Strategic modularisation and performance implications in the Brazilian automotive industry

Ronaldo Parente*

School of Business, Rutgers University, Camden, NJ 01802, USA
E-mail: ronaldo@parente.com
*Corresponding author

Jian Gu

Management Department, School of Business, Salem State College, Salem, MA 01970, USA
E-mail: jgu1126@yahoo.com

Abstract: This research revolves around strategy determinants and performance implications of modular production – a production method that has been increasingly adopted by global manufacturing firms. A conceptual framework is proposed and then tested using data from a large-scale survey of 103 automobile firms in Brazil. The conceptual framework examines the relationships between the strategic modularisation and its determinants on both the industry level and the firm level. Furthermore, the framework studies the impact of modularisation to firm performance as well as how the moderating effects of codesign, physical proximity, and face-to-face communication on the modularisation/performance relation.

Keywords: Brazilian automotive industry; codesign; conceptual framework; empirical study; performance; physical proximity; strategic modularisation.

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Biographical notes: Dr Ronaldo Parente is an Assistant Professor at Rutgers University in New Jersey, USA. His research focuses on international strategy, modularisation, global supply chains and knowledge management.

Dr Jian Gu is an Assistant Professor at Salem State College in Massachusetts, USA. His research focuses on cross-border acquisitions, international joint ventures, globalisation, government corruption and economic development.

1 Introduction

In the new era of global competition, the erosion of global boundaries and the rapid transformation of markets due to technological change are causing the 'deconstruction' of organisational systems (Hitt et al., 1998; O'Grady, 1999; Schilling and Vasco, 2000; Snow et al., 1992). The recent trend of product modularisation (also hereafter modularisation)

is being experimented with and adopted by many manufacturers, especially in the new plants such as the automakers and suppliers in Brazil (For a thorough review over the recent transformation of the Brazilian auto industry, see Zilbovicius et al., 2002). Researchers have defined product modularisation as the process of assembling final products from a number of predetermined and interchangeable modules (Hoogeweegen et al., 1999; O'Grady, 1999; Worren, 2001). The strategic meaning of product modularisation is not only the sharing of investment and risks between the assemblers and the suppliers but that firms can produce a wide variety of products in extremely short lead times. More importantly, modularisation reshapes the boundaries of the companies and diffuses knowledge among the different companies (Salerno, 2001). According to Baldwin and Clark (2000) modularisation is a strategy for organising complex products and processes efficiently.

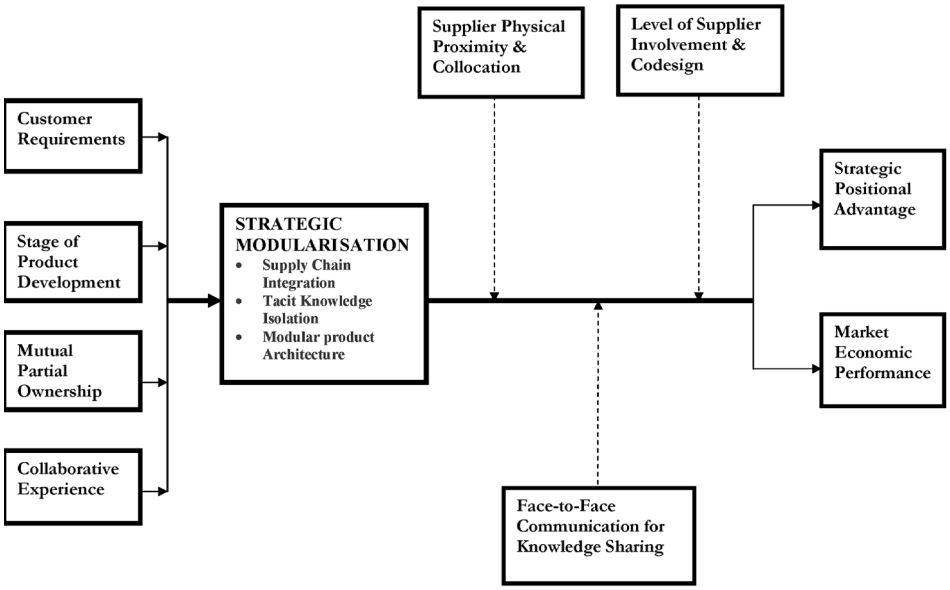
The focus of this study is that a strategic approach to product modularisation can create dynamic capabilities through modular product and process architectures by integrating resources and competences in way that allows managers of different projects, departments or external partners to mix and match their varied skills, functional backgrounds and expertise in order to deliver revenue producing products and services and satisfy individual customer requirements.

There is rich previous literature on modularisation as it applies to the automobile industry (Belzowski et al., 2003; Graziadio and Zilbovicius, 2003; Marx, 1997; Salerno, 2001). However, our literature survey suggests that the study of modularisation is in its early theory building stage with most studies on the topic being in-depth case studies or industry surveys. These studies provide rich information and deep insights, but very few birds-eye-view comprehensive theoretical frameworks to summarise the antecedents, as well as the performance implications, of modularisation. In addition there are only a few large scale empirical studies across a large number of firms on how the adoption of modularisation affects performance outcomes, with the exception of the recent studies by Worren et al. (2002) and Zilbovicius et al. (2002). Worren et al. (2002) examined the impact of product modularity to strategic flexibility in the home appliance industry, while Zilbovicius et al. (2002) examined the gap between first, second and third tier suppliers, the denationalisation of the components sector, the winners of modular supply and the spread of codesign activities. Building on recent empirical findings and the insightful previous case studies in the automobile industry, this research intends to make an academic contribution by developing and testing a normative framework integrating the antecedents of the decision to adopt product modularisation and its impact to performance outcome at the firm level using large-scale survey data and academically rigorous statistical methods to empirically test the framework. Another important theoretical contribution of our research is that our main construct of strategic modularisation is defined and measured as a multidimensional construct that moves beyond product modularisation. It is a strategic approach to modular production that incorporates the firm's resources and capabilities associated with its ability to deal with problems of integrating the supply chain and managing tacit knowledge integration within the production process. This definition is based on, and deepens, Salerno's view on modularity as 'a new form of relationship among assemblers and suppliers that reshapes the boundaries of the industry and even the definition of the business and the risks linked to it' (Salerno, 2001). Moreover, strategic modularisation is a continuous construct where firms adopting a higher degree of strategic modularisation tend to design more

modular product architectures, develop higher levels of supply chain integration allowing for the effective transfer of innovation capabilities among members of their modular network, and are able to isolate tacit knowledge away from the interfaces among components at the supplier level. This study therefore represents a significant step forward in theory building for strategic modularisation literature.

In addition, our findings should also have important managerial implication in helping managers to develop a clear understanding of the factors associated with the adoption of strategic modularisation and consequently the performance implications of such strategy. It is expected that the empirical results from this research can shed some light on the management decision processes to adopt modularisation and its overall applicability in today's global business context. Figure 1 depicts our framework to be tested.

Figure 1 Strategic modularisation conceptual framework



As the Brazilian market has become the testing ground for the modular manufacturing practice for global automakers (Zilbovicius et al., 2002), we conducted plant visits and in-depth interviews with four major automakers in Brazil (i.e. General Motors, Volkswagen, Ford and DaimlerChrysler). The interviews shed some light on how automakers in Brazil have implemented strategic modularisation in these plants and informed us of the survey development.

The organisation of the research follows: Firstly, a literature review on modularisation and the auto industry is provided. The following section provides the research methodology along with an explanation of the sample and data collection process. The theoretical framework is therefore developed and testable hypotheses are proposed. In another section an analysis of the empirical results and hypotheses testing is presented. Finally, the final discussion containing research findings and the theoretical and managerial implications are presented, along with the study limitations and potential for future research in this area.

2 Literature review

In the 1980s Toyota brought a revolution to manufacturing that moved away from Ford's mass production and toward the adoption of a production method based on the concept of 'lean' production (Womack et al., 1990), which focuses on eliminating waste and inventory from the supply chain and aggregates value in every step of the production process. From transaction cost economics (Williamson, 1975), the decision to integrate activities can generate efficiency gains when there are market imperfections (i.e. opportunism, asset specificity and uncertainty) creating excessive transaction costs. Thus, the decision to vertically integrate is usually motivated by exchanges that require high levels of transaction-specific investments and are characterised by information asymmetry (Williamson, 1975, 1985). A vertical integrated firm is usually inert and inflexible, thus internal transaction (bureaucracy) costs can be extremely high (D'Aveni and Ravenscraft, 1994).

In many markets, the globalisation trends of the 1990s was a period characterised by intense competition and shortened product life cycle, which pressure many organisations to form strategic alliances and other collaborative arrangements in other to leverage their strategies and resources. In order to share the large investment (and the risks associated with the investment) with suppliers, many multinational enterprises begin to experiment modular production in new markets such as Brazil. (Becker and Zirpoli, 2003; Filho et al., 2003; Zilbovicius et al., 2001). Moreover, our fieldwork suggests that the strategic approach to modularisation encompasses both the supply (i.e. design and production) and the demand (i.e. customer requirements) side of the business and it has being adopted in many industries ranging from computers (Baldwin and Clark, 2000), home appliances (Worren et al., 2002) and automakers (Cusumano and Nobeoka, 1998; Salerno, 2001;). Modularisation is argued to help organisations to achieve mass customization,[1] shorten product development cycles, speed technological change, and lower costs (O'Grady, 1999). Baldwin and Clark (1997) suggested that 'by delegating the manufacturing process to many separate suppliers, each one of which adds value, the assembler gains flexibility and cuts costs.'

Recently Zilbovicius and his colleagues (2002) conducted a survey in Brazilian auto industry. They found that although the number of major suppliers for the large assembler firms was decreasing, there was significantly more coordination, codesign and coinvestment between the suppliers and the assemblers. According to Salerno (2001), the actual boundaries of the firms adopting modular manufacturing are becoming fuzzy. Instead, the modularity requires more cross-firm sharing of design and knowledge. The erosion of global boundaries is pressuring firms to reconfigure their value chains in a more efficient way. Organisations are therefore increasingly engaged in cooperative arrangements and alliances to leverage their capabilities. New coordinating technologies and knowledge management processes based on modularity concepts are making it possible for organisational form to be managed strategically (Sanchez and Mahoney, 1996). Thus, we must address the issue of modularisation not only from the actual production and assembly of independent modules, but also by taking into account the complex interactions between buyers (e.g. module integrators) and suppliers (e.g. module providers),[2] as well as the structure of the supply chain.

Resource-based theory (Barney, 1991; Teece, 1987) suggests that it is important to consider complex sets of organisational resources in understanding how strategic flexibility may result in competitive advantage. For example, to harness the knowledge flow between the modular assembler and the suppliers, both sides need existing common knowledge base and flexible organisational structure to allow for firm-boundary spanners (Belzowski et al., 2003; Salerno, 2001). In addition, the adoption of modularisation implies having or acquiring advanced 'architectural knowledge' about relevant components and/or activities and their interactions and interdependencies (Sanchez and Mahoney, 1996). Worren et al. (2002), suggested that modularisation can be seen as a set of principles involving modular product and process architectures that provide the organisation with strategic flexibility and the ability to manage complexities.

Recently modularisation has gained much attention, because it is now being linked more specifically to the assembly or design strategies of large multinationals. Several recent case studies (Becker and Zirpoli, 2003; Filho et al., 2003; Fujimoto, 2001; Graziadio and Zilbovicius, 2003) suggest that one important dimension of modularisation is the integration of the supply chain. This aspect of modularisation relates to the type of relationships developed with internal and external suppliers and to the cross-functional management between design and engineering. Modularisation therefore goes beyond the delivery of sequenced and subassembled modules to the final line. Module providers are now sharing physical facilities, investments and risks and are more responsive to demand fluctuations (Max, 1997; Salerno, 2001). For instance, our interviews with executives from the Volkswagen plant in Resende and the General Motors plant in Gravatai confirmed the importance of automaker's relationship with their module providers located inside the plant campus (or even under the same roof) as an important aspect of their modular strategy.

Our interview findings provide additional support for recent studies (Graziadio and Zilbovicius, 2003; Salerno, 2001; Zilbovicius et al., 2002) confirming that a modularisation strategy may be characterised by a high degree of involvement and commitment between module integrators (assemblers) and module providers (suppliers), where the role of suppliers goes beyond the traditional subassembly and physical delivery of modules. In our field interviews, suppliers assumed responsibility for technical assistance in the subassembly process and also participated directly in problem-solving activities in the assembly line. Module providers were involved with schedule changes, small product design change, warranty, product design and so on. In addition, module suppliers shared capital investment and market risks. Therefore, module providers are delivering not only a whole subassembly 'just in sequence', but also technical assistance (i.e. sometimes with some of their blue-collar workers and engineers working inside the client's facility), adjusting delivery to frequent changes in scheduling caused by marketing issues and/or productive problems, and even customer services (Salerno, 2001). Consequently, modularisation went beyond the idea of subassembly delivery practiced in lean manufacturing, to include an organisational and managerial system linking module integrators and module suppliers in a search to reduce the costs of managing tacit knowledge in addition to reducing fixed costs and the vulnerability to external factors.

Finally, we argue that the ability to efficiently structure and organise production through a modular supply chain is a critical capability for the assemblers' (e.g. automakers and other module integrators) competitiveness. According to O'Grady (1999), there is evidence that firms that adopted modularity as an strategic approach have increased

product variety and strategic flexibility, achieved economies of scale, reduced order lead-time, lower capital costs, lower overall costs, simplified control mechanisms, and increased feasibility of product/component change. It is easy for those firms to perform product upgrade, maintenance, repair and disposal. Karlsson and Weimarck (2001) also reports that extensive outsourcing strategy seems to support the firm objectives of profitability, efficiency, innovation and long-term growth. In addition, this study proposes that leveraging capabilities through the integration of the supply chain facilitates the diffusion of technology and expertise among buyers and suppliers, which help these 'extended enterprises' to achieve competitive advantage. Consequently, the adoption of modular production should have a positive impact on firm performance. The following section provides a description of the methods used in this study.

3 Methods

3.1 Field interviews and survey questionnaire

This study intends to go one step beyond the traditional case study method used in much previous research. In order to achieve stronger external validity, we combined the insightful interviews with a survey method to collect data from as large a sample as possible. Equipped with data from a large pool, the study sets to undertake the regressional empirical tests on the theoretical framework based on our interviews, as well as many previous case studies and surveys.

The qualitative data obtained in these interviews in conjunction with the case studies and literature review provided important insights about the causes and consequences of modularisation in the automobile industry. The field study consisted of plant visits and in-depth interviews with several plant managers, manufacturing supervisors, supply-chain managers and purchasing managers working in the automobile industry in Brazil. The purpose of this study was theory construction (i.e. elaboration of constructs and propositions) and testing. Consequently, it was important to explore a wide range of approaches and perspectives in the context of supply-chain management, production and design of cars during the qualitative data collection. Therefore, the sample selection was decided by making sure that it included strategy, as well as manufacturing managers of several automakers adopting innovative modular arrangements in the Brazilian market.

Of the 34 individuals interviewed, 19 were either plant managers or manufacturing supervisors from Ford (Sao Bernardo do Campo, São Paulo), DaimlerChrysler (Sao Bernardo do Campo, São Paulo), General Motors (Gravatai, Rio Grande do Sul), and Volkswagen (Resende, Rio de Janeiro). Also, as part of our visit to Brazil, an opportunity came up also to visit a small traditional Brazilian manufacturer in Fortaleza named Troller. In addition, one professor at the University of São Paulo who was currently studying the recent developments of the automobile industry in Brazil was also interviewed. Four of those interviewed were executives at Anfavea (Brazilian Automakers Association) and Sindipecas (Brazilian Suppliers Association). Our final sample included two automakers (i.e. Volkswagen and General Motors) representing modular production in greenfield investment; a brownfield investment (i.e. Ford) in a partial modular production plant; and a traditional auto manufacturing plant (i.e. DaimlerChrysler). In addition to the automaker's personnel interviewed in these plants, interviews were conducted with ten workers from suppliers (module providers) during the visits to the GM and VW plants.

The companies interviewed were from different nationalities, including Brazilians, Europeans and Americans.[3] Therefore, the sample reflects a diverse set of companies within the automotive industry including automakers and suppliers and, in conjunction with the literature review and case studies, is well suited to obtaining a rich set of ideas and insights regarding modular production.

A relatively general format for the interviews was followed. Firstly interviewees were provided with a brief description of the research project. Each interviewee then was asked questions around the several issues relating to their production process.[4] The personal interviews lasted an average of 60 minutes and were recorded, unless requested otherwise. All interviews were followed by a tour of the production facilities, where the interviewer also had the opportunity to speak to other employees on the floor, including some of the suppliers. The interviews were conducted between October 21st and November 4th of 2001 in the states of São Paulo, Rio de Janeiro and Rio Grande do Sul in Brazil.

Likert-type measurement scales for the constructs described in the strategic modularisation normative framework were developed as a methodology for our research. The scales related to market-context factors, firm-specific factors, strategic modularisation construct, moderating factors and firm performance. Wherever possible, items were reused, or the general question format from existing scales was maintained. However, it was difficult to apply existing scales in their entirety. Existing scales could not be found for most of the constructs. Therefore scales were adapted or developed to test the conceptual model. In most cases completely new measurement scales were developed. The development of the new items was informed by the field studies, which included semistructured interviews with managers and executives in four leading automobile manufacturers and their suppliers in Brazil, as described earlier.

Before deciding on the final version of the questionnaire, a preliminary version was tested with a Ford plant manager who was fluent in English. Then during our first visit to Brazil we discussed potential wording problems and confusions with Ford's plant manager in São Bernardo do Campo, which helped to further refine the items. The final version of the questionnaire was then translated into Portuguese and then back into English to assure that the translation had not missed any meaning of the questions. The survey was distributed to those identified for a sample group in hard copies, along with a request for participation and a brief description of the research in question. In addition, the survey was published on a dedicated website to provide an alternative means of response. Following Dillman (1978), the total questionnaire was kept as short as possible in an attempt to increase the response rate.

3.2 Sample and data collection

As described above, firms were chosen from the automobile industry in Brazil to test the conceptual model. Since, it is expected that a firm can simultaneously assume the role of module integrator (buyer) and module providers (supplier), the sample included both types of firms. The final sample was therefore composed of automakers as well as auto suppliers.

Administration of the survey followed guidelines prescribed in Dillman (1978). The automobile and auto suppliers manufacturers were identified through lists provided by the Anfavea (Brazilian Automakers Association) and by the Sindipecas (Brazilian Auto Suppliers Association). In addition, the two associations' lists were cross-checked with the Brazilian magazine *Automotive News*, which is published once a year and which

profiles firms and executives in the auto industry in Brazil. After combining these data sources and deleting duplicated entries, the questionnaire was sent to the remaining sample of 493 business units in the automobile industry of Brazil, including automakers and suppliers. As mentioned above, the questionnaire was mailed along with an introduction letter requesting participation in the research, giving a brief description of the research in question, and listing the benefits of participating in the survey. The survey was mailed to managers at the plant/divisional level, who were asked to respond based on the products and characteristics of their division. To try to increase the response rate, the questionnaire was also posted on a password-protected website, which gave respondents the option to respond the questionnaire online.

After the initial mailing, a total of 37 questionnaires were returned because of incorrect addresses, which reduced the sample size to 456 business units. After two follow up letters we received a total of 103 valid questionnaires with a response rate of 23%.[5] Early respondents were compared to late respondents to test for nonresponse bias (Armstrong and Overton, 1977). The first 70% of the returned questionnaires were defined as early responses and the remaining 30% as late responses and thus deemed representative of firms that ultimately did not respond to the survey. Firstly, the means of four background variables (geographical scope, firm size, firm age and division age) were compared and no significant differences were found. Then the means of eight explanatory variables were also compared, and, again, no significant differences were found.

The construct validation followed the usual steps in exploratory factor analysis and created indices summarising the items. In general, the structure of the constructs that were defined in this study ended up being confirmed by factor analysis. The reliability factor of each of the scales was estimated by computing Cronbach's alpha. Each of the scales was refined by removing questions that exhibited low inter-question correlations. The reliability coefficients (alphas) of each of the refined scales ranged from 0.64 for relative low-cost performance to 0.93 for collaborative experience. The refined scales generally have acceptable reliability coefficients as recommended by Nunnally (1978). Only one variable had alpha below the customarily cutoff point of 0.70, but it was kept in the model. Some researchers have argued that the 0.70 cutoff is inappropriate unless other types of information are taken into account (Cortina, 1993; Schmitt, 1996). Finally, the distributional properties of the data were investigated using residual scatter plots and normal probability plots. No departure from the assumption of equal variances was found. Indices were constructed by calculating the mean for all of the questions in each construct. These indices (means) were used in the subsequent analysis. Next, we provide some insight on our construct measurements.

3.3 Measurements

As mentioned above the data used in this research originate from a survey questionnaire sent to automakers and suppliers in the Brazilian automotive industry. Our main dependent variable strategic modularisation is a multidimensional construct calculated as the mean of its three dimensions identified in the factor analysis. The initial correlation coefficients among strategic modularisation dimensions – supply chain integration, tacit knowledge isolation and product modular architecture – were all above 0.5. In addition, the coefficients were all statistically significant justifying the use of the mean strategic modularisation index (MODULAR) as the dependent variable in the analysis. Moreover, since the measure for modularisation is derived from five Likert type questions in the

survey, it is a continuous variable rather than a 0/1 categorical variable. The standard deviation for this variable is 0.68. The higher value indicates a higher degree of strategic modularisation. The continuous measure for modularisation is necessary for testing the relationship between modularisation and performance. In order to measure strategic modularization, respondents were asked whether their product were decomposed into separate modules that can be re-combined into new product designs to achieve higher variety and reduce development time; whether they can make changes in key components without having to redesign other components, if overall their unit adopts a high degree of modularity, whether major suppliers are responsible for sequence delivery to the assembling line, if they use cross-functional teams, if there were high degree of cooperation with suppliers and the level of knowledge retained and shared with suppliers.

Our other two important dependent variables capturing performance implications from modularisation were strategic positional advantage and market economic performance. Hayes et al. (1988) suggested that in order to be competitive in international markets, firms must have factories that offer high product quality, quick speed for product development and a low cost structure. The distinction between the three dimensions of strategic positional advantages (low cost, speed and quality) discussed in this study has begun to diminish (Lanctot, 1995; Lanctot and Swan, 2000). We therefore constructed a mean index measuring strategic positional advantage that was calculated by collapsing individual dimensions from our survey data analysis (i.e. speed-to-market, product quality and lower cost) into one product performance index (POS_ADV) calculated as the mean of three dimensions. Respondents were asked questions regarding the time to determine product features, production costs, sales price, feasibility of proposed technologies and overall speed-to-market of their products. They were also asked about their product quality, and about production and labour costs. Regarding market economic performance (MKT_PERF) respondents were asked how their business units were doing in comparison to their three major competitors in the last 12 months in terms of sales growth, market share, profitability, customer loyalty, customer satisfaction, return on investments and return on sales. Next, the rationale for hypotheses development is provided.

4 Theory development and research hypotheses

Based on our field interviews and on previous field studies by Max (1997) and Salerno (2001) on the Brazilian auto industry, the determinants for the attractiveness of adopting strategic modularisation can be classified into two levels: the industry/market requirements; and the firm-specific factors.

4.1 Market context factors

4.1.1 Customer requirements

Today's changing business environment is characterised by lower switching costs and empowered customers equipped with 'fast evolving technologies that allow them to buy from markets scattered across the globe' (Kamrani and Salhieh, 2000). Therefore, the more heterogeneous the demands made upon the organisation, the more valuable will be

the ability to deliver variety from flexible production configurations (Schilling and Steensma, 2000). An organisation adopting strategic modularisation will be able to deliver assembly flexibility to customers, which is a function of the configuration options available through the 'reusability', 'substitutability' and 'upgradeability' attributes of a modular design (Garud and Kumaraswamy, 1995). In addition, modularisation can reduce customer's opportunity cost associated with an integrated products design that is equivalent to the next best option available (Schilling, 2000).

The relatively recent changes in customer attitude toward a lack of tolerance to mass-produced standard products can be associated with technological, political, social and economic factors. Consequently, customers are pressuring organisations for customised products at mass production costs. This trend toward mass customisation is pressuring organisations to develop business models that can leverage existing competences to take advantage of emerging customer requirements and lead to temporary competitive advantage (Worren et al., 2002).

In practice, many firms operating in today's dynamic market environment enter many different market segments, which require them to develop the ability to do business with many different types of customer's needs and preferences. Today customers require variety, high quality products, low cost, fast delivery times and products that are easy to upgrade. Therefore, when customers have idiosyncratic needs and preferences, a firm will more likely adopt a modularisation strategy to achieve scale and scope economies from 'reusability', 'substitutability' and 'upgradeability' (Garud and Kumaraswamy, 1995), which in turn, can be transferred back to customers as perceived value. The customer perceived value from flexibility and compatibility may translate into customer loyalty and consequently in superior performance. Alternatively, when a firm operates in one or few market segments and customer requirements are relatively homogeneous, then an integrated product design is more likely. Based on the above arguments the following hypothesis is suggested:

Hypothesis 1: In assembly-type industries (i.e. automobile), where there is high customer requirement for heterogeneity, the assemblers are more likely to adopt a high degree of strategic modularisation.

4.1.2 Stage of product development

The stage of product development as stated here refers to the predictability of products. In other words, looking at the global computer industry, products at an earlier stage of development such as personal computers are less predictable and may be subject to sudden or continuous change due to technological breakthrough or model developments. In addition, there is uncertainty on which suppliers to use for outsourcing. On the other side, more predictable products at a more mature stage of development, such as mainframe computers, may be less affected by incremental technological or model changes.

Strategic modularisation requires a reduced number of suppliers (or module providers) and a decentralised development process that allows module providers to be creative and innovative (i.e. foster autonomous innovation) as long as providers comply with the standard interface. For products with unpredictable specifications (unpredictable products), strategic flexibility and the ability to adapt to sudden and continual change are important issues that can be achieved through modularity. Therefore, firms manufacturing

these products may benefit most from strategic modularisation and may be in a better position to adopt strategic modularisation.

Even for the auto industry, usually considered a mature industry, the demand for product specifications is more unpredictable than it is in Europe and North America. According to a recent survey on Brazilian automobile industry (Zilbovicius et al., 2002), most model designs are developed by large multinational companies. For these foreign companies, the Brazilian market (and the larger MECOSUR market they target) has different demands and tastes than their traditional triad markets in North America, Japan and Europe. While the companies usually keep their base models from other markets, the special variations present unpredictability for the firm. Keeping flexibility for product heterogeneity, making room for further alternations, is therefore more important for multinational firms in Brazil than in triad markets. This is part of the reason that strategic modularisation may be popular among foreign large automakers in the Brazilian market. Based on the above arguments the following hypothesis is suggested:

Hypothesis 2: In assembly-type industries (i.e. automobile), where there is a high level of unpredictability of product specifications (i.e. markets where products are still in the earlier stages of product development), the assemblers are more likely to adopt a high degree of strategic modularisation.

4.2 Firm-specific factors

4.2.1 Mutual partial ownership

New organisational forms such as 'loosely coupled' systems (Hitt et al., 1993; Orton and Weick, 1990), 'modular structures' (Daft and Lewin, 1993) and Japanese Keiretsu (Dyer, 1996b; Kotabe, 1998) have been noted to facilitate advanced manufacturing technologies. According to Lei et al. (1996), these organisational forms share some common organisational features such as 'the cultivation of new sources of tacit organisation-embedded knowledge, cross-functional integration and coordination of value-adding activities, and relative ease of selectively cooperating with other organisations in dividing the industry-wide value chain' (p.502). In other words, knowledge transfer, flexibility, integration, cooperation and coordination are important issues to be considered in the study of modularisation and organisational systems.

Module integrators must be able to resolve conflicts with external module providers. There is therefore, one dimension of inter-firm relationships between buyers and suppliers that becomes important in the decision to adopt a modularisation strategy, which is the degree of mutual ownership between the assemblers and their suppliers. The key here is not the traditional argument for majority ownership and control. The ownership can be only minor and mutual. The key here is that even minor and mutual ownership can facilitate trust between assemblers and the suppliers. The trust then should stimulate the coinvestment and risk sharing in strategic modularisation.

This dimension can be observed among Japanese manufacturing firms adopting their well-known keiretsu (inter-firm) relationships with their suppliers, either for strategic or cost purpose (Fujimoto, 2001). Those firms might be in a better position to develop and implement strategic modularisation since the keiretsu has the ability to enhance mutual trust and long-term commitment in a buyer-supplier relationship through their mutual partial ownership characteristics (Kotabe, 1998). Kotabe also suggested that

Japanese keiretsu should not be seen as simply a contractual base buyer-supplier relationship as noted in the following passage.

> "Technically speaking, suppliers in a Japanese vertical keiretsu are not necessarily owned in any significant way by a principal company. In most cases, a principal company owns no more than 10% of the stock of its suppliers, and those suppliers also hold some of the principal company's shares. Such a mutual partial ownership is designed to enhance mutual trust and long-term commitment to each other. A transfer of executives, engineers, and some R&D funding from the principal company to its keiretsu member suppliers in exchange for the suppliers' commitment to the principal company is so common that a keiretsu can be considered a highly integrated corporate system (thus, intra-firm sourcing) rather than a buyer-supplier relationship on a spot or contractual basis." (Kotabe, 1998, p.118)

A possible drawback causing a firm to hesitate adopting a modularisation strategy is the issue of opportunistic behaviour and the concerns of protecting proprietary knowledge. Within firms sharing mutual partial ownership with their partners and/or suppliers these issues become less important due to the mutual trust and commitment that develops from the relationship. Since these threats are reduced for these firms one can argue that firms sharing mutual partial ownership may be in a better position to adopt strategic modularisation. Based on the above arguments the following hypothesis is suggested:

Hypothesis 3: In assembly-type industries (i.e. automobile), where there is a high degree of mutual partial ownership within the buyer-supplier relationship, assemblers are more likely to adopt a high degree of strategic modularisation.

4.2.2 Collaborative experience

Another firm-specific factor is the length and experience with the buyer-supplier network relationship. Most firms today are involved to some extent in outsourcing strategies, partly due to increased pressure towards downsizing and the possible benefits of cooperative inter-firm relationships (Jarillo, 1988; Miles and Snow, 1984; Takeishi, 2001). Outsourcing some internal activity and building cooperative and long-term relationships with suppliers can bring some benefits such as combining different capabilities, sharing fixed costs, and gaining economies of scale (Takeishi, 2001). Takeishi (2001) suggested that the competitiveness of a producer (or buyer) is highly dependent on the capability of its suppliers and how effectively the producer manages the division of labour with these suppliers. When supplier and buyer develop relation-specific knowledge and have substantial experience working together they are less likely to misread the specification of the standard interfaces and misinterpret information (Dyer, 1996a). Long-term communication and effective feedback in buyer-supplier relationships increase the ability of both parties to learn from prior experience.

Firms possessing long-term experience in buyer-supplier relationships may therefore find themselves in a better position to adopt strategic modularisation since they may have better knowledge and information of the competencies and capabilities of available suppliers. This knowledge will be helpful for selecting the modular network that will match customer requirements to the available resources and capabilities of suppliers when defining modules and standard interfaces. Based on the above arguments the following hypothesis is suggested:

Hypothesis 4: In assembly-type industries (i.e. automobile), where firms possess a high level of experience in buyer-supplier network relationships, the assemblers are more likely to adopt a high degree of strategic modularisation.

4.3 Performance implications from strategic modularisation

The fieldwork and literature review indicated that strategic modularisation is expected to help organisations to improve 'mass customisation' capabilities, to shorten product development cycles, speed technological change, improve product quality and lower costs. More importantly, strategic modularisation is also expected to leverage supply chain integration and isolate tacit knowledge at the supplier level. In turn, this should reduce the costs associated with managing tacit knowledge and improve the firm's relative positional advantage. Karlsson (2001) observes that extensive outsourcing strategy supports the firms' objectives of profitability, efficiency, innovation and growth. Strategic modularisation is a special form of extensive outsourcing. Therefore, strategic modularisation is expected to enhance the manufacturer's performance.

Next, the impacts of strategic modularisation on two performance indicators are discussed.

4.3.1 Relative strategic positional advantage

The impact of strategic modularisation on firm performance can be evaluated utilising a strategic (i.e. positional) measure of performance (Lanctot and Swan, 2000). The change in a firm's positional advantages is a measure of performance (Day and Wensley, 1988). Knowledge-based resources and asset-based resources are sources of competitive advantage that can be used to gain positional advantage through

- a lower relative cost position
- a superior customer value position (Lanctot and Swan, 2000).

According to Porter's (1980) framework, firms adopting a low-cost position expect to benefit from riding down the experience curve. In addition, firms are able to generate a superior customer value position when they can create something that is perceived as being unique from its competitor's offering. Superior value position can be achieved along various dimensions, but two of the most salient ways to measure superior customer value are product quality and speed to market (Lanctot and Swan, 2000).

There are three components to the firm's strategic positional advantage: cost, speed-to-market, and quality. The distinction among low cost, speed-to-market and high product quality has begun to diminish in the literature. It has been noted that faster product development time leads to cost reductions, to superior customer service and to superior product quality (Bower and Hout, 1988). Firms competing globally must have high-performance manufacturing that can offer high quality products, quick speed and low costs (Hayes et al., 1988). In addition, lower relative cost position and superior customer value (from quality and speed-to-market) might not be mutually exclusive (Lanctot and Swan, 2000). This study is in agreement with the above arguments. Consequently, this research suggests that in highly competitive environments, superior product differentiation and lower relative costs may collapse into a single strategic positional advantage. Therefore, following Lanctot and Swan (2000), the term 'strategic positional advantage' will be treated as a single construct that is achieved from a

combination of low cost, speed to market, and high product quality. Moreover, strategic modularisation is suggested to reduce the costs associated with coordinating and managing tacit knowledge and in turn leads to superior positional advantage.

Thus, following Lanctot and Swan (2000), superior product differentiation (i.e. quick speed and high product quality) and lower relative costs will be collapsed in a single strategic positional advantage when testing the impact of modularisation strategy to the firm's relative strategic positional advantage. Based on the above arguments the following hypothesis is suggested:

Hypothesis 5: The higher the degree of strategic modularisation, the higher the level of relative positional advantage.

4.3.2 Relative market/economic performance

Following the work of Lanctot and Swan (2000), the impact of modularisation on firm performance can also be evaluated utilising a market/economic measure of performance (Capon et. al., 1990; Hunt, 1997; as cited in Lanctot and Swan, 2000). Resource-based view of firm proposes that a firm's resource advantage leads to strategic advantages such as lower relative cost and superior customer value. Consequently, strategic advantages should lead to superior market performance such as customer satisfaction, loyalty, market share and profitability.

Moreover, firms should use a technology strategy for acquiring, developing and applying technology for competitive advantage. Strategic modularisation might also help the firm's market and economic performance since it can internalise its product technology and leverage this knowledge for use in other product configuration. Following Lanctot and Swan (2000), traditional indicators such as sales growth, market share, customer loyalty, customer satisfaction and profitability should provide an indication of the impact of strategic modularisation on firm's market and economic performance. Based on the above arguments the following hypothesis is suggested:

Hypothesis 6: The higher the degree of strategic modularisation, the higher the level of relative market performance.

4.4 Moderating factors enhancing performance

4.4.1 Codesign and level of involvement

An interesting aspect of modularisation refers to the type of relationships developed with internal and external suppliers and on the cross-functional management between design and engineering. Thus, strategic modularisation involves handing off more of the design and assembly work to the supplier base. In practice, the suppliers must take on more of the engineering and development work, and should get involved earlier in the design process. For instance, the case studies indicated that in General Motors many system suppliers have set up shop inside the plant and have been involved in the project since the design phase. In this case, the 'module integrator' (i.e. general motors) and the 'module providers' (i.e. internal departments or external partners) are working together from the project conception since; the crucial design problem is one of designing the interfaces between modules (O'Grady, 1999).

The existence of tacit knowledge also has a significant impact on the degree of interdependence among components and activities. A high degree of tacit knowledge within component interfaces can limit the achievement of an optimal degree of strategic modularisation in any given system. In other words, high levels of tacit knowledge if not isolated within the hidden parameters at the component or module provider (i.e. supplier or external partner) level will limit the module integrator's (i.e. the firm receiving the customer order) ability to successfully implement strategic modularisation since the interactions among components will not be fully specified. Therefore, the degree of tacit knowledge is a significant limitation to the effectiveness of strategic modularisation because it affects 'design rules' (Baldwin and Clark, 1997), and may limit designers' ability to fully specify standardise interfaces that efficiently facilitate the flow of knowledge between components. Consequently, since this kind of knowledge cannot be codified, designers must encapsulate or isolate it at the component or module level.

Recently, General Motors opened its US$ 554 million 'Blue Macaw' small-car assembly complex in Brazil to build a version of the Opel-Corsa called Celta. According to Mr Roberto Tinoco (plant manager), the goal of the 1997 top-secret project was to 'build profitable small cars using supplier modules pre-assembled within a multi-manufacturing complex that functions as a single plant'. The Blue Macaw project completely innovate every aspect of production from design to distribution and according to the field interviews has cut production costs significantly. There, key suppliers worked together with GM to codesign components and simplify production processes while suppliers have established operations of their own in the grounds of the complex, and are linked electronically to GM, making it easier to schedule a build-to-order system. In this type of modular production, GM suppliers, through codesign, actively participate in product development and handle much of the engineering work once done in-house. The Blue Macaw complex reached out to its supply base, seeking input on the design and engineering and it was designed to unlock creativity and innovation and to attempt to leapfrog the famous Toyota lean production system, which has been the measure of manufacturing efficiency in the automotive world. Thus it is important to address how the level of codesign and early involvement moderates the relationship between strategic modularisation, relative strategic positional advantage, and relative market performance. Based on the above arguments the following two hypotheses are suggested:

Hypothesis 7a: The positive association between the degree of strategic modularisation and relative strategic positional advantage becomes stronger as the level of codesign increases.

Hypothesis 7b: The positive association between the degree of strategic modularisation and relative market performance becomes stronger as the level of codesign increases.

4.4.2 Physical proximity and collocation

Physical proximity between supplier and manufacturer has been argued to represent the key to success of just-in-time systems (Neto and D'Angelo, 2001). At General Motors, suppliers have established operations of their own inside the factory grounds and are linked electronically to GM, making it easier to schedule a 'build-to-order' system. In this

type of modular production (i.e. GM's modular condominium) suppliers actively participate in product development and handle much of the engineering work once done in-house. In addition, the interview findings indicate that both at Ford and at VW modular plants, tier-one suppliers are even responsible for recall and warranty costs arising from their work.

GM's strategic modularisation approach was implemented such that major suppliers such as Delphi, VDO, Goodyear and Valeo built their own production facilities inside their plants. At GM, 16 module providers have set up shop inside the plant and have been involved in the project since the early design phase. According to Mr Tinoco, the plant manager at Gravatai, 'The new arrangements allow 85% of the models produced at Gravatai to rely on components and modules assembled on site, while in most auto plants, 60% of a car's components by value are sourced from outside the factory.'

The VW plant in Resende has broken new ground in the relationship between automakers and their suppliers. As Mr Luca mentioned, 'If my module supplier is next door, he is already too far.' At VW Mr. Luca and representatives from all seven major module providers located inside the plant meet for 30 minutes every morning before the manufacturing shift starts to discuss potential problems and solutions first hand. 'Everyone in this meeting needs to have the power to make decisions and resolve problems right away. I do not accept a person taking notes and saying he will consult with other managers at his facility. Decisions are to be made on the spot.' Another important characteristic of the modular production (i.e. VW's modular consortium) is that each supplier is expected to bring improvements and process innovation to the production process. As Mr Luca noted:

> "Our suppliers working inside our plant can better monitor our production line. Our suppliers can sense demand fluctuations and volatility in the market at the same time we do. Because of this close interaction they are always willing to sit with us to renegotiate prices and conditions. This gives us a competitive edge when biding for large contracts such as the one we just close for selling 700 trucks to Saudi Arabia."

In general, respondents agreed that physical proximity and collocation can facilitate the implementation of modularisation by reducing potential delivery problems and allowing any eventual problem in the production line to be dealt with and solved on the spot. Also, collocation facilitates cooperation and communication. Mr Jorge at Ford said, 'The only reason some of our module suppliers are not located inside our plant is because this was a relocation project and we had space restrictions and could not accommodate everyone here.' Finally, it is expected that collocation and physical proximity will improve the relationship between strategic modularisation and firm performance. Based on the above arguments the following two hypotheses are suggested:

Hypothesis 8a: The positive association between the degree of strategic modularisation and relative strategic positional advantage becomes stronger as collocation increases.

Hypothesis 8b: The positive association between the degree of strategic modularisation and relative market performance becomes stronger as collocation increases.

4.4.3 Degree of face-to-face communication for knowledge sharing

In the context of high technological and dynamic industries, modular product components are conforming to standardise interfaces and firms are more and more engaging in network alliances with their suppliers, customers, distributors and competitors. In those network alliances and other modular organisational structures knowledge sharing becomes a central issue and it is associated with organisational flexibility and learning. The effective transfer of knowledge and technology among product components, organisational units and partners of a network might, therefore, impact the relationship between strategic modularisation and performance.

Media Richness Theory argues that a richer medium of communication such as face-to-face interaction is better for knowledge sharing and learning (Daft and Lengel, 1986). In other words, personal and more open communication increases the richness of communication channels. Greater interpersonal familiarity and personal affinity can be expected to increase the openness of communication between interacting parties (Gupta and Govindarajan, 2000). Researchers have emphasised the importance of both internal and external communication for the performance of product development organisations (Ancona and Caldwell, 1992; Brown and Eisenhardt, 1995). Therefore, in the case of strategic modularisation where the module provider is involved in product development, effective coordination through frequent communication between module integrator and module provider is critical (Takeishi, 2001).

Dyer (1996a) concluded that Toyota and Nissan had more frequent face-to-face interaction with their suppliers then the US competitors, in turn contributing to their 'short model cycle'. The author also found that Toyota and Nissan had more guest engineers at their sites than US automakers, which indicates the importance of extensive communication between collocated engineers. Toyota's network is able to efficiently transfer information and technology because there are a variety of processes available to transfer both explicit and tacit knowledge in a multilateral setting (Dyer and Nobeoka, 2000). One way of accomplishing this efficient knowledge flow is through frequent face-to-face communication among those involved in the design and implementation phases of the manufacturing processes. Therefore, the degree to face-to-face communication for knowledge sharing among members from module integrator and module providers involved in the design and production processes should be associated with more efficient outcomes from the adoption of strategic modularisation. More specifically, the degree of face-to-face communication is expected to improve the relationship between strategic modularisation and firm performance. Based on the above arguments the following two hypotheses are suggested:

Hypothesis 9a: The positive association between the degree of strategic modularisation and relative positional advantage/performance becomes stronger as the level of face-to-face communication increases.

Hypothesis 9b: The positive association between the degree of strategic modularisation and relative market performance becomes stronger as the level of face-to-face communication increases.

The proposed hypotheses and conceptual framework in Figure 1 revolves around strategy implications of modular production – a production method that has been increasingly adopted by global manufacturing firms. The model examines the relationships between

the determinants of strategic modularisation and its effect on the performance of firms. In addition, the model also describes the moderating effects of codesign, physical proximity and face-to-face communication to the relationship between strategic modularisation and strategic positional advantage and relative market performance. Next, the hypotheses testing and empirical results will be discussed.

5 Analysis and results

The conceptual framework was tested with the General Linear Model (GLM) procedure, using the software package SPSS version 11 for Windows. Table 1 shows descriptive data and correlation matrices for the variables use in this study. Table 2 shows the results for testing hypotheses 1–4. The hypothesised explanatory constructs (e.g. customer requirements, stage of product development, degree of mutual ownership, and experience in collaborative relationships) were regressed on the strategic modularisation construct (MODULAR) along with three control variables (SIZE, AGE and PRD_TYPE). The model had acceptable adjusted R-square of 0.568 significant at the 0.001 level, and all the control variables were nonsignificant.

Hypothesis 1 states that where the level of customer requirement is high, assemblers will be more likely to adopt a high degree of strategic modularisation. The results of the GLM procedure in Table 2 strongly support this hypothesis. Customer requirement (CUST_REQ) had a statistically significant beta coefficient of 0.413. This indicates that the greater the level of customer requirements, the more likely a firm is to adopt a higher level of strategic modularisation.

Hypothesis 2 states that in industries where there is a high level of unpredictability of product specifications (i.e. markets where products are still in the earlier stages of product development), the assemblers will be more likely to adopt a high degree of strategic modularisation. Results of the GLM in Table 2 did not support this hypothesis. The stage of product development (STG_DEV) had a nonsignificant negative beta coefficient of –0.118, indicating that the stage of product development does not have any implication in the degree of adoption of strategic modularisation.

Hypothesis 3 states that in industries where there is a high degree of mutual partial ownership within the buyer-supplier relationship, assemblers will be more likely to adopt a high degree of strategic modularisation. Results of the GLM in Table 2 marginally support this hypothesis. The degree of mutual ownership (MUT_OWN) had a beta coefficient of 0.121 significant at the 0.10 level. This indicates that there are mutual ownership (MUT_OWN) relationships between assembler and suppliers, these relationships seem to have a slight significant effect on the firm's degree of adoption of strategic modularisation.

Hypothesis 4 states that when firms possess a high level of experience in collaborative buyer-supplier network relationships, the assemblers will be more likely to adopt a high degree of strategic modularisation. Results of the GLM in Table 2 strongly support this hypothesis. The collaborative experience variable (COLL_EXP) had a statistically significant beta coefficient of 0.193. This indicates that the greater the firm's experience in collaborative relationships, the more likely a firm is to adopt a higher level of strategic modularisation.

Table 1 Correlation matrix and descriptive statistics

	Variables	*N*	*Mean*	*S.D.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1	MODULAR	*103*	*3.60*	*0.68*	1												
2	CUST_REQ	*102*	*3.41*	*0.76*	0.66**	1											
3	STG_DEV	*103*	*3.50*	*0.61*	0.14	0.18	1										
4	MUT_OWN	*103*	*2.48*	*0.93*	0.54**	0.57**	0.35**	1									
5	COLL_EXP	*103*	*3.60*	*1.08*	0.59**	0.45**	0.28**	0.50**	1								
6	LOW_COST	*103*	*2.70*	*0.57*	–0.26**	–0.36**	–0.12–	0.38**	–0.22*	1							
7	SPEED	*103*	*3.48*	*0.65*	0.48**	0.34**	0.01	0.35**	0.43**	–0.20*	1						
8	QUALITY	*103*	*3.71*	*0.57*	0.39**	0.27**	0.03	0.24*	0.28**	–0.19	0.57**	1					
9	POS_ADV	*103*	*3.30*	*0.37*	0.35**	0.15	–0.04	0.13	0.28**	0.30**	0.78**	0.75**	1				
10	MKT_PERF	*103*	*3.60*	*0.62*	0.44**	0.39**	0.04	0.27**	0.49**	–0.17	0.64**	0.59**	0.59**	1			
11	CODESIGN	*103*	*3.13*	*1.02*	0.71**	0.66**	0.14	0.45**	0.47**	–0.28**	0.27**	0.26**	0.15 .	0.29**	1		
12	PHYSPROX	*103*	*3.48*	*0.81*	0.35**	0.36**	0.04	0.28**	0.21*	–0.24*	0.05	0.03–	0.08	0.03	0.57**	1	
13	FACEFACE	*103*	*3.50*	*0.89*	0.54**	0.51**	0.14	0.43**	0.42**	–0.29**	0.43**	0.24*	0.23*	0.54**	0.59**	0.29**	1

Notes: * Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 2 Determinants of strategic modularisation

	Model[a]	
Independent variables	*Beta coef.*	*sig.*
Intercept	1.562	0.000
Explanatory variables		
CUST_REQ	0.413	0.000
STG_DEV	–0.118	0.145
MUT_OWN	0.121	0.077
COLL_EXP	0.193	0.000
Control Variable		
SIZE	0.175	0.174
AGE	0.156	0.166
PRD_TYPE=1	–0.055	0.725
PRD_TYPE=2	–0.051	0.760
Adjusted r-square	0.568	0.000

Note: [a]Dependent variable: strategic modularisation

Table 3 shows the GLM results for testing hypotheses 5 and 6. The strategic modularisation variable (MODULAR) and the three control variables were regressed on the two performance indicators – relative strategic positional advantage (POS_ADV) and relative market performance (MKT_PERF). Both GLM models in Table 3 had acceptable adjusted R-squares of 0.191 for the model having strategic positional advantage as the dependent variable and 0.216 for the model having market performance as the dependent variable. In general, the strategic modularisation construct (MODULAR) had significant beta coefficients. As predicted, a significant relationship was found between strategic modularisation and performance indicators such as speed to market (SPEED), product quality (QUALITY), overall relative positional advantage (POS_ADV), and market performance (MKT_PERF). The control variables SIZE and AGE were nonsignificant for all models. The control variable PRD_TYPE seems to have a significant negative effect on all performance variables, indicating that maybe suppliers of modules are not getting the promised benefits of modularisation.

Hypothesis 5 states that strategic modularisation will be positively related to relative strategic positional advantage. Table 3, containing the GLM results, shows support for this hypothesis. This model has an acceptable adjusted R-square of 0.191. The strategic modularisation construct (MODULAR) had a beta coefficient of 0.247 significant at the 0.001 level. This positive significant relationship indicates that the degree of strategic modularisation is positively associated with relative strategic positional advantage.

Table 3 Strategic modularisation and performance implications

	Dep. Var.=POS_ADV		*Dep. Var.=MKT_PERF*	
Independent variables	*Beta coef.*	*sig.*	*Beta coef.*	*sig.*
Intercept	2.462	0.000	1.906	0.000
Explanatory variable				
MODULAR	0.247	0.000	0.485	0.000
Control variables				
SIZE	0.044	0.638	–0.025	0.872
AGE	–0.091	0.274	–0.025	0.855
PRD_TYPE=1	–0.021	0.844	–0.031	0.859
PRD_TYPE=2	–0.385	0.001	–0.451	0.019
Adjusted r-square	0.191	0.000	0.216	0.000

Note: Dependent variables: strategic positional advantage and relative market performance

Hypothesis 6 states that a higher degree of strategic modularisation will be positively related to a higher level of relative market performance. Table 3, containing the GLM results, shows strong support for this hypothesis. This model has an acceptable significant adjusted R-square of 0.216. The strategic modularisation construct (MODULAR) had a beta coefficient of 0.485 significant at the 0.001 level. This positive significant relationship indicates that the degree of strategic modularisation is positively associated with relative market performance.

Table 4 and 5 show the GLM results for testing hypotheses 7 through 9. The GLM models in Table 4 show the interaction effects for each of the hypothesised moderators of the relationship between strategic modularisation and relative strategic positional advantage. The GLM models in Table 5 show the interaction effects for each of the hypothesised moderators of the relationship between strategic modularisation and relative market performance. Three control variables were incorporated in the models. In Table 4, each model tests the effect of each of the moderators (CODESIGN, PHYSPROX and FACEFACE) on the POS_ADV performance indicator in order to test hypothesis 7a–9a. Following the same rationale, in Table 5, each model tests the effect of each of the moderators (CODESIGN, PHYSPROX, and FACEFACE) on the MKT_PERF performance indicator in order to test hypothesis 7b–9b. The control variables SIZE and AGE were nonsignificant for all models. But again PRD_TYPE seems to have a significant negative effect on performance, which will be discussed in more detail below.

Table 4 Strategic modularisation and interactions effects on strategic positional advantage

	Dependent variable: strategic positional advantage (POS_ADV)					
Independent variables	*Beta coef.*	*sig.*	*Beta coef.*	*sig.*	*Beta coef.*	*sig.*
Intercept	2.535	0.000	2.897	0.000	3.081	0.000
Explanatory variables						
MODULAR	0.290	0.035	0.205	0.273	0.050	0.776
CODESIGN	–0.131	0.446				
PHYSPROX			–0.158	0.409		
FACEFACE					–0.209	0.284
Interaction variables						
MODULAR*CODESIGN	0.015	0.745				
MODULAR*PHYSPROX			0.020	0.723		
MODULAR*FACEFACE					0.063	0.251
Control variables						
SIZE	0.040	0.665	0.053	0.564	0.045	0.631
AGE	–0.110	0.202	–0.093	0.264	–0.072	0.393
PRD_TYPE=1	–0.003	0.976	0.030	0.789	–0.042	0.695
PRD_TYPE=2	–0.383	0.002	–0.336	0.007	–0.410	0.001
Adjusted r-square	0.198	0.000	0.208	0.000	0.186	0.000

Hypothesis 7a states that the positive relationship between the degree of strategic modularisation and relative strategic positional advantage becomes stronger as the level of codesign and early involvement increases. This hypothesis is not supported, because the GLM results in Table 4 show a nonsignificant beta coefficient for the interaction term (MODULAR*CODESIGN). This model had an acceptable significant adjusted R-square of 0.198.

Hypothesis 7b states that the positive relationship between the degree of strategic modularisation and relative market performance becomes stronger as the level of codesign and early involvement increases. This hypothesis is not supported, because the GLM results in Table 5 show a nonsignificant beta coefficient for the interaction term (MODULAR*CODESIGN). This model had an acceptable significant adjusted R-square of 0.205.

Table 5 Strategic modularisation and interactions effects on relative market performance

	Dependent variable: relative market performance (MKT_PERF)					
Independent variables	*Beta coef.*	*sig.*	*Beta coef.*	*sig.*	*Beta coef.*	*sig.*
Intercept	2.376	0.001	3.866	0.000	3.458	0.000
Explanatory variables						
MODULAR	0.364	0.111	–0.012	0.969	–0.274	0.302
CODESIGN	–0.244	0.396				
PHYSPROX			–0.634	0.046		
FACEFACE					–0.326	0.264
Interaction variables						
MODULAR*CODESIGN	0.062	0.434				
MODULAR*PHYSPROX			0.160	0.080		
MODULAR*FACEFACE				0.179	0.032	
Control variables						
SIZE	–0.027	0.860	–0.019	0.898	0.037	0.791
AGE	–0.010	0.944	0.002	0.987	0.055	0.662
PRD_TYPE=1	–0.055	0.759	–0.054	0.769	–0.115	0.467
PRD_TYPE=2	–0.498	0.016	–0.490	0.017	–0.507	0.005
Adjusted r-square	0.205	0.000	0.237	0.000	0.354	0.000

Hypothesis 8a states that the positive relationship between the degree of strategic modularisation and relative strategic positional advantage becomes stronger as physical proximity increases. This hypothesis is not supported, because the GLM results in Table 4 show a nonsignificant beta coefficient for the interaction term (MODULAR*PHYSPROX). This model had an acceptable significant adjusted R-square of 0.208.

Hypothesis 8b states that the positive relationship between the degree of strategic modularisation and relative market performance becomes stronger as physical proximity increases. This hypothesis is marginally supported, because the GLM results in Table 5 show a positive significant beta coefficient of 0.160 at the 0.10 level for the interaction term (MODULAR*PHYSPROX). This model had an acceptable significant adjusted R-square of 0.237. This indicates that, as the degree of physical proximity increases, there will be a positive effect on the relationship between the degree of strategic modularisation and market performance.

Hypothesis 9a states that the positive relationship between the degree of strategic modularisation and relative strategic positional advantage becomes stronger as the level of face-to-face communication increases. This hypothesis is not supported, because the GLM results in Table 4 show a nonsignificant beta coefficient for the interaction term (MODULAR*FACEFACE). This model had an acceptable significant adjusted R-square of 0.186.

Hypothesis 9b states that the positive relationship between the degree of strategic modularisation and relative market performance becomes stronger as the level of face-to-face communication increases. This hypothesis is strongly supported, because the GLM results in Table 5 show a significant positive beta coefficient of 0.179 at the level of 0.05 for the interaction term (MODULAR*FACEFACE). This model had an acceptable significant adjusted R-square of 0.354. This indicates that as the degree of face-to-face communication between assembler and suppliers increases, there will be a positive effect on the relationship between the degree of strategic modularisation and market performance. In the next section the findings and implications of the research are presented.

6 Discussions and implications

In the strategic management literature, researchers have widely recognised that '[o]rganisational capabilties are difficult to create and costly to adjust' (Henderson and Clark, 1990: 9; Nelson and Winter, 1982). Recently, researchers have emphasised that a firm's integration capability is a key organisational capability. Although integration capabilities have emerged as a critical element in determining a firm's performance, it has received only initial conceptual development and little empirical investigation (Mitchell and Shaver, 2003). The automotive literature have widely recognised either explicitly or implicitly the importance of integration and modularisation in the supply chain, knowledge management, and new product development (Becker and Zirpoli, 2003; Filho et al., 2003; Fujimoto, 2001; Graziadio and Zibolvicius, 2003; Karlsson and Weimarck, 2001; Salerno, 2001; Zilbovicius et al., 2002).

In response to the scarcity of empirical studies on integration capabilities, Collis and Montgomery (1998) have argued that a firm derives its corporate advantage not only from its resources that determine the products it offers, but also from its integration capabilities. In addition, a firm's ability to integrate various activities help safeguard its knowledge (Liebeskind, 1996). Similarly, Helfat and Raubitschek (2000) have echoed that integration capabilities are crucial in coordinating tacit and codified knowledge within and across vertical chains. A firm's ability to implement modularisation in tier product process may therefore help gain a significant advantage over well-entrenched, dominant firms.

Dynamic capabilities theory suggests that firms that accumulate resources do not necessarily possess useful capabilities, especially in a dynamic and uncertain environment (Eisenhardt and Martin, 2000; Teece et al., 1997). Although some manufacturers in the automotive industry have begun utilising modularisation to compete in a dynamic and uncertain global marketplace, many firms have not completely succeeded in implementing such strategy. Some firms seem to be able to benefit from higher degrees of modularisation more than others. The reason is that even though firms have acquired the

necessary relational and technological resources, they may not possess all the critical capabilities. Several case studies and surveys have discussed the implications of modularisation in the automotive industry (Graziadio and Zilbovicius, 2003; Salerno, 2001; Zilbovicius et al., 2002). Building from these literatures, we extended our knowledge of modularisation by conducting a large sample empirical study with a large data sample collected in the Brazilian automotive industry. Our comprehensive framework addresses a research gap by bridging the automotive and administrative literature on modularisation and by examining the relationship of four antecedents of modularisation and *how* modularisation impacts on business performance. In addition, we investigated the moderating factors affecting the relationship between modularisation and performance.

This research therefore represents the first effort to build a foundation for systematic development of a strategic modularisation framework for the manufacturing industries that will help researchers understand the technological trend currently underway in these industries. In sum, the broad aim of this research is to contribute to the understanding of the implementation and adoption of strategic modularisation, as well as its links to customer relationship and supply chain management in manufacturing industries.

Overall the analysis of the empirical results supports the prediction that strategic modularisation is beneficial for performance in the firms that adopted this strategy. Our findings provide a good support for the deterministic models (direct effects) but only partial support for the contingency models (interaction effects). In general, the findings indicated that the degree of adoption of strategic modularisation is positively associated with the degree of customer requirements and with the extent of the firm's experience with collaborative relationships. In other words, the findings indicated that the degree of adoption of strategic modularisation is positively associated with the degree of customer requirements and with the extent of the firm's experience with collaborative relationships. In addition, our findings lend additional support for the automotive literature indicating that strategic modularisation is positively associated with our performance indicators. In other words, firms adopting a higher degree of strategic modularisation seemed to have better relative strategic positional advantage and relative market performance in our sample of the Brazilian auto industry.

Graziadio and Zilbovicius (2003) suggested that there is sharing in design, production and knowledge between partners. Surprisingly, our empirical results did not find significance for codesign, although physical proximity and the degree of face-to-face communication seem to enhance the positive relationship between strategic modularisation and relative market performance. Although the moderating effects did not come out as expected, the results and possible alternative explanations point toward interesting directions for future research, whereby the implications of codesign, physical proximity and face-to-face communication can be systematically examined and compared in cross-national strategic relationships.

Many of the factors found to be associated with strategic modularisation in the analysis can be controlled or influenced by management decisions and can therefore be altered by managers to improve the probability of success when implementing strategic modularisation. Overall, the literature review, fieldwork data, conceptual framework and research results provide managers a comprehensive view of what strategic modularisation is, the ways to operationalise it and how it is likely to affect performance outcomes. In terms of the managerial implications therefore, our research findings provide normative guidelines to managers on managing the transition to

modular production strategies and relationships. The research findings confirm that modularisation is the current technological trend in the automobile industry in Brazil and should have direct managerial implications. The complexity of this strategic approach requires managers to develop a good understanding of its antecedents and outcomes to be able to take full advantage of the opportunities. This study can help managers develop a comprehensive understanding of this process and allow them to implement modularisation strategically in ways that will lead to firm success.

An important recommendation from this research is that managers need to better understand modular production and relationships to better manage the factors associated with how firms continuously improve internal processes to reduce job turnaround times, reduce cycle time and cut waste. The empirical findings in this study offer knowledge that should allow for quick response to customer demand and changes in the market. Managers can therefore benefit from the results in this research by developing a set of managerial tools that will help firms become more competitive by offering customers better delivery times, higher quality delivery and cost savings.

Moreover, knowledge exchange practices and strategic modularisation may help firms switch from a traditional adversarial relationship with suppliers, so that suppliers become strategic partners and integrate their businesses. Suppliers can then respond faster to product demands, because they can better anticipate the firm's needs. The goal should be that suppliers start to see a module integrator as a valued partner and not simply as another sale.

Management literature suggests that organisations use alliances to gain technologies (or other capabilities) more quickly than they could develop them in-house (Harbison and Pekar, 1998; Heinsl, 2000; Powell et al., 1996; Schilling and Steensma, 2000). Empirical findings support the above argument and the hypotheses that the degree of customer requirements and the extent of the firm's experience in collaborative relationships are positively related to the degree of adoption of strategic modularisation. In addition, research findings support the idea that manufacturing firms can avoid rigidity and obsolescence by adopting a strategy based on the concept of modularisation, which in turn will allow the organisation to build a high degree of flexibility, enabling it to adapt to changes on a continuous basis. The results presented here support the hypothesis that the degree of adoption of modularisation has a positive effect on firm success.

The beta for the control variable of 'producer type' is almost always significantly negative in the models. This result suggests that module suppliers may not be getting all the promised benefits from strategic modularisation relationships. Future research is warranted and should extend this conceptual model to address this aspect of modular production from the suppliers' point of view by trying to understand what suppliers really think about such modular relationships with automakers and how knowledge is exchanged between buyer and supplier and to try to link this modularisation trend in the auto sector to supplier performance improvements. A better understanding of the modular production process from the supplier's perspective would allow auto executives to understand the overall structure of the industry in the light of these trends toward modular production in the Brazilian auto industry.

Our study has several limitations. Firstly, this study is subject to the usual limitations inherent in cross-sectional research designs employing subjective measures, thus we did not capture the temporal effects among variables in our study. Secondly, our sample

consisted of firms operating in Brazil only, thus our results may not be generalisable to other settings. Thirdly, our study is based on a single industry; therefore, we should be cautious in generalising the implications.

In conclusion, our empirical findings suggest that the adoption of strategic modularisation could help firms to identify 'modules' (i.e. systems, activities, and/or processes) that undergo frequent technological change and then to often outsource the development of these to module suppliers with distinctive capabilities. Consequently, the benefits of this more efficient supply chain could apply to the entire industry by helping small- and large-scale automakers and suppliers to eliminate process redundancies and cut production waste.

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Notes

[1] *Mass customisation* (Kotha, 1995; Pine, 1993) emphasises the need to provide outstanding service to customers in providing products that meet customer's needs (through maximising individual customisation) at a low cost (through modular components). In addition, *mass customisation* is the process by which consumers can order, and have delivered quickly, custom-designed products, but at mass-market prices (O'Grady 1999).

[2] Here we use the definitions provided by Peter O'Grady (1999) that defined module integrators as producers of products that use modules from module providers and assemble these modules to form the final products. Module integrators have the responsibility to 'make sure that the customers' requirements can be met, usually with as short a time delay as possible, and with the lowest cost and highest quality.' Module providers produce modules to be assembled into final products by the module integrators. Module providers must produce module that conform to the interfaces and usually have great latitude in the design of the module.

[3] At this stage of this research, no Japanese company was interviewed. Japanese companies are newer entrants than US and European firms in the Brazilian auto industry, so they have not yet fully established modular structure in their plants.

[4] A complete list of questions used in the interviews can be obtained from the author.

[5] A third follow-up letter was sent out but at the time of the analysis we worked only with the questionnaires returned from the second wave resulting in 103 valid responses.