highlighted the new opportunities presented by Internet-based e-commerce, the strategic and operational benefits, implications for intermediaries, and the new organisational forms and market systems that are developing to take advantage of them. The research presented in this paper aims to take business history as a starting point for understanding changes brought about by the introduction of e-commerce technology.

Business historians Chandler (1977) and Porter and Livesay (1971) carried out a study of the US economy for the years 1830-1900 which described how the economic growth that was fuelled by the development of railway and telegraph systems led to a pattern of manufacturer domination over product distribution and marketing arrangements. Among the new distribution systems developed were company-owned sales offices and travelling salesmen. The role of the independent intermediary was diminished, as large hierarchical organisations were favoured over market systems to carry out the distribution function. Central to the argument of Porter & Livesay was that new technology, and its impact upon products and markets, was a key driver in the development of new distribution channels and marketing strategies, and shifts in power relations amongst trading partners that control and operate within them.

Of particular interest recently has been the identification of industries that might be at risk from the development of e-commerce technology. Researchers have focussed upon financial markets (Bakos 2000) tourism and leisure (Chircu and Kauffman 2000), (McCubbrey 1999), or car dealerships (Watson and McKeown 1999; Marshall, Sor et al. 2000) as markets potentially subject to upheaval.

Those most anticipated as at risk are intermediaries involved in the information processing requirements of other customers and suppliers, where those functions are open to potential improvements. Other researchers posit competition from Internet-only companies, the so called ‘dot-coms’ or ‘cybermediaries’ e.g. (Jin and Robey 1999). In the early stages of development of the Internet, EDI and other electronic networking technologies, researchers argued that we would see much disintermediation (Malone, Yates et al. 1987) (Tapscott 1996) i.e. traditional intermediaries would be bypassed in the process of reshaping certain industrial sectors. More recent research has questioned whether this disintermediaton process is as universal as first suggested. For example, we consider the more sophisticated model of Chircu and Kauffman (2000) who introduce the concept of the intermediation / disintermediation / reintermediation (IDR) framework which they argue applies to the introduction of new IT innovations that cause structural adjustments. The idea is that changing market conditions also bring new opportunities for intermediation to which the threatened intermediary should adapt, or reintermediate:

“A disenfranchised traditional player is able to compete again by leveraging technological innovations with cospecialized assets.” (Chircu and Kauffman 2000)

The historical perspective has concentrated on, firstly, the conflict between competition and cooperation in markets, and secondly the question of how to balance between markets and hierarchies as alternative ways to organise production and distribution. Markets have the advantage of flexibility in that components which become unproductive or unnecessary can be easily changed for better options. However, market mechanisms do not usually produce good information flow. Integration via hierarchies has the advantage of improving coordination and control between the component parts, and doing so at a lower cost. This perspective suggests that there is a tendency towards market systems when the nature of the product is generic, and the market is diffuse. This describes the situation in the case study (assuming that products can be sold ‘off the shelf’). We hypothesise therefore, that in the supply chain we examine, market intermediation will remain a very important function.

However, in the context of new ICT, research (Fabris 1997; 2001) emphasises the importance of collaboration over competition amongst members of the value network. This perspective is justified by the increasing interdependence amongst companies, and the growing sales in extranet and other interorganisational networking technology. Academics are increasingly turning their attention to trade networks as the unit of analysis of their research, as alternative to the more traditional view of individual companies as essentially unitary elements. These two points taken together imply that it might be less useful for researchers to consider the dichotomy between markets and hierarchies and between competition and cooperation as the focus of a study of e-commerce. An alternative viewpoint (Rayport and Sviokla 1996; Swaminathan, Smith et al. 1998) proposes that organisations are increasingly organising into 'virtual value chains' for the duration of individual projects, providing both flexibility *and* high levels coordination within trade networks. The reason there is a less clear distinction between electronic markets and hierarchies is that better information is available through market mechanisms augmented by networking technology. This allows companies to collaborate better by coordinating those activities undertaken jointly. Benjamin and Wigand argue that:

"It is becoming increasingly difficult to delineate accurately the borders of today's organizations. Driven by IT's ability to produce ever cheaper unit costs for coordination, organizations are implementing, increasingly rapidly, new links for relating to each other…the new forms indicate an ongoing transformation of value chains due to technological change." (Benjamin and Wigand 1995)

The focus of this paper is on the role of the intermediary and the development of a potential new marketing and distribution arrangement, namely direct sales via the Internet channel. We use the methods of case study research with stakeholder participation in conjunction with agent-based modelling (described in part 3) but first provide more details about the case study (part 2). The subject of the next section is how the case study lets us address these themes of the research (exploring the impact of e-commerce on the supply chain, the historical perspective of change) and lets us test our methodological approach (integrating qualitative and quantitative approaches to agent-based modelling research).

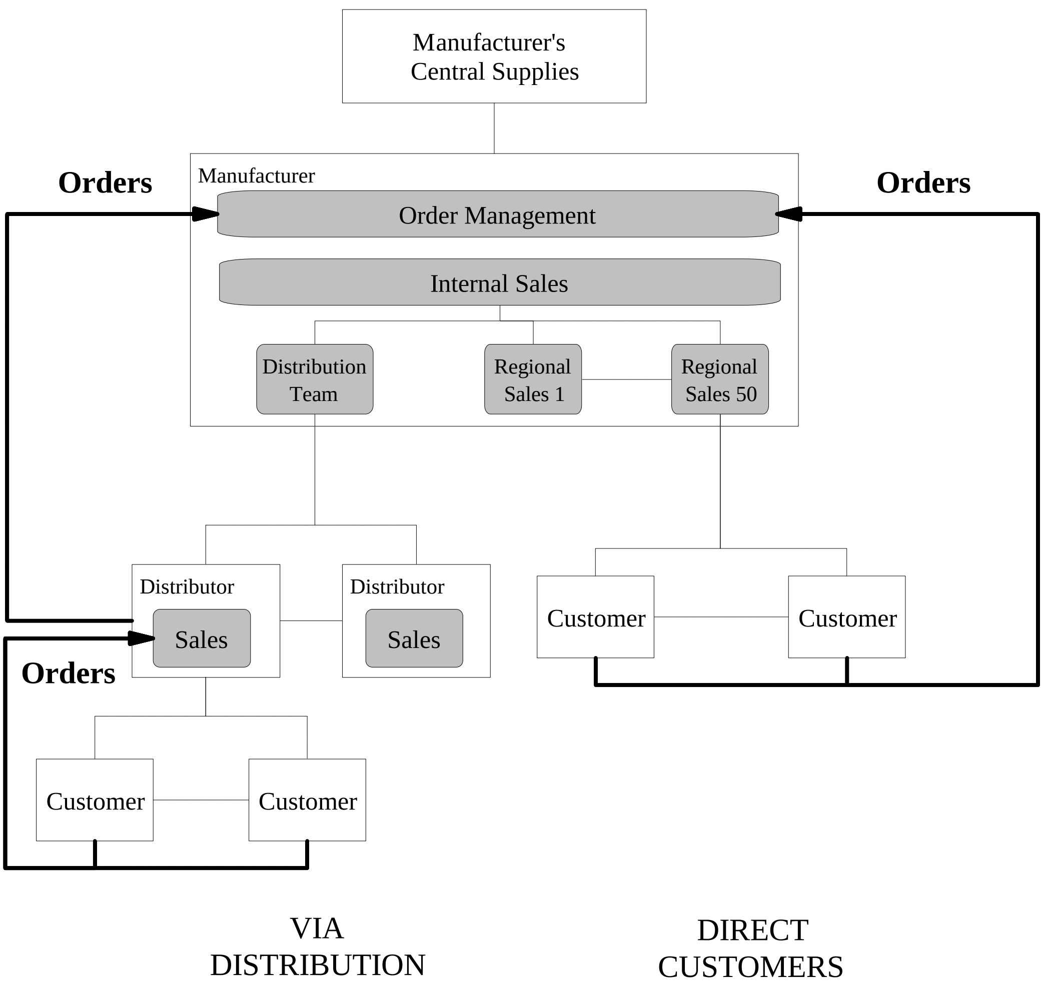
2. The Case Study

Several reasons justified our decision to carry out a case study. Firstly, it would supply us with real problems and issues to address in e-commerce and with which to test our approach. Secondly, it would provide us with a good supply of qualitative and quantitative data with which to inform, and give an empirical basis to, our model. Thirdly, it would enable us to enlist the input of a 'stakeholder' group to evaluate the model and the simulation results. We define the stakeholder as the person or persons who play an interactive role in the social system under study, and have expert knowledge about how that system works both in terms of its macro- and micro- properties. The role of the case study, therefore, is to ground the modelling techniques under development in a process involving qualitative data and the participation of industrial collaborators. In addition, we can argue that the models thus developed are more likely to be relevant to those issues and more likely to be demonstrably useful to industrial practitioners.

For the case study, our ideal requirements were access to the organisation and close cooperation over a period of several months to enable us to carry out an iterative process of data collection, modelling, and analysis. Secondly, we looked for substantial business process-reengineering involving e-commerce taking place, where statistical data about the actual uptake and usage of the e-commerce systems could be collected. Thirdly, we wanted to make contact with large manufacturing companies, situated and operating in the North West of England, since large companies are likely to have several employees working in e-commerce, and the logistics of access would be simplified in the vicinity of MMU. Fourthly, we required contacts at the company that had an interest in the success of the project, who could see the value potential of the research and were willing to become stakeholders, providing input and working closely with the researcher. We were fortunate to find one company that fitted the bill very well.

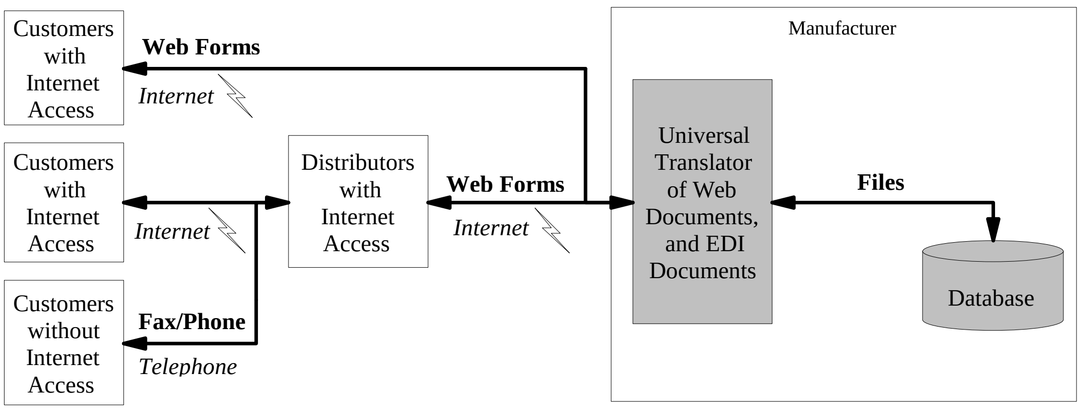
As part of a large multinational based in the UK, our industrial partners manufacture a range of products to equip factories with Industrial Automation equipment. The market is exclusively business-to-business: engineers work closely with customers who rely on their technological expertise to help design new production facilities. The company has thousands of direct customers who are supplied directly from a central European store. There are also a large number of independent distributing companies (distributors) who hold inventory and cover every region of the UK. Distributors hold stock locally and offer technical assistance to speedily, and cost-effectively, serve the smaller customers. Unlike the manufacturer, they provide for credit card purchases and are willing to take the financial risk of dealing with smaller customers. Another important benefit distributors give to the manufacturer is in having local sales forces, thus acting as a 'multiplier' of their products, reaching customers that they otherwise would not. The distribution arrangement is shown in Figure 1.

Figure 1: Market structure. Heavy lines show the flow of orders and normal lines show the market relationships (representing all other kinds of information flow).



Electronic Data Interchange (EDI) is one well-established e-commerce technology that has been used with business partners (some distributors and some large customers) for a number of years. The focus now is on providing e-commerce to the remaining partners through use of Internet-based e-commerce. The company are undergoing business process reengineering to integrate EDI, existing dial-up Internet systems and telephone/FAX-based communication into a gateway system to interface with their own internal systems and databases. The centrepiece of this transformation would be an Internet-based electronic mall, specifically designed to encourage e-commerce amongst customers. Direct customers would be able to check product information and availability, make their purchases, and track their orders. The proposed EC system is shown in Figure 2.

Figure 2: Proposed information infrastructure. Type of document is shown in a bold font; transmission media is shown in italics.



The new system would be operated in parallel with existing manual systems, which involves manual input of the orders received by FAX, though the company do envision the eventual replacement of all manual transactions with ones conducted electronically. The advantages of the Internet EDI compared to traditional EDI are that it is cheaper to adopt, more widely used and compatible with other companies' systems, and more flexible with regards to the kinds of information that may be shared. However, as the initiator of the technological change, it is essential that the manufacturer set up processes to effectively manage the customer and distributor adoption of EC. The company needs to ensure that the system also meets the needs of their customers, who also find it useful and share the benefits. It appears that the manufacturer is well aware of these needs: carrying out customer readiness surveys, publicising and putting forward EC to their distributors, and having a dedicated e-business team.

Initial discussions with the stakeholders established that it would be appropriate to address issues within the Customer Services (CS) department the area that was estimated to be the most affected in the short to medium term by the introduction of the electronic mall there exists some degree of uncertainty over policy-making options in this area, thus it comprises a good test of the value of the modelling approach as a tool to aid managers in understanding some of the possible outcomes, and their implications for policy makers. Secondly, focussing on issues within CS would be appropriate because it would allow us to study the interactions between the manufacturer and its many customers and distributors. This leads naturally to a model design with many agents, i.e. a Multi-Agent System (MAS), with a decentralised architecture composed of autonomously acting parts.

Relevant information was introduced by the managers: a general background on the company including an overview of the present organisation of the Customer Services department, the information technologies which currently were being used by the organisation itself and by its business partners and customers, the roadmap for the introduction of new e-commerce technologies, and the goals of the management team in this regard. We interviewed company employees about how they anticipated the impacts of Internet-based EC on the function of the department and the likely benefits and problems associated with this transformation. The interview respondents were selected by our contacts: they included the people responsible for promoting e-commerce systems to business partners, and those using the EDI and Internet systems on a daily basis. The research questions and hence the research design were jointly defined by the author and the stakeholders, over a series of meetings. The objective was to address the following issues:

?? How will business processes be affected by the introduction of EC?

?? What is the likely impact of EC on efficiency gains and productivity?

?? How will EC impact the role of intermediaries?

?? What are the important factors that determine customer take-up of EC?

The research questions therefore centred on the impact of Internet-based e-commerce upon intermediaries role and market share, upon the internal processes, efficiency improvements and resource savings that could be realised, and the identification of inhibitors and incentives for customer adoption of the electronic mall. Section 1 identified a number of research propositions and hypotheses from the literature in this area: other questions were raised by stakeholders at the inception of the project, and emerged during the evaluation phase. For example, they were interested in understanding better the impact of e-commerce upon internal productivity and upon the company's reputation amongst customers. Some of these issues would be addressed with fieldwork interpretation and some by means of the ABSS modelling, as described in the following section.

3. Methodology

The research methodology outlined in this section incorporates agent-based social simulation (ABSS) with qualitative fieldwork and stakeholder participation in the design and evaluation phases. The research therefore draws upon several different paradigms and combines individual methods, in particular integrating the qualitative with the quantitative. We emphasize here that the qualitative nature of this research allows a perspective that is fundamentally inclusive because it permits collection of a wide spectrum of different data types. The approach is justified by the argument that flexibility in choice of research methods allows a richer understanding to develop of complex issues such as the impact of technological change. This is what Mingers (2001) terms strong pluralism where "all research situations are seen as inherently complex and multidimensional, and would thus benefit from a range of methods." It is argued that the research presented herein exemplifies this multi-methodology approach.

The methods outlined in Table 1 below each contribute significantly to the research design, and as we shall argue, complement each other well in developing a richer understanding and meeting our research aims. By the definition of Mingers, this design is multi-method. The methods are listed with the corresponding research approach (underlying philosophical perspective of the research) and the type of data which we are at each stage working with:

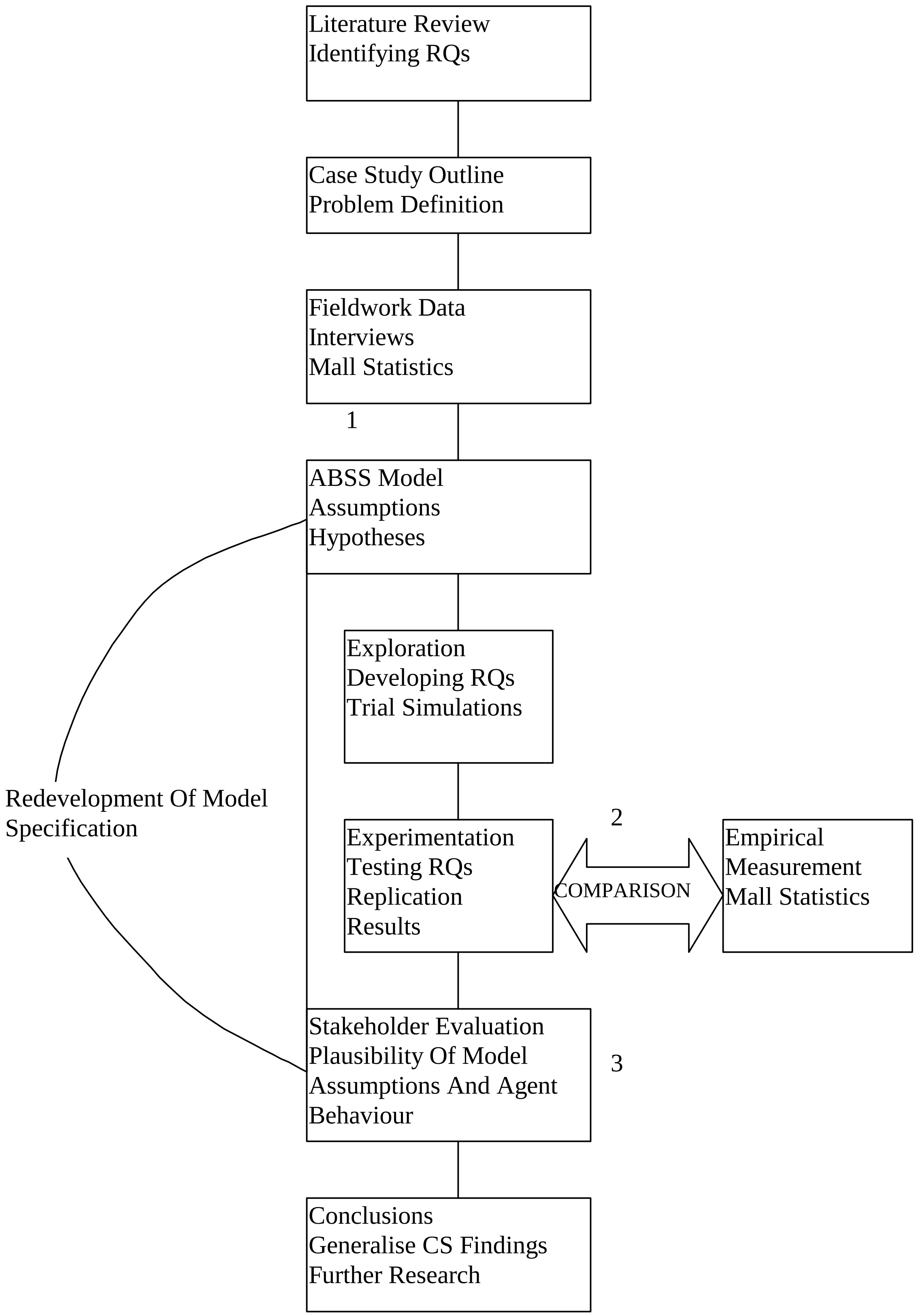
Table 1: Summary of the research methods

Method	Data Type	Approach
1. In-depth Interviews & Analysis	Qualitative	Interpretive (emergent findings)
2. Formal Modelling & Statistical Analysis of Simulation Results	Qualitative & Quantitative	Grounded (interplay between data collection & analysis)
3. Stakeholder Evaluation	Qualitative	Interpretive
4. Mall Statistics & Analysis	Quantitative	Positivist

The originality of the work presented here was to combine the qualitative with the quantitative in the development of an agent-based model which closely represents the system described in the case study. The qualitative aspect is encapsulated by the data provided by the case study fieldwork, and the quantitative by sales and other data. The key problem is to relate the quantitative to the qualitative, and vice versa, i.e. to translate the qualitative data into a form suitable to apply the numerical methods of computer modelling, and to interpret numerical outputs of simulation experiments in terms of qualitative descriptions of modelled social phenomena.

This methodology involves a large qualitative element which is based upon the principles set out by Yin (1994) on the case study method, and by Easterby-Smith, Thorpe et al. (2001) on management research. However, the ABSS modelling and stakeholder involvement in this project demand further clarification. Figure 3 (below) maps the stages of the project, and helps us to understand the interplay between data collection and analysis.

Figure 3: Methodology flow diagram



As described in the figure, the first stage entailed a review of the existing literature on e-commerce, concentrating upon qualitative studies but considering also the broader view of technological change (see Section 1), the objective being to identify research propositions that are pertinent to the current work. Following this, we sketched an outline of the case study and discussed it with the stakeholders. Their input was instructive in defining the problem, identifying research questions, and evaluating plausibility and practicality of the methodological approach (see Section 2). This was followed by the actual data collection: semi-structured interviews took place with nine employees in a variety of positions at the company, including members of the e-commerce team, order management and internal sales. Data were collected using a tape recorder, and transcripts were made which were imported into ATLAS.ti (2002) for analysis.

ATLAS is widely used by researchers in the social and management sciences to organise their primary data and to facilitate the qualitative analysis. The first task using ATLAS involves identifying *'quotations'* in passages of text. These are tagged with *'codes'* that are mnemonic aids which link together sets of quotations discussing the same concept. Codes therefore act as very useful aids to navigation of the primary data, because they allow user to click backwards and forwards among sets of quotations. ATLAS also uses the idea of *networks* that the user can construct by linking codes together. Different windows open on network views (or on parts of the network), providing a means to visualise the semantic relationships between these codes and quotations. The main benefits of using ATLAS were in making explicit the validation of model assumptions with primary data, and the standard organisational benefit in navigating and comparing passages of text, documenting, and writing up the emergent findings of the case study. However, in terms of producing the model design and experimental design, the ATLAS.ti package but was not found to be very useful because this aspect of a case study relies too heavily upon judgement and interpretation of the researcher.

Our analysis was carried out in accordance with the principles of the grounded theory methodology, where the collection and analysis of data are difficult to regard as separate stages. Fundamentally, this is because the research propositions were very loosely defined in this project. The agent-based model was informed by the qualitative fieldwork and quantitative data supplied by the stakeholders.

However, in order to improve the relevance and accuracy of the model, we needed to take simulation results back into the field and involve the stakeholders in the evaluation process. We therefore have a continuous interplay between data collection and analysis, and the evaluation of the technique of ABSS modelling with stakeholder participation depends upon successfully developing them in synergy.

The model was programmed using the SDML (Wallis and Moss 1994) platform. SDML is based on Smalltalk, which is a declarative, object oriented, programming language. SDML was specifically designed for developing agent-based models of social and economic scenarios, and has a large range of functionality that makes it highly suited to this task.

The model consists of a set of assumptions regarding the nature and behaviour of the modelled system, and we have a number of hypotheses that we wish to explore and test with the model. Exploration aims to develop theory and allow the modeller to understand better the range of behaviour possible via trial simulations. Experimentation on the other hand, is carried out to address particular hypotheses that we have in mind. In this research we defined our simulation experiments through model scenarios, as described in the next section. After initial simulations have been carried out, the model specification, experiments, and results are explained to the stakeholders. This involves examining both the assumptions on which the model is based and the micro behaviour of the agents to assess whether or not these are plausible. The critical evaluation of the stakeholders is very important since they are the domain experts. Evaluation links our findings back to the model specification in a cycle that can be repeated as necessary, a process which aims to improve the model design and strengthen the validity of results.

The research design provided several ways to validate the model, proving to be a good demonstration of the cross-validation (Moss and Edmonds 2003) approach. It was centred upon three main areas where the model could be compared with the e-commerce system: these are the numbers marked on Figure 3. Number (1) marks where the model assumptions were informed by interview data: this was an integral part of producing the model design, and in the following section we show how concepts were taken from the fieldwork. Number (2) marks the comparison between simulation results and statistical logs from the mall: we aim to assess the macro-behaviour of the model in terms of that of the empirical system (see part five). Number (3) relies upon the participation of the stakeholders in an iterative evaluation and redevelopment process. This involves assessing both the assumptions upon which the model is based, and the micro-behaviour of simulated agents, in terms of their plausibility, as out lined in (Moss, Downing et al. 2000).

We suggest that this model is well-validated in terms of the nature of the value chain and of the issues facing the manufacturer, though less in terms of the behaviour, attitudes, and expectations of customers and distributors. Of the different methods of validation, stakeholder evaluation should be the most reliable because stakeholders are sensitive to results that ‘do not look right’, i.e. are not like anything they have observed. However, potential problems with qualitative data are that respondents may be misinformed in their assertions, or we may misinterpret their degree of certainty in them. Quantitative data is more reliable but is limited to those concepts we can measure easily, which is quite restrictive in this type of model. This is why qualitative methods are also used: a model involving qualitative data requires qualitative methods of validation.

There were two methodological issues encountered during the course of the research which may be considered unique to the approach taken. Firstly, significant collaboration was required between the researcher and the stakeholders via frequent e-mail, telephone and face-to-face discussions, presentations, etc. Consultation was important to develop the partnership, to ensure the stakeholders fully understood the nature of the project, and were able to contribute to it and benefit from it. It was necessary that stakeholders were aware of key modelling concepts in order that they could understand the significance of the simulation experiments and, very importantly, contribute ideas of their own to the research design. Secondly, qualitative data were used to inform a quantitative model amenable to the techniques of numerical simulation. Descriptions provided by the fieldwork respondents needed to be translated into a suitably formal and precise language. However, it was important to preserve much of the semantic content in order that explanations for behaviour of the model could be generated to which the stakeholders could relate and therefore more easily identify.

4. Model Description

In this section, we show how the qualitative fieldwork informed the model assumptions by making explicit the links between data and model, identifying quotations and showing how these were built into the model specification.

We developed an agent-based model of the supply chain described in the case study in which direct customers are supplied by the manufacturer, and other customers are supplied by independent intermediaries. Therefore we have very different sets of rules governing the behaviour of direct customers and intermediated customers.

Customer and intermediary agents are located on a grid where the concept of 'neighbourhood' is important in defining how interactions take place: a neighbourhood is defined as the area including eight squares in each of the cardinal directions (North, South, East, and West), and neighbours are all the agents lying within these squares. The geographical aspect is important because communication takes place exclusively amongst neighbouring agents, and because the provision of local customer service factors is a benefit when choosing from amongst alternative intermediary suppliers. Intermediaries are also distinguished by their selling price (which may offer customers a small discount on the manufacturer's list price) and by technological competence which, as reported by interview respondents, varies greatly:

"Some of our distributors are much better than others: some are more technically competent. They employ the right people with the right backgrounds and training. At this moment in time I have some reservations about the ability of some of our distributors to serve our customers in the way we would like." (P4)

In other words, intermediary agents are heterogeneous in terms of technological competence (their knowledge of the products, and the product areas in which they operate) as well as the price at which they sell the product. We model low, medium, and high levels of technical competence by coding with the integer values 1, 2, and 3 respectively. Selling price is an integer value drawn from the interval [71, 100] (list – discount, list). Intermediaries make a profit on their sales because they buy at a discounted price and sell on to customers at a higher ‘selling price’. Each cycle, intermediaries buy back from the manufacturer only the equivalent number of units to what has been sold. Moreover, it is assumed that they have an infinite amount of stock to supply their customers. Intermediaries that are not profitable, having zero profits over the trading cycle, (i.e. they do not achieve any sales) are removed from the simulation in subsequent cycles.

Customer agents also differ in their demands: we modelled demand with an exponential function that, according to one of the respondents, was a good approximation of the company’s markets. We used the function:

$$D \ ? \ ae^{bx} \qquad \text{with a = 1, b = 4.605, and } 0 \ ? \ x \ ? \ 1$$

The quantity x is drawn at random from a uniform distribution over the interval [0,1], giving a demand, D, ranging from 1 to 100 units. The largest 20% of the customer population, i.e. those with $x \ ? \ 0.8$, purchase directly from the manufacturer, and the remainder have a small probability to purchase directly commensurate with their size. We define two kinds of customer demand: non-urgent stock to be held as inventory at the production site, and stock required urgently onsite as replacement. Orders for urgent products can only be fulfilled by suppliers local to the customer. Aside from this requirement, customers buy from the highest ‘endorsed’ supplier they can locate.

The model is simulated through discrete time-steps, called trading cycles, in which agents interact via market transactions, and through various communication interactions. In simulation experiments we used: a large model with grid size of 50 x 50 cells and a cardinal range of visibility of 8 cells, and a small model with grid size of 35 x 35 cells and a cardinal range of 6 cells. In reality the company has very many more customers than captured by these figures: we found these parameters presented a reasonable balance between system scale and computational performance.

Communication processes include referrals communication, where the customer receives information about the existence of alternate potential suppliers, and ‘endorsements’ communication or persuasion processes. We define ‘*customer referrals’* as the process where, each trading cycle, the customer has a 'word of mouth' communication interaction with one of its neighbours, chosen at random. The customer receives information about the existence of alternate suppliers through this interaction: the neighbour communicates the identity of the supplier it used in the previous trading cycle. On the other hand, *'manufacturer referrals'* describes the case where a customer contacts the manufacturer directly and requests a referral to an alternate supplier. Then the manufacturer informs the customer of the location another potential supplier, which the customer may subsequently contact and order from. The Fermi function:

$$f(z) ? 1/(e^{? (z ? z^*)} ? 1)$$ with z* = 2 and ? = 1[1]

where z is the number of suppliers known to the customer, is used to calculate the probability, f(z), that a customer will request a referral from the manufacturer. The parameter z* is a transition value defineing a cut-off point where the probability of new relationships forming begins to decline, and ? is the parameter that controls the shape of the fall off at z*. Use of the Fermi function is based on the assumption that a customer is less likely to contact the manufacturer, the larger the number of alternative suppliers known, justified on the grounds that there is a cost to maintaining such connections amongst agents in terms of time and effort.

In addition, we may also have interactions taking place in which information is passed about the characteristics of the supplier and about the nature of the electronic mall. The stakeholders described face-to-face type interactions between the company and their direct customers, and between the company and their distributors, relating to the issue of e-commerce. We model these interactions as social influence interactions, where beliefs are communicated in the form of 'statements'. Social influence interactions may take place amongst neighbouring customers, as well as through persuasion processes initiated by the manufacturer. In our model, two beliefs selected at random are communicated from the source customer to the target customer; three beliefs selected at random from the manufacturer's list are communicated to a subset of fifty direct customers / intermediaries in each cycle.

In our analysis, we identified several hypotheses about e-commerce (HEC) and about distributors (HINT) that were considered by the interview respondents to be influential in shaping customer attitudes (see Table 2). These qualitative data were then incorporated into the model specification.

Table 2: The HEC and the HINT

HEC:	Belief	Qual.
It is extra work for us to use the mall compared to a manual system	Subj.	False
Almost everybody will soon be using Internet-EC: we should be doing it too.	Ver.	True
Instantaneous and quick access to information (compared to traditional channels) is a benefit to us.	Ver.	True
The 24-hour availability of access provided by the mall is of benefit to my company.	Ver.	True
The provision of up-to-date and accurate information on the mall is of benefit to us.	Ver.	True
The digitisation of product data sheets and the availability of software updates is a benefit.	Ver.	True
The reduced possibility of errors occurring in orders going through the mall is a benefit.	Ver.	True
The provision of more user-friendly ways of accessing account information on the mall is a benefit.	Ver.	True
It is expensive for us to set up and maintain Internet-based systems compared to manual ones.	Subj.	False
I am concerned about security issues with Internet-based systems compared to manual systems.	Ver.	False
I am receptive to Internet-based EC because I expect we shall receive extra discounts if we adopt.	Subj.	True
I am concerned about the lack of technical support and experience within the company of using EC.	Subj.	False
I am receptive to EC because I expect we will receive more customer referrals if we adopt.[2]	Subj.	True
HINT[3]:		
The supplier offers a good discount on the selling price of the product.	Ver.	True
I am concerned that the distributor may lack technical competence.	Ver.	False
The location (ability to offer a local service) of the supplier is a benefit.	Subj.	True

We define a ***belief*** as a simple expression of agreement or disagreement with particular hypothesis, held by an agent. We then characterise as *verifiable beliefs* those hypotheses which are objectively true or false: characteristics of a technology upon which people generally agree, for example, that the 24-hour availability of the Internet is a benefit). *Subjective beliefs* are those that are wholly

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[1] Simulations were run with different integer values for parameters z* and ? in order to find the best match with the shape of the curve for the customer referrals simulations.
[2] This hypothesis is relevant to distributors only.
[3] This set of hypotheses is relevant to intermediated customers only.

dependent upon the circumstances of the agent (for example, the lack of technical support available within the company). Whereas verifiable beliefs may be communicated amongst agents, it is less meaningful to communicate subjective beliefs since individual situations are different: the latter are simply inferred to be true or false depending on the individual case. Each hypothesis also has an associated ***qualification***, which in our model is a Boolean that takes the value ‘True’ or ‘False’, and denotes whether it is a hypothesis that is supportive (True) or dismissive (False) of the decision to adopt / choice of supplier. The second and third columns in Table 2 identify the type of belief, and its associated qualification. If the qualification is ‘True’ and the agent believes the hypothesis to be true, then this belief will have a positive impact upon the attitude of the agent. Similarly, if the qualification is ‘False’ and the agent believes the hypothesis to be true, then the belief will have a negative impact upon the attitude of the agent. If, however, the hypothesis is *not* believed to be true, then it will not contribute towards the attitude of the agent. This formulation is intended to capture the idea that customers are risk-averse. In other words, what this means is that a hypothesis can have either a positive or a negative impact, but not both.

Central to the model is the 'endorsements scheme' based on the work of Cohen (1985) in which qualitative data structures (called endorsements) determine agent cognitive processes. Endorsements can be viewed as reasons to believe or disbelieve a hypothesis. In our model, agents collate data relating to hypotheses about intermediary performance, and about the benefits and disadvantages of using Internet-EC. Information is gathered through interactions with neighbouring agents, with the manufacturer, and through experience of using the Internet-EC system. The endorsements scheme uses a lexicographical ranking system whereby different beliefs are assigned a different level of importance: those regarded as more important take precedence over lesser ones. The advantage of the endorsements model is that it allows the use of qualitative data to initialise the model, and preserves the structure of that data throughout the course of the simulation.

In the model, we defined four different types of endorsements: *inferences*, which are specific to the situation of the agent and not subject to external influence, *observations*, which are the first-hand experiences of the agent, *statements*, information received through social interaction with other agents, and *initial perceptions*, which are based on the assumption that all agents know about the existence of the mall from the initial cycle, and have some beliefs about its qualities (which may be misperceptions). However, as more evidence is gathered[4], initial perceptions will tend to play a lesser role. The following algorithm defines how endorsements are used to determine beliefs:

If there are either

One observation that negates the hypothesis or

Three statements that negate the hypothesis

Then the belief is asserted as the **negation** of the qualification.

Otherwise, if there are either

Three observations that support the hypothesis or

Three statements that support the hypothesis

Then the belief is asserted as the **confirmation** of the qualification.

(If the agent has fewer than three statements or observations as evidence to support the hypothesis, then it is not regarded as adequate to believe or disbelieve it.)

Otherwise,
If there is an initial perception that supports the hypothesis,
Then the belief is asserted as 'True'

Agents are endowed either with a manual/card-based internal, or IT/computer-based system. Two IOS also exist for placing orders - FAX/telephone or EDI. They can subsequently adopt the Internet mall system for ordering (direct customers) or for collecting information (intermediated customers). Each trading cycle, a user of the Internet-EC system will experience two aspects of the system and the simulation will generate two new observation endorsements. These will be positive or negative experiences depending on the outcome of a probabilistic trial, which is governed by a system performance parameter. We model system performance failures by varying these parameters over time, allowing us to measure the effect of such problems on the number of users and their attitudes.

[4] We model a form of agent memory decay, where agents retain only the three most recent of each type of endorsements relating to each hypothesis.

E-commerce is regarded as strategically highly important for future development of the company. The aim is to increase market share of sales by 10%: this is a very important context for the development of the mall because management hope that it will provide them with competitive advantage to carry out the expansion. The company also aims to reorganise CS by switching some direct sales through their distributors (the policy of channel alignment), as it is a more cost effective solution. With regard to e-commerce, their main policy is to take responsibility for informing customers and distributors of new possibilities for doing business electronically, to encourage and provide incentives to use their systems. These incentives would include offering financial support (funding and equipment) to help with setting up EC, technical support and training for use of EC systems, and a discount incentive, as became clear through the fieldwork:

"We are starting to incentivise them by giving them an extra percent [of discount] if they can trade with us electronically." (P8)

"Maybe it's a case of [us] having to invest in those distributors and give them the tools they need to be able to trade with us electronically and get on board with the email, conferencing training things that we are going to do." (P8)

"It may be a case of getting somebody to get in his car and go round and see everybody and promote it and say "this is how to do it" and get people in there and help customers set it up because they haven't always got the resources to put time into setting it up at their end." (P7)

As we can see, the appropriate role of the company in supporting the adoption of the EC system was an issue discussed at length by the interview respondents. In our model we defined EC Set-Up, EC Technical, and EC Discount support strategies, providing arguments for the amount of support and trading cycle when the offer is made. This permits flexibility and allows us to explore the role of manufacturer interventions in shaping customer attitudes towards the Internet.

Another respondent reported that the company had a certain amount of influence through manufacturer referrals, the process where customers are passed on to an intermediary supplier:

'*It is quite important in encouraging our distributors that we provide referred business.'* (P6)

This is an important finding because it suggests that the company can indirectly influence the customer's choice of supplier, hence providing leverage over distributors that are not adding value by, for example, having a proactive sales force, providing technical expertise, or using e-commerce.

The difficulty with the above statement is that it could have several different interpretations, these would be formalised into very different rules, and could have a significant impact upon the result. For example, we can suppose a strong preference for any Internet – enabled distributor, or a weak preference, all other things being equal, when there is a choice of two local suppliers. Alternatively, we might hypothesise that some referrals are linked to a specifically adoption decision. We can overcome this vagueness or uncertainty with the involvement of stakeholders to clarify such issues.

5. Simulation Experiments and Results

Simulation experiments were designed to address the research questions by exploring the behaviour of the model in terms of the role of intermediaries and distribution of market share, and the rate of customer adoption of the mall, under different market scenarios. These scenarios include different specifications of agent interaction and communication protocols, manufacturer strategies for the support of EC adoption, and system performance failures. We also include a sensitivity analysis of model outcomes to initial conditions and different parameterisations of the model. This section concludes with a comparative analysis of simulation results with statistical data collected from the first fourteen months of operation of the mall provided by the stakeholders.

In the first two scenarios, S1 and S2, we compare the effect on model behaviour of the specification of different communication scenarios. We specify two different ways in which customers can locate suppliers, following the construction of 'neighbourhoods' during the initialisation cycle. One way is through customer referrals via 'word of mouth' communication in S1, and the other is through manufacturer 'referrals' in S2. The customer, over the course of many cycles, gets an increased choice of suppliers and can select according more to his individual preference. This can be interpreted as a trend of increasing competition where suppliers compete more for customers.

Figures 4 and 5 illustrate simulation results from a single run with the large model under S1. Examining intermediaries, market share, the first noticeable outcome is the large variation in the first few cycles of the simulation. When the graph gradually settles, we observe a group of four distributors clearly separating from the rest from around TC40, each having a large volume of sales. Whereas the largest distributor, intermediary-14 reaches 1687 units at TC100, and the second, third and fourth largest all manage sales of 900+ units, there is a clear cut-off point between these four and the rest of the distributors, all of which manage sales of under 500 units per cycle, from TC 20 onwards. In fact, in the later stages of the simulation, the four larger distributors receive orders for more than twice as many units than the next largest distributor. Profits are more evenly distributed, however, with five large distributors sharing a similar amount of profits, at around 10-15,000 each, but also with a group of six medium-sized distributors making profits of 5-10,000, and the rest making between 1-5000 profits. In this simulation, all of the intermediaries survive until TC100, and seventeen of them are consistent users of Internet-EC.

The number of users of EC is high for direct customers, reaching a maximum of 236 at TC64. As illustrated in Figure 6, the number of users gradually drops after TC70: this can be explained by the fact that the number of new adopters is lower than the number of direct customers getting referred to distributors each cycle. This also explains why the number of intermediated customers continues to increase slowly. The graph also illustrates a notable gap between the number of adopters and the number of users via distribution. This reveals that some customers after having adopted the mall subsequently stop using it.

In contrast to the first scenario, in S2 we specify customer referrals rather than manufacturer referrals. Figures 7 and 8 were obtained from the same simulation run with the large model, specifying customer referrals but no communication of endorsements. The results in Figure 7 show the domination of the intermediation function by a single intermediary, intermediary-14, obtaining more than twice the volume of sales than the second largest intermediary (2685 units compared to

1319 units). Although five intermediaries manage sales volumes of greater than 500 units, there is markedly greater inequality in this distribution: the majority have sales of less than 200. This inequality is also reflected in the result that there is one intermediary casualty: intermediary-2 survives only up until TC19. The largest intermediary also makes a profit of more than 18,795 in TC100, compared to 15,190 (an increase of 24%) in the first scenario. In fact, Figure 8 shows a sharp decline in profits for many distributors, whereas other distributors grow quickly in terms of profitability. Intermediary-18 is the most visible example of this: starting with a very low profitability in the early part of the simulation, int-18 overtakes many other distributors that are experiencing declining profits, rapidly increases to a profitability of more than 15,000 by cycle 20, and becomes the most profitable intermediary in TC27. This demonstrates an interesting dynamic resulting from the customer referrals process – intermediaries experience highly changeable fortunes in the early part of the simulation, which eventually result in a very different state from the initial one. In comparison with S1, this suggests greater short to medium-term variation.

The path of adoption of Internet-EC is virtually identical to that of the first scenario: high adoption amongst direct customers but low adoption amongst customers supplied via distribution. The extent of the market domination by few large distributors in these simulations clearly gives us an important result: it suggests that customer referrals leads to more distributor inequality compared to manufacturer referrals (i.e. scenario one). As all other parameters were exactly the same, this result must be attributed to the specification of communication processes: customer-to-customer ‘word of mouth’ communication results in large majorities of customers choosing the same (few) suppliers.

In the simulation results shown in Figure 9 below, where we do specify endorsements, we find that the number of customers via distribution reaches a maximum of 260 agents in TC100. This is approximately three times as many as in the case without endorsements (83) or in S1 (109), whilst the number of direct adopters is approximately the same. This suggests the increase in intermediated customers adopting must be attributed to the communication of endorsements during those interactions. Our conclusion is that the specification of communication of endorsements information drives the high level of adoption: through customer-to-customer persuasion interactions, intermediated customers can collect information relating to the benefits (and disadvantages) of e-commerce, and in this case, many of them are persuaded to adopt.

Finally, Figure 10 shows the results of a test for the existence of the Pareto Power Law distribution, which states that there is a logarithmic relationship between the cumulative frequency of events (in this case, number of units sold) and the smallest to largest ordering of objects to which those events are ascribed (in this case, intermediaries). The figure shows five plots for the small simulations with customer referrals without endorsements communication[5]. If we discount the first two or three data points, there appears to be a linear relationship. However, suppliers with sales of fewer than ten units per cycle may only be viable if they can supply a range of products from many different manufacturers.

In the following simulation experiments, we consider manufacturer support strategies for Internet-based EC: support with EC set-up, with technical knowledge, and extra discounts. All of these simulations are carried out with customer referrals and endorsements communication, without preferential referrals. The results of the four simulations with the small model are shown in Figure 11, where number of users is plotted against time cycle on a single graph. It is clear that in the simulation runs where no support is offered to direct customers usage is the lowest (43 customers in TC 100) whereas offering some kind of support always results in a higher level of usage. This is hardly a surprising result, since in the model specification we assume that the customers always view these support interventions positively. In the 'Set-Up Support Only' simulation there is a small increase to 56 customers, and in 'Technical Support Only' there is an increase to 62 customers. The 'Extra Discounts' incentive resulted in the largest increase in level of usage to 69 customers (a 60% increase over 'No Support'). In simulations with the large model we found 'Tech. Support Only' and 'Set-Up Only', to produce similar patterns of a small increase in whilst 'Extra Discounts Only' again resulted in much larger usage, although this had dropped off in the larger simulation by TC100. Figure 11 also demonstrates s-shaped adoption/usage curves, indicating a slow initial take-up, moving into a period of faster adoption, and gradually slowing to a

[5] We only show the one graph, but the model did exhibit similar outcomes both for manufacturer referrals as well as for the non-endorsement case. This was observed also in the large simulations.

saturation point after about thirty cycles. This is an important result because it shows that the model exhibits an outcome resembling a pattern identified in empirical studies of technology diffusion.

We carried out a sensitivity analysis to test the robustness of the model to changes in program implementation: in the poorly validated model assumptions, and in the parametric values used. The first test examined various grid sizes, and hence different densities, for the small model. The grid was varied in size from 35 square cells to 55 cells, in steps of five. In all cases we found the market share for intermediaries to be very similar to that illustrated in Figure 7. The main difference was in the lower number of known suppliers, with the sparseness the grid reducing social cohesion in the value chain. Secondly, we looked at the effect of changing the distribution of initial perceptions. Whilst many important perceptions have been identified, far less is known about the distribution of those attitudes. We changed the parameter governing the probability an agent has initial perceptions about EC, and found little notable difference, except that the speed of adoption was a little slower. These results demonstrate robustness to small changes of this type. We can therefore conclude that such details are not critical to the model: sensitivity does not appear to be problematic.

We examined the simulation results concerning intermediary success (market share, profitability and survival rate) with respect to their characteristics of pricing and technical competence. It should be noted here that intermediaries do not have dynamic strategies for adjusting these characteristics during simulation runs. We found that profitability is strongly correlated to intermediaries' technical competence, but it is not correlated to intermediaries' selling price. As the six most profitable intermediaries are all those with high technical competence, it is clear that this characteristic is a decisive factor in the success of intermediaries. Eight out of the next ten highest (i.e. the 7^{th} to the 16^{th} in the ordering) had a medium level of competence. In contrast, the price characteristic shows no clear pattern of correlation with profitability. Market share is closely related to price, but due to variability in intermediary mark-up, agents with large sales are not necessarily the most profitable. Very low price (below 80 units or 20% discount) intermediaries are ordered as 2^{nd}, 7^{th}, 8^{th} and 14^{th} most profitable, which is only slightly better than average success rate. In addition, the two agents that did not survive in this simulation both had tech. competence level of 1 (low). This reinforces the conclusion that intermediary success correlates with competence.

Finally, we compared the macro behaviour of the simulation model with the mall statistics provided by the stakeholders. Figure 12[6] shows the number of mall orders and the total number of order lines included in those orders. Each order consists of a number of order lines specifying the type of product and the number of units required. Orders therefore range from the very large (many units of many different types of product) to the very small (a single line requesting one unit) so the mall statistics therefore only give us an estimation of the value of Internet sales. The chart illustrates an increasing number of orders and order lines over the period October 2001 to July 2002 that varies considerably from month to month.

In addition, the mall statistics in Figure 13 show an increasing number of customers (i.e. number of registered users on the web site). It is evident that over the same time period, customers use the mall for an increasing number of transactions, i.e. 35 customers submitting a total of 36 orders during the month of October 2001 (1.029 orders per customer) compared with 201 customers submitting 258 orders during July 2002 (1.284 orders per customer) which represents an increase of 25% orders per customer. They submit an increasing number of order lines: from 306 lines in 36 orders (average 8.5 lines per order) to 2882 lines in 258 orders (average 11.17 lines per order), an increase of 31%. This analysis reveals a significant increase both in number of orders per customer, and in number of order lines per order that not only illustrates an increase in the total value of transactions through the mall, but also that customers may be increasingly feeling at ease in participating in the new system.

When we compare on the same chart (Figure 13) the mall statistics and the results from one of our simulations (from S2), we see similarities in the shape of the curve in the first part of the simulation. We plotted the mall statistic ‘number of customers’ against the first 14 data points of the simulation results ‘number of direct customer-adopters’ and found very close correlation in the shape, when adjusted for scale on a 2-axis combination chart. This demonstrates that the model exhibits similar characteristic behaviour to that evidenced in the mall statistics.

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[6] This chart was produced by one of the stakeholders.

Figure 4: Chart of intermediary sales. Large simulation: manufacturer referrals.

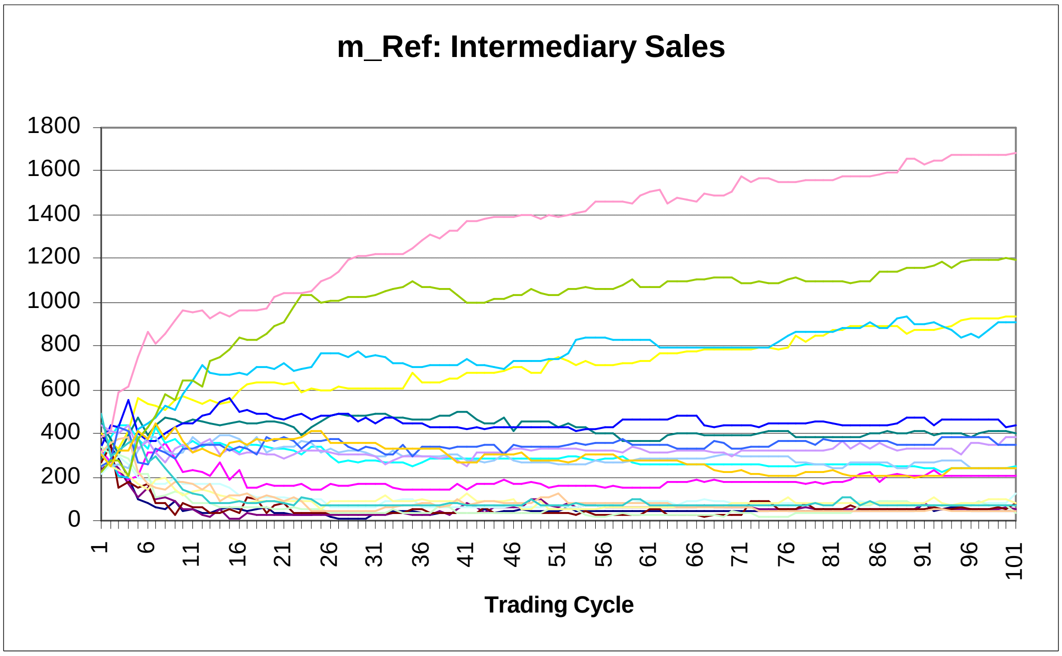


Figure 5: Chart of intermediary profits. Large simulation: manufacturer referrals.

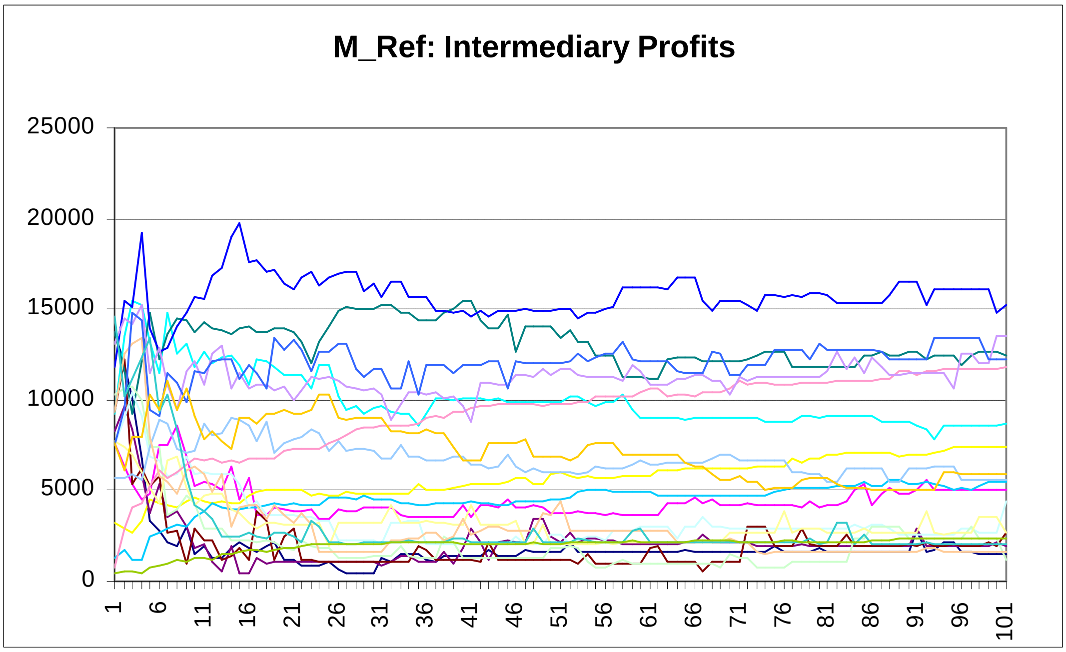


Figure 6: Chart showing number of adopters. Large simulation: Manufacturer referrals.

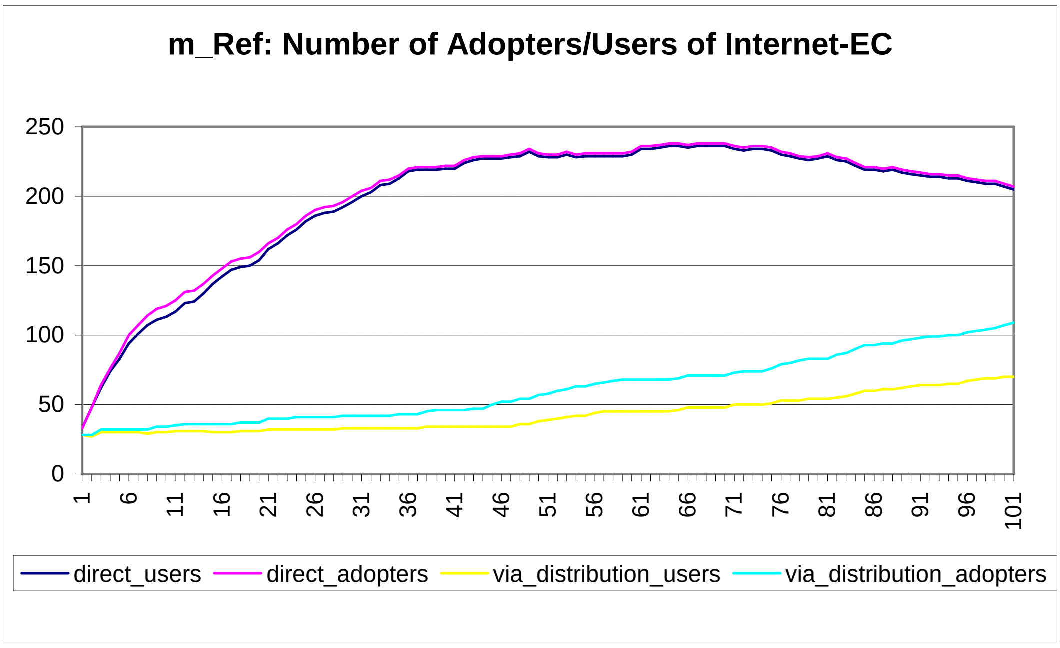


Figure 7: Chart showing intermediary sales. Large simulation: customer referrals.

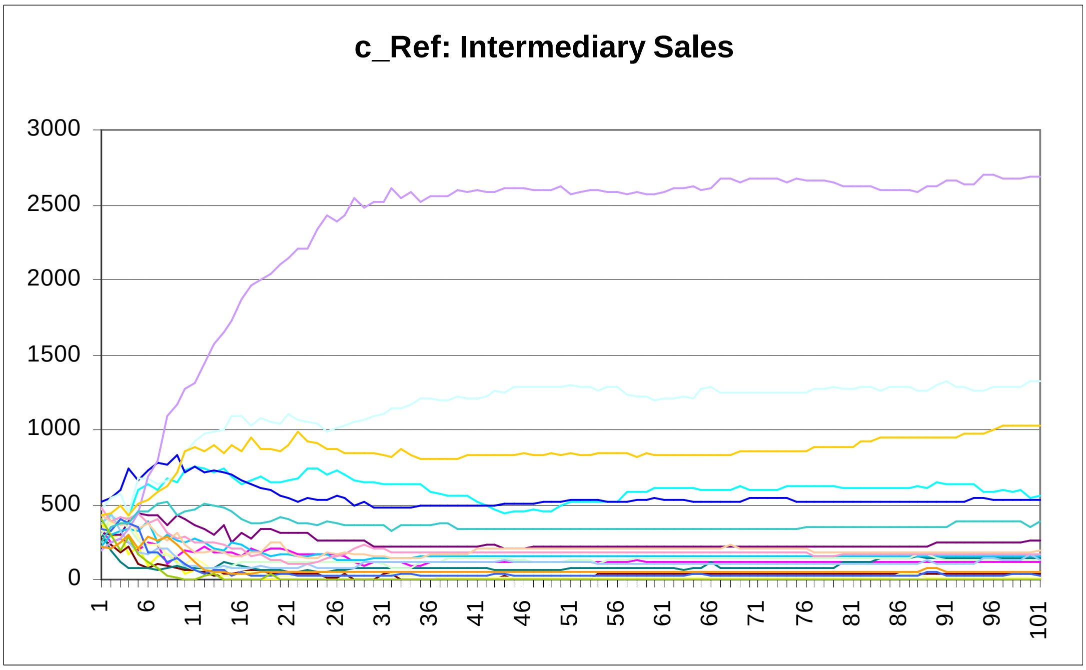


Figure 8: Chart showing intermediary profits. Large simulation: customer referrals.

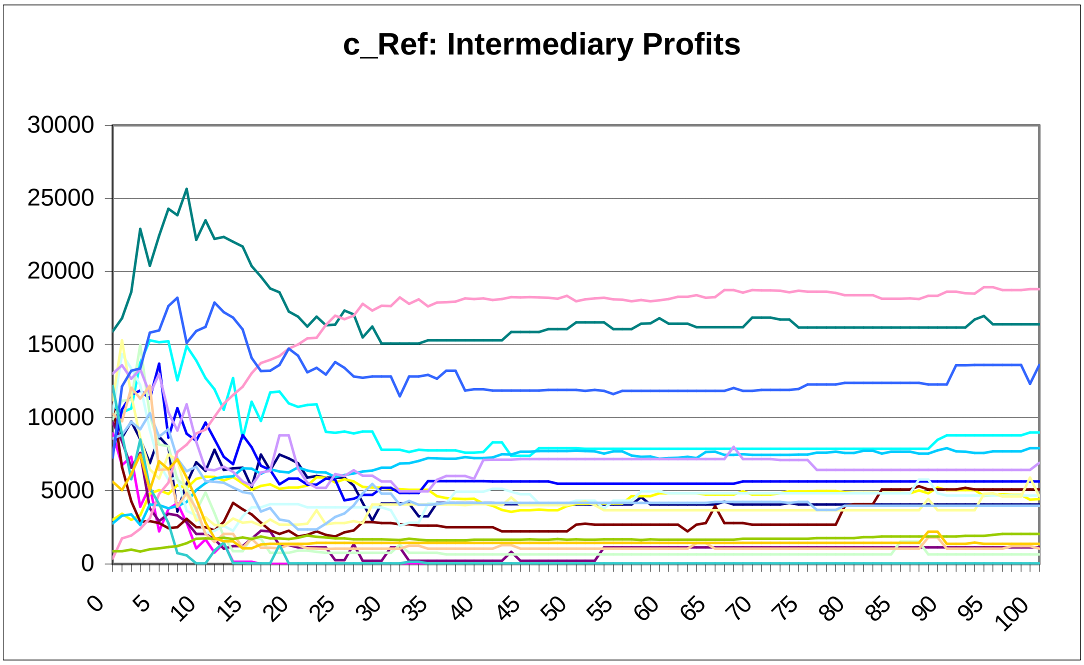


Figure 9: Chart showing number of adopters and users of Internet channel. Large simulation: customer referrals with endorsements.

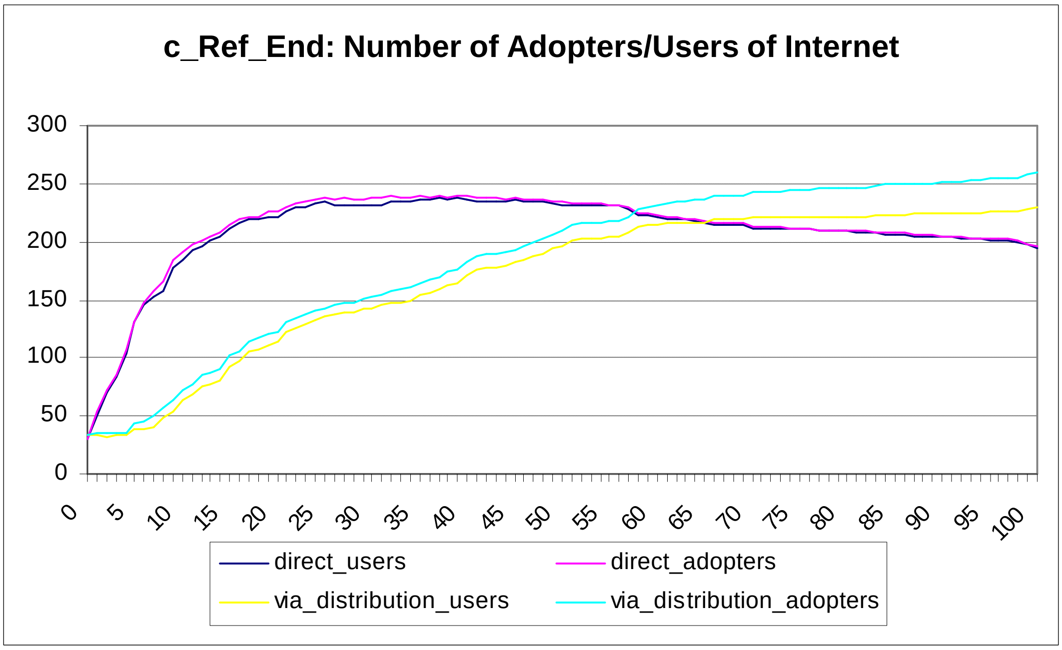


Figure 10: Log of cumulative sales test for power law distribution. Small simulations: customer referrals with communication of endorsements.

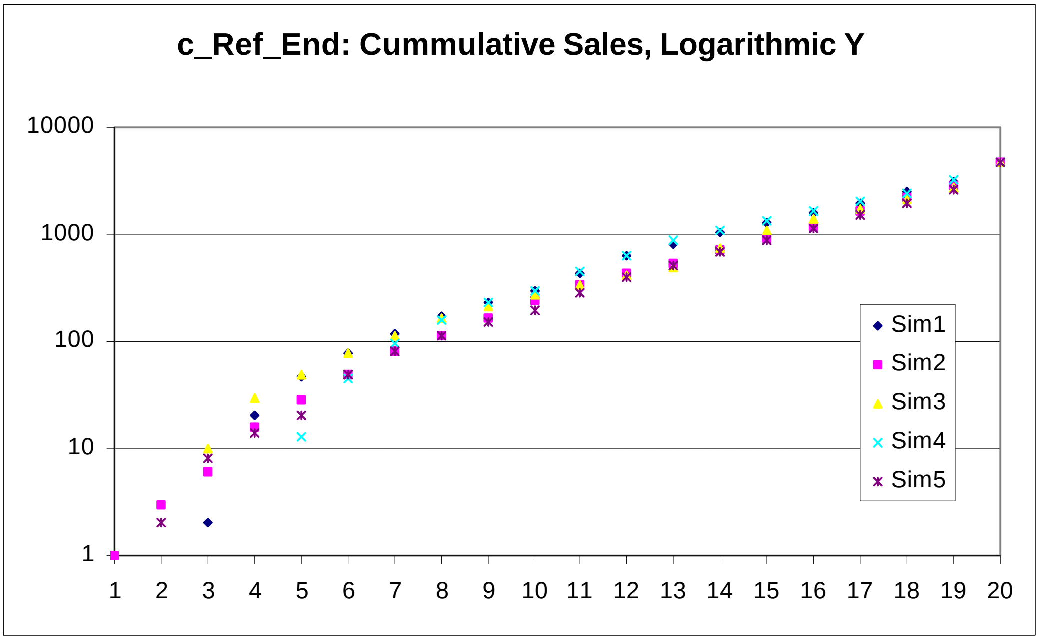


Figure 11: Comparison of number of direct customer users under various manufacturer strategies. Small model: customer referrals with endorsements communication.

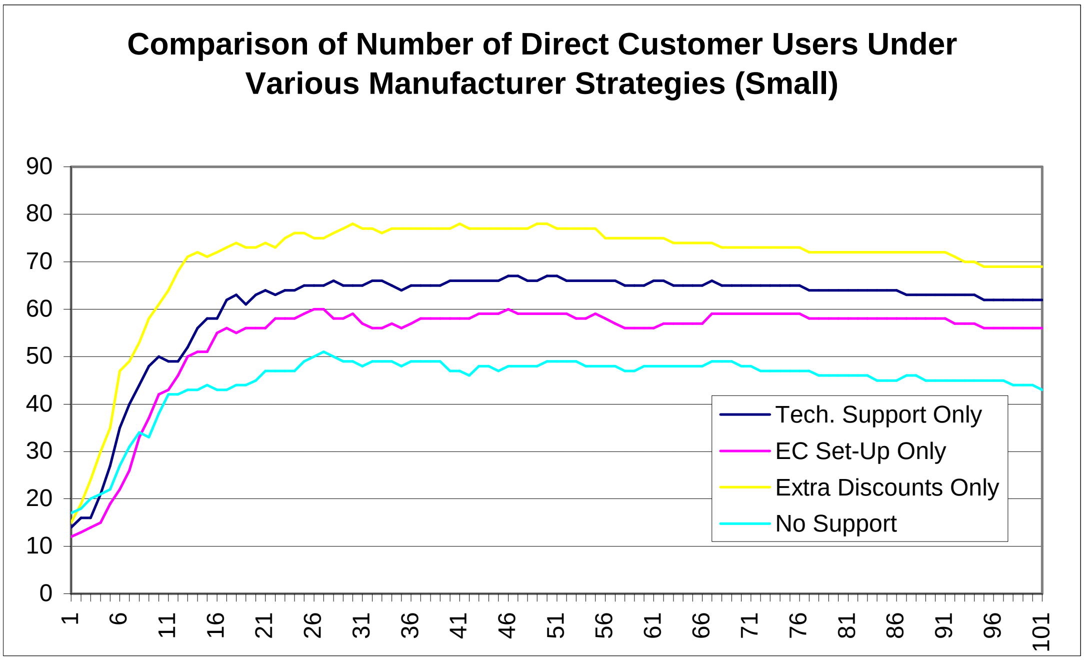


Figure 12: Chart showing mall statistics between Oct 2001 and Jul 2002: number of mall orders and total number of order lines received.

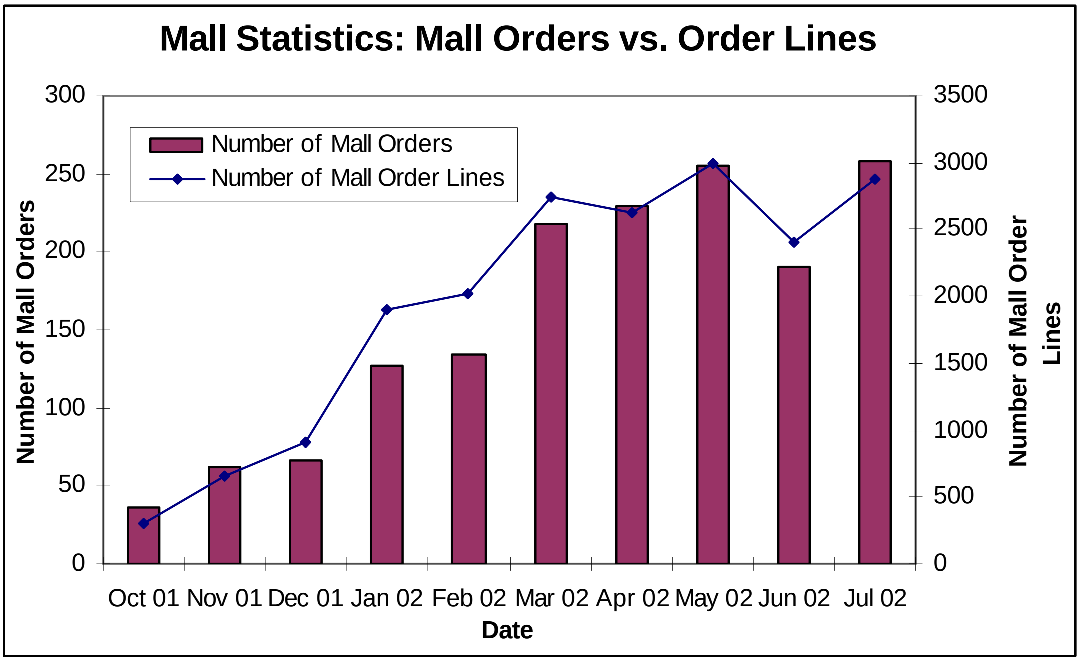
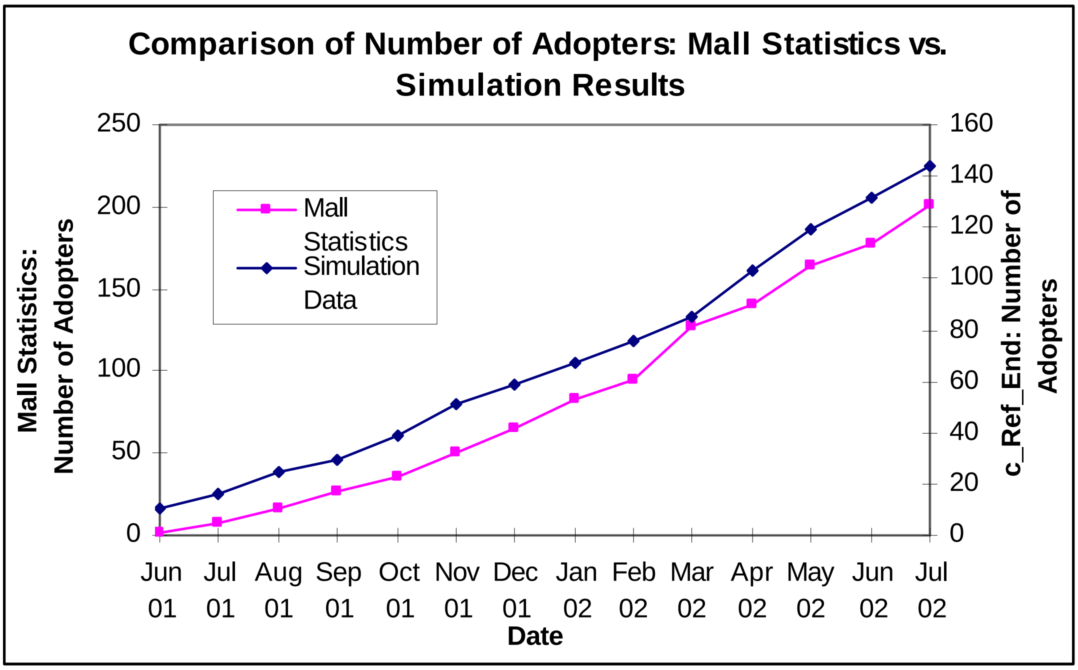


Figure 13. Chart comparing mall statistics with simulation results: the adoption curve. Large model, customer referrals with endorsements communication.



6. Discussion

We can argue, with reasonable confidence, that the model corresponds well with the supply chain described in the case study. Firstly, because it was based on information provided by the stakeholders identifying the main units of agency and processes involved, and secondly because of the extensive linking and validation procedures that were carried out. Finally, the model also exhibited statistical features such as power law distributions and s-shaped adoption curves, and these properties were robust over many simulation experiments and different scenarios. These factors lead us to conclude that the model should not be ruled out on the basis of implausibility as a model of the value chain described in part 2. Furthermore, when used to explore research questions about the impact of Internet-EC on the supply chain, it produced some reasonable results.

In terms of contribution to knowledge about value chain issues, we have the emergent findings of the fieldwork as well as interpretation of simulation results of section five. We explored research questions centring upon diffusion of e-commerce systems, drivers and inhibitors of adoption, the impact of e-commerce upon the role of intermediaries, their market share and profitability, disintermediation and reorganisation of the value system, manufacturer and intermediary strategies, and the importance of social influence processes. Case study findings were supportive of a weak disintermediation hypothesis - that some limited disintermediation could be expected, and that this could form part of a manufacturer strategy to improve information flow throughout the value chain.

We were also able to identify the main inhibitors and drivers to adoption of e-commerce, and these factors were prominent aspects of our simulation model. The model was also based on the assumption that social influence plays an important role in the attitude formation of potential users of the system. Scenario analysis suggested that interaction amongst customers would lead to greater inequality in market share for intermediaries and changes in levels of adoption and use.

The methodological approach was evidently appropriate because it allowed us develop a model of a complicated e-commerce business system (and we doubt that other modelling approaches could do the same). However, we found that the complexity of such a case study presented its share of difficulties: much work needs to be done to find appropriate techniques and methods. Some have been suggested in this paper, for example, the problem of incorporating qualitative data into formal models, and maintaining close contact with domain experts to clarify modelling issues. Whilst we do not propose that the technology is sufficiently advanced to use as replacement for multiple case studies in qualitative research, we strongly believe that there is much to be gained from using agent-based modelling in parallel. In essence, this is the argument for multimethodology – a debate which is attracting much attention in the area of management of information systems. In this paper we advocate ABSS modelling as one such alternative.

In the process of carrying out the case study, there were also some unforeseen difficulties which appeared. One issue was the changing circumstances within the company itself, which resulted in difficulties with the case study. For example, the model development cycle was hindered by the imminent arrival of a new director and by the approaching retirement of one of the key stakeholders, which would, it was anticipated, provoke changes both in the way the department was run and in the focus of development for the e-commerce team. After the initial high level of enthusiasm for the project, these factors led to a lessening of involvement in the project in the face of changing circumstance and more pressing commitments. For the case study research, the consequences of this reduced involvement were: lack of access to data, difficulties in completing the model evaluation process, and eventually an abrupt ending to the project. A secondary problem we encountered was that the stakeholders did not deliver the data and access they had agreed to in the case study design, despite repeated requests. This is a typical pitfall of doing management research: contacts are very busy and can afford little time to be involved in research projects. Unfortunately, these data were useful information that would have benefited the case study greatly. Specifically, we were not able to obtain data on intermediary characteristics, or to gain access to customers for the quantitative survey. These were both very important aspects of the case study.

A main criticism of the paper would be that there was a lack of information about the nature and characteristics of intermediaries and customers and the perceptions that drive their behaviour. Since we did not speak to any intermediaries to get their views and their understandings of the perspectives of intermediated customers, this probably led to a one-sided view of e-commerce development. It also meant that we explored the strategic options for the manufacturer only, and we have very little conception of customer and distributor alternatives, i.e. their responses to manufacturer actions. In general, the lack of information was problematic because it left us with a number of model assumptions that were less well validated than they might have been.

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