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Examining Circular Economy Business Models for Engineer-To-Order Products

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Abstract. Realization of the circular economy (CE) and its full potential requires firms to rethink their supply chains and business models. Although several frameworks in the literature propose circular economy business models (CEBMs) to redefine how companies create and capture value while adhering to CE principles, there has yet to be an examination of CEBMs in engineer to order (ETO) context. To address this gap, this study maximizes the depth of the phenomenon under investigation by leveraging a case study of a Norwegian company that deals with a large number of small ETO projects. Our findings increase knowledge of how ETO products can adapt to CEBMs.

Keywords: Circular Economy, Circular Economy Business Models, Engineer-To-Order Products.

1 Introduction

Victor Hugo's infamous quote, "you can resist an invading army; you cannot resist an idea whose time has come", is what possibly best encapsulates the concept of circular economy (CE) being the idea, that needs to replace the current production and consumption system – take-make-dispose linear model [1]. Most would agree that CE has become mainstream. It would be hard-pressed to find a firm that has not at least started a recycling initiative or engaged in some kind of community development project, even if the efforts were sparse. Auspiciously, many firms have gone far beyond, overhauling products and processes and looking outwards at system-wide innovation, and CE initiatives that promise to radically reshape their businesses now and in the future [2]. As more firms begin to recognize the potential of this novel approach, the CE quickly moves from theory to practice and the demand for businesses to embrace it strategically and operationally, and for the governments to establish a consistent set of rules for CE [3] is growing accordingly. More importantly, CE calls for novel business models that will simultaneously ensure the creation of environmental quality, economic prosperity, and social equity to benefit current and future generations [4]. This is understandable since a business model is the essence of a firm, representing the architecture through

which firms create value, deliver value to their customers and capture value for themselves. Thus, if the role of the firm is vital for a successful transition to CE, then the implementation of new business models is warranted.

The extant literature addresses related topics, including a framework that integrates circular economy business models (CEBMs) and circular supply chain management [5], the development and application of a circular business experimentation framework [6], and a visualization tool to map CEBMs [7]. Although the literature provides useful insights, further research is still required on how firms can implement CE practices for value creation and capture [8]. This is crucial because CE implementation strategies are mainly associated with individual products [9]. As such, in this paper we use product as a unit of analysis when examining CE implementation strategies. Since CEBM implementation largely depends on individual products, with the assumption that varied products might require varied manufacturing plants, settings and strategies, and business models, the present study focuses on engineer-to-order (ETO) products. Against this backdrop, this study seeks to empirically identify the characteristics of specific ETO products and examine their appropriate CEBMs. To the best of our knowledge, no study has specifically investigated the CEBMs for ETO products and considering the uniqueness and relative complexity of ETO products, insights from this paper should be of interest to scholars, practitioners, and policy makers.

The paper proceeds as follows. We commence by reviewing literature related to CEBMs and production of ETO products. We then provide a framework that shows the general applicability of CEBMs for ETO products, which is followed by a methodology section and presentation of the case study. Finally, we discuss the findings and provide an outline for further work.

2 Circular Economy Business Models (CEBMs)

Before discussing CEBMs, it is important to understand the business model concept and its implications. A business model is defined as “the design or architecture of the value creation, delivery, and capture mechanisms [a firm] employs. The essence of a business model is in defining the manner by which the firm delivers value to customers, entices customers to pay for value, and converts those payments to profit” [10]. In operational terms, a business model includes a value proposition (product and service; customer needs; geography), a revenue model (pricing logic; channels; customer interaction), and a cost model (core assets and capabilities; core activities; partner network). To be successful, these components must be coherent and internally aligned [11].

A CEBM can be defined as “the rationale of how an organization creates, delivers, and captures value with and within closed material loops” [12]. Studies on CE have addressed the design of CEBM in light of CE principles, and approaches to reconfigure and realign business model components according to CE practices [e.g., 8, 12]. Such models embrace cyclical material flows, renewable energy sources and cascading-type energy flows [13]. Put succinctly, to be regarded as ‘circular’, a model does not necessarily need to close material loops by itself within its own internal system boundaries;

it could also be part of a larger system that together close a material loop echoing the Industrial Ecology thinking.

Studies by Stahel [14], and Bocken et al. [15], describe three key strategies for CE, from the resource perspective. 1) *slowing* loops, which extend a product's life to slow down resource usage (e.g. through repair); 2) *closing* loops between post-use and production through recycling, resulting in a circular flow of resources; and 3) *narrowing* loops, which aim to use fewer resources per product (e.g. through efficient manufacturing processes). Clearly, each of these strategies requires a different configuration of the value proposition, the revenue model, and the cost model, i.e., the business model. An intriguing question, then, is how to implement these for ETO products? Before addressing this question, the next section sets the scene by presenting ETO production.

3 Production of ETO Products

ETO refers to a strategy whereby design, engineering and production is based on specifications provided by a specific customer order. As such, the customer order's decoupling point for ETO is at the design stage such that each order is tied to the design phase of a product [16]. Given the product-process characteristics of this type of environment, the products are highly customized, produced in low volumes (often one-of-a-kind), and customer specific; also, the processes are labor intensive, usually non-repetitive, and often demand highly skilled labor [17]. The entire execution of the ETO product is often organized as a project particularly for capital goods. Since companies are generally unaware if and when a customer will place an order, accurately forecasting demand, ordering materials and producing products in advance are very challenging [18].

Drawing on Willner and colleagues' [19] ETO matrix, products can be produced using four ETO archetypes (complex, basic, repeatable, and non-competitive), depending on the number of units sold per customer order, the existence of repetitive customer orders and the engineering hours needed to produce the product. Given these four ETO archetypes, CE strategies for ETO products will plausibly vary according to the type of ETO production.

The subsequent section examines the appropriate CEBMs in ETO context.

4 Examining appropriate CEBMs for ETO products

CEBMs require the appropriate reconfiguration of value creation, delivery and capture, activities according to the nature/type of the product. We provide a framework, which shows the general applicability of CEBMs in ETO context (see Table 1). The framework proposes four major CEBMs for all ETO products (circular supplies, product life extension, product value extension and resource value). We further divide these major CEBMs into sub-CEBMs and describe them along four business model dimensions (value proposition, value delivery, value creation and value capture). This is derived from major frameworks such as business model canvas [20] and widely accepted conceptual analyses [11, 21]. This alignment is essential in ensuring that ETO companies can understand and apply these CEBMs.

Table 1. Circular Economy Business Models (CEBMs) and Circular Economy (CE) practices related to Engineer-To-Order (ETO) products. The highlighted rows = major CEBMs, the column under each major CEBM = reviewed CEBMs, which are further divided into sub-CEBMs.

CEBMS	CE practices related to ETO products							
	Value proposition		Value delivery		Value capture		Value creation	
	Products	Services	Target Customer	Value delivery Processes	Revenues	Costs	Partners and stakeholders	Value creation Processes
Circular supplies								
Industrial symbiosis (IS) [15, 22].	Waste as production inputs	Cost and supply risk reductions; synergistic partnerships; third party waste reduction.	Manufacturers; B2B suppliers.	Sharing communal services (e.g. maintenance, recycling); set up geographically proximate collaborations (e.g. eco-industrial parks).	Additional revenues through new IS products/component s; new revenue potential through green image.	Reduction of waste disposal costs; reduction of material and energy costs; reduction of transportation costs.	Manufacturers; B2B suppliers	Physical exchange of materials, energy, water; using own waste and/or third party's as inputs for production.
Product life extension								
Classic long-life model [15].	Long-lasting products	Repair; maintenance; upgrading	B2B customers (Quality- and cost-conscious)	Offering long-lasting products & corresponding repair/ maintenance services; upgrading services.	Price premium for longevity & high quality of products; additional revenue through extended usage	Long-term service & product warranty cost	After-sales service agents.	Designing long-lasting products; repairing & upgrading of products and/or components.
Repair and maintenance [24]/ Reuse & Redistribute [23].	Repaired components; spare parts; Reusable components/parts.	Securing uptime & lifespan of products; shipping/installation; maintenance; repair; customer education; facilitate collaboration.	Quality-conscious (those willing to pay more for quality services); cost-conscious customers (those with constrained budgets)	Providing (product-based) services & results; Making reused components accessible & affordable; take back used components.	Additional revenues from the services provided; additional product or component revenues.	Reduction of material costs (through reusing/repairing components/parts); increase of labor and logistics costs	B2B customers (shipyards & ship owners); after-sales service engineers; manufacturers.	Components upgrading or upcycling; reselling and/or taking back components Maintaining or repairing products & components
Refurbishment and remanufacturing [24].	Repaired, refurbished products; used components as inputs; remanufactured components;	Upgrading; shipping and installation, warranties (auxiliary services).	Cost-conscious/B2B customers; B2B suppliers.	Providing used components, materials; taking back used components.	Additional product/component revenues.	Reduction of material costs (through upgrading); transportation, logistics.	B2B customers; manufacturers; After-sales service engineers.	Restoring the functionality of components; upcycling and taking back components.
Product value extension								
Extending product value [15].	Used products or components in as-new quality; repaired products.	Taking back used components.	B2B customers.	Taking back used components; selling used components.	New revenue potential from retaining material ownership.	Reduction of material costs; increase of labor and logistics costs.	Collaborations with B2B customers; after-sales service engineers.	Repairing or remanufacturing own components.
Product as a service [22].	-	Leasing; renting; product maintenance, repair & control.	B2B customers.	Specifying functionality, retaining product ownership,	Leasing fee; rental fee.	Product longevity; product maintenance costs; material costs reduction.	Manufacturers; B2B suppliers; B2B customers.	Using products longer; maintaining, repairing & controlling product.
Resource value								
Recycling and waste management [23, 24].	Reusable/recyclable production inputs; components based on recycled waste;	Waste sorting; waste recycling; take-back management.	Some key customers (B2B) interested in using such waste as production input (downcycling)	Providing used components, materials, waste; taking back used components, waste.	Additional product/component revenues	Waste handling processing; resource inputs; logistics; transportation.	Key customers; municipality	Components recycling; upgrading or upcycling of components; taking back components.

‘Circular supplies’ are business models based on industrial symbiosis in which the residual outputs from one process can be used as feedstock for another [22]. Through it, ETO companies may replace linear resource approaches and phase out the use of scarce resources while reducing waste and removing inefficiencies. Whereas, ‘product life extension’ business models aim to extend the lifecycle of products through engineering solutions including repair, maintenance and/or upgrade [22, 23]. With this model, ETO companies can help ensure that products stay economically useful for as long as possible and that product upgrades are done in a more targeted way (e.g., fatigue/ obsolete components are replaced instead of the entire product). Moreover, ‘product value extension’ business models offer product access and retain ownership to internalize benefits of circular resource productivity [15]. This model would be attractive to a few ETO companies with high cost of operation for their products and that have skill advantage relative to their customers in maintaining the products, hence, giving them an advantage in selling services and recapturing residual value at end-of-life. ‘Resource value’ business models for these ETO products, is built on mostly ‘recycling and waste management’ [24], and generally, they can take different forms, thus, upcycling (which creates higher quality materials and improved functionality) and downcycling (e.g., the conversion of used materials into materials of lower value). This model is a good fit for most ETO companies especially where waste material from products can be reclaimed through take-back management and reprocessed cost effectively.

Nevertheless, for a CE to function these different types of CEBMs will need to interact and work together. For example, in the case of an advanced equipment to maritime industry, the ‘product value extension’ business model implies the equipment manufacturer either takes back used components of the products or retains ownership of the products, and is incentivized to repair/refurbish/upgrade the equipment over time to maintain maximum efficiency. However, the full circular benefit is only realized if the business models would allow for product and process design change, so that the products/components are repairable, upgradable and disassemblable to reduce the use of virgin materials [3]. Based on a CE, these ETO firms have the opportunity to expand their services they offer or collaborate with others to maximize value. For instance, a firm which bases their CEBM on refurbishing and remanufacturing their components may need to partner with a ‘tracking facility’ provider so they can monitor the whereabouts of their products, and then work with a logistics company or some of their B2B customers to ensure the end of life components are returned (take-back management).

Next, we present key methodological choices for the present study.

5 Research methodology

Our study explores an emerging phenomenon – CEBM, hence an embedded single-case design was deemed appropriate since single case design is suitable for revelatory purposes [25]. We selected a company (hereafter company X) that manufactures and supplies propulsion systems to shipyards and ship owners. With more than 1000 engineering hours per unit and 120 bespoke units sold annually, the propulsion system is a perfect example of an ETO product. We used three data collection approaches: face-to-

face semi-structured interviews; direct, non-participant observation and document review. The next section describes company X and its ETO product characteristics, which are then matched with CEBMs identified in the developed framework.

6 The case company, its ETO products and suitable CEBMs

Company X's business concept is to design, manufacture, market and service complete systems for the propulsion, positioning and maneuvering of larger vessels. Products are highly customized, manufactured on-site, and are manifested through a project organized execution model covering engineering design, procurement and production, which are done in-house to ensure quality in integration of systems. Most of the equipment is designed to meet the demanding requirements of North Sea offshore standards and is used on different types of vessels (e.g. offshore, fishing, cruise, coast guard). In general, company X creates value by understanding customer requirements, translating them into specifications at the product and component levels, and integrating components and subsystems into products. Table 2 presents company X's ETO products characteristics and their descriptions.

Table 2. Company X's ETO product characteristics and their descriptions

ETO product characteristics	Description
Low volume	On average, 120 units are produced and sold annually. This varies significantly year by year, depending on the condition of the market, etc.
High degree of customization	The products have high-engineering complexity (i.e. more than 1000 hours per unit) and are engineered per precise customer specifications.
Project-based environment	The ETO operations are typically project-oriented, thus, the customer is exposed to the lead-time that encompasses the entire project duration.
Product design	Each product is engineered/designed according to specific requirements, which vary from one customer to another.
Customer involvement/ Customer specific	Customer orders drive production. Each project is highly customer-specific and requires over 1000 engineering hours. The main drivers are different propulsion system requirements, regulations imposed by class, authorities and customer preferences (shipyards and ship owners).
Labor intensive/ high-skilled labor	Given the complexity of the products, the manufacturing process is labor intensive and often demands highly skilled labor.
Type of modularization	There is a slight product modularization. Its design elements are split up and assigned to modules based on a formal architecture or plan.

7 Appropriate CEBMs for company X

From Table 1, we propose two major CEBMs that are appropriate for company X's propulsion systems: 'product life extension' (which builds on 'repair and maintenance', 'reuse and redistribute', and 'refurbishment and remanufacturing'), and 'resource value' (that builds on 'recycling and waste management').

'Repair and maintenance' business models are part of product sales and stand-alone services for company X; they are more about offering superior product experiences and

engaging customers in co-creation (e.g. following maintenance schedules), than they are about selling products [2]. These models are addressing almost all the business model dimensions, indicating how issues, such as customer-centric services, fast learning and problem-solving capabilities, and up-to-date product expertise, are essential and of high value to company X. Since company X provides these services itself, there may be a reduction in the costs for virgin materials.

Given the nature of the propulsion systems, ‘reuse and redistribute’ business model is the most relevant; there are only a few components and/or parts that are/can be reused. Instead of having used components flow (back) to company X directly or via an intermediary for repair and replacement, the company’s aftersales service engineers typically decide whether components can be reused (whilst in the field with customers), depending on their level of wear or fatigue. The same applies to the ‘refurbishment and remanufacturing’ business models, which require that company X establishes the necessary reverse logistics to have access to used components [26]. It should be noted that, in this type of industry, buying back used components by contacting customers directly is challenging; it is extremely time-consuming to trace customers all over the world, and it is even harder to identify them after ship ownership changes. More so, buy-back method would involve high logistics costs. Since the products are located under the waterline, there are also the practical difficulties involved of obtaining the components except when the vessel is up for the 5-year class and maintenance dockings.

Considering ‘recycling and waste management’ business model, company X pays much attention to the downcycling of very few components such as electrical and electronic equipment. This is because recycling is quite challenging as most components have material grades and material mix adapted to the specific requirements, which over time changes due to technological improvements and most components degrade in seawater rendering them slowly less and less attractive for reuse or upcycling.

Put succinctly, these identified CEBMs would therefore allow company X greater control of their resource streams, innovation through the supply chain and enhanced collaboration within the supply chain amongst all actors.

8 Conclusion and further work

Most ETO manufacturers stand to benefit more from the multifarious collaborations that can be built based on these CEBMs and from component take-back to complex industrial symbiosis networks. CEBMs for ETO products mostly address one of the three key CE strategies: the *slowing* resource loops. There is, nonetheless, a need to convince manufacturers to adapt *narrowing* and *closing* loops strategies to retain product and material value, respectively, if they are to successfully transition to CE; to do so, companies must rethink their supply chains and how they create and deliver value. We have noticed that a recycling business model for ETO products is greatly underutilized partly due to the complexity of the product. Hence, further work may elucidate distinctly how ETO manufacturers should design a collection and recycling infrastructure for such a recycling business model, and how they may capture value from it.

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