



Product-service systems business models for circular supply chains

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ABSTRACT

Shifting supply chains from linear to closed-loop models is an important step towards circular economy. This paper investigates business model innovation for circular supply chains, and proposes that product-service systems (PSS) business models can enhance the circularity of supply chains through value creation in inner circles, circling long and cascading use circles. It adopts an exploratory case study method of a large Chinese manufacturing firm operating a traditional product-based business model and three types of PSS business models (i.e. product-, use- and result-oriented PSSs). The supply chain operations of the four distinct business models are analysed and their associated circularities are discussed. The findings show that business models akin to result-oriented PSS, have tighter and more efficient cycles of supply chain operations; which means, the repair, reuse and remanufacturing system is faster and the rate is higher. This research contributes to a better understanding of the relationship between business model innovation and supply chain circularity.

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1. Introduction

Most organisational supply architectures are linear, adopting a ‘take, make and dispose’ value chain model and thereby contributing to the depletion of our planet’s natural resources (WEF 2014). Sustainable development agendas are increasingly calling for supply chains to shift from linear to a closed-loop models, in which circularity ideals such as reuse, reconditioning, remanufacturing and recycling become the ‘new normal’ practices (Nasir et al. 2017). Embedding circularities within supply chains thus has been considered by many researchers, practitioners and policymakers as an approach for businesses to improve its sustainability outcomes (Ellen MacArthur Foundation 2014; Lewandowski 2016; Murray, Skene, and Haynes 2015; Nasir et al. 2017; Smart et al. 2017). A number of companies (e.g. Unilever, Toyota, P&G) and third sector organisations (e.g. Ellen MacArthur Foundation) are seeking solutions to accelerate the scale-up and transition efforts towards more circular supply chain operations. This change requires not only product, process and technological innovation but also business model innovation that has to consider novel recycling systems to bring back used products. Also, making supply chains circular cannot be achieved by a specific firm, as it requires collaboration between the organisations across the supply chains and other stakeholders from similar and/or diverse sectors (Bourlakis et al. 2014; Kumar et al. 2017). A change in one organisation’s business model will affect the business activities of other organisations in their supply chains.

Therefore, a systemic approach to manage better utilisation of the materials, energy and other valuable resources through higher rates of recycling, reuse and remanufacturing is imperative for success. However, there is limited theoretical and empirical knowledge on this phenomenon of interest (Reefke and Sundaram 2016; Evans et al. 2017).

This paper aims to explore the relationship between business model innovation and circularity in supply chains. We propose that product-service systems (PSS) business models, whereby manufacturers sell services rather than products alone (Goedkoop et al. 1999), have the potential to trigger greater levels of circularity within associated supply chains. In order to understand this phenomenon we begin in Section 2 by summarising related works in sustainable supply chain operations, business model innovation and PSS. Section 3 articulates the research question and describes the research method for this study. Section 4 describes the case study of a global market leading manufacturing company that operates a traditional product-based business model and three types of PSS business models, and analyses the circularity of the supply chains associated with the distinct business models. Section 5 discusses and concludes the exploratory findings.

2. Literature

This section analyses the literature in the field of sustainable supply chain operations, business model innovation in the context of circular economy.



The notion of 'circular' in supply chain operations is closely associated with the vernacular of a circular economy, which has been seen by many researchers as an approach towards sustainable business development success (Genovese et al. 2017; Lacy and Rutqvist 2015; Murray, Skene, and Haynes 2015). Supply chain operations management is a crucial component of the move towards a circular economy ideal (Genovese et al. 2017). Such research has focussed on different aspects of supply chain operations, such as reversed logistics (Govindan, Soleimani, and Kannan 2015), remanufacturing (Östlin, Sundin, and Björkman 2008), reuse (Atasu, Guide, and Van Wassenhove 2008) and recycling (Papachristos 2014). In general, circular supply chain operations is an emerging research focus and there remains limited theoretical and empirical knowledge in this burgeoning sub-field (Genovese et al. 2017; Nasir et al. 2017).

2.1. Circular economy as context

Circular economy is defined as *an industrial system that is restorative and regenerative by design* (Ellen MacArthur Foundation 2015). In this system, the flows of materials, energy, labour and information is closed-loop. The word 'circular' is an antonym of 'linear', and is related to the concept of cycle, so circular economy is a cyclical closed-loop system, in which the environmental protection and economic development are balanced (UNEP 2006). There are two types of cycles which are particularly important in the circular economy: biological nutrients cycle, which are designed to re-enter the biosphere safely; and technical nutrients cycle, which are designed to circulate without entering the biosphere through end-of-life activities (Ellen MacArthur Foundation 2012). Thus, the 'Reduce, Reuse, Recycle and Recover' ideas are essential to the notion of a circular economy (Murray, Skene, and Haynes 2015).

Circular economy has been studied with three levels: firm-level, inter-firm level and entire industrial level (Murray, Skene, and Haynes 2015). The management of supply chain operations at all three levels plays an important role in moving towards a circular economy ideal. This may be accomplished by the activities of reduce, reuse, recovery, remanufacturing and recycle within supply chains (Cooper 1999). UNEP (2006) proposed the general characteristics of circular economy as: low consumption of energy, low emission of pollutants and high efficiency. Hu et al. (2011) emphasised that the circular economy needs to be resource productive. The Ellen MacArthur Foundation's investigation with a practical emphasis summarises three principles, five key characteristics of and four sources of value creation in a circular economy (Ellen MacArthur Foundation 2012, 2014, 2015).

2.2. Circularity within supply chains

Developing circularity (or circularities) within supply chain operations is regarded as a fruitful approach to enhancing business revenues and environmental impact. Such ideas are closely linked to sustainable supply chains (Ahi and Searcy 2013; Seuring, Seuring, and Muller 2008; Winter and Knemeyer 2013). In their literature review on supply chain operations, Reefke and Sundaram (2016) identified the major themes of planning, execution coordination and collaboration, and subsequently proposed related research opportunities associated with the

concept of circularity, i.e. use of renewable resources in planning. However, there are still no acknowledged theories of sustainable supply chain management and limited applications in practice (Carter and Liane Easton 2011; Lambert and Cooper 2000; Reefke and Sundaram 2016; Winter and Knemeyer 2013).

To move towards enhanced circularity, supply chain operations need to shift from a linear model to a closed-loop (i.e. more circular by design) model. Closed-loop supply chain management is 'the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time' (Guide and Van Wassenhove 2009). An increasing number of researchers have studied closed-loop supply chain from different perspectives, for example, Govindan, Soleimani, and Kannan (2015) reviewed and investigated the reverse logistics systems for closed-loop supply chains; Guide and Van Wassenhove (2009) explored the business perspectives of closed-loop supply chains; and Jayaraman and Yadong Luo (2007) studied its value chain strategies. Closed-loop supply chain is increasingly regarded as a revenue opportunity rather than a cost reduction approach (Guide and Van Wassenhove 2009).

Govindan, Soleimani, and Kannan (2015) conducted a comprehensive review on reverse logistics and closed-loop supply chain, and addressed the need for more integrative studies. Winkler (2011) noted the importance of establishing closed-loop production system to reduce environmental impact, and proposed the idea of 'designing-in' a sustainable supply chain into such systems. Summarising from literature (Ellen MacArthur Foundation 2012, 2014, 2015; Hu et al. 2011; Murray, Skene, and Haynes 2015; Nasir et al. 2017; UNEP 2006), circular supply chains should have the following characteristics:

- (1) The inner cycles are prioritised over outer ones (e.g. reuse and recover comes before recycling)
- (2) Slowing the cycles (e.g. using resources for as long as possible)
- (3) Reducing waste at every stage of the product life cycle
- (4) Reduce, reuse, recycle and recover resources as much as possible

2.3. Business model innovation and circularity

Innovation in the business models of organisations has inevitable implications for their supply chain operations. Business model refers to 'the logic of how a firm does business' (Magretta 2002; Teece 2010). It describes how a firm creates, delivers and captures value for all stakeholders within the value network (Richardson 2008; Zott, Amit, and Massa 2011). In competitive environments, relying on one business model per firm may not be enough, however multiple business models should complement each other (Casadesus-Masanell and Tarzijan 2012; Markides and Oyon 2010; Velu and Stiles 2013). Osterwalder and Pigneur (2010) developed a business model canvas, using nine components to describe a business model: value proposition, customer segment, customer relations, key resources, key activities, partners, channels, cost structure and revenue streams. Designing and developing business models that are conducive to a circular economy need to identify new sources of value

creation in the context of the nine components, for example, turning the waste from production facilities and the end-of-life products into revenue streams.

A circular business model is defined by Linder and Williander (2017) as 'a business model in which the conceptual logic for value creation is based on utilizing the economic value retained in products after use in the production of new offerings'. Some other researchers, such as Loomba and Nakashima (2012), believe that the circular flow does not only include the products after use, but also the production wastes and by-products. The Ellen MacArthur Foundation (2012) identified four sources of value creation within circular economy, which implies that business models for circularity could create value from the inner circle, circling longer, cascading use and the pure circles. To some degree, every business model is both linear and circular (Lewandowski 2016; Mentink 2014). Lewandowski (2016) investigated how circularity could be embedded into each of the business model components and proposed a conceptual framework for circular business models. Planing (2014) regarded business model innovation as one of the fundamental building blocks for the transition to circular economy. Mentink (2014) described the required changes of business model components for developing circular business models, and proposed a tool for business model innovation in circular economy. Laubscher and Marinelli (2014) identified six components of embedding circular economy principles into business models, among which the reversed supply chain logistics is regarded as the most important component of circular business models. A number of methods and tools have been developed to support firm transition towards a more circular operations, such as the Business Model Scan developed by Van Renswoude, Wolde, and Joustra (2015), 7-P Model proposed by Scott (2015) and Sustainable Value Analysis Tool by Yang, Vladimirova and Evans (2017). In general, the research on circular business models is in its infancy, yet continues to attract attention from operations management, innovation and strategy scholars.

2.4. Product-service systems

PSS offer value propositions, part of a business model, through which manufacturers sell integrated products and services as opposed to products alone (Goedkoop et al. 1999). PSS-related concepts include servitisation (Bustinza et al. 2017; Kastalli and Van Looy 2013), service-dominant logic (Vargo and Lusch 2017), pay-per-use services (Gebauer et al. 2017) and outcome-based services (Batista et al. 2017; Visnjic et al. 2017), etc. According to the ratio of products/services, PSS can be classified into different types (Hockerts and Weaver 2002; Tukker 2004): (a) product-oriented PSS, when manufacturers sell products while providing related services, such as maintenance and consultancy; (b) use-oriented PSS, when manufacturers sell the utility or accessibility of products without transferring the ownership to customers, such as leasing, renting and sharing; (c) result-oriented PSS, when manufacturers retain the ownership of products and sell the results of products, such as selling printed documents rather than printers. The transit from traditional product-based firms to service orientation is complex and contextual. Bustinza, Parry, and Vendrell-Herrero (2013) proposed that this requires a reconsideration of the management of supply and demand chains.

Vendrell-Herrero et al. (2017) explored how servitisation affect upstream-downstream firms interdependencies in the context of digital business models, and found that digital services could empower upstream and downstream firms differently under certain circumstances.

Many researchers have considered PSS as promising sustainable business models because they have the potential to reduce the total production and consumption throughout the entire product life cycle (Maxwell and van der Vorst 2003; Tukker 2015). A number of firms have witnessed the potential of PSS to bring significant revenue and meanwhile reduce negative environmental impact (Baines et al. 2007; Tukker 2004; Yang, Evans, et al. 2017). Some researchers investigate how sustainability could be embedded into PSS development (Geum and Park 2011; Manzini and Vezzoli 2003; Yang 2015), and a number of methods and tools have been developed to assist companies develop sustainable PSS business models or increase sustainable value creation in PSS, such as (Matzen and McAloone 2006; Yang et al. 2014).

Ellen MacArthur Foundation (2012) put forward the idea that in order to achieve circular economy, it is essential for manufacturers or retailers to transform to 'functional service models', in which customers buy services or the use of products, rather than the ownership of products. The manufacturers retain the ownership of products, and therefore have a greater motivation to extend the cycle of products and increase the reuse and remanufacturing rates of the used products. Some other researchers also regard PSS as a promising form of circular business model. For example, Mentink (2014) implied that selling performance-based services is an approach that moves firms towards greater circularity in their business model. Ellen MacArthur Foundation (2015) proposed a RESOLVE framework, in which sharing is regarded as one of the important actions for businesses moving towards circular economy. Ellen MacArthur Foundation (2012) took washing machines as an example and calculated the circularity of the washing machines in different business models. The result shows that leasing model could achieve more cycles than the normal models. However, the examples in this report are not based on the real cases and the calculation is based on estimated data. There is lack of sound empirical data regarding the restorative and regenerative effects of PSS business models on circular supply chain operations, and it is not clear that how different types of PSS could affect the circularity.

3. Research design

3.1. Research framework

Summarised from literature, little research has investigated business model innovation for circular supply chains. PSS business models seem to have a positive effect on the circularity of supply chains (Ellen MacArthur Foundation 2012, 2015; Lacy and Rutqvist 2015), but the relationships between PSS and circular supply chains is not clear. This paper addresses this gap and proposes the research question: *What is the impact of PSS business models on the circularity of supply chains?*

The paper then develops a research framework (Figure 1) to study the relationship between different types of PSS business models and circular supply chains, in particular how each of type of PSS would affect the key sources of value creation for circularity.

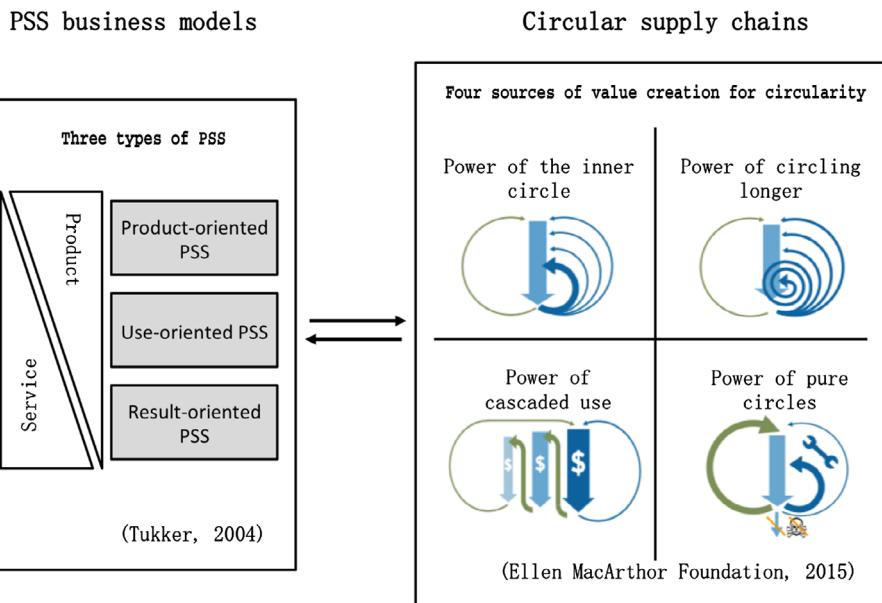


Figure 1. A research framework of PSS business models for circular supply chains.

As is shown in Figure 1, we propose that the three types of PSS business models (i.e. product-, use- and result-oriented PSSs) might affect the circularity of supply chains through the four sources of value creation:

- (1) *Power of the inner circle*, referring to minimise material usage and reduce cost through the inner circles such as production, reuse and refurbishment, and then through outer circles such as recycling;
- (2) *Power of circling long*, aiming to maximise the number of circles as much as possible and prolong the product longevity;
- (3) *Power of cascaded use*, applying 'waste-is-food' logic, and suggesting a different use of the used products through symbiosis approaches;
- (4) *Power of pure circles*, using uncontaminated material stream so that the redistribution efficiency and material productivity could be increased.

The four sources of value creation are highly related to the end-of-life strategies, which implies their potential linkage with PSS business models because PSS extends the opportunities of value creation from production phase to product usage and end-of-life phases (Yang 2015).

3.2. Research method

This research adopts the case studies method (Yin 2009) because it studies a complex, contemporary real-life phenomenon with few existing theories. The unit of analysis is business model (i.e. the form of creating, delivering and capturing value). The selection of the cases followed the sampling strategy that all cases need to be in the same company; the core products need to be the same; and that each case needs to represent a different type of business models.

Following the sampling guidance, the case studies were conducted in a large manufacturing firm producing air separation

units (also called gas generators). The reason for choosing this firm is that it has multiple business models of the air separation units, such as coexistence of selling and leasing products. Data collection took place between December 2014 and January 2016. Qualitative data analysis method was used to analyse data following the processes of data reduction, data display and conclusion drawing and verification (Miles, Miles, and Snow 2005). The case studies included eleven semi-structured interviews and four workshops with the general manager and eighteen managers from various departments, including design, manufacturing, supply chains and procurement, and security. Each interview took about 50 mins and each workshop took 100–120 mins. In the interviews, the interviewees described different ways of creating, delivering and capturing value in the company. It is identified that the company has mainly four types of business models: a traditional product-based business model in which the company produces and sells products alone, and three different types of PSS business models based on Tukker (2004)'s classification. Then, four workshops were conducted aiming to identify the supply chains of each business model and the sources of value creation of each business model. The identified sources were analysed and compared with the four sources of value creation for circularity described in Ellen MacArthur Foundation (2015).

4. Case study: exploratory findings

4.1. Description

The case study was conducted in a state-owned company in China. The company is one of the biggest air separation unit manufacturers in the world. Its products are mainly used as part of engineering equipment in areas such as metallurgy, petrochemical and coal chemical industries, chemical fertilizers, non-ferrous smelting and aero industries. The traditional business model of the company is making and selling air separation units to their customers. Now the company has extended its business to include the sale of integrated engineering

equipment as a total product-service solution (e.g. petrochemical equipment) and even further to the sale of industrial gases.

4.2. Co-existence of PSS business models in the company

In addition to the traditional product-based model, the company has implemented three types of PSS business models.

(1) Product-oriented PSS: selling products and providing technical services

The company sells the air separation product units and also provides technical services, including installation, maintenance and repair as extra market propositions. This is the most common PSS business model operated in the company. It is a product-oriented PSS because the ownership of products is transferred to the customer and the technical services are included as part of the original sales package.

(2) Use-oriented PSS: leasing products and providing technical services

The company leases air separation units, or an entire engineering system, to customers under contracts that usually last for certain years. Leasing contracts are mainly tailored to customers with special financial needs (e.g. without the financial capability to buy equipment or build projects). This forms a use-oriented PSS since the company retains ownership of the products and customers just pay for the use of products and services.

(3) Result-oriented PSS: selling industrial gases

The company also provides 'industrial gas' rather than 'gas generators'. This is result-oriented PSS because the company owns the gas generators and customers pay for the gases consumed. The company started the first industrial gas project in 2003, but not until 2010, when the company went public, it started the second one and made an extensive investment in industrial gas projects. Industrial gas projects have increased rapidly in recent years. In 2015 more than 38 gas centres have been built in industrial parks in China. The gas centres produce industrial gases such as O₂, N₂, CO₂, H₂, rare gases (e.g. Ar, He) and special gases, to customers in various industrial sectors in the industrial parks. There are four ways of providing gases: bottled gas, liquid gas (e.g. cold air separation of liquid), gasification and pipeline industrial gas supply for industrial parks.

4.3 Supply chain operations of different business models

In order to understand the impact of these different business models on supply chain operations, the interviewees were asked to describe the supply chains of each business model. Table 1 shows the supply chains of the traditional product-based model (i.e. making and selling products) and the three types of PSS business models.

The circularity of the supply chain operations of each business model is analysed.

(a) Traditional product-based model

As shown in (a) of Table 1, the supply chain of the traditional product-based model mainly includes design, procurement, production, distribution, consumption and disposal process. It follows a linear 'take, make and dispose' pattern. The company

purchases materials and parts from suppliers, produces the products, and sells it to the customers all over China, who then discards the products when they no longer function. There is no materials and information flowing back to the company. The rate of remanufacturing and reuse is very low. Sometimes the whole products are discarded only because small parts are broken.

(b) Product-oriented PSS

In this business model, the company provides technical services for the products during usage phase. Compared to the supply chain of product-based business model, product-oriented PSS extends the product life through regular maintenance and repair, as shown in (b) of Table 1. Both the company and customers have a high motivation to have technical services because it increases the service revenue for the company, and also reduces the cost for the customers compared to build their own service teams. The advantage of the manufacturer providing technical services is that the company understands their own products better and could provide more professional services than the customers or other third-party companies.

(c) Use-oriented PSS

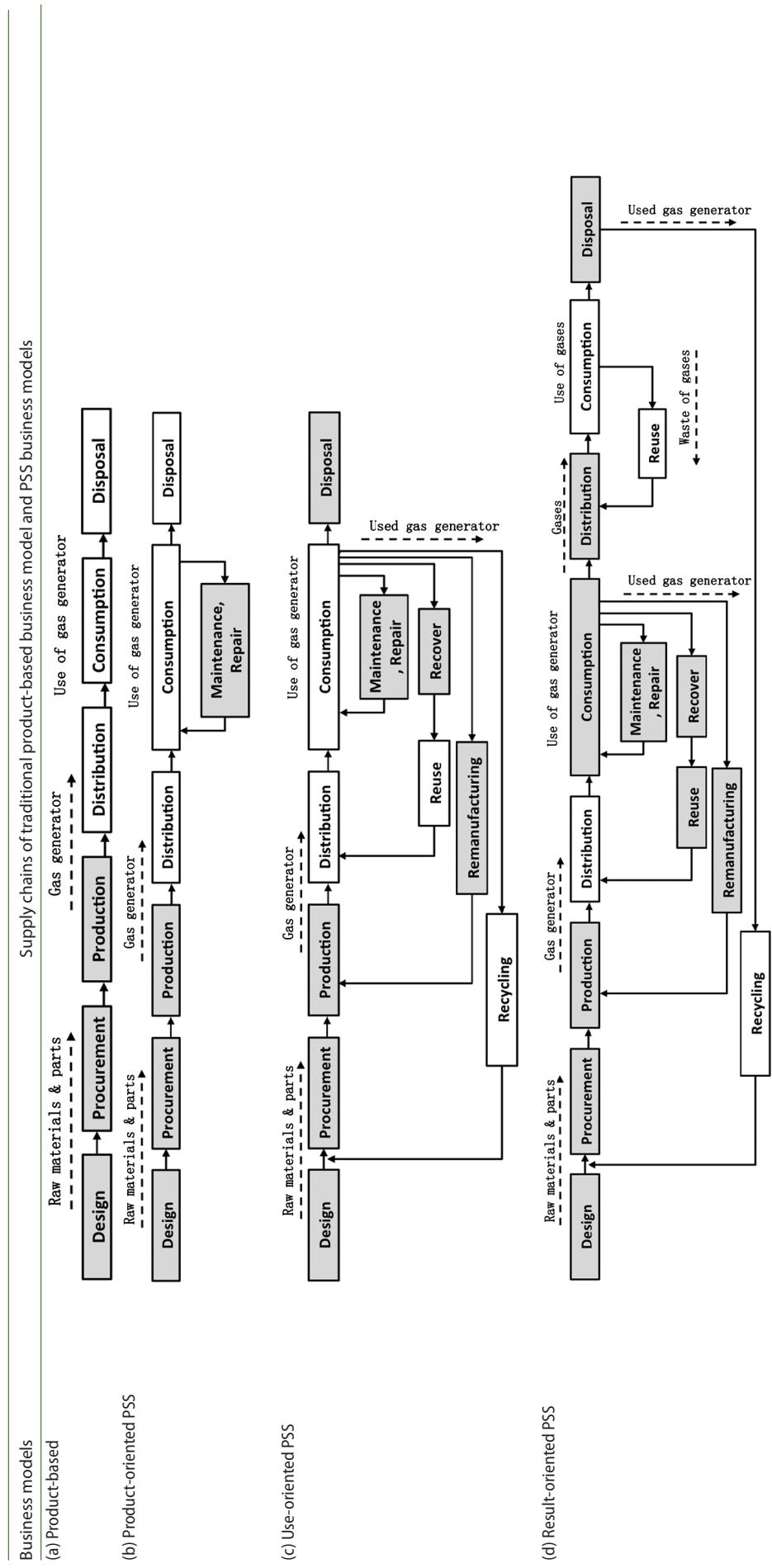
For use-oriented PSS, the company leases products to the customers and provides technical services. Compared to the previous two business models, the leasing projects have more cycles to reuse, recover, remanufacture and recycle the used gas generators, as is shown in (c) of Table 1. The reason is that the company retains the ownership of the products and is incentivised to extend the product longevity and capture value from EOL products as much as possible. The longer the customers use a product, the more revenue the company could get from leasing.

(d) Result-oriented PSS

In this business model, the company sells industrial gases rather than gas generators. Instead of making and distributing gas generators to customers, the company built its own gas centres in industrial parks which are close to customers. The company became the actual consumer of gas generators, and the produced gases were distributed to various customers in the industrial parks. As shown in (d) of Table 1, the power of maintenance, repair, reuse, recover, remanufacture and recycle is much stronger than the previous three business models, because the company is the actual users and could control the usage phase. In addition, the company created value from by- or co-products (e.g. N₂ is regarded as by-products of the production for O₂). The potential value from gases, which was previously ignored by customers (since customers did not have the expertise to fully use gases), is now captured by the manufacturer in result-oriented PSS business model. In this way, the manufacturer internalises the potential value of the products' products and is incentivised to maximise value from it. This also applies with co-products. In this business model, the company has greater incentive to increase the use of gases. It has utilised different gases for different customers, coordinated use of gases among customers during peak and off-peak times and therefore reduced gas emissions. Therefore, in this business model, the company does not only establish an inner circle of reuse of the products (i.e. gas generators) but also the reuse of the products' products (i.e. gases).

The case study shows that the closer to result-oriented PSS, the tighter and more efficient the cycle is, which means, the repair,

Table 1. Supply chain architectures of different business models.



reuse and remanufacturing system is faster and the rate is higher, and the product has to be changed less to come back to the cycle again. The more efficient the cycles are, the higher potential savings on the material, energy, labour, operations and lower waste of emissions. The result-oriented PSS also extends the reuse of products to the reuse of products' products. The main reason for this is that the manufacturer has the ownership and is the actual user of the products, so that it could control the usage and EOL phases of the products.

4.4. Circularity as a source of value creation for PSS

Circularity through increasing the inner cycle, cycling longer, cascaded use and pure circles are regarded as four main sources of value creation (Ellen MacArthur Foundation 2015). In order to compare the circularity of different business models, we use these four sources (explained in Section 3.1) as the criteria to analyse the product-based business model and the three types of PSS business models in Table 2.

Table 2 shows that the product-based business model in the company adheres closely to linearity in its supply chain. Each of the PSS business models has inherent circularity to varying degrees. Both the product-oriented PSS and use-oriented PSS predominantly create value through increased times of inner circles and circling longer, whereas, the use-oriented PSS has stronger impact on the two sources. It means that use-oriented PSS has more frequent inner circles and circling longer than product-oriented PSS.

In addition to the inner circle and circling longer, the result-oriented PSS could also create value from cascaded use through a symbiosis approach of co-products and by-products in other value chains, for example, the application of co-produced gases in new fields. Several managers had high expectations of new gas applications, for example, as said by the Deputy General manager:

There is too much waste in the co-produced gases. If we can re-use the co-produced gases in new approach, this will be a good opportunity for us. If we can seize this opportunity and investigated new gas applications, we can lead the market need.

This type of circularity only happens in result-oriented PSS in this case because only in this business model the manufacturers can control the co-products and by-products of their original products, and create value through cascaded use of the co-products.

Table 2 also shows that the pure circles seem to be irrelevant to the PSS business models in these cases, but the interviewees showed higher motivation to achieve pure reuse of materials under the result-oriented business models.

Underlying the phenomenon, the fundamental reason of the difference of circularity of the business models seems to be related to ownership of products. The company retains the ownership in use-oriented PSS and result-oriented PSS, and has strong control on products over the life cycle and therefore is more incentivised to create value from the whole product life cycle (air separation units) and even the products' products (e.g. O₂, H₂, Ar, He, Xe and Kr). The company therefore has the responsibility and incentive to reduce the environmental impact of the products in use, especially when these affect the economic value. For other PSS business models these issues are the responsibility of customers, for example, in the product-based model the company does not have a detailed level of information of the used

products because the information is controlled by the customers. Therefore, use-oriented and result-oriented PSS business models are more appropriate for circular supply chain development because of product ownership characteristics.

4.5. PSS as enabler for circular value creation

All three types of PSS could be enablers for circular value creation. Compared to the linear model of 'take, make and dispose' pattern, PSS increases the rate of repair, recover, reuse, remanufacturing and recycling, which makes the model more circular. Manufacturing companies owning the products motivates them to create economic value from the entire product life cycle, including end of life. From a customer's viewpoint, PSS means shifting from a 'buy and consume' pattern to 'rent, consume and return', or 'consume and return'. From a manufacturer's viewpoint, PSS can get closer to customers, gain continuous revenues and prolong product lifetime. PSS increases designers' motivation of design for sustainability, which aligns with the 'design out waste' principle of circular economy.

4.6. Challenges for capturing value in EOL

Although the circularity of supply chains is improved in PSS business models, the company still feels challenged the implementation of recycling and remanufacturing. The main barrier is that the value exists at the EOL stage of an air separation unit is still little compared to the company's core businesses, and the cost of recycling and remanufacturing was very high. The life of an air separation unit is approximately 20 to 30 years. After 30 years, most of the components are too old to be reused or remanufactured. In addition, the air separation units are highly customised products, which would add to the difficulty and cost of remanufacturing, i.e. low value but high cost of circularity. Also, there was little demand from customers, governments and other stakeholders for recycling and remanufacturing, therefore the company did not consider implementing circular economy an urgent issue but focussed instead on the development of other strategies for the company. As mentioned by the Design Manager of the company:

Most of the air separation units for gas projects are far away from their EOL, so we do not consider much the recycling now.

When asked about the added value from circularity, the Design Manager

I think your suggestion (design for recycling and remanufacturing) is very good but it is not our core business now. It might not add value to our businesses. Even if there is value potential, we don't know how to identify it.

The challenges imply that practical methods and tools are needed to guide practitioners on identifying value opportunities in the circular cycles.

5. Discussion, implications and concluding remarks

In general, the current research in the burgeoning field of circular supply chains and business models is not yet mature, as indicated by the lack of agreed concepts and practices. This paper extends the study of three types of PSS business models (Tukker 2004) and the value creation theory of business model

	Four sources of value creation for circularity			
	Power of the inner circle	Power of circling longer	Power of cascaded use	Power of pure circles
(a) Product-based PSS	None	None	None	None
(b) Product-oriented PSS	Power: + Increased inner circles through maintenance and repair	Power: + Extended product longevity	None	None
(c) Use-oriented PSS	Power: ++ <ul style="list-style-type: none"> Increased inner circles through maintenance and repair, recover and reuse Increased number of outer circles through remanufacturing and recycling Improved utilisation of resources in inner circles 	Power: ++ <ul style="list-style-type: none"> Reduced energy consumption Extended product longevity Increased number of cycles of repair, reuse, recover, remanufacturing and recycling 	None	None
(d) Result-oriented PSS	Power: ++++ <ul style="list-style-type: none"> Increased inner circles through maintenance and repair, recover and reuse Increased outer circles through remanufacturing and recycling Improved utilisation of resources and reduced waste in inner circles and outer cycles 	Power: +++++ <ul style="list-style-type: none"> Reduced energy consumption Extended product longevity Increased number of cycles of repair, reuse, recover, remanufacturing and recycling 	Power: +++++ <ul style="list-style-type: none"> Symbiosis use of co-products and by-products in other value chains (e.g. using previously wasted N₂ for other customers who need N₂) Increased utilisation of resources and products across different supply chains 	None

innovation (Richardson 2008) to the field of circular supply chains. It examines the four sources of circular value creation (Ellen MacArthur Foundation 2012) through PSS business models with strong empirical evidence.

5.1. Theoretical implication

The novelty of this paper is that it explores the relationship of innovation in PSS business models and circularity in associated supply chains. Our empirical analysis has four important insights that contribute to the understanding of PSS business model innovation for circular supply chains. First, our findings confirm that PSS business models have the potential to trigger and enhance the circularity features of supply chains. Even though some existing literature implied that 'product as a service' and 'leasing rather than selling' could generate a positive effect on the circularity of supply chains (Ellen MacArthur Foundation 2012, 2015; Lacy and Rutqvist 2015), there was still a lack of solid empirical data to support this assumption, and this paper provides strong empirical evidence to fill in the gap. Second, we further studied how different types of PSS business models could affect the circularity of their supply chains, which has not been done in any literature. The method of analysing the impact relationship is novel – this is done through the analysis of the four sources of circular value creation (i.e. inner circle, cycling longer, cascaded use and pure cycles [Ellen MacArthur Foundation 2012, 2015]) and three types of PSS business models (i.e. product-, use- and result-oriented PSSs [Tukker 2004]). Third, our empirical analysis demonstrates that different types of PSS business models are associated with distinct circularity signatures within their supply chains. In particular, we proposed that use-oriented and result-oriented PSS business models are more appropriate for circular supply chain development because of product ownership matters. Fourth, the research shows that PSS business models could enable the circular value creation through inner circle, cycling longer and cascaded use, but not pure cycles.

This paper therefore highlights the potential of business model innovation for the circular economy, and also extends the dimensions of previous research on PSS by incorporating supply chains circularity into the analysis. Future research might further explore the mechanisms on using PSS business models for developing circular supply chains, and investigate new business models that could enhance circularity through pure cycles.

5.2. Practical implication

The research in this paper can be used in practice to facilitate the transition to circular supply chains through developing appropriate PSS business models. The case study can inspire business model innovation for circularity in different industries. The research findings could be embedded into some business model tools, such as Business Model Canvas (Osterwalder and Pigneur 2010) and Sustainable Value Analysis Tool (Yang, Vladimirova, and Evans 2017), to assist practitioners in designing and analysing circular business models and supply chains.

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