Title:

Causal loop modelling of Rebound Effects Mechanisms in product-service systems
The case of clothing rental

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Abstract:

The Product-Service Systems (PSS) research overlooks the risk of an overall increase in consumption due to rebound effects (RE). This study focused on identifying the RE mechanisms due to the implementation of use-oriented clothing PSS solutions, and is based on a model-based case study employing secondary data combined with a literature review on RE. The system model shows direct and indirect effects and mechanisms leading to RE in the system. Direct rebound effects further trigger indirect effects due to economic factors and psychological motives (e.g. when choosing to rent over purchasing). Those rebound effects could lead to an increased consumption of the service provided or other services. The findings highlight the further need to quantify the identified mechanisms into simulation models, which would help prioritize critical areas to mitigate RE.

Introduction

Background

The textile and fashion industry is one of the most polluting industries (Yoshitaka, 2021), contributing to many environmental, social and economic issues (Johnson and Plepys, 2021). Particularly, the premise of fast fashion and the increasing clothing underutilization, Figure 1, leads to higher production of clothes, which systematically last less than their technical lifespan (Johnson and Plepys, 2021; Roos *et al.*, 2016).

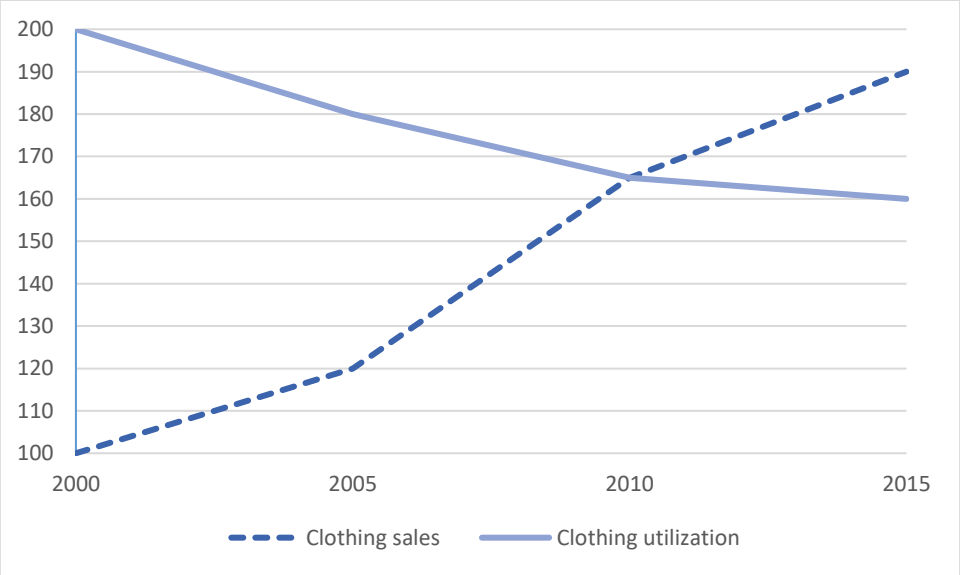

*Figure 1 Growth of clothing sales and decline in clothing utilization over years, [*Clothing sales index 100 in 2000; Clothing utilization number of times garment is worn], adapted from:* (Ellen MacArthur Foundation, 2017)

Circular Economy (CE) strategies targeted at business model (BM) innovation are seen as possible solutions to enhance the sustainability performance of the textile and fashion industry (Johnson and Plepys, 2021), especially the so-called in the context of the so-called product-service systems (PSS) (Bocken *et al.*, 2014). PSS combines tangible products and intangible services to fulfil the consumers' needs (Tukker and Tischner, 2006), which essentially aims to change consumption patterns and provide incentives for optimizing the supply chain and product design towards maximized value creation (Johnson and Plepys, 2021). Thus, PSS solutions for clothing have the potential to reduce environmental impact compared to linear models of ownership (Goedkoop *et al.*, 1999). However, the advantage of PSS will highly depend on the BM structure, consumption behaviour, ability to displace primary production and ownership, making the whole benefit somewhat uncertain (Johnson and Plepys, 2021; Zink and Geyer, 2017).

Moreover, renting clothes can potentially result in rebound effects (RE) (Johnson and Plepys, 2021; Yoshitaka, 2021), i.e., effects that offset the benefit of the implemented improvement (i.e. circular strategies and initiatives) due to systemic and behavioural responses (Kjaer *et al.*, 2017). In this context, PSS for clothing can facilitate consumption (e.g. offering a service contract that includes regular replacement of items) (Johnson and Plepys, 2021; Verboven and Vanherck, 2016) and promote higher consumption due to consumer behaviour changes (Goedkoop *et al.*, 1999; Kjaer *et al.*, 2017). Renting clothes, for example, offer consumers unique items without the obligation of ownership, with lower costs and therefore higher disposable income which can result in more items being rented (e.g. more frequently closet update), or even a higher spent on other products/services

with a higher sustainability impact (e.g. buying new electronic devices or traveling overseas) (Johnson and Plepys, 2021; Sorrell and Dimitropoulos, 2007).

Nevertheless, most of the studies to date have not yet accounted for RE (Yoshitaka, 2021) and are mostly focused on implementing PSS solutions for clothing and its impact on the environment, assuming consumption as usual (Girod et al., 2011). This gap is significant especially for emerging PSS companies and policies interventions (such as reducing VAT rate), which could lead to the RE (e.g. promotion of additional consumption) through sustainability-oriented actions (Yoshitaka, 2021). In summary, while several benefits of clothing PSS can be noted (i.e. extension of the active lifespan), the lack of a proper approach for identifying and managing the possible RE is critical (Yoshitaka, 2021).

Understanding the cause and effect of PSS on the whole system level is necessary to enhance the knowledge of potential RE and enable companies and policies to address them better (Yoshitaka, 2021). Moreover, a deep analysis could help to expand the ground of understanding systemic and behaviour changes happening due to PSS implementation and how system structure contributes to the changes. Identifying RE could help design CBM (and PSS) that can successfully support the transition to sustainable CE. However, as acknowledged in the literature, this is a difficult task (Balanay and Halog, 2021; Johnson and Plepys, 2021).

Thus, this paper aims to explicitly discuss the causes and effects of mechanisms leading to potential REs in use-oriented PSS solutions for clothing. In order to achieve those aims, the potential occurrence of RE is analyzed based on a model-based case study of a specific use-oriented PSS for women formal dresses (Johnson and Plepys, (2021) using qualitative System Dynamics (SD) analysis - the Causal Loop Diagrams (CLDs).

Theoretical Background

PSS as a Circular Business Model (CBM)

This section focuses on the critical characteristics of PSS and positions them within the CE to understand the essential elements and variables of the PSS as CBM.

CE is seen as a promising approach to reach sustainability goals (Stahel, 2016). It can be defined as a regenerative and restorative system achieved by slowing, closing, and narrowing resource loops (Ellen MacArthur Foundation, 2013; Geissdoerfer *et al.*, 2017). CE is achieved by long-lasting design and nine recirculation strategies: upgrade, repair and maintenance, reuse, refurbish, repurpose, recycle, cascade and recover as per The Circular Strategies Scanner (Blomsma *et al.*, 2019).

PSS originates from the sustainability field (Kjaer *et al.*, 2018), and it has been recently seen as a way of implementing CE (Kjaer *et al.*, 2019) and the sharing economy (Verboven and Vanherck, 2016). While not being always necessarily circular by nature (Kjaer *et al.*, 2016), PSS can encourage circularity (e.g. by selling access rather than ownership (Bocken *et al.*, 2014), incentivizing product life extension (Kjaer *et al.*, 2018); and enabling reuse, repair, and remanufacturing (Johnson and Plepys, 2021), keeping the highest value of a product for as long as possible.

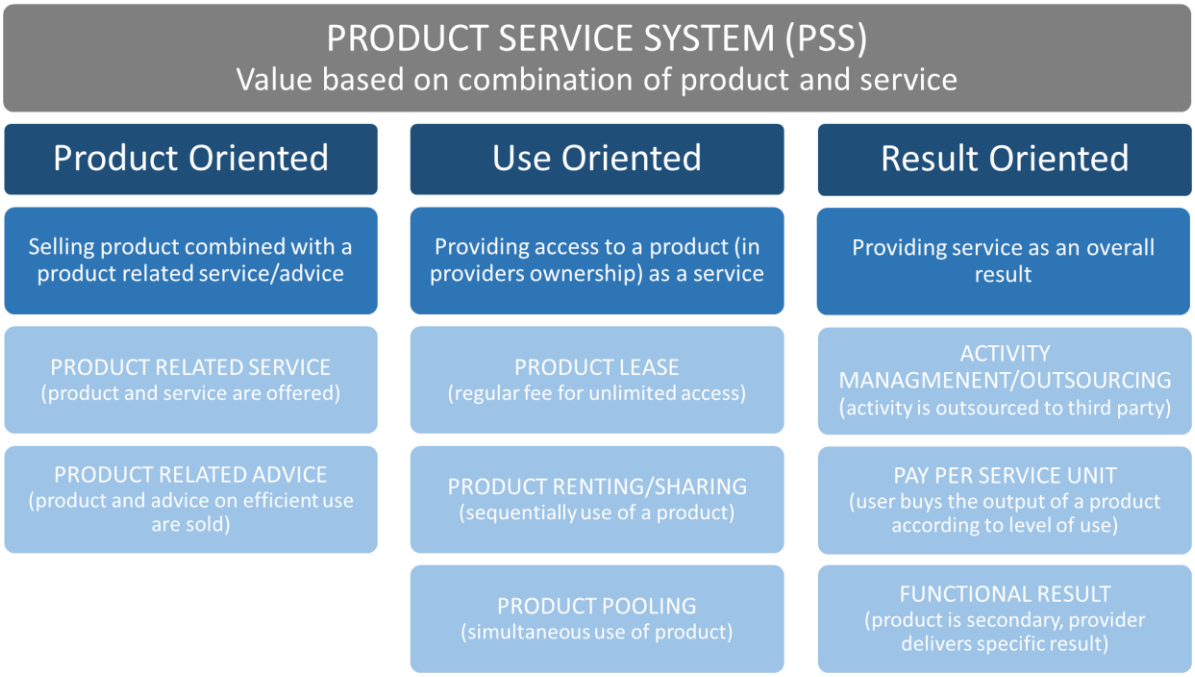

Figure 2 Types of PSS and examples of use-oriented PSS solutions in the clothing industry adapted from Johnson and Plepys, (2021); Tukker, (2004)

PSS can be classified into product-oriented, use-oriented and result-oriented (Figure 2). Product-oriented PSS is mainly based on a product sale while services/advice are provided additionally (e.g., maintenance contract) (Johnson and Plepys, 2021; Tukker, 2015). Use-oriented PSS focuses on providing consumers access to a product as a service in exchange for a specific fee while retaining the ownership of the product (e.g., renting clothes) (Johnson and Plepys, 2021; Tukker, 2015). And result-oriented PSS refers to selling a result instead of a product (i.e. laundry service) (Johnson and Plepys, 2021; Tukker, 2015). In use-oriented PSS solutions, the scope of this research, the product can be offered in leasing, sharing or renting and pooling (Tukker, 2015).

Rebound effect research

Over the past decades, RE gained popularity both in the academia and policy areas, especially within the energy efficiency context (Font Vivanco *et al.*, 2016). The growing literature offers a wide range of definitions, types, mechanisms, triggers, and drivers, as well as approaches to estimate the RE magnitude (Font Vivanco *et al.*, 2016; Madlener and Turner, 2016). RE is often referred to as an umbrella term for various mechanisms that reduce the expected benefit due to the interplay of triggering and driving factors (Sorrell, 2014). The RE mechanisms describe how and why RE occur (Walnum et al., 2014), and are often used to draw implications regarding the outcome of the change in driving factors (e.g., economic, consumer behaviour, time, space savings) (Azevedo et al., 2013; Girod et al., 2011; Sorrell and Dimitropoulos, 2007).

RE mechanisms are often classified in direct-, indirect- or economy-wide RE (Greening *et al.*, 2000) and the level of analysis to micro-, meso- or macro (Lange *et al.*, 2019). Direct RE is observed in cases where improvements lead to lower than expected benefits due to enhanced overall consumption of the same product (Otto *et al.*, 2014). Indirect (or secondary) RE results from increased demand for other products and services, which may increase demand and supply (Sorrell, 2007), i.e. implemented improvements in one product or service can cause changes in demand/supply for other products. Economy-wide effects refer to an aggregation of direct and indirect effects, involving

supply and demand-side responses to changing prices and quantities (Sorrell, 2009; Sorrell and Dimitropoulos, 2007; Wei and Liu, 2017).

Micro-level effects focus on an individual consumer, household or company/producer (Lange *et al.*, 2019) of a single service or a product (Laurenti *et al.*, 2016). Meso-level effects occur in single markets or sectors by combining micro effects at both the consumer and the producer levels (Lange *et al.*, 2019), focusing on the symbiotic relationships among system actors for sharing resources (Saunders, 2013). Macro-level effects occur because of "interactions between various actors in the market, both producers and consumers" (Hertwich, 2005), encompassing whole cities, regions, and nations. The total RE at a given level comprehends the sum of effects at lower levels (Arrobbio and Padovan, 2018). Figure 3 represents fundamental RE mechanisms identified across literature (Metic and Pigosso, 2022, in review).

RE research within CE has recently emerged in light of questioning its premises (Corvellec *et al.*, 2021), such as the extent to which circular activities such as reuse (i.e. secondary production/consumption) displaces primary production and consumption or ends up increasing overall demand (Van Der Voet *et al.*, 2004; Zink and Geyer, 2017). Furthermore, collaborative consumption, PSS and access-based consumption can, in many cases, stimulate more consumption due to easier access to goods and services (Zink and Geyer, 2017). CE rebounds occur when circular initiatives do not succeed in outpacing increases in consumption, causing increased production levels and reducing their expected decoupling benefits (Zink and Geyer, 2017).

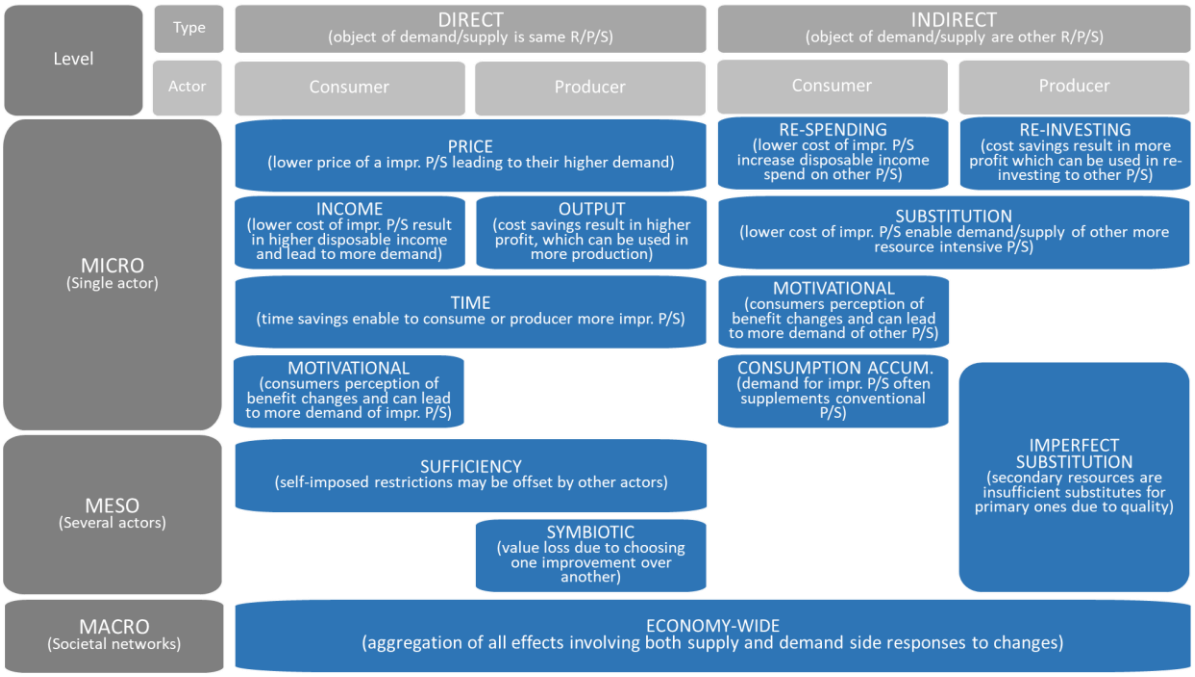

Figure 3 RE across level analysis, types and different actors with key mechanisms found across literature [R=resource, P=product, S=service]

RE in clothing rental

RE research in use-oriented PSS for clothing has been limited. So far, studies primarily focused on life-cycle assessment (LCA), such as Johnson and Plepys, (2021). LCA studies identified several important factors that can affect the environmental benefit of use-oriented PSS clothing solutions, such as: (i) the number of times a rented garment is used per rental, which is reciprocal to the number of total users sharing the rented item, (ii) the potential for lifespan extension, and (iii) the transportation modes and distance (Johnson and Plepys, 2021).

Piontek *et al.*, (2019) discuss the possibility for RE but do not explicitly account for them. The RE within the fashion and textile industry and clothing rental will highly depend on the replacement rate (RR), which can be defined as the degree to which production and ownership of an item are substituted by second-hand or rental of a similar item (Yoshitaka, 2021). The RR is determined by market forces and consumers' perceived value. Therefore, 1:1 RR of reused for purchased items can be unrealistic and hard to quantify accurately (Johnson and Plepys, 2021; Kjaer *et al.*, 2018; Yoshitaka, 2021). In other words, the provision of second-hand market and clothing rental possibly adds to the supply, rather than completely replacing it (Makov and Vivanco, 2018), offsetting the initial intended benefits (Zink and Geyer, 2017).

The rebound of use-oriented PSS solutions in clothing is defined as: ''*when one facilitation of wearing a use-oriented PSS solutions garment does not fully lead to a decrease in purchase rate of linear clothing, that is, when it fails to substitute for one wear of linear clothing, or when it does substitute but at the expense of compromising their utilization*'' (Yoshitaka, 2021). As examples, they refer to the additional item offered to mitigate fit mismatch, or when item received is disliked and not worn at all, the facilitation of these items still requires transportation, packaging and cleaning, which uses the lifespan of an item – phantom wear (Yoshitaka, 2021). Moreover, even if the item is worn and the RR is 1, the effective RR of wear is compromised as long as it does not contribute to reducing the purchase rate of linear items (Yoshitaka, 2021).

Methodology

This research follows a qualitative approach based on system thinking to create Causal Loop Diagrams (CLDs) that can fully explore the complexity of use-oriented PSS for clothing. The investigation aims to answer the three following questions:

1. How does use-oriented PSS clothing solution influence system behaviour?
2. What are the potential RE mechanisms triggered by use-oriented PSS clothing solutions?
3. How to avoid potential RE in use-oriented PSS solutions?

In order to answer these questions, the following research process was followed in this research:

i. Identify critical varibles of the model.

ii. Model the as-is linear purchasing solution using CLDs.

iii. Model the use-oriented PSS solution scenario using CLDs.

iv. Identify potential RE in the use-oriented PSS solution scenario using the developed canvas of mechanisms (Metic and Pigosso, 2022 in review).

v. Model the identified RE mechaisms using CLDs.

The main source of the model-based investigation was the original case study of use-oriented PSS clothing solution described by Johnson and Plepys, (2021). This study was selected due to the level of detail, indicators and variables included in the environmental impact analysis of the use-oriented PSS clothing solution. The original case study relied on surveys to investigate micro-level decisions when choosing between the linear purchase of a formal dress and rental models (Johnson and Plepys, 2021). Furthermore, it applied quantitative LCA to compare the impacts of the rental PSS and linear BMs (Johnson and Plepys, 2021). A modelling study on use-oriented PSS clothing solution Yoshitaka, (2021) served as a complementary reference to contrast variables and causal assumptions.

The case company is within the business-to-consumer market of formal rental dresses in Sweden, categorized as use-oriented PSS clothing solution. It offers access to second-hand formal dresses and its inventory in a pay-per-renting scheme, including additional laundry, maintenance and repair services (Johnson and Plepys, 2021). Most of the dresses in the inventory are procured as second-hand products, while the rest are from clients who rent their own dresses. The company offers online and physical options for renting.

System Dynamics (SD) was employed to enhance the learning of complex systems in a broad, long-term, dynamic view (Sterman, 2000). Specifically, CLD functioned as a graphical and qualitative tool to explore and represent the interconnection between the critical variables in the analyzed system (Bassi *et al.*, 2021). It was employed as an early exploratory tool to assess the potential effects of change in the system. It supports the analysis of causality from the PSS implementation, connecting drivers leading the change to the systemic impacts (Bassi *et al.*, 2021), which corresponds to the problem defined for this study.

The variables collected from the original study Johnson and Plepys, (2021) and from the modelling study Yoshitaka, (2021) were adapted for the best representation of the research problem or aggregated to communicate central feedback structure. The variables obtained provided background for conceptualization of the feedback structure governing the dynamics. All variables and their detailed explanation are available in the Supplementary material. The following section details the CLDs obtained from the investigation.

Results and Analysis

Qualitative analysis of the original case study

The following sections portray the case study in stages by separating the linear and rental BMs. Finally, the identified RE mechanisms are outlined. Variables and detail descriptions are available in Supplementary material.

The dynamics of purchasing dresses

Figure 4 represents the dynamics of a purchased dress. Due to *the annual demand for wearing a dress*, *the annual demand for wearing a purchased linear dress* will increase, causing *the annual purchase rate of linear dress to increase*. Every linear dress purchased due to its positive link will be disposed of (Loop B1), and *the disposal rate d*epends on its *lifespan*. *The use and the washing rate* of purchased dresses make their lifespan decrease. Moreover, the balancing loop (B1) drains the *number of linear dresses purchased*. *The annual purchase rate of linear dress* contributes to increased *consumer transportation impact* and *production impact*. Both *disposal rate and washing rate* contribute to the *total environmental impact*, regarded as the total impact of a life cycle of a dress.

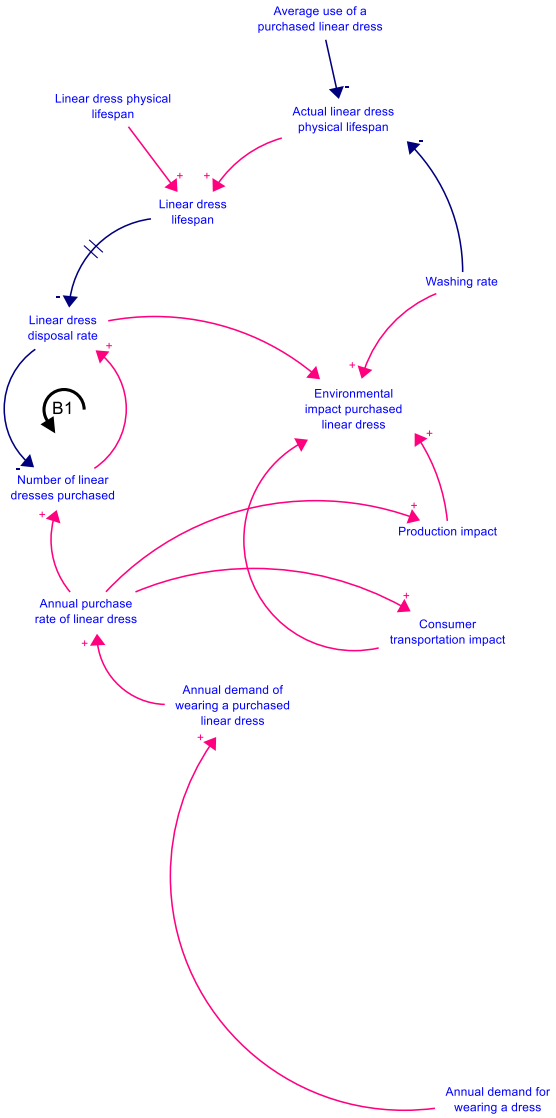

Figure 4 Dynamics of a purchasing a dress

The dynamics of a use-oriented PSS clothing solutions

Figure 5 represents the dynamics of the use-oriented PSS solutions for a dress rental. As in dress purchasing, *the increased annual demand for wearing a dress* increases the annual demand for wearing a rented dress and the *annual rented dress order rate. The order rate* and the *acquisition rate* increase *company dresses inventory*. *Rent company dresses inventory* as in linear case number of purchased dresses, are disposed of *(disposal rate)* after a certain period due to lifespan. As the *disposal rate* increases, *the acquisition rate of the rental dresses* increases, creating a reinforcing loop R1. *The inventory* is drained with a delay by the *number of dresses rented in a* specific *pay-per-use time frame*. Moreover, *the rented company disposal rate* drains the *company inventory*, resulting in the balancing loop B2.

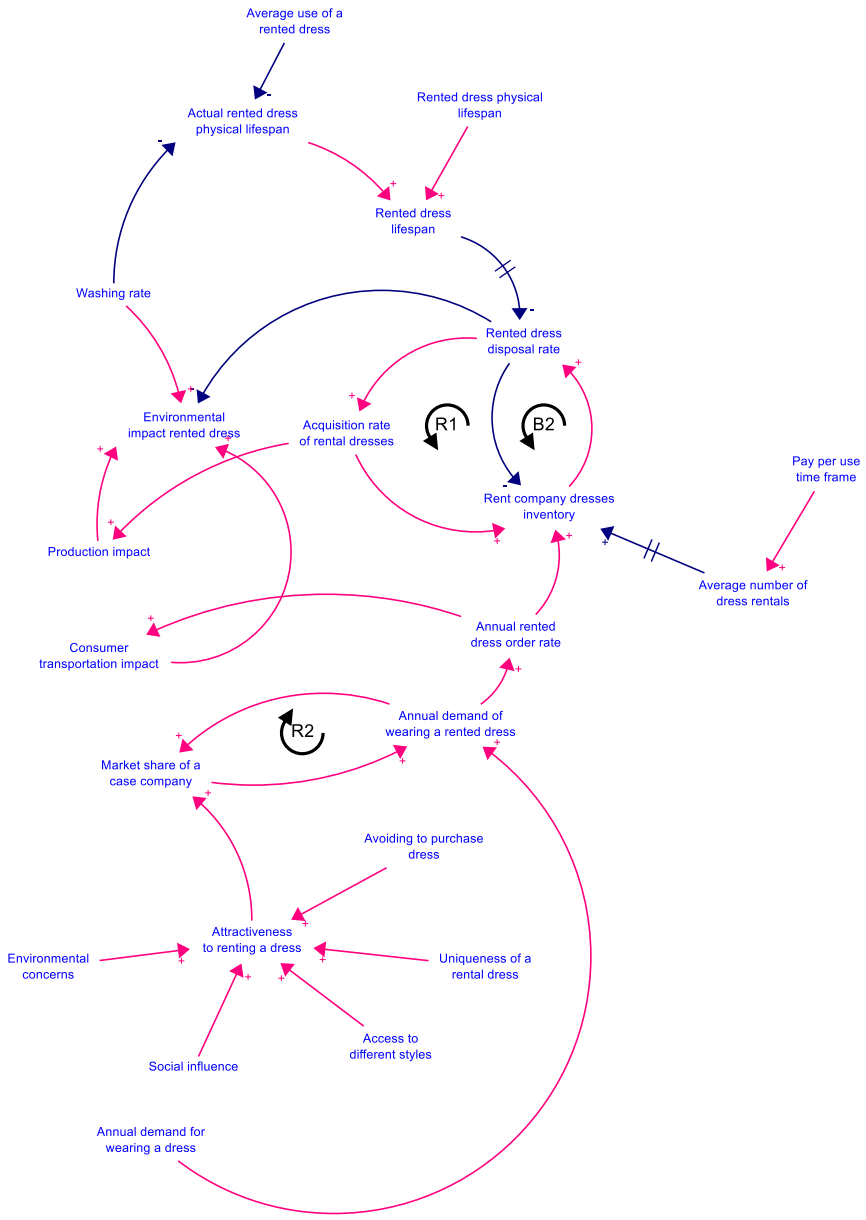

Figure 5 Dynamics of use-oriented PSS clothing solutions

Moreover, the att*ractiveness of renting the dress* rather than purchasing a dress is influenced by certain factors, such as: *avoiding to purchase the dress, uniqueness of the rental dress, access to*

different styles, environmental concerns and social influences. If attractiveness increases, *the market share of the case company* will increase. An increase in the market share of a case company will increase annual demand for wearing a rented dress, which again increases the company's market share, creating a reinforcing loop (R2). On the other hand, the increase in the company's market share will decrease the annual demand for wearing a linear dress, Figure 6.

The *production impact, the consumer transportation impact,* and the *washing rate* will lead to environmental impact. However, when comparing to the purchasing case, the *environmental impact* might be lower in the use-oriented PSS case as different consumers will use the dress and, therefore, fewer dresses are needed to meet demand; therefore, the *rental dress disposal rate* will be lower, decreasing the *environmental impact*.

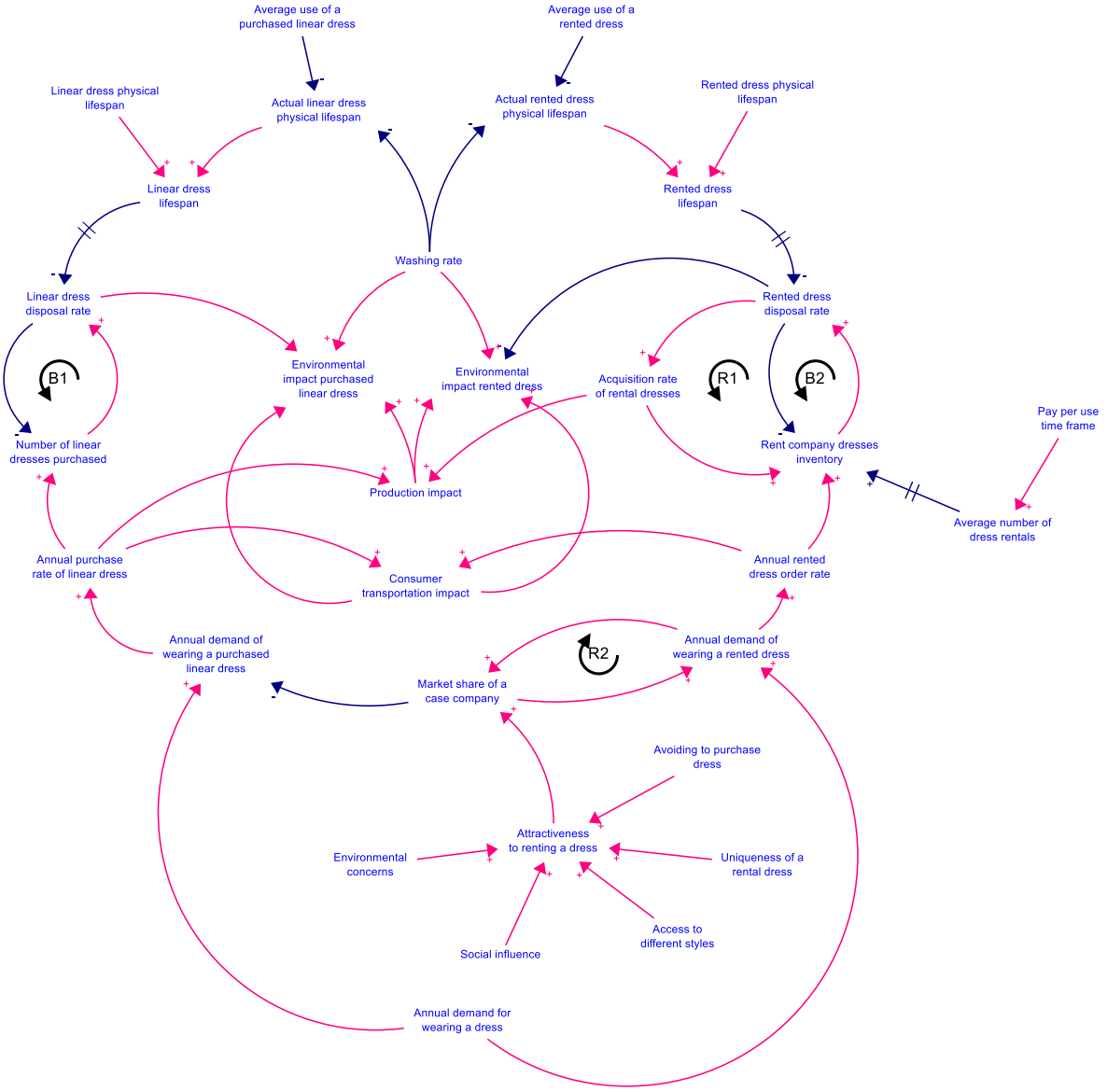

Figure 6 CLD of linear and use-oriented PSS solutions rental dress

The rebound effects of a use-oriented PSS clothing solutions

The focus of the original study is on direct and indirect, micro level mechanisms from a consumer perspective (Figure 7). Figure 8 represents the model of the direct and indirect, micro-level mechanisms identified in the case. The effects on the direct consumer-level can trigger indirect effects and mechanisms. Since the cause and effect of certain mechanisms are often a combination of similar factors, they have been grouped and analyzed according to the type of RE (direct or indirect). The expanded CLDs with RE included variables and key concepts based on the RE mechanism canvas (Metic and Pigosso, 2022 in review), as detailed in the following sections.

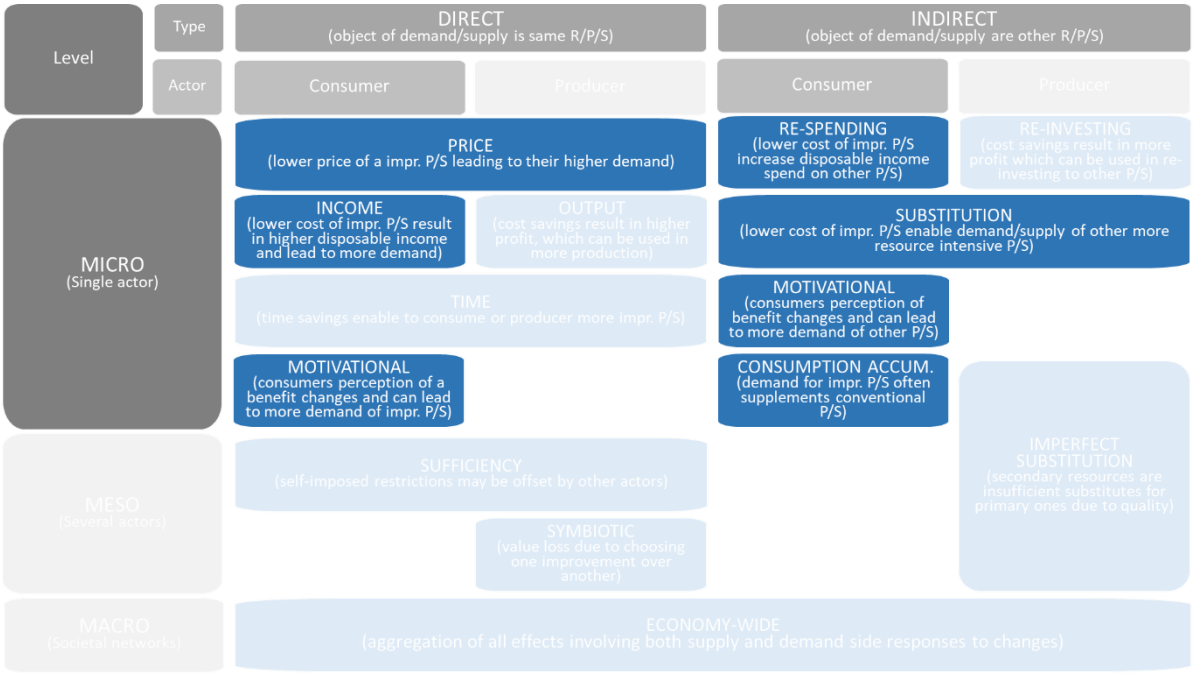

Figure 7 Mechanisms modelled and analyzed based on the case study

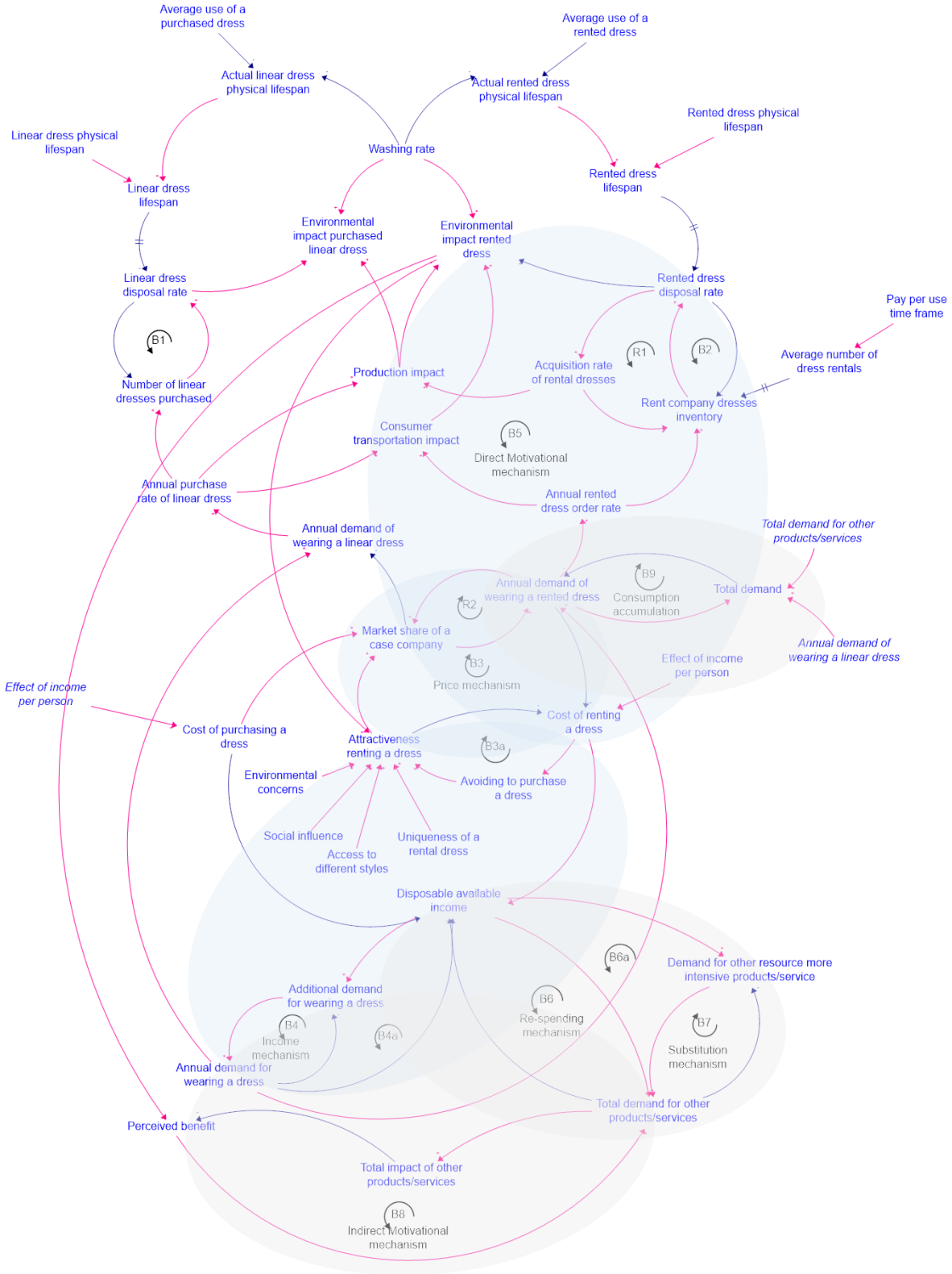

Figure 8 Complete use-oriented PSS clothing solutions CLD including RE (direct=blue, indirect=grey) and mechanisms

Direct RE: Price, Income and Motivational mechanism

Price mechanisms

Figure 9 shows when *the cost of renting a dress* is lower than a purchasing the renting option positively influences the *avoidance to purchase a dress.* Avoiding purchasing *a* dress increases the

attractiveness of renting a dress and, therefore, increases market share of the case company and the annual demand for wearing a dress. The annual demand of wearing a rented dress decreases *the cost of renting* and creates a balancing loop (B3), i.e. the price mechanism. Moreover, the attractiveness to rent a dress decreases *the cost of renting*, creating another balancing loop B3a.

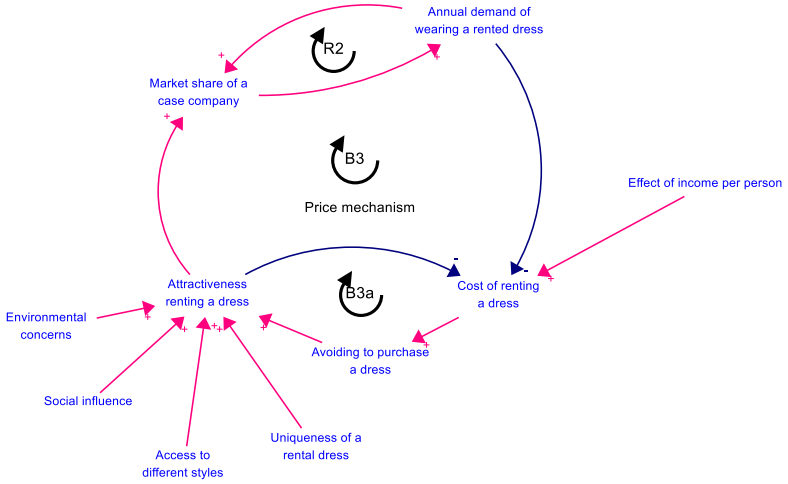

Figure 9 Price mechanism

Income mechanisms

Furthermore, the cost of renting a dress influences the *available disposable income*. If renting is a choice for a consumer and the *cost of renting a dress* is lower (due to increased demand and attractiveness), it increases *the available disposable income*. Furthermore, an increase in disposable income leads to *additional demand for wearing a dress*. Moreover, *disposable income* is limited by the *effect of income per person*. Therefore, additional demand might increase *the annual demand*, which decreases *the additional demand and disposable income*, creating balancing loops (B4 and B4a), i.e. the income mechanism (see Figure 10).

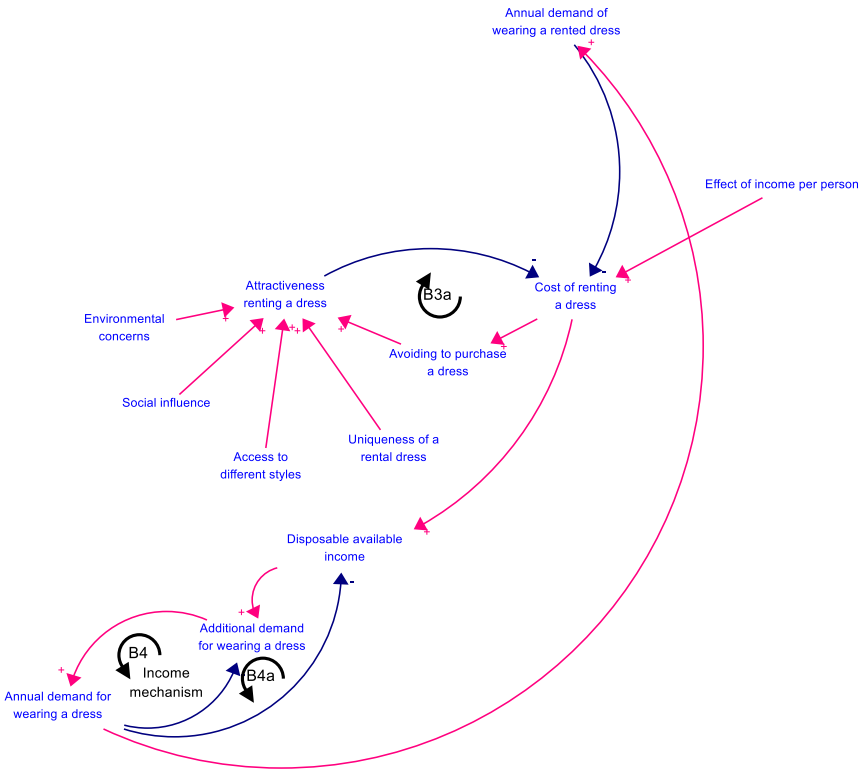

Figure 10 Income mechanism

Direct Motivational mechanism

It is not only price and income that affect consumers' decision to purchase or rent a dress. There are other psychological factors influencing consumer behaviour changes, which we refer to as motivational mechanisms. In this case, *the attractiveness of renting a dress* is motivated by different factors mentioned before; however, environmental concerns are one of the most important for the conscious consumer. *Attractiveness to renting a dress* increases the *market share of the company*. The market share of the company increases *the annual demand for wearing a rented dress*, and therefore *the annual rented dress order rate*. *The annual rented dress order rate* increases *the company dresses inventory* by being shared among various users (*the average number of dress rentals*). The company dresses inventory is disposed of (*the rented dress disposal rate*) after a certain lifespan. As stated, the *production impact,* the *consumer transportation impact* and the *washing rate* will lead to environmental impact. Compared to the linear case, the environmental impact might be smaller in the renting case as different consumers will use the dress and, therefore, fewer dresses are needed to meet demand (*lower rental dress disposal rate*). The perceived *lower environmental impact* of renting a dress than purchasing increases *the attractiveness to rent a dress*, which can lead to an increase in *demand for more often renting of a dress*, creating a balancing loop (B5) of motivational mechanism, Figure 11.

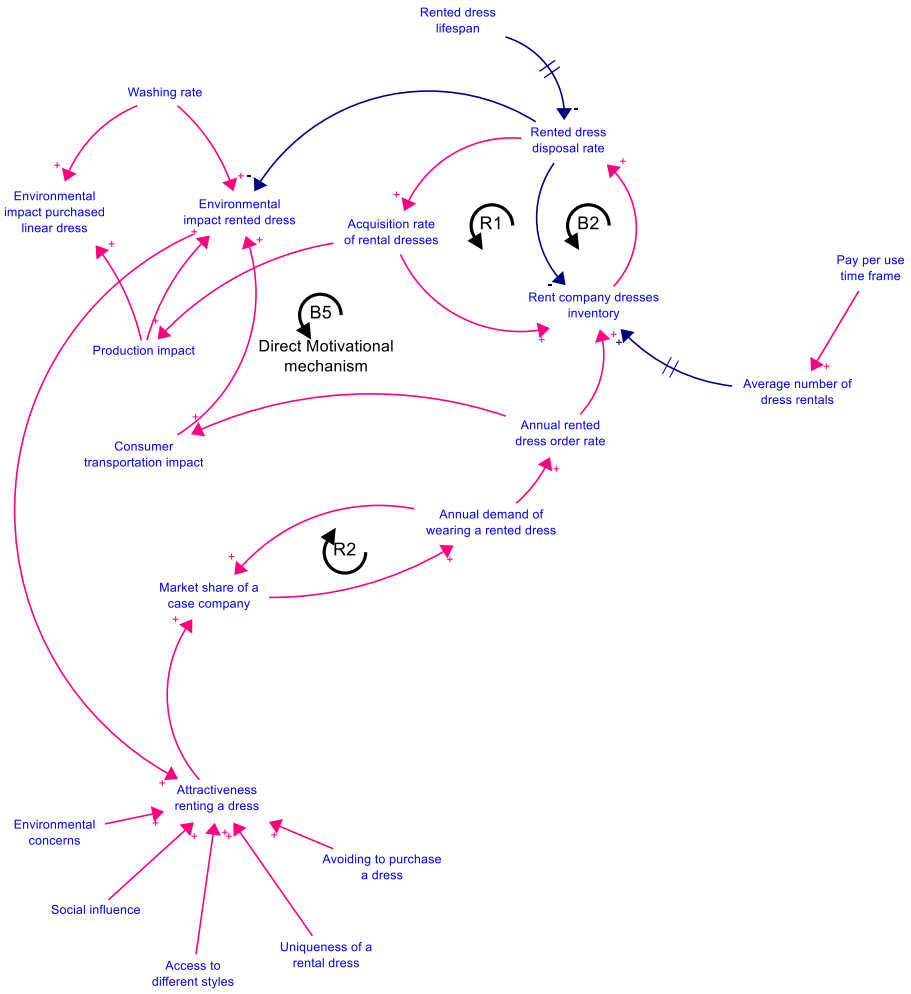

Figure 11 Direct Motivational mechanism

Indirect RE: Re-spending, Substitution, Motivational and Consumption Accumulation mechanism

Re-spending mechanism

For this scenario, if renting is a choice for a consumer and if the *cost of renting a dress* is lower (due to increased demand and attractiveness), it will increase *available disposable income*, which originates from direct effect. An increase in *disposable income* can result in *the demand for other products or services available*. An increase in *the demand for other products or services* will increase *total demand*, which drains the *available disposable income*, creating a balancing loop (B6) or re-spending mechanism, Figure 12.

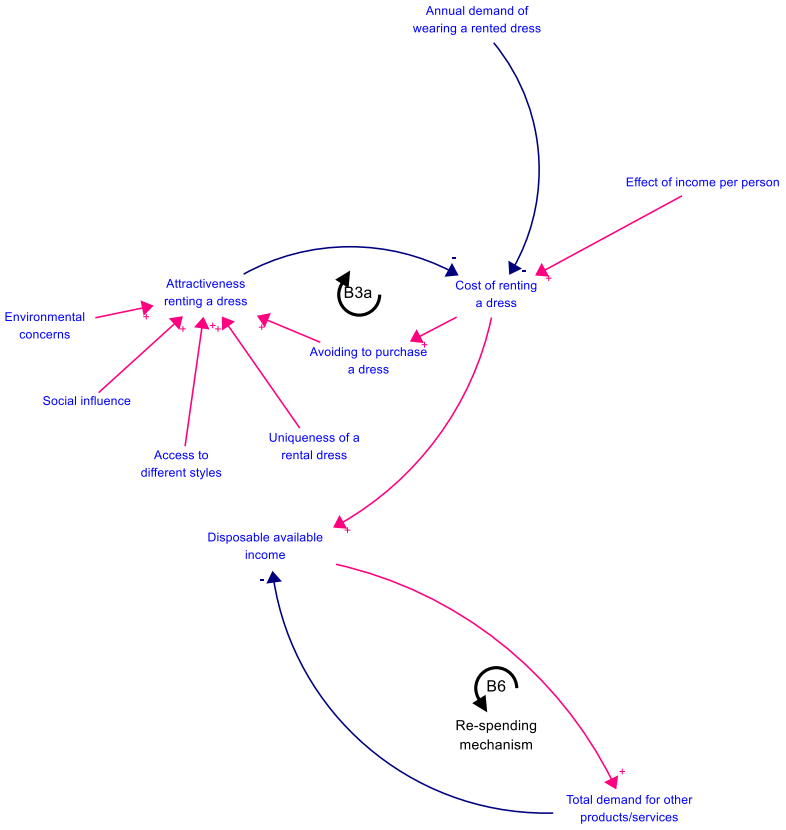

Figure 12 Re-spending mechanism

Substitution mechanism

Due to lower *costs of renting* and increased *available disposable income* can also lead to an increase in *the demand for other more resource-intensive products or services* (e.g. renting a car or travelling overseas). *The demand for other more resource-intensive products or services* increases to *total demand for other products or services,* which drains *the demand for more resource-intensive products/services,* creating another balancing loop of substitution mechanism, B7, Figure 13. Moreover, *the total demand for other products/services* drains *the available income* contributing to the re-spending mechanism, B5a.

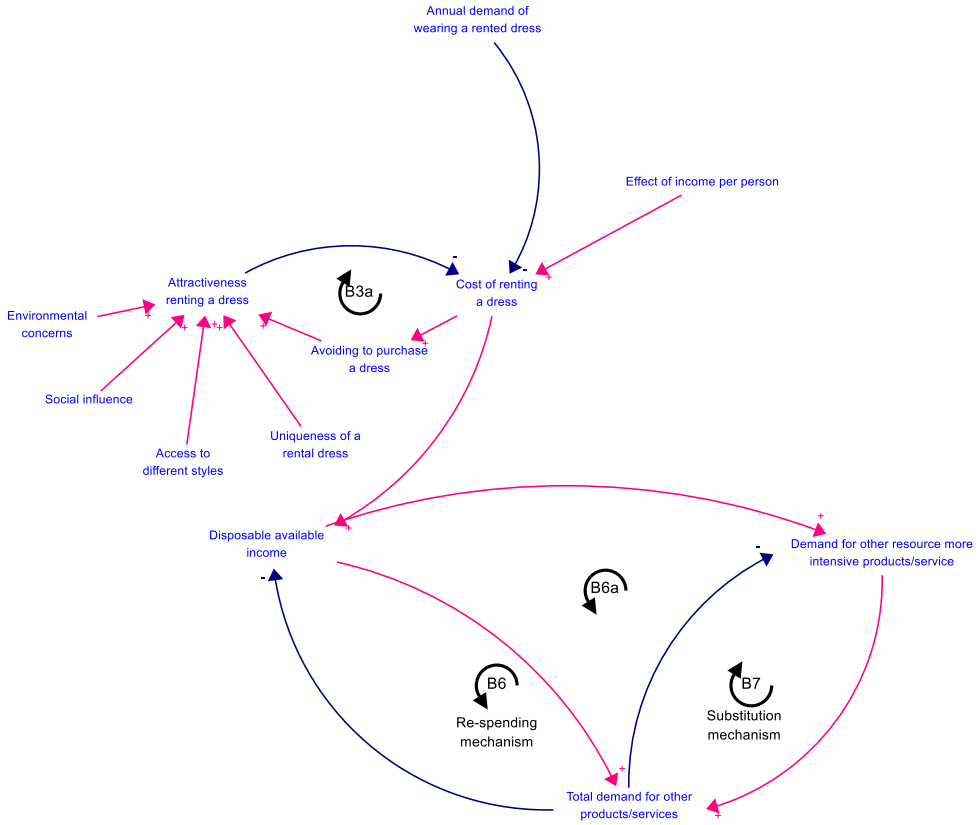

Figure 13 Substitution mechanism

Indirect motivational mechanism

The indirect motivational mechanism can be explained based on the perception that renting a dress has a lower environmental impact than the linear dress purchase (see The dynamics of a use-oriented PSS clothing solutions). The lower *environmental impact of rented dress* can increase the *perceived benefit* of doing a good thing. However, this mental accounting stimulates users to consume other products or services (e.g. buying plant-based food or simply eating more out), which will increase *the total impact* and therefore decrease *the perceived benefit*. This is creating a balancing loop, Figure 14, of indirect motivational mechanism, B8.

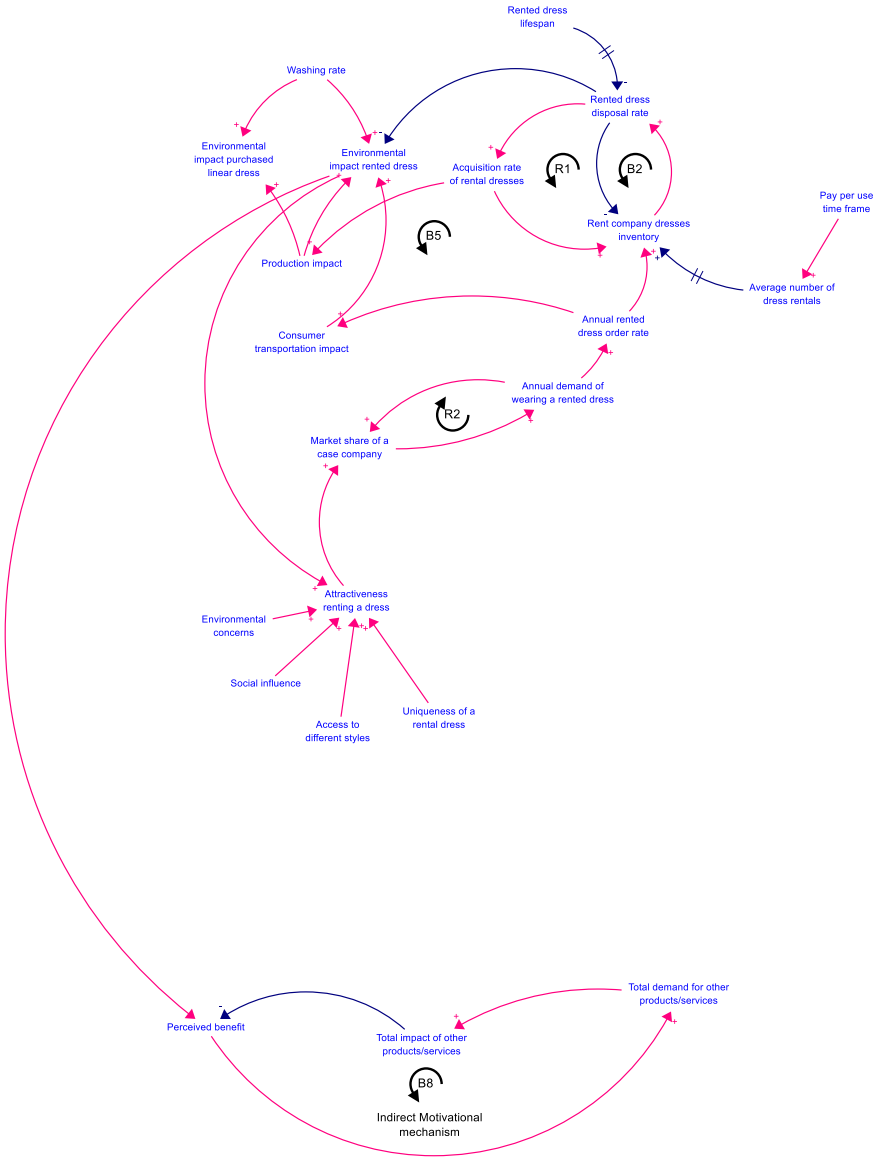

Figure 14 Indirect Motivational mechanism

Consumption accumulation

Furthermore, services such as renting clothes often do not fully satisfy the consumers' needs but lead to an increase in their total demand (the basic clothes such as white t-shirt, will probably not be substituted by renting). Meaning renting (*the annual demand of wearing a rented dress*) often does not replace but instead supplements or increases *total demand* with linear dress demand and demand for other products and services. *The annual demand of wearing a rented dress* drains the *total demand*, creating a balancing loop B9 or consumption accumulation mechanism, Figure 15.

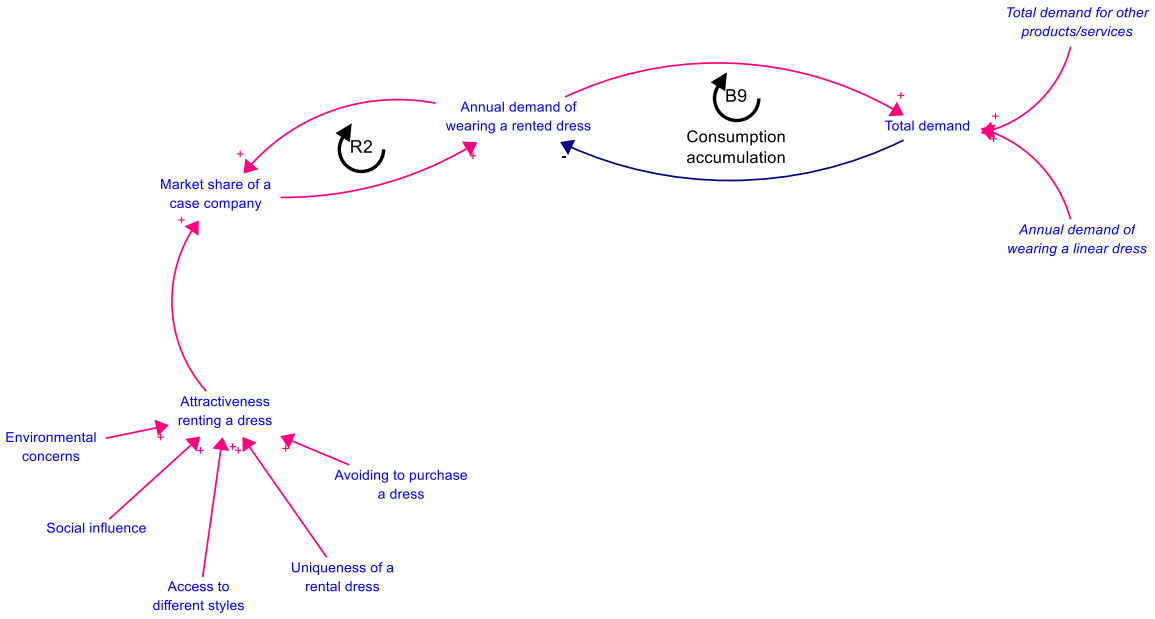

Figure 15 Consumption accumulation

Discussion

This chapter provides a short discussion of the key findings of this research, structured around the aformentioned research questions. We argue that proper dynamic analysis and early identification of causes and effects due to implementation of use-oriented clothing PSS solutions is essential for early identification and mitigation of RE.

1. **How does use-oriented PSS clothing solution influence system behaviour?**

The PSS implementation evidently can lead to a promotion or enable easier access to a higher level of consumption of rental clothes. It can be due to lower cost and, therefore, positive disposal income without ownership obligation. Moreover, implementing the use-oriented PSS solution changes the consumer's perceived benefit. The analysis shows that the consumer can use that perception of doing good as a reason for more consumption of the same service or as an excuse to demand/consume other products and services.

2. **What are the potential RE mechanisms triggered by use-oriented PSS clothing solutions?**

The expansion of the original study model to account for mechanisms leading to RE due to use-oriented clothing PSS solutions implementation has led to the identification of factor that can result in a possibly higher environmental impact when compared to the original study. The potential direct mechanisms identified are price or cost, income, and motivational mechanisms. Price mechanism can be regarded separately in the system and lead to a rebound, as lower cost of renting than purchasing can increase demand. The Price mechanism leads to an Income mechanism due to savings, e.g., the consumer might have more disposable income to spend on additional demand for a dress. Furthermore, the Motivational mechanism can influence the perceived benefit of renting clothes to be more valuable than it is; consumers may use that to decide to consume more of the renting service. The main determinants regarded here are cost savings, available income and attractiveness to rent due to perceived benefit.

The indirect mechanisms identified are Re-spending, Substitution, Motivational and Consumption accumulation. The Re-spending and Substitution mechanism is connected to the direct Price and Income mechanism. Due to lower costs and increased disposable income, consumers may decide to spend it on other products/services or even resource more intensive products/services. The Indirect Motivational mechanism, similar to the direct type, influences the perceived benefit of renting clothes to be more valuable than it is why consumers can also not feel culpable consuming other products or services. Consumption accumulation refers to the scenario where the actual demand for renting the dress does not entirely substitute the purchase of a linear dress or other garments. Consumers probably rent in addition to the demand for conventional products/services. In this case, the primary detriments of the indirect mechanisms begin with direct cause and effect.

3. **How to avoid potential RE in use-oriented PSS solutions?**

Concerns on how to lower the relative impact of use-oriented PSS solutions are growing, specificaly by identified outcomes of the PSS implementation such as (i) high production impact of linear dress (ii) lifespan expansion (iii) multiple wears of rental dress per user (iv) minimizing transportation impact. However, by observing the CLD, these areas could be better addressed by first focusing on the areas or mechanisms leading to increased demand for renting service, by portraying the more explicit benefit/constraints of the use-oriented PSS solutions BMs from the side of companies to potentially change the consumption patterns (often the goal is an economic benefit for the

company). In a system, where relationships drive the outcomes, without understanding the them or the system structure as represented in CLD, we cannot change the outcomes in long term manner. Identifying potential mechanisms is essential for understanding the RE due to PSS implementation in order to enhance the knowledge of potential risks and enable companies and policies to address them better.

Conclusion and Further Research

This study focused on addressing the current gap in research of CBMs and use-oriented PSS solutions on a clothing rental case. Research until today has contributed greatly to address the environmental impact of the use-oriented PSS solutions without accounting for possible RE and its mechanism. Therefore, this study adds a systemic perspective to identify potential REs and detail the mechanisms triggered by the clothing rental implementation on the micro-level. Further, to expand the scope of research on all direct and indirect mechanisms identified in RE canvas (Metic and Pigosso, 2022 in review).

The expansion of the original study (focused on the environmental implications of use-oriented PSS clothing solutions) to include key variables lead to the identification of various other RE mechanisms that can increase the demand of (i) renting more dresses (direct), and (ii) other products or service (indirect). An increase in demand possibly increases the overall total impact, which has not been acknowledged or accounted for in the original study. The use of CLD to snapshot each mechanism or relationship enabled the identification of processes through which different variables interact to generate possible problems. This paper is stepping-stone towards the development of an approach that can support the early identification and further mitigation of RE. The approach is based on the use of system thinking to analyze the dynamic feedbacks causality when implementing clothing use-oriented PSS solutions and therefore possible RE

The identification of potential mechanisms is essential for understanding the underlying effects and causes of RE, addressing the systemic and consumer behaviour. Transitioning towards more CBMs will require the inclusion of economic and motivational factors to change that behaviour. The identification of the appropriate triggers and drivers using system thinking highlights the importance of a need for interdisciplinary research in order to investigate and mitigate mechanisms leading to unintended consequences.

This study has several limitations. First, the focus on only one published case study limits the generalization of the analysis. Second, the micro-level perspective for the system disregards economy-wide and meso level effects. Third, there is space to include other factors such as space-saving due could be another incentive to rent more, creating another mechanism for increased demand. Fourth, the study assumed individuals to be consumers of both linear and use-oriented PSS solutions. However, in reality, not everyone will be willing to rent. Fifth, only one type of BMs is considered, pay-per-use. Finally, even though the study survey showed most consumers would not increase their consumption if the company offered unlimited swaps, our analyses show that there might be a possibility for increased consumption due to other factors influencing attractiveness to rent. We argue that 100% RR is unlikely, especially in formal dresses.

The next research steps would include data collection, estimation and assumptions of certain variables to develop a stock and flow model based on the CLDs presented to quantify the magnitude of the RE and its mechanisms. The quantitative analysis would help prioritise key areas to mitigate RE that could lead to the higher overall impact.

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