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The Strategic Management of Product Service Systems

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Abstract

Product-service systems (PSSs) have been seen as a viable means of substantially improving the resource efficiency of production and consumption systems. This paper investigates the strategic management options facing firms choosing to implement a radical closed-loop PSS, predicated on new forms of product ownership, stewardship, design and producer-user interaction. It employs established theories of the firm, including transaction cost economics and the resource based view of the firm, to analyse the choices facing organisations in managing three key elements of such systems; product take-back, modular product design and producer-user information feedback loops. It is predicted that the 'unification' of each of these previously discrete elements into a single PSS will present firms with novel challenges in managing sometimes competing motivations to vertically integrate or outsource activities.

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The Centre started work in October 2001 under the leadership of Professor Ken Peattie of the Business School, Professor Terry Marsden of the Department of City and Regional Planning and Professor Bob Lee of the Law School. The funding of the Centre covers an initial five-year period, but this should just mark the beginning of BRASS' contribution to creating more sustainable and responsible businesses locally, nationally and globally.

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Introduction

A product service system (PSS) has been described as

'a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models' (Mont, 2002a).

At its core, the PSS concept is based upon a fundamental shift in the relationship between the producers and the consumers of a product or service. Instead of being centred on 'traditional' forms of sale, ownership, consumption and disposal of products, many PSSs focus on the delivery of a 'function' to the customer that might, in practice, mean the provision of combinations of products and services that are capable of *'jointly fulfilling users needs'* (Goedkoop *et al.*, 1999). In doing so, they embrace a range of elements relating to the management of products throughout their life-cycle in an effort to minimise environmental impacts, improve resource efficiency and identify alternative profitable revenue streams.

Previous research on the PSS concept has categorised each of the elements that might comprise a PSS into three discrete 'types' of service; product-oriented, use-oriented and result-oriented (e.g. Brezet *et al.*, 2001; Zaring, 2001; Behrend *et al.*, 2003). This system of classification has been an important tool in helping to deepen understanding of the sustainability potential of existing PSS categories. This has lead to the conclusion that future efforts to optimise the sustainability performance of PSSs should be channelled into the promotion of certain types of use and result-oriented services (Tukker, 2004, p.259). However, this article argues that whilst such a strategy is undoubtedly valid in terms of *existing* PSS offerings, there is a risk that it would fail to recognise the latent potential of possible *future* and alternative approaches to the design and delivery of product-oriented PSSs, in particular those that combine elements of more than one PSS type[1], made possible via the adoption of emerging notions of closed-loop systems (Geyer & Jackson, 2004; Krikke *et al.*, 2004; Williams, *forthcoming*).

In this light, this article aims firstly to explore how such limitations might be overcome, in particular by proposing that the existing typology be expanded to accommodate those types of PSS that combine elements such as leasing, product take-back, modular product design, upgrades, and producer-user information feedback loops within a single *closed-loop PSS*.

[1] A well documented example is Xerox, which provides a photocopier leasing, take-back and remanufacturing service for business customers, thus incorporating elements of a product-oriented, use-oriented and (via 'pay-per-copy' services) result-oriented PSSs (Xerox, 2002).

Furthermore, this process of 'unification' means that firms are likely to be faced with a number of choices regarding the most appropriate means of managing each of the previously discrete elements of the PSS, as well as the complex set of interdependencies that may emerge. In particular, they may need to decide whether to keep such activities 'in-house' via vertical integration or other hybrid structures, or to outsource responsibility using market mechanisms. To deepen understanding about the factors that might influence these choices, this article employs established theoretical perspectives of firm behaviour, including transaction cost economics and the resource-based view of the firm, to help in conceptualising the decisions made by firms. These theories are then applied to each of the key elements of a closed-loop PSS in an effort to summarise the principal motivations to keep activities in hierarchy or outsource, as well as the influence that the adoption of PSS principles might have on these motivations. A concluding section discusses these findings, with particular attention paid to the implications for the establishment of closed-loop PSSs, as well as the key areas of tension facing firms should they move towards such radical new business models.

Strategies to optimise the sustainability benefits of PSSs

Earlier research (e.g. Brezet *et al.*, 2001; Zaring, 2001; Behrend *et al.*, 2003) has classified PSSs according to three main categories (i) *product-oriented services*, where the business model is still largely associated with the sale of products to consumers, with some additional services, such as a maintenance contract or an end of life (EOL) take-back agreement; (ii) *use-oriented services*, where products remain central, but are owned by service providers and made available to users in different forms (e.g. leasing, sharing or pooling); and, (iii) *result-oriented services*, where customers and service providers agree on a desired outcome (e.g. clean clothes) without specifying the product involved.

A later study (Tukker, 2004) concluded that, with the exception of certain types of result oriented services[2], most types of PSS offered at best only incremental environmental improvements. In particular, it was argued that radical changes cannot be expected via product-oriented services since there is no associated change in the technological system (ibid. p. 258). In terms of use-oriented services, it was concluded that, although leasing type PSSs had the advantage of providing users with access to their 'own' product, they could possibly lead to less

[2] For example, where the PSS provider is, in principle, free to decide how to deliver a desired result to users. Tukker provides the example of a company offering to deliver a specified 'pleasant climate' in an office as opposed to gas or cooling equipment (Tukker, 2004, p.249).

responsible user behaviour and an associated *increase* in environmental impacts. Moreover, although it was established that product renting, pooling and sharing are promising from a sustainability perspective, it was suggested that accompanying 'tangible and intangible user sacrifices' mean that they probably have a considerably lower market value than competing products (ibid. p.259, see also footnote).

In response to these findings it was proposed that the market and sustainability objectives of PSSs might be more closely aligned via the pursuit of a number of identified solutions. These include; the design of product renting, sharing and pooling systems that simultaneously minimise sacrifices to tangible value whilst offering high intangible value; the development of concrete performance indicators for functional PSSs; and, the development of approaches which reduce the liability risks and enhance control over 'production' uncertainties related to functional PSSs (Tukker, p.259).

Closed-loop PSSs - An alternative approach?

The above analysis suggests that future theoretical and empirical research aimed at achieving radical resource efficiency via PSSs should focus solely on overcoming the shortcomings of renting, pooling and sharing type use-oriented services, and refining the development and delivery of result-oriented services. However, although such a strategy may well offer an appropriate means of realising the potential of these types of PSS, there is a risk that it will fail to fully recognise the latent potential of alternative approaches to the design and delivery of PSSs, particularly product-oriented and leasing types. There are several reasons for this; firstly, result-oriented, pooling and sharing type PSSs require users to make sacrifices to tangible value by foregoing unlimited access to their 'own' product. This approach seems to work against the prevailing logic of existing user preferences; like it or not, people are used to, and prefer, unconstrained access to products, a trend that is likely to continue for the foreseeable future. Secondly, there is a danger that a limited focus on result-oriented services would fail to identify and capture the potential sustainability benefits accruing from product-oriented services, especially when accompanied by a radical change or reorganisation of the underlying technological system. For example, there is a growing body of evidence to suggest that closed-loop supply chains are not only profitable business propositions, but can also lower the overall environmental burden of the production and consumption system they are a part of (See e.g. Geyer & Jackson, 2004; p.57). Furthermore, when combined with novel approaches to product

design, such as modularity, these benefits may be further enhanced (Krikke *et al.*, 2004). In the context of the PSS concept it has been suggested that, when modular products are offered to consumers as part of long-term leasing, upgrade and replenishment arrangements, there are a broad array of potential sustainability benefits across the entire life cycle (Williams, forthcoming). Thirdly, the potential of such closed-loop systems highlights the deficiency of the existing classification of PSSs, based on three discrete 'types' of service, with no recognition of any potential overlap between them. In this light, it is proposed here that a fourth category of PSS, to be known as *closed-loop product service systems*, should be used to describe PSSs that combine previously discrete elements such as product recovery, leasing and innovative product design into a single coherent system.

Key elements of a closed-loop product service system

In 'traditional' sales transactions, the relationship between the manufacturer and ultimate consumer of a product is very limited. In most cases, once products leave manufacturing sites they are distributed to a network of retail outlets, where consumers purchase them. Following purchase, the responsibility for product use and disposal lies with the consumer. Within this business model, beyond their basic contractual and legal obligations[3], manufacturers have no responsibility towards the product following its sale, and the intermediate retail function means that there is rarely any direct contact between producers and purchasers. Within a closed-loop type PSS, a product still forms the basis of the relationship between producer and user. However, instead of purchasing the product, the user buys only the *output* of the product according to the desired level of use (Tukker, 2004, p.249). In such a way, the manufacturer retains ownership of the product and utility is provided through the sale of functional 'service units.' Although the idea of 'functional sales' is not entirely new (see e.g. Mont, 2002b), when employed as part of a closed-loop PSS, such an approach has the potential to radically change the behaviour of both manufacturers and users. The rest of this section briefly discusses the potential effect of these changes in the structure of product ownership and purchasing behaviour in three key areas: product take-back, the design of products and services, and producer-user interaction.

[3] E.g. basic statutory consumer rights or extended warranties.

Product take-back

As outlined by Toffel (2004, pp.121-123), manufacturers already have a number of motivations to voluntarily recover their products following use. These motivations include: the reduction of production costs through the substitution of recovered parts for virgin parts in remanufacturing, the promotion of an image of environmental responsibility, meeting customer demands, protecting aftermarkets and pre-empting regulation. This last motivation has become increasingly important in recent years with the advent of a raft of extended producer responsibility (EPR) regulations that oblige manufacturers to assume physical and/or financial responsibility for the management of their products at the post-consumer stage (Toffel 2003). Against this background, it is likely that the type of changed ownership structure envisaged within a closed-loop PSS will further motivate manufacturers to engage in product take-back activities. This is because the retention of product ownership by manufacturers means that instead of representing profit centres, products instead become cost centres (Mont, 2002a). Since, within this model, producers assume responsibility for the physical and financial management of a product throughout its lifecycle, they have an incentive to minimise the associated costs. As a result, they might be motivated to assess or reassess the most efficient means of coordinating product return and reverse logistics systems.

Design of products and services

The changed incentives in relation to the management of products at the post-consumer stage may also have a number of implications for the way in which companies approach the design of products and services. To begin with, they will benefit financially by designing products that are easier, and therefore generally cheaper, to disassemble, refurbish or recycle after the initial use phase. In addition, manufacturers may be motivated to improve the durability of products in order to realise the maximum amount of revenue through use of the minimum amount of resources. If the lifetime of a product is extended, more potential profit may accrue through an accompanying increase in the sale of 'functional units.' For example, if a car is leased on a 'pay per mile' basis, a more durable and reliable engine will result in a greater overall mileage, thus a greater return on the initial investment.

Within this context, concepts such as product modularity and upgradeability may become an increasingly important part of the design process. If individual components, or 'modules' are

regularly repaired, replaced or upgraded as part of an ongoing contract between producer and consumer, the concept of producing entirely new products and disposing of used ones becomes increasingly obsolete. Earlier studies have already alluded to this potential. For instance Garud *et al*. (2003, p.2) assert that modularity facilitates the retention and reuse of system parts, whereas Krikke *et al.* (2004, p.31-33) point to the fact that value recovery from returns is best accomplished in closed loop supply chains based on modular reuse, because much of the added value of the forward chain is regained while quality upgrades are possible to assure customer value. Moreover, the development of mass customisation 'requires modular product designs for cross compatibility of components' (Ibid. p.31). To return to the above example, if a car is designed on the basis of modular principles it is possible that regular technical or aesthetic upgrades can be offered as part of a closed-loop PSS. Moreover, if modularity extends to a separation of body and chassis, it is possible that more fuel efficient, or even alternatively powered, powertrains could be installed in existing models, thus extending vehicle lifetime and environmental performance simultaneously (Williams, *forthcoming*).

New forms of producer-user interaction

A further implication of the changed ownership structure highlighted above is its effect on the forms of dialogue between the supplier and the user of products and services. The field of customer relationship marketing (CRM) reveals that the shift towards mass customisation and flexible production means that, in many cases, the consumer has become as important as the firm in determining the direction of production, and that firms must now recognise the customer as a valid interlocutor (Vavra, 1995). This perspective contends that, in order to face the world of emerging economic realities, marketing must abandon the transaction-based logic of the traditional economy to embrace a new relationship-based orientation. Thus, the hope of the CRM paradigm is 'to establish, maintain and enhance relationships with customers and other partners at a profit, so that the objectives of the parties are met.' This is achieved by a *'mutual exchange and fulfilment of promises'* (Gronroos, 1990). This transformation of the firm is accompanied by a parallel transformation from the viewpoint of the consumer (Addis & Holbrook, 2001). In particular, the complex relationship entails not only a product, but also the services that surround it, and the information that a consumer and firm impart to each other.

In terms of more radical visions of PSSs, it is possible that such channels of communication will further improve the environmental benefits that might be attained. For example, in many

product groups it is during the use phase that a significant proportion of negative environmental impacts occur. However, the types of long-term producer-consumer relationships that might be facilitated via a closed-loop PSS present opportunities for the provision of information to users on how to minimise the environmental consequences of product use. The manufacturers of products are likely to possess better information on the conditions of usage under which such impacts might occur or be exacerbated and, within a PSS, can provide users of products with guidance on how to best avoid such types of usage.

In keeping with CRM's view of the enhanced role of the customer, another facet of producer-consumer interaction that might be facilitated within a radical version of a PSS is the reverse flow of information relating to aspects of a product's environmental performance. It is possible that, through long-term usage of a product or service, consumers might discover important facts relating to how best to reduce environmental impacts at the use stage as well as how such improvements might be facilitated through changes in product and/or service design. Within a radical PSS, the establishment of formal information feedback loops would allow such insights to be conveyed to manufacturers or service providers and be considered as part of an ongoing process of continuous PSS design and improvement.

It is likely, at least within conventional modes of product manufacture, distribution, use and reuse, that retailers would form a pivotal role in facilitating such exchanges of information between producers and consumers. For example, at the point of sale, retailers might provide users with information on environmentally optimised product use. They might also act as a first point of contact for users when they make suggestions for product improvements intended for manufacturers.

Strategic Management Options

The analysis above has shown how the establishment of a closed-loop PSS, and the changes in product ownership structure that this entails, might incentivise manufacturers to undertake a fundamental reassessment of how they (i) manage product take-back activities in order to minimise associated costs; (ii) approach product design in a way that maximises the intensity of resource use, particularly via product modularity and upgradeability; and, (iii) manage their relationship with the users of their products, specifically through the establishment of information feed-back loops. It is argued here that, should such a reassessment exercise lead to

the simultaneous establishment of the full range of changes envisaged, the combined effect may be a more radical improvement in resource efficiency than previously envisaged for this type of PSS. Furthermore, such a system may also motivate firms to explore new and innovative means of pursuing alternative and profitable revenue streams.

However, in order to realise this economic and ecological potential, it is likely that many firms will be faced with a number of organisational challenges, particularly where the establishment of such a system may require firms to undertake activities beyond their traditional core competencies. For example, a manufacturing firm might have no experience in the management of product take-back systems or the coordination of long-term relationships with the users of their products. In this light, they must make a decision over whether they wish to gain the necessary expertise to undertake such activities themselves, or through close co-ordination with other organisations, or to outsource responsibility by entering into contracts with external suppliers or service providers. A number of established theories of firm behaviour predict the circumstances in which activities are carried out in 'hierarchical' form (vertical integration), 'hybrid' form (joint ventures, alliances or partnerships) or the market.

Transaction Cost Economics (TCE)

This theory predicts that such decisions depend on transaction costs (including those associated with the identification of transaction partners, the negotiation and drafting of agreements, monitoring of the exchange and the enforcement of its terms) and transaction hazards (Williamson, 1998). According to TCE, the main hazard associated with transactions carried out across the market is that, in order to carry out the transaction efficiently, one firm must invest in *transaction-specific assets* (Williamson, 1983; Klein *et al.*, 1978). The fact that investment in such assets would lose value if deployed for any other transaction means that the investor becomes dependent on the other firm. TCE predicts that the dependent firm is vulnerable to 'opportunism' by the other, since the latter would seek to leverage its position by renegotiating the contract or threaten to 'hold-up' activities. The implication of this theory is that, the greater the need for a firm to invest in transaction specific assets, the more likely it is to keep activities in hierarchy or hybrid form. This is because, by avoiding the market as the medium of exchange they are better positioned to ensure that the necessary flow of inputs are available to keep the specialised asset fully employed (Teece, 1984).

Resource Based View of the Firm, Dynamic Capabilities and Core Competencies

These theories are based on the assertion that firms possess a unique range of resources, capabilities and competencies, which together form the basis of competitive advantage (Mahoney, 2001; Teece *et al.*, 1997; Foss & Knudsen, 1996; Barney, 1991; Grant, 1991; Wernerfelt, 1984). Toffel (2004, pp. 127-128) provides a succinct analysis of the conditions where such competitive advantage might occur. This analysis is summarised in Table 1.

Type of unique 'asset'	**Source of competitive advantage when…**
Resources – capital equipment, skills, brand names, finance, customer loyalty & production experience acquired from learning-by-doing.	Resources are rare, non-substitutable, difficult to imitate, valuable and costly to transfer across firms.
Capabilities – the capacity for a team of resources to perform some task or activity	Firms can leverage capabilities into new opportunities.
Core competencies – collective organisational learning, including coordination of diverse production skills/ integration of multiple streams of technologies to enhance product value	Core competencies are difficult for competitors to imitate. Also 'distinctive competencies' where firm can organise/coordinate a set of activities better than other firms.

Table 1 – Resources, Capabilities & Competencies as Sources of Competitive Advantage (after Toffel, 2004)

These theories predict that it is more difficult to transfer tacit knowledge and leverage related competencies between firms than within them. As a result, where tacit knowledge or competencies are sources of competitive advantage, firms are more likely to keep activities in hierarchy. Furthermore, since firms gain competitive advantage by leveraging core competencies into new activities, vertical integration is more likely when the required competencies are

'something about which the firm already has some degree of relevant knowledge' (Winter, 1988, as cited in Toffel, 2004).

Product take-back, reverse logistics and product recovery

Several studies have investigated the factors that might influence product manufacturers to engage in hierarchical forms of product recovery or to use third parties. Daniel *et al.*, (2001) highlight the advantages of advance disposal fees (ADFs), credits towards future purchases, cash payments and leasing for the management of product recovery activities. They argue that where manufacturers are better positioned than recovery companies to employ these tools, they can gain competitive advantages in conducting product recovery. Majumder and Groenevelt (2001) outline the advantages held by manufacturers in retrieving products from customers, including their ability to provide trade-in rebates on new equipment and offering prebates. Fleischmann (2001) describes how the efficiency of reverse logistics systems can be influenced by whether a manufacturer or a third party manages the process. The study argues that OEMs possess several advantages in predicting the quality and timing of EOL product flows because they can monitor equipment usage by using real time electronic sensors and can forecast return flows through end of lease returns. Guide *et al*. (2000) suggest several reasons why manufacturers may seek to acquire EOL products from third parties, including buffering against supply fluctuation to facilitate production planning, and to improve asset utilization. On the other hand, obtaining EOL products direct from customers can provide OEMs with better control over condition and quality, thus avoiding 'cherry picking' by intermediaries. Savaskan et al. (*forthcoming*) compare alternative collection methods for OEMs incorporating EOL components into new products. Compared to self-management and third party contracting, OEMs that incentivise retailers to collect EOL products achieve higher collection rates and encourage retailers to reduce prices thereby increasing sales and profitability. Toffel (2004) employs TCE theory to predict that if a product recovery technology is product or transaction specific, there is a greater motivation for hierarchy or hybrid structures. Conversely, where technology is generic, there is a greater likelihood that a market approach will be more efficient. Furthermore, where asset specificity is accompanied by uncertainty, there is a further motivation to integrate activities. This is especially relevant since it has been shown that reverse supply chains associated with product recovery are subject to much more uncertainty than forward supply chains (Daniel & Guide, 2000). The Toffel (2004) study also adopts a resource/capabilities perspective and concludes that

'companies with extensive manufacturing, service and repair experience may be more likely to vertically integrate into EOL product recovery.'

Krikke *et al.* (1999) suggest that dismantling, preparation and reassembly processes situated in the same location can facilitate the dissemination of tacit knowledge that can boost productivity. Although there is no reason by such a co-location strategy would preclude the involvement of third party providers, it seems likely that vertical integration or hybrid structures might be more efficient, particularly in terms of promoting a more innovative form of information exchange between dismantlers and product designers. This is at least partly because, while disassembly facilities owned by manufacturers find it difficult to get recovery know-how to designers, it is even more difficult

'to get designers to listen to feedback and advice from independent remanufacturing companies, despite the valuable experience they have' (Ferrer & Whybark, 2001).

Table 2 summarises these earlier studies in terms of the motivations for product manufacturers to adopt vertical integration/hybrid or outsourcing strategies in relation to product recovery.

Motivations for vertical integration or hybrids	**Motivations for outsourcing**
Where manufacturer is better positioned than recovery company to employ ADFs, credits, cash payments, leasing, trade-in rebates & prebates. OEM possesses advantages over third parties in predicting quality/timing of EOL product returns. May provide OEM with better control over condition & quality, this avoiding 'cherry picking.' Where product recovery technology is product or transaction specific. Where reverse supply chains are subject to 'uncertainty.' Where firms possess extensive manufacturing, service and repair experience. Where co-location of dismantling, preparation, reassembly (design & manufacturing) processes is feasible & may boost productivity.	May facilitate buffering against supply fluctuation to facilitate production planning, and improve asset utilization. Provision of incentives to retailers to collect EOL products may help to achieve higher collection rates, encouraging retailers to reduce prices & increase sales/ profitability. Where product recovery technology is generic.

Table 2 – Motivations for Hierarchical or Outsourced Management of Product Recovery

Influence of closed-loop PSS on product take-back decision

The establishment of a closed-loop PSS of the type outlined earlier is likely to influence a firms' decision on the most appropriate method of managing product recovery in the following ways:

- Although the studies outlined above do not speculate on the effects of the sale of functional units on product recovery, it is probable that a strategy based on the combination of functional sales and long-term contracts with users would allow firms to offer a range of incentives to users for the return of products or components, thus yielding similar benefits to those envisaged for leasing etc., such as reductions in the recovery firms' product inventories and disposal costs, as well as increased equipment utilisation;
- Long-term contracts stipulating regular and planned product returns and upgrades would enable a better balance between demands and returns, and allow managers to more effectively predict and control the supply of EOL products/components, thereby improving the chances of profitable product recovery (Thierry *et al.*, 1995). This would facilitate the more efficient planning of reverse flows for product/material acquisition purposes and reduce uncertainty;
- Product design based on modular principles would reduce complexity and facilitate more efficient management of closed-loop supply chains (Krikke, 2004).

Design and manufacture of modular products

As defined by Baldwin & Clark (1997, p.6), modularity is

'a strategy for organizing complex products and processes efficiently.'

Modular systems are composed of independently designed modules that still function as an integrated whole. This system decomposition involves the partitioning of information into *visible design rules* and *hidden design parameters*. Visible design rules consist of three elements (ibid. p.6):

- An *architecture*, which specifies what modules will be part of the system and what their functions will be;
- *Interfaces* that describe in detail how the modules will interact, including how they will fit together, connect and communicate;

- *Standards* to test a module's conformity to design rules and measure its performance relative to other modules.

Visible design rules must be widely shared and communicated. In contrast, *hidden design parameters* are encapsulated within modules and

'need not…be communicated beyond the boundaries of the module' (Langlois, 2002, p.23).

This insight has lead some commentators on the management of product modularity to articulate the assumption that modularity in product design leads to modularity in organisational design (see esp. Sanchez & Mahoney, 1996). The fact that modularity allows for *information hiding* (Parnas, 1972; Baldwin & Clark, 2002), in which knowledge about the inner workings of one component need to be shared with the makers of other components, means that less communication is required during the product design process. In this light, a TCE perspective would suggest that a firm may be more likely to outsource given high product modularity. This is because less frequent communication would reduce transaction hazards and the risk of opportunism by making it easier to *'switch suppliers in the midst of the design process'* (Hoetker, 2002, p.9). Hoetker also summarises earlier work outlining the advantages of organisational modularity. These include (i) easier outsourcing allows firms to take advantage of capabilities beyond their boundaries (Baldwin & Clark, 1997; Fine, 1998); (ii) it allows firms to link together the capabilities of many organisations to support product development (Sanchez, 1995); (iii) the ease of reconfiguring the set of organisations involved in designing or producing a component allows a firm to select the best supplier for a given component at a given time (Garud & Kumaraswamy, 1995); (iv) this allows a firm to consider the outcomes of multiple experiments in how to design each component, increasing the expected value of the approach ultimately chosen (Langlois & Robertson, 1992; Baldwin & Clark, 2000); and, (v) it also allows for modular innovation, where firms improve their end product by incorporating improvements in various components of the product, which may occur at different rates for different components (Langlois & Roberston, 1995).

Sako (2003) outlines a range of motivations for OEMs to outsource the design or manufacture of modular components including;

- where open and well-defined interfaces between modules exist;
- where a radical solution is available for a module whose technical and economic benefits outweigh established advantages of integration through close supply chain coordination;
- where outsourcing would enable the retention of, or reversion to, arms length trading with a supplier without 'lock-in' to committed relationships;
- where the existing supply chain architecture is loosely or non-integrated
- where outsourcing allows the exploitation of lower wages, either in emerging markets or non-unionised workplaces;
- where it enables assets to be moved of OEM books to suppliers, thus shifting initial investment costs and risks to suppliers;
- where it enables a shift in R&D responsibility to suppliers to help in the management of complexity (since suppliers bear the upfront cost and risk of R&D outsourcing eases OEM access to supplier developed technologies by promoting design/concept competition);
- where there is a stable product architecture; and,
- where the OEM has high systems integration capabilities.

Sako also presents a number of reasons why OEMs may choose to keep module design or production in hierarchy including, (i) where the existing supply chain architecture is highly integrated; (ii) where the OEM has made significant investments in deep and diverse technical knowledge; (iii) where outsourcing would have a detrimental effect on labour relations, core capabilities, or power relationships with suppliers; and, (iv) where outsourcing would raise the overall cost of capital (assuming that smaller suppliers face a higher cost in raising capital than OEMs, costs which must be absorbed somehow, possibly through higher prices for the OEM). The findings of this and the other studies outlined above are summarised in table 3.

Motivations for Vertical Integration or Hybrids	Motivations for Outsourcing
Existing supply chain architecture is highly integrated; Where significant investments have been made in deep and diverse technical knowledge; Where outsourcing would have a detrimental effect on labour relations capabilities or power relationships with suppliers; Outsourcing of module production may raise the overall cost of capital; Where product architecture is relatively 'unstable'	Where open and well-defined interfaces exist between modules; Existing supply chain architecture is loosely or non-integrated; Allows access to capabilities beyond the boundaries of the firm; Allows firms to link together capabilities of several organisations to support product development; Enables easier reconfiguration of organisations involved in module design/production thus allowing selection of best supplier for given module at a given time; Enables assessment of multiple experiments in module design and 'modular innovation'; Enables the continuation of 'arms length' trading without 'lock-in' to committed relationships; Allows exploitation of lower wages, either in emerging markets or non-unionised work-places; Transfers initial investment costs and risks to suppliers; Where product architecture is relatively 'stable'; Where company strategy is aimed at move away from product assembly towards 'brand management' strategies;

Table 3 – Motivations for Hierarchical or Outsourced Management of Product Modularity

Influence of closed-loop PSS on product modularity decision

As outlined earlier, the adoption of modular principles in product design and manufacture may have a number of economic and ecological benefits. However, when applied as part of a closed-loop PSS, the decision over whether to integrate or outsource responsibility for module design and/or manufacture may have broader implications. In particular, if elements of product design, engineering and/or production are outsourced, there may be a detrimental impact on a manufacturers' ability to leverage knowledge and proprietary information acquired during these stages and apply it to the product recovery stage through activities such as disassembly. This is especially the case where such knowledge is tacit in nature, because it cannot be easily transferred between independent organisations (Toffel, 2004). This implication is of particular importance to firms with existing capabilities in product design, engineering and/or manufacture

that may possess cost advantages over third parties in disassembly. If such firms wish to continue leveraging this cost advantage within a radical PSS system they may be forced to keep some elements of modular design and/or production in hierarchy and potentially forego any other advantages that may accrue from outsourcing. Alternatively, to optimise overall ecological/environmental benefits and ensure the continued transfer of relevant information, it might be necessary to co-develop modules with suppliers, or to co-locate a design team whilst 'fully' outsourcing production and assembly.

Management of Producer-User Feedback Loops

Although the field of customer relationship management (CRM) has provided useful insights into the evolving relationship between the producers and users of products, as well as the transformation in the role of the consumer in such relationships (Addis & Holbrook, 2001; Gronroos, 1990; Vavra, 1995), there is currently a lack of research or empirical evidence relating to the more innovative types of producer-user feedback loops envisaged in this paper. As a result, there have been no previous investigations of the factors that might influence a firms' decision regarding the most appropriate governance structure to manage such novel relationships. Nevertheless, the TCE and other theories of the firm outlined earlier permit a tentative first analysis of strategic management decisions relating to this element of radical PSSs.

Within many 'traditional' sales transactions the responsibility for direct communication with users is allocated to retailers. In this sense, a product manufacturers approach to the management of the retail function is a key aspect of the transition to a radical PSS. At a basic level, a manufacturer faces a choice between vertically integrating into the retail function and communicating with users directly, or continuing to contract independent retailers. The points below highlight some of the main points that a firm may need to consider when making such decisions.

- Since the outsourcing of the retail function would add an extra 'tier' in the communication channels between user and producer, TCE predicts that there is more chance of hold-up risks through delays in the transmission of information or the relaying of incorrect data.
- As the reliance of manufacturers on user information as a source of competitive advantage grows, (for example by using data to improve resource/energy efficiency in the use phase), TCE predicts that retails may seek to leverage their position through 'opportunism.'

- Where producer or user information is tacit in nature, and therefore not readily transferred between independent organisations, firms may be more motivated to keep the retail function in hierarchy.
- The capabilities perspective of the firm asserts that *'a lack of relatedness reduces the likelihood of integration'* (Conner, 1991). In this respect, if a manufacturer does not have retail competencies prior to the transition to a PSS, this may mitigate against integration strategies.
- The logic of the above analysis is that integration strategies are most likely where tacit knowledge increases the efficiency of the PSS and the firm already possesses some competency in the retail function.

Conclusion

This paper has employed established theories of the firm to highlight the strategic management challenges facing firms in the transition to radical closed-loop PSSs. In doing so, it has attempted to provide further insight into the factors that might influence the decision to integrate or outsource product recovery, modular product design and the management of the retail function. The analysis has shown that the process of 'unification' necessary for the transition to a closed-loop PSS means that firms are likely to be faced with a number of choices regarding the most appropriate means of managing each of the previously discrete elements of the PSS, as well as the complex set of interdependencies that may emerge. To begin with, it has been demonstrated that organisations may often be faced with competing pressures in deciding on the most appropriate governance structure for the management of individual elements of PSSs. Furthermore, it is possible that the unification of key elements into a single system may help to alleviate such pressures, especially where it helps to align motivations to integrate or outsource. For example, a firm with an existing competitive advantage over third parties in product recovery that adopts a functional sales model will be motivated to offer financial incentives for product or component returns. In this case, the combination of factors is likely to increase the likelihood of a vertical integration or hybrid solution to product recovery.

However, as well as alleviating some of the identified pressures, the analysis has shown that the transition to a radical PSS may also serve to intensify some pressures. As demonstrated in relation to the tension between leveraging capabilities in product recovery and realising the benefits of outsourcing the design or manufacture of modular components, firms may face new challenges in balancing the relative transaction costs relating to each element of the PSS when

deciding on the most appropriate governance structures. To assist firms in making rational choices in managing such radical transformations, there is now a pressing need for further research, at both the conceptual and empirical level. *Inter alia*, this research should focus on a deeper investigation of the economic and ecological benefits of the types of PSS envisaged, particularly when compared with traditional business models; as well as an investigation of how transition trajectories might be most appropriately aligned with firms existing capabilities and core strengths.

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