Proceedings of EuromaPoms 2003,
June 16-18, Como, Italy, Vol. I, p. 323-332

THE SIGNIFICANCE OF MANUFACTURING – AN ANALYSIS OF OUTSOURCING STRATEGIES IN THREE COMPANIES

Stefan Westin and Lars Bengtsson

University of Gävle, Sweden

ABSTRACT
In this paper we analyse how the role of manufacturing and use of manufacturing competence changes when outsourcing. The analysis is based on three case studies representing three different outsourcing strategies. The study indicates that manufacturing competence is of significant importance not only for efficient manufacturing, but also for new product design and procurement, regardless of the extent of outsourcing. The different ways of integrating manufacturing with various functions and processes both within the organisation and with suppliers are discussed.

Keywords: manufacturing strategy, outsourcing

INTRODUCTION
The strategic role of manufacturing in business has been frequently addressed. Related to traditional industrial company, with extensive internal manufacturing, prior discussion in this field was mainly related to the need for more closely integrating manufacturing with different functions and processes in the organisation, such as design, marketing and procurement, as well as the strategy process. During the nineties, the rapid growth of the outsourcing phenomenon (Outsourcing Index, 2000; Bailey et al., 2001) brought new dimensions to this matter. Besides dealing with internal integration, the issue was extended to the network of actors constituting the supply chain.
However, researchers do not agree on this need for close integration between manufacturing and various functions of the firm. On one hand it is argued that manufacturing is a non-differentiating activity that easily can, and should, be outsourced to specialised suppliers (e.g. Arnold, 2000). One the other hand, there are authors treating the manufacturing function and its importance to different aspects of the competitive advantage of the company with much more respect. There are vast numbers of studies on the strategic role of manufacturing, in which manufacturing's significance for competitive advantage is a matter at issue. A review of the literature arguing for the strategic role of manufacturing reveals a number of distinct contributions to the competitive advantage. The most obvious and direct contribution regards the provision of the desired quality, delivery ability, cost levels and flexibility (Brown, 1996; Hill, 2000). Other areas of importance are

to provide the needed competence for an efficient procurement and supply process (e.g. Brown, 1996) and to participate actively in the new product development process in order to provide manufacturing competence (e.g. Swink, 1999). These three areas are well in line with the model for three dimensional development of products, processes and the supply chain, as argued for by Fine (1998). These are the three major areas of concern for innovation success. However, this is not thoroughly reviewed in detail, and the knowledge about what the concrete contribution actually is needs to be further investigated.
The general purpose of this paper is to analyse the role of manufacturing in companies with different outsourcing strategies. More specifically, the aim is to discuss the implications of outsourcing manufacturing for the three suggested roles of manufacturing: efficiency, new product design and procurement.

METHOD

The paper builds on three case studies in three Swedish industrial companies. They all produce heavy lift trucks. All of them have their largest share of sales abroad, and they are in direct competition with each other, as they market essentially the same products. Furthermore, they all build their competitiveness on basically the same factors, which are functionality and customisation ability. What makes the companies so well suited for our purpose is their approach to manufacturing. Their manufacturing outsourcing strategies represent three essentially different positions on a continuum. One of the companies performs extensive internal machining, thus not making use of outsourcing. Another company is quite the contrary to the first. The only manufacturing it performs is the final assembly. Consequently, it relies on suppliers to provide all the machining, and can be described as positioned at the other end of the continuum. This company has basically applied this strategy since the starting up of the business. It is thus an appropriate case for studying the role of manufacturing in a long-term perspective. The third company has just recently made a strategic shift due to its parent company's explicit strategy of avoiding production-related investments, and the company has thus begun outsourcing manufacturing. The aim is to keep only the manufacturing of a few core components along with the final assembly. This company could thus be described as moving on the continuum, consequently making it well suited for studying how the role of manufacturing changes in the short term when outsourcing manufacturing.
Interviews have been carried out at each company on two different occasions. The first interviews were with representatives from top management or with part-owners. These interviews provided a solid background understanding of the companies, their businesses and strategies. They also served the purpose of establishing confidence and providing access to the right persons for the next round of interviews. The follow-up interviews were performed with at least three managers at each company in different key positions such as sourcing, design, production, logistics, and NPD project managers. In order to get a more concrete picture of the questions of interest, we have chosen to analyse one specific NPD-project at each firm.

THEORETICAL FRAMEWORK

As this paper aims to analyse manufacturing's contribution to competitiveness in general terms, and particularly to the capacity to innovate, we take the resource-based view (Barney, 1991) as point of departure. This view puts great emphasis on the resources

controlled by the firm when analysing competitive advantage. Closely related to this standpoint is the concept of core competence, as it was presented by Prahalad and Hamel (1990). They highlight the systemic interdependencies between different competencies within the firm, and their importance for sustainable competitive advantage. Especially those interdependencies between the firm's diverse production and technology skills are highly relevant when discussing outsourcing manufacturing. The core competence is the foundation of future competitiveness, as it is the origin of new, innovative products. The competencies building up this ability are corporate-wide technologies and production skills, consolidated and coordinated by a strategically farseeing management. Manufacturing's role is thus made explicitly important. However, what has been argued is whether it should be mainly kept under hierarchical governance, or if there are benefits to be gained from utilising external expertise.

A dilemma is represented by the advantages of control and the possibility of closely integrating manufacturing with other functions, such as design and sourcing, versus the advantages of utilising the specialised functional competence provided by focused external actors. One solution, often argued in the literature when considering outsourcing manufacturing, is that the so-called core activities, or core products, should be kept internal. Highly standardised products with no differentiating features should be bought from external actors kept at arms length and played out against each other in order to achieve the best possible deals. In between there are various degrees of supplier relations varying with the degree to which the activity is to be regarded as core, or having high transaction costs and asset specificity (Arnold 2000; Quinn and Hilmer 1994; Cox 1996). However, this interpretation of the concept of core competence is not unproblematic, and several authors stress the systemic interdependencies and claim manufacturing's importance to a number of issues of great concern to the competitiveness of the firm. At this more concrete level, manufacturing is often argued to have an important role in the three areas introduced above.

Efficient production

This is the most obvious of the three suggested roles of manufacturing. By efficient production we mean to provide the products requested by the market at the highest quality and lowest cost, at sufficient delivery performance, and with the required flexibility. In other words, efficiency in the operations. The performance of the manufacturing function is not to be optimised without connections with other functions in the firm, but rather in coherence with other functions. What constitutes efficient production is determined by the demands of the market (Hill, 2000).

To assist in new product development

Several authors claim the importance of design and manufacturing integration for a successful NPD process. The NPD process can be described as dealing with two major issues, providing new or improved functionality and providing more efficient production of products. Often argued for is the need to effectively match new products to process technology. This, according to theory, is achieved by closely integrating the design and the manufacturing function at an early stage of the new product development process (Brown, 1996). Terms such as Design for Manufacturing (DFM) and New Product Manufacturability (NPM) relate to this issue.

Swink (1999) points out the benefits of an integrated development process. However, his findings suggest that early and active participation by suppliers is as important for NPM as manufacturing involvement is. As firms are outsourcing more and more of their manufacturing, firms must to a great extent rely on suppliers to provide the manufacturing competence in the NPD process. Susman and Dean (1992) suggest three more specific contributions from manufacturing to the NPD process, each more proactive than the one before. First, to inform design about its existing capabilities. This makes it possible for design to take these capabilities into account when designing the product. It is a conservative and reactive approach, since designers are asked to adjust to existing manufacturing capabilities. Second, manufacturing can contribute in a more active way to the NPD. This is achieved by suggesting possible designs of the product which would make it easier to manufacture. Unlike the first approach, this is more proactive in the way that manufacturing makes suggestions rather than just informing about its capabilities. Third, and most ambitious and proactive, is if manufacturing can design the manufacturing process in parallel with the product design. This requires the most intimate communication of the three, and also has the most to be gained from. The benefit lies principally in the time saved.
Ulrich (1995) distinguishes between modular and integrated products. Integrated products are characterised by their de-coupled interfaces and multifunctional components. When designing integrated products, Fine and Whitney (1999) claim the need for a top-down design process, referred to as systems engineering. During this process the focus is on the entire system, and not on any single element in the system.

To render the procurement process more effective
The requirements on the procurement and sourcing process of the company have increased (Christopher, 1998). The share of supplied articles in the products produced is generally higher than before, and often as high as 70-80%. This leads to direct implications for the supply process. One important explanation for this increase is outsourcing manufacturing. This also puts higher demands on the procurement function. A transition is made from the previous buying of components to the sourcing of complete functions. As complete subsystems previously being manufactured in house are outsourced, higher demands are put on the sourcing function to be able to judge potential and existing suppliers in terms of cost, quality, delivery ability, flexibility and development potential.

THE EMPIRICAL STUDY

Company A
The company has just shy of 80 employed, of which 45 are blue collar workers. The volume of production is about 200 lift trucks per year, sold to roughly 125 different customers. The turnover has steadily increased, from 40 million SEK to 350 MSEK the past ten years. Prior to 1994 the company performed most manufacturing in house. Due to a precarious financial situation, the company was reconstructed and all manufacturing, except for the final assembly, was outsourced. At the same time nine top managers, including the technical director, the production manager, and important positions within product design and logistics, were recruited from Company C. The current strategy is to remain responsible for product design, final assembly, marketing and after-sales service.

Company A claims to compete primarily on the technical superiority of their product, as well as their customisation ability. 75% of the units sold are claimed to be customised. The new product development (NPD) process in Company A is run in project form. An NPD project initially includes representatives from marketing and design, and once the order is received, representatives from logistics and production are included. At this moment the significant suppliers are being contacted, even though they do not get an explicit position in the project. Primarily, it's the designers that discuss the suppliers' possibilities to meet the requirements and suggest components which match the customer demands. The designers also deal with manufacturing issues, such as how to design the component for efficient manufacturing by the supplier. When a solution is reached and the contract is signed, sourcing/logistics and production take over the contact with the supplier. The studied project concerned the first-time development of a lift truck, with several major design changes. The total NPI lead time, from inquiry to delivery, was about 15 months. Once the offer was accepted and the actual design and production phase was initiated, the lift truck was delivered within about 10 months. Order-to-delivery lead time is 10 weeks in 90% of the deliveries, mainly due to a highly modularised product. Only the most extensively customised orders require an extended lead time.

The company considers close collaboration with their suppliers as a main way to rationalise manufacturing and to lower the total product cost, due to the low value added by the company itself. Only about 5% of the working hours are performed internally, in the final assembly. One of the reasons the company keeps the final assembly in house is to preserve the value-added level. The company furthermore believes that no external actor can perform the final assembly more efficiently. An additional reason to keep it in house relates to competence. Design puts great value in the final assembly as an input of ideas and knowledge. It is also regarded as an important source of knowledge needed when dealing with the after-sales market. Yet another motive is the risk that the potential supplier would turn into a competitor; what prevents it from marketing the product once it assembles it? The managers recognise a risk of losing manufacturing knowledge over time. They stress that it's crucial to choose efficient and competent suppliers. Suppliers with design responsibility are seldom the problem. In order to judge the suppliers, the company feels that it must have a continuous contact with the market, including potential competitors to present suppliers. A supply strategy recently applied is to use two different types of suppliers for different phases: one local supplier for production start-up, which represents a high production competence, and one supplier in a low-wage country. Once the NPI is carried through, the local supplier can transfer its technology and knowledge on the product to the low-cost supplier.

Company B

This company was formed in 1977. The company could be described as a family business, run by true entrepreneurs. It employs about 200 people, of which 160 are blue collar workers. The production volume amounts to about 210 trucks per year and sales for 2001 were 470 MSEK, and 360 MSEK for 1998. Ever since the establishment of the company, the manufacturing strategy has been to perform extensive machining in house. The reasons are several. Perhaps most important is that the owners have a deep interest and involvement in manufacturing. A further reason is the stable financial situation, which means that the fixed costs related to manufacturing can be kept at a minimum. They also

see disadvantages in outsourcing the machining of components, since most components are highly customised and run in small series or even single units. Based on these circumstances, their conviction is that their internal manufacturing is very cost-effective and competitive. In addition, they see quality advantages in having their own manufacturing, as well as flexibility and customisation advantages.
The internal manufacturing is regarded as very important by the designers, as they believe it promotes opportunities to work closely integrated during the entire NPD project. Formally, the manufacturing personnel is not given an explicit role in the NPD projects, and most of the manufacturing competence needed for the project is provided by the designers. However, as manufacturing is conducted at the same location, any questions and problems can be sorted out immediately in collaboration with manufacturing personnel. The design manager also concludes that without their internal manufacturing, it would not be possible for the designers to hold this high manufacturing knowledge.
The company does buy some machined and assembled components, in addition to the vital engine, transmission and driving shaft. The suppliers are generally not explicitly involved in NPD projects. The company feels that the suppliers lack understanding of the final product. The procurement function has no responsibility for technical discussions with suppliers, but rather a more traditional "buying" role, including price and terms of delivery negotiations. In NPD projects, it thus does not take a principal part. Rather, it gets involved once the technical negotiations are handled, primarily by design.
The manufacturing in Company B is regarded as "good enough". The function manager says much could be improved, probably mainly in terms of capital reduction from improved production logistics. But this has traditionally not been an area of emphasis in the company, and the production philosophy has always been "better safe than sorry", which is also seen in the dimensions chosen in the product's material, which is often overdimensioned in comparison with the competitors.
Company B states its primarily competitive advantage is the robustness and reliability of its product along with its customisation ability. Their after-sales service is said to be top of the line, partly due to the flexibility their internal manufacturing provides. The customisation ability is also claimed to be superior due to internal manufacturing. When it comes to innovation capability, Company B claims that a lot of the "so-called innovations" introduced at the market are not actually improving the products. Often it is frivolity which rather lowers the reliability of the product. They claim the truck lift should rather be robust and reliable than full of unnecessary functions.
Company B gives no less than 25 weeks order-to-delivery lead time. However, their customers accept this condition, and business runs better than ever. The lead time does not, however, significantly increase when major changes are required. In the studied project, the lead time was about nine months, the ordinary six plus an additional three for the design time.

Company C
This is the largest of the three companies, with production facilities in several nations. The case study concern one of its facilities in Sweden where lift trucks in the medium range are produced, i.e. 9-18 tons lifting capacity. At the studied plant, which has about 800 employees, the production volume is about 900 units per year. Previously, extensive in-house machining was conducted. The corporate strategy, however, is to minimise the

production investments by focusing on a few core production activities. These include the final assembly and the manufacturing of the pole. The cabin production is also kept within the corporation, but at another plant. This strategy has implied that several components recently have been outsourced, to external suppliers as well as companies within the corporate group. The interviewed managers do not consider the "internal outsourcing" to be of any advantage with respect to different performance measures.

The NPD projects are systematically organised, since they are valid for larger expected volumes. Their NPD incorporates prototypes as well as pilot and zero series manufacturing before serial production is initiated. The project studied at Company C was the exchange of a complete product line, constituting 500 units per year, i.e. half the volume at the plant. A number of options were designed, but roughly 60% of the orders fall outside these specifications and require some degree of design work.

The NPD project included all major functions, but no suppliers had a formal position in the project. Several suppliers were, however, closely collaborated with in the different sub-design projects. Particularly components designed in house and manufactured by suppliers require intimate co-operation. The designers must learn about the process technology at the supplier in order to design the component in a way that can be efficiently produced.

The manufacturing of the pole is kept internal due to several reasons. Company C regards themselves as the best producer of poles existing today. Besides, it is a lead-time-critical component with very complex logistics. Furthermore, the production of poles requires customer contact, and the contact with the customer is not to be outsourced.

The final assembly is also kept internal. It is regarded as highly important due to several reasons: the risk of opportunistic behaviour of the supplier, i.e. it could move up the value chain and market the product itself; it provides a possibility to test the product and thus secure the quality before delivery; it maintains customer contact; and the knowledge about the product is kept within the company, especially important for design.

Procurement occupies a very crucial role in Company C. The recently adopted outsourcing strategy has contributed to this, as no longer only single components are bought, but rather complete assembled products. This puts much more complex demands on the supplier, and thus on the procurement function.

The studied project required slightly more than 30 months to take from the feasibility study to the series production. Order-to-delivery lead time is 6-8 weeks. This lead time can be maintained for about 40% of the orders. The other 60% require extended order-to-delivery times due to the degree of customisation and thus construction work.

DISCUSSION

When analysing the NPD process in the three companies, similarities as well as clear differences appear. One interesting common characteristic of the three companies is that even though their outsourcing strategies, and thus reliance on suppliers, differ so distinctly, they have no formal participation of component-related manufacturing personnel in the NPD projects. However, in accordance with Swink (1999) the cases still show that manufacturing knowledge is important. The engineering and manufacturing competence needed is instead represented by the product designer. In the two companies practising outsourcing, suppliers are indeed collaborated with, but in the early stages the communication is generally aimed at securing capacity and making the capabilities of the suppliers clear. Occasionally this early communication extends to a more ambitious degree

of collaboration, where suppliers suggest new and more efficient designs that better utilise the manufacturing process and technology of the suppliers. The integrated company does not formally involve manufacturing personnel in NPD projects either, but the manufacturing integration and involvement in the development process is still more extended. This occurs partly because the informal communication between manufacturing and design is extensive and takes place on a daily basis, and partly because the designers operate in direct connection with manufacturing. The designers have considerable manufacturing knowledge in general, as well as about the specific process of their own company. The need for formal manufacturing personnel involvement in NPD projects is thus restricted to an operative role, concerning mainly securing and planning production capacity.

Another aspect of the manufacturing role for NPD is that all three companies have chosen to keep the final assembly in house. This is not at all surprising in the integrated company. But why did the other two also express strong desires to keep the final assembly internal? One reason stated by both companies is its importance as a source of knowledge and feedback to designers. It thus has an explicit importance which could be described as an activity maintaining the system engineering competence in the firm (Fine & Whitney, 1999). This competence is also one reason why all three companies choose to keep the design responsibility for externally manufactured components. The rather integrated type of products manufactured compels the studied companies to hold on to the design responsibility for most of the external manufactured components. The need to design the end product with a comprehensive view is considered more important than the advantages possible to obtain from an intra-organisational design - manufacturing integration. This can be regarded as a trade off between the need for a holistic approach to design, resulting in an optimized functionality and manufacturability at end product level, and the possibility of achieving maximum design for manufacturability (DFM) at component level. The company recently adopting the outsourcing strategy also confirms DFM problems when shifting from internal to external manufacturing. They do, however, claim this is a problem of a temporary nature. This is also confirmed by Company A, which reports no such problems. Company B is not brought face to face with this trade-off to the same degree. They do, however, also source some components from external suppliers, and the pattern is the same, they keep the design responsibility.

One major advantage to gain from a high level of DFM is the ability to rapidly introduce new products to the market (e.g. Swink, 1999). The most interesting comparison in time to market in this case is between companies A and B. The projects studied are very similar, and the comparison shows a considerable faster NPI process in Company B. Reasons could be the better possibilities for concurrent engineering. In Company B, manufacturing and assembly of the truck is begun in parallel to product design. This is also an example of the third manufacturing contribution suggested by Susman and Dean (1992), i.e. the concurrent development of product and process.

Interesting is the lead time of the order fulfilment process. Both companies making extensive use of external suppliers offer a significantly faster order-to-delivery lead time. They offer a lead time at around 8 weeks, compared to the 25 that Company B offers. This is such a remarkable difference that it cannot only depend on the efficiency of the NPI process. One reason is the capacity limitations of their production. Top management considers outsourcing as an alternative to increase capacity. This outsourcing would

however be for capacity reasons only, and similar manufacturing would still be performed internally. Only components of a commodity character would be considered, and the outsourcing would thereby be classified as the best outsourcing opportunity according to Fine and Whitney (1999).

To this date, Company B has, however, not seen any reasons to take actions to increase the capacity. Part of its financial success lies in the full capacity utilisation, and this strategy minimises the negative effects of a temporary demand decline, which only leads to a decrease in the order stock. The short-term drawback is of course missing out on prospective buyers due to the long lead time, and the long-term drawback is that a considerable increase of the company sales is impossible without capacity enhancement. This requires time, during which the competitors may already establish lasting relations with the new customers.

Companies A and C avoid low-capacity utilisation through outsourcing, but according to the SCM literature (Christopher, 1998), the most interesting aspect is not the capacity utilisation in one single company, but rather in the supply chain as a whole. Outsourcing obviously puts greater emphasis on supply chain management and the procurement process. This is also evident in this study. The buying function in Company B has a less strategic and more operative role. The responsibilities lie first of all in price negotiations and delivery planning. Make or buy decisions are rather made by top management and technical personnel, and procurement would be involved at a later stage, responsible for the operative management of the supplier. The pattern is the same in NPD projects, where Company B involves no buyer in the NPD project, and early supplier communication on technical issues is managed by the designers. Company C, which is currently adopting a new manufacturing strategy, involves procurement from the very beginning of an NPD project. The responsibilities are more comprehensive, and hold for price and logistic-related issues as well as for technical details and make or buy decisions. Company A, with only the final assembly in house, puts great emphasis on supply chain management, and thus involves this competence early in NPD projects.

CONCLUSIONS

This study has provided insight into the role of manufacturing in three companies with similar competitive advantages at the market, but very different operation strategies. Obviously, manufacturing competence and internal manufacturing have an important role regardless of the extent of outsourcing manufacturing.

There are two facts pointing to this. First, all three companies do have internal manufacturing competence. This is not only provided by the manufacturing function, but to a great extent by design. Since the products are integrated, the design responsibility is kept internal. In order to be able to design for manufacturability and efficiently manage procurement, the designers must possess manufacturing competence. Second, this is proven by the fact that all three companies emphasise the importance of the final assembly stage. It provides several benefits: it constitutes a source of input to designers, both at the component design level, and more important, at the system engineering level; it provides an important customer interface; it serves as quality assurance since there are no intermediaries; the supply chain is better managed when the company itself is part of the physical flow of goods; it provides a source of value; and the risk of dispersion of the

system engineering competence is minimised, since an external final assembler would be a potential competitor.

The case studies also support the existence of systemic dependencies among different competencies, especially between production and innovation-related activities. It can further be argued that in this kind of industry, with an integrated product and a very high degree of customisation, it appears as if the final assembly is an activity of crucial importance to the competitiveness. In terms of Prahalad and Hamel (1990), it cannot be called a core competence, but the system engineering competence could. The final assembly provides a vital source of this core competence.

The study finally indicates that the manufacturing competence is not utilised particularly differently in the three companies, in spite of their different outsourcing strategies. One observation is that the buying function is restricted to supply issues, leaving all technical manufacturing-related issues to design. This is also the case in the integrated company, even though their internal manufacturing function fills an important role as a source of this manufacturing competence. Manufacturing competence thus seems to be of significant importance not only for efficiency but also for new product development and procurement.

REFERENCES

Arnold, U. (2000), New dimensions of outsourcing: a combination of transaction cost economics and the core competencies concept. *European Journal of Purchasing & Supply Management*, Vol. 6, pp. 23-29.

Bailey, W., Masson, R. and Raeside, R. (2002), Outsourcing in Edinburgh and the Lothians. *European Journal of Purchasing & Supply Management*, Vol. 8, pp. 83-95.

Barney, J. (1991), Firm Resources and Sustained Competitive Advantage. *Journal of Management*, 17, 1.

Brown, S. (1996), *Strategic Manufacturing for Competitive Advantage.* Prentice Hall Europe, Hertfordshire.

Christopher, M. (1998), *Logistics and Supply Chain Management – Strategies for Reducing Cost and Improving Service.* Prentice Hall, London.

Cox, A. (1996). Relational competence and strategic procurement management. *European Journal of Purchasing & Supply Management*, Vol. 2, No. 1, pp. 57-70.

Fine, C., H. and Whitney, D., E., (1999), Is the Make-Buy Decision Process A Core Competence?, *Proceedings of the 4th ISL conference, Logistics in the Information Age*, Florence, Italy

Fine, C.H. (1998), *Clockspeed – Winning Industry Control in the Age of Temporary Advantage.* Perseus Books, Reading, UK.

Hill, T. (2000), *Manufacturing Strategy – Text and Cases.* Palgrave, New York.

Prahalad, C.K. and Hamel, G. (1990), The core competence of the firm. *Harvard Business Review*, May-June, pp. 79-91.

Quinn, J.B. and Hilmer, F.G. (1994), Strategic Outsourcing. *Sloan Management Review*, Vol. 35, pp. 43-55

Susman, G.I. and Dean, J.W. (1992). Development of a model for predicting design for manufacturability effectiveness. In: Susman, G.I. (Ed.) (1992), *Integrating Design and Manufacturing for Competitive Advantage*. Oxford University Press, New York.

Swink, M. (1999), Threats to new product manufacturability and the effects of development team integration process,. *Journal of Operations Management*, Vol. 17, pp. 691-709.

Ulrich, K. (1995), The role of product architecture in the manufacturing firm, *Research Policy,* Vol. 24, Issue 3, May, pp. 419-440.