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Doctoral Thesis

The Environmental Attribute of Manufacturing strategy
An Evolutionary Institutional Approach

G. Papachristos

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ΠΡΑΚΤΙΚΟ ΣΥΝΕΔΡΙΑΣΗΣ

Επταμελούς Εξεταστικής Επιτροπής για την κρίση της διδακτορικής διατριβής του κ. ΓΕΩΡΓΙΟΥ ΠΑΠΑΧΡΗΣΤΟΥ

Η Τριμελής Συμβουλευτική Επιτροπή, αποτελούμενη από τους κ.κ. Εμμανουήλ Αδαμίδη, Αναπλ. Καθηγητή του Τμ. Μηχανολόγων & Αεροναυπηγών Μηχανικών του Πανεπιστημίου Πατρών (επιβλέποντα), Νικόλαο Καρακαπιλίδη Καθηγητή του Τμ. Μηχανολόγων & Αεροναυπηγών Μηχανικών του Πανεπιστημίου Πατρών, και Πάτροκλο Γεωργιάδη, Αναπλ. Καθηγητή του Τμήματος Μηχανολόγων Μηχανικών του Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης, συμπληρώθηκε σε Επταμελή Εξεταστική Επιτροπή με τους κ.κ. Γεώργιο Χρυσολούρη, Καθηγητή του Τμ. Μηχανολόγων & Αεροναυπηγών Μηχανικών του Πανεπιστημίου Πατρών, Ιωάννη Γιαννίκο, Αναπλ. Καθηγητή του Τμήματος Διοίκησης Επιχειρήσεων του Πανεπιστημίου Πατρών, Σταύρο Γούτσο, Επικ. Καθηγητή του Τμ. Μηχανολόγων & Αεροναυπηγών Μηχανικών του Πανεπιστημίου Πατρών και Γεώργιο Σταμπουλή, Λέκτορα του Τμήματος Οικονομικών Επιστημών του Πανεπιστημίου Θεσσαλίας σύμφωνα με την υπ' αριθμ. 2/16.10.2012 συνεδρίαση της Γενικής Συνέλευσης με την Ειδική Σύνθεση του Τμήματος Μηχανολόγων & Αεροναυπηγών Μηχανικών του Πανεπιστημίου Πατρών.

Η Εξεταστική Επιτροπή συνήλθε σήμερα **14 Νοεμβρίου 2012** και ώρα **14:00** σε συνεδρίαση κατά την οποία η διατριβή με τίτλο «*Η περιβαλλοντική παράμετρος της στρατηγικής παραγωγής: Μια θεσμο-εξελικτική προσέγγιση*» υποστηρίχθηκε από τον υποψήφιο διδάκτορα κ. Γεώργιο Παπαχρήστο. Στην συνέχεια υπεβλήθησαν ερωτήσεις στον υποψήφιο και ολοκληρώθηκε η εξέταση.

Μετά την αποχώρηση του υποψηφίου και των ακροατών, η επιτροπή συζήτησε επί της γενόμενης εξέτασης και αποφάσισε ομόφωνα να κάνει δεκτή την διατριβή, επειδή αυτή είναι πρωτότυπη και αποτελεί ουσιαστική συμβολή στην επιστήμη, ο δε υποψήφιος την υπερασπίστηκε με άκρως ικανοποιητικό τρόπο και τον βαθμολόγησαν με βαθμό ..Άριστα...

Η Επταμελής Εξεταστική Επιτροπή:

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"The dogmas of the quiet past are inadequate to the stormy present, the occasion is piled high with difficulty and we must rise with the occasion. As our case is new so we must think anew and act anew. We must disenthrall ourselves and then we shall save our country."

Abraham Lincoln
2nd Annual Meeting of Congress December 1862

*"Do not seek to follow in the footsteps of the wise.
Seek what they sought."*

Matsuo Basho 1644 – 1694

"If you improve it, please let us all know."

J.D.Sterman 23/5/2011 (personal communication)

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This thesis is a piece of work that carries reflections of personal traits and competencies formed in interaction with people in more than a decade.

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Abstract

This thesis analyses competition and competition in supply chains. It focuses on the case of coopetition between an Original Equipment Manufacturer (OEM) and retailers, that collaborate in the forward supply chain and compete in the reverse. The thesis concentrates on the strategic options available to OEM in order to keep the remanufacturing operations of the retailer from eroding its market share. It analyses the impact that OEM strategic responses have on the environmental impact of the entire supply chain and each actor independently.

The main contribution is in demonstrating the inherent trade offs in such a supply chain context. In attempting to abate competition, the OEM has a range of options available. It faces a stale mate: it can neither defend completely against competition, not improve substantially the environmental performance of the supply chain.

Methodologically the analysis is based on the Resource Based View of theory competition, sociotechnical systems theory, system dynamics modelling and simulation methodology, and organizational complexity theory.

Initially the supply chain is analysed through modelling and simulation at the micro level of the OEM and the retailer. In light of the trade offs inherent in the configuration of the supply chain, the case for the difficulty of endogenous change towards an configuration with an enhanced environmental performance is build based on organizational complexity, and manufacturing theory. Consequently, the problem of change is analysed at the level of sociotechnical systems theory, where the supply chain is viewed as part of the overall industrial production system. Drawing on this, propositions about system intervention are established. Their implications in terms of the environmental performance of the supply chain are tested at the micro level by modifying appropriately the model. The results show that a different supply chain configuration of increased environmental performance is possible.

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Chapter 1 Introduction

1.1 Research Question & Methodology

Climate change and environmental degradation are more than just an interesting research topic. Their effects are manifest, in the natural and the social world, at the individual and the collective level. They have been researched in scientific forums, made headlines in newspapers and received a lot of attention in the public debate. Climate change is occurring and it has been convincingly linked to anthropogenic activities (IPCC, 2007). This has brought a shift in our perception about the impact of human activities. It has placed a responsibility on humans both at an individual and a collective level. For businesses, in particular, environmental management is becoming a significant strategic parameter that goes beyond publishing annual carbon footprint accounts and actions under Corporate Social Responsibility programs or even promotional activity intended to stir eco-consumerism.

Firms, particularly those operating in the manufacturing sector, through their manufacturing activities, resource management and use, have an impact on other firms, on their supply chains, and on the natural environment and human welfare. This impact can be considered at two scales using different approaches (Figure 1.1):

i. At the micro level of the individual firm and its supply chain by using an operations strategy perspective to analyse the way that firm resources and capabilities are deployed to achieve business objectives and maintain competitive advantage (Slack & Lewis, 2002).
ii. At the macro level of the prevailing paradigm of the industrial system by using sociotechnical transition approaches in order to contextualise the assumptions under which firm operations strategy is formed (Geels, and Schot, 2007).

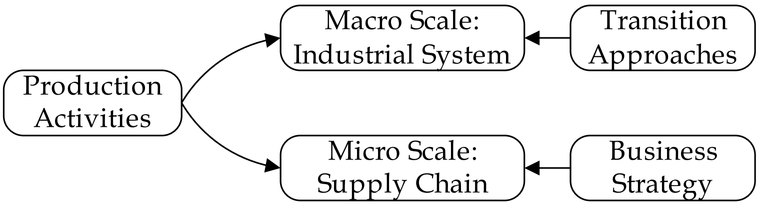

Figure 1.1: Considering manufacturing activities at two levels

At the micro level, the introduction of environmental attributes and initiatives in business strategy such as recycling and remanufacturing, have been proposed as a possible solution to mitigate a firm's impact and increase its competitiveness (Hart, 1995). Such activities assume various forms in supply chains, including the development of internal supply chain competition. This is an issue of concern for Original Equipment Manufacturers (OEM) since such activities can enhance their environmental performance and reputation, but can also present a business opportunity for third parties or supply chain partners (retailers, distributors). In the first instance they represent an opportunity for competitive advantage, while in the second a competitive threat. In either case, the short and long term implications of the OEM's strategic response should be assessed. This response involves incorporating environmental requirements, conformance goals and/or challenges for innovative strategic action, in the following two ways:

i. As constraints, or widening characteristics of the general objectives of performance (cost, flexibility, quality, speed, reliability in delivery with an environmental parameter).
ii. As a distinct performance goal (cost, flexibility, quality, speed, reliability in delivery and environment), which carries certain interdependencies with other goals.

Research so far has focused in introducing environmental parameters in well known and researched manufacturing strategy frameworks, in which the firm's operations system is relatively stable and aims on environmental improvements (Seuring, and Muller, 2008b). Strategy is concerned with the link of the organization's specific capabilities to its wider institutional environment at the macro scale, which in turn imposes a certain set of assumptions on the firm's operations. Inevitably, there are limits to what a single firm can accomplish through its strategies under a given institutional setting i.e. the underlying, resilient, normative, regulative and cognitive aspects of social structure and the processes by which they become established as pillars of social behaviour (Scott, 2008). In the existing institutional environment this can be problematic, since achieving good competitive and environmental performance simultaneously may not be attainable under any available operations strategy.

This is what this thesis is attempting to investigate: (i) the current institutional environment where OEMs are faced with internal supply chain remanufacturing competition, and both competitive (business) and environmental strategic objectives are difficult to achieve simultaneously and (ii) a different institutional environment, where among other changes, products are substituted by services and collaboration in supply chain prevails over competition, provides a more supportive setting for remanufacturing. For remanufacturing companies this represents a shift in the assumptions of the prevailing production paradigm, under which firm operations strategy is formed.

Since it is difficult for a single firm to muster the capacity or market power to unilaterally bring about these changes to its broader institutional environment, it cannot change its underlying assumptions either. Conversely, it is not possible to sustain operations that follow a logic against the prevailing wisdom of the institutional environment, unless it changes and facilitates a favorable market response. Therefore, a shift to a macro scale perspective is required to view the OEM supply chain operation strategy in relation to the wider network of interactions in which it is embedded. This shift includes institutional, regulative, market, science and technology actors. Put succinctly, there are social and technical elements to a supply chain that are indispensable to its operation.

It follows that the step from the micro scale firm centric changes to the macro scale institutional changes, requires a corresponding shift of focus from the OEM firm to the sociotechnical industrial production system. This change in perspective, consists in taking into account all of the relevant actors implicated in industrial production, the institutional environment and the consumers – users. It thus involves considering broader system boundaries and different temporal and organizational scales. At the macro level of analysis, the focus shifts from pollution prevention strategies to sustainability (Figure 1.2). There is a certain link between the levels of scale. If there is no significant progress on the pollution-prevention front it is difficult, if not impossible, to successfully adopt a product-stewardship strategy i.e. take steps to monitor and minimize the environmental impact of the product over its life cycle. If a firm attempts to differentiate its products as "green" or promote an environmentally responsible image while continuing to produce high levels of production waste and emissions, it runs the risk of stakeholders (e.g. regulators, environmental groups) exposing this inconsistency, thereby destroying the firm's credibility, reputation and hurting the legitimacy of this strategy for other firms. Conversely, the overall direction of the industrial production system towards sustainability has to be supported by strategies at the micro level of pollution prevention and product stewardship. Sustainability is a long term vision that materialises through short term actions (WCED, 1987).

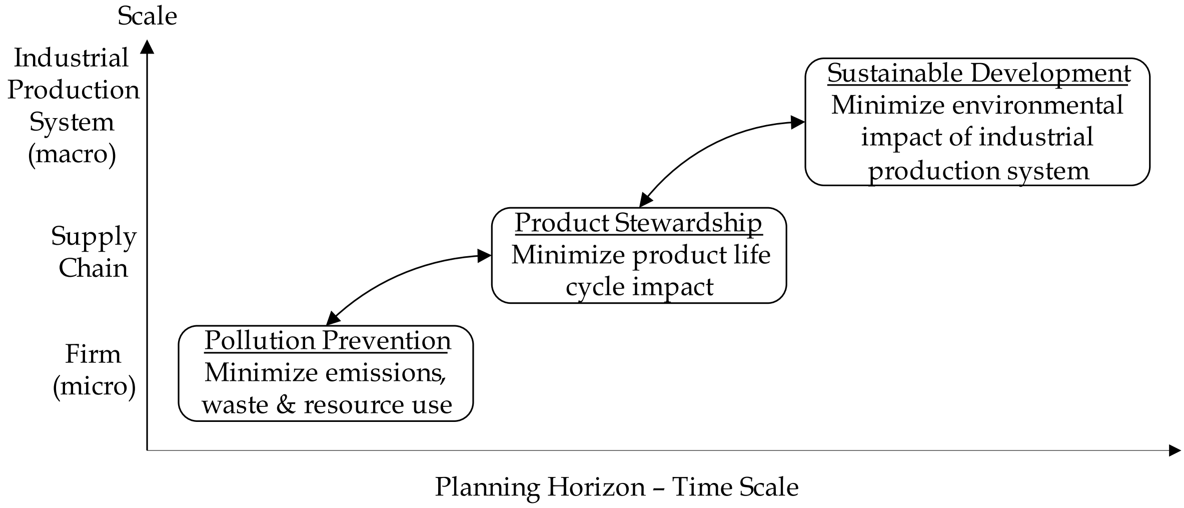

Figure 1.2: Firm strategies, time & organizational scales

Hence, it becomes obvious that changes at the industrial production system paradigm (macro scale) are required in order to facilitate changes in firm business strategy and vice versa. One is not feasible without the other. In this thesis, this kind of change is conceptualised using sociotechnical system transition theory (Geels, 2004) as a system transition from state 1 (S_1) to state 2 (S_2) (Figure 1.3). Consequently, this thesis sets and explores the following hypothesis:

In certain industries, when there is internal supply chain competition, remanufacturing as a competitive and environmental strategy can be effective only in an institutional setting that diverges from the current one, i.e. in a sociotechnical system with users of services rather than consumers of products, where remanufacturers are considered as service providers rather than producers.

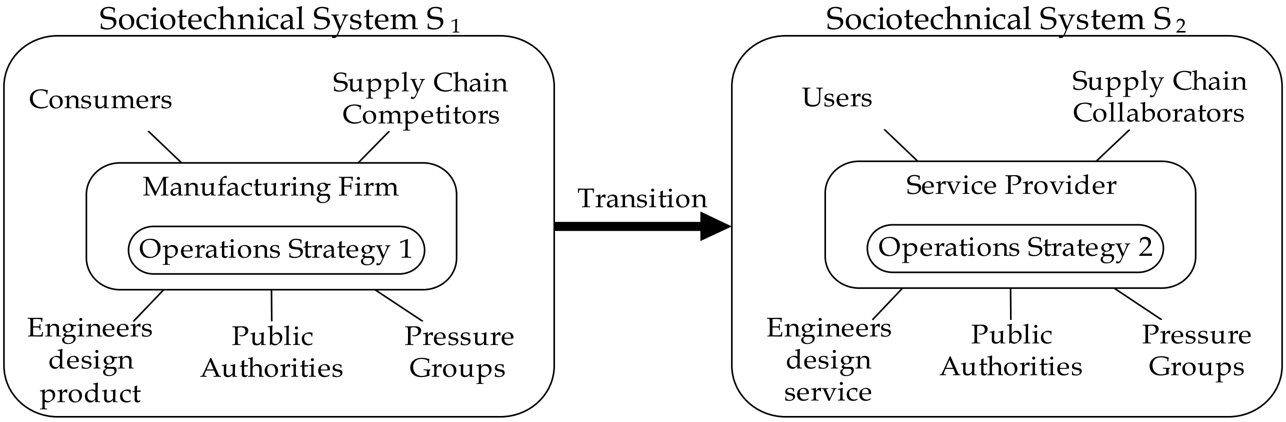

Figure 1.3: Change at the macro level – industrial production system transformation

In order to explore this hypothesis, the Resource Based View of competition (RBV) is adopted to analyse the problem at the micro level (Wernerfelt, 1984). A system dynamics simulation model of a remanufacturing supply chain is developed, that involves an Original Equipment Manufacturer (OEM), and a retailer that remanufactures used products. The model represents a setting where the OEM and the retailers cooperate in the forward supply channel and compete in the reverse. It is shown that under this modus operandi the OEM is faced with choices that can improve its competitiveness vis a vis the downstream remanufacturer and partner, or can improve the environmental performance of the supply chain at the expense of its own market share and thus its long term prospects. Additional model assumptions are used to represent the current state (S_1) of the sociotechnical system i.e. the institutional environment and consumer behaviour where the supply chain is embedded. For example, there is competition in the flow of collected used products in reverse supply chain flow and consumer market is segmented in branded and non branded (remanufactured) products.

A number of simulation scenarios are developed to explore the effect of different operations strategies under the assumptions of S_1 and answer the following questions:

i. How can the OEM respond to retailers in the supply chain that seize the business opportunity and engage in remanufacturing in the reverse channel of the supply chain? How effective these responses can be in improving the competitive position of the OEM against the retailer – remanufacturer, or the environmental performance of the supply chain?
ii. Is it possible for the OEM, under the prevailing manufacturing paradigm, to have the best of both worlds, i.e. respond successfully to the retailer – remanufacturer and simultaneously improve the environmental performance of the supply chain?
iii. Are there alternative supply chain configurations towards which the OEM and the retailer can aim at, that exhibit superior overall performance? If so, what are the issues implicated in such a shift and how can it be facilitated?

The answers to these questions demonstrate that the set of the OEM's operations strategies with regard to increasing its environmental performance is insufficient. The simulation results indicate that there are inherent tradeoffs in the operation of the supply chain under the institutional assumptions of state S_1. The OEM can operate successfully in a highly competitive way with high environmental impact, or it can operate uncompetitively with low environmental impact.

Since the OEM is not in a position to alter the institutional context in which it forms its operations strategies, it will remain locked-in into its current competitive position. Hence it will implement strategies in order to defend its competitive advantage and market share. This way though, the possibility of improving the environmental performance of the entire supply chain is foregone. Due to the complexity of simultaneously addressing competitive and environmental goals, it is unlikely that modifications to its operations strategy will make a substantial difference. This observation is supported with relevant research work from the exploration – exploitation literature (March, 1991), organizational theory (Levinthal, 1997) and operations and manufacturing literature (Kumar and Putnam, 2008; Subramoniam et al., 2010).

Therefore, it seems that changes at the macro scale of the industrial production system (IPS in Figure 1.4) are required to achieve simultaneously good competitive and environmental performance and resolve this stale mate. These can create windows of opportunity for the OEM (and potential remanufacturers), in effect allowing the occupation of a new competitive position where remanufacturing (and recycling) constitutes an essential part of supply chain operations and competence of its competitive advantage.

In the sociotechnical transition framework of the Dutch school (Geels and Schot, 2007), the emergence of remanufacturing (RMFG in Figure 1.4) can be conceptualised as a niche of OEMs that engage in such activities under the industrial production system in S_1. The emergence of this niche is a stepping stone towards shifting the entire industrial production system to a more sustainable state. This will include "end of pipe solutions" and environmental regulation just as in the current paradigm, but it will also involve remanufacturing and recycling (RMFG) operations as an integral part of the prevailing industrial production paradigm. Drawing on sociotechnical transition framework to technology evolution and in particular the Multi Level Perspective (MLP), a further development of the niche requires a simultaneous change at the macro – system level from S_1 to S_2. This change of assumptions at this scale, is conceptualised as a system transition from S_1 to S_2. The new transformed system will be in a better position to respond to the landscape pressures of population, affluence and consumption that have an impact on the natural environment.

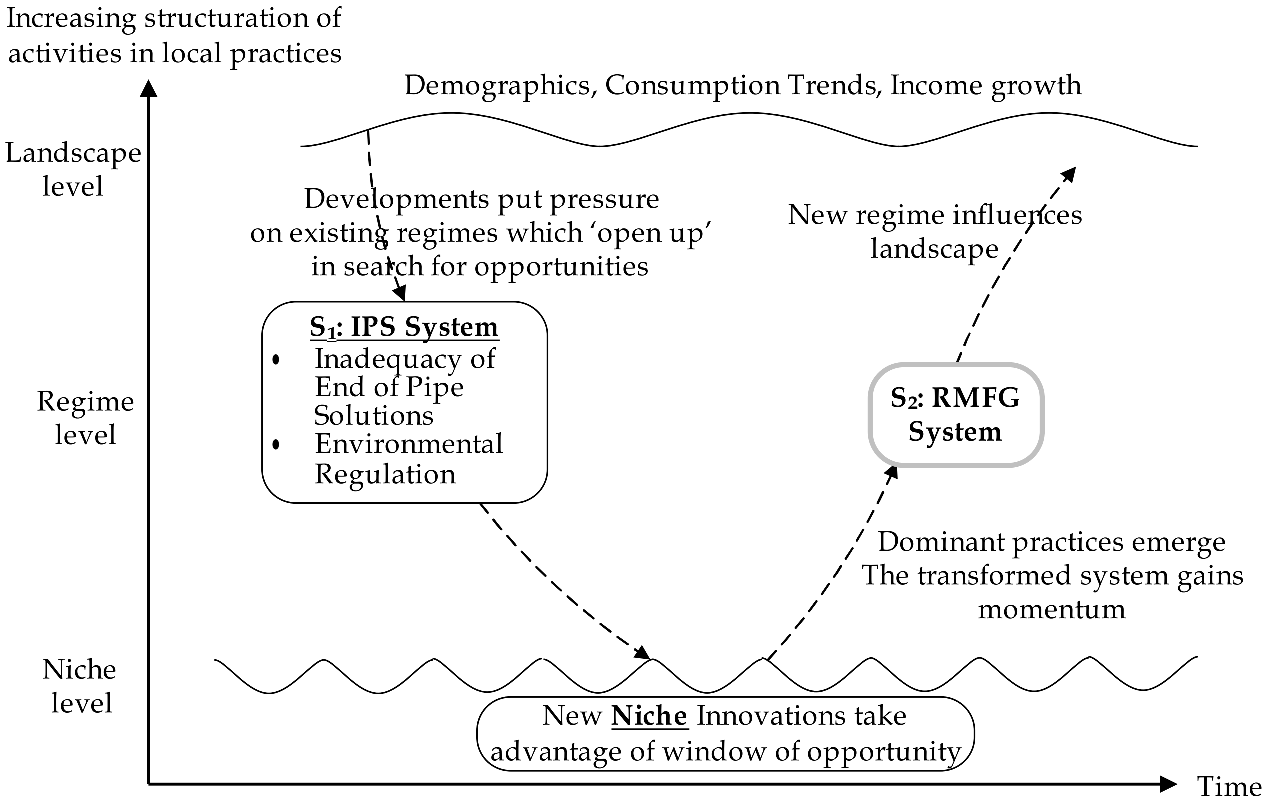

Figure 1.4: Industrial production system transition

Based on this perspective, the simulation model assumptions are modified to represent the altered system state (S_2), i.e. a different institutional environment or sociotechnical system state. Drawing on the complexity and operations literature, two assumptions are made about this new system state:

i. Regulation will be in place in order to reduce complexity and allow supply chain actors to innovate, and share the responsibility and gains. This entails sharing the reverse flows of used products as well the internalised environmental costs. The reduction in complexity is also required to allow these practices to be imitated and diffuse promptly. A reduction in complexity also entails that competitive 3rd party remanufacturing is prevented, and that the OEM is allowed to choose partners for its reverse supply chain operations.

ii. Knowledge external to the industrial production regime is utilised which facilitates the development and use of new practices and products on the supply side, and new consumption patterns on the user side. Third party intervention is required in order to facilitate this transfer and use of new knowledge in products design for ease of reuse and remanufacture and educating – influencing consumers to change their product preferences and their behaviour towards returning used products.

Simulation results of the model under the assumptions of state S_2, show improved environmental performance of the supply chain with significant change in profitability.

1.2 Thesis Structure

This thesis consists of five chapters in total. In particular, chapter 2 presents an overview of the current state of industrial production system, chapters 3 and 4 provide a simulation analysis of the research questions at the micro and macro level, and chapters 5 discusses the results and draws conclusions:

Chapter 1. Sets the broad context of the thesis, the issues, methodologies and aims of it as well as the contribution.

Chapter 2. Presents an overview of the current state of the industrial production system, its current state of operations, the factors that contribute to its environmental impact and inevitably stress the need for changing it. It sets the context for the analysis of the problem, and makes the case for studying the problem at two levels, the micro of the supply chain and the macro of the manufacturing system as a whole.

Chapter 3. Applies system dynamics modelling to the analysis of competitive/coopetitive supply chain dynamics when the retailer undertakes remanufacturing operations and the OEM recycles. The implications of the results are discussed in terms of the strategies that are available to supply chain actors in the current institutional environment, their impact on competitiveness and the environmental impact of the supply chain operations.

Chapter 4. Draws on the results of the analysis and argues on the difficulties of changing the modus operandi of the supply chain endogenously. Two assumptions are made about the changes at the macro scale that can help the OEM to overcome the state of lock in. The model of the supply chain in chapter 3 is modified appropriately in order to reflect the change in the institutional environment and test how this altered set of assumptions performs. A comparison of the performance of the supply chain under the two states, was conducted. The environmental performance of the supply chain in the second state is superior under all the scenarios tested.

Chapter 5. Provides answers to the research questions set in a succinct form. It draws conclusions and outlines possible interesting extensions to the work presented in this thesis.

1.3 Contribution

The contribution of the thesis lies in the analysis of closed supply chain issues and their analysis at two levels. Specifically:

i. It utilises system dynamics methodology and the resource based view of competition in order to address competition and environmental issues in reverse supply chains.
ii. It presents and analyses a case of industrial equipment production.
iii. It considers remanufacturing and recycling operations under a broader sociotechnical perspective utilising the Multi Level Perspective (Geels, 2004; Geels and Schot, 2007).
iv. It approaches sustainability issues on two scales: (i) at the micro scale of supply chain operations strategy and (ii) the macro scale of sociotechnical systems transitions.

Analytically, with reference to point i and ii, in order to investigate how business strategies are linked to, and are influenced by system transitions, a close look is taken at the micro scale with a case of an industrial equipment closed supply chain. Adopting the resource based view of competition, a simulation based analysis is conducted on the competitive and environmental effects of operations strategies of Original Equipment Manufacturers (OEM) and semi-independent actors which simultaneously cooperate as retailers and compete as remanufacturers in different market segments of a closed-loop supply chain.

The results of simulation experiments show that in the long run, the OEM operation strategies cannot eliminate completely the advantage gained by the retailer that acts as a remanufacturer. At the same time, a number of alternative strategies moderately improve the environmental performance of the entire supply chain.

This thesis thus, documents the trade off in the strategies that the OEM can follow under the current institutional environment and the potential for improving the competitiveness and environmental performance of the supply chain. In contrast, a fundamental strategic reorientation, where the OEM innovates, offers the prospect of overcoming the trade off and improving across a range of competitive and environmental performance goals that include the environmental performance of the supply chain, the total quantity of materials used, and the total quantity of materials disposed.

The difficulties that a single manufacturer faces in making a strategic reorientation are documented both in organizational change and supply chain management literature and have to do with complexity of the business environment and managerial behaviour. In order to move the supply chain towards a state where it will integrate remanufacturing practices and thus meet both competitive and environmental impact goals, changes at the institutional level that are necessary to reduce the complexity that firms face, and induce a change in managerial behaviour, are proposed and tested (points iii and iv). These are: (i) regulation and (ii) the transfer of external knowledge to the supply chain and the market.

Chapter 2 Perspectives on Industrial Production & Sustainability

2.1 Introduction – Impetus for Change

There is a long line of thinking, contemplating on the possibility and the extent of human effect on the environment. Occasionally it leads to effective action. The list is long and includes works such as the IPCC group reports, the Stern report (2006), Diamond (2005), numerous activist and NGOs actions, the Limits to Growth report (Meadows et al., 1972), economists such as Herman Daly (1974; 1992), ecologists (Odum and Odum, 2001), Rachel Carson's Silent Spring (1962), Thomas Huxley (1888), and Thomas Malthus (1798).

Attention on this line of thinking has waxed and waned over the decades, and in recent decades it has begun to grow again. This hopefully marks a permanent shift in the understanding of the relationship of nature and human beings that has been based so far on the separation of human impact on environment and economic activity (Hopwood et al., 2005; Murray and King, 2012). The environment has largely been managed as an inexhaustible source and sink to be explored and exploited, and therefore any ensuing environmental degradation or pollution problems were usually dealt with on a local scale.

The first time that internationally coordinated action was taken on an environmental issue was in 1987, with the Montreal protocol, that banned the use of CFCs in manufacturing. Still though, the predominant thinking at the time was that human ingenuity and technology would overcome most ensuing problems, including environmental ones. In this context, economic growth was seen as imperative for providing solutions and development. This was in complete alignment with historical patterns of industrialization, mass manufacturing, capitalism and science (Dryzek, 1997).

Economic growth is still the all encompassing lens of human activity, and a main political and business priority (Heinberg, 2011). It is seen as key to perpetual human well being. Through growth, the argument goes, poverty can be overcome. When its benefits reach everyone, those at the bottom will be raised out of poverty. However, population grew by 13% in the last decade, and it is projected to reach 7.7 billion by 2020 (WRI, 2010). The needs of this ever expanding population, have been supported so far by an extraordinary expansion of the global economic activity and a corresponding explosion of production and consumption. The environmental impact of the manufacturing activity that supports economic growth, implies that ever expanding consumer societies cannot be supported indefinitely by manufacturing corporations. They have to alter their patterns of material consumption and adjust their lifestyles.

Environmental concerns emerged in the 1960s and 1970s, and slowly crept into the mainstream debate on development and growth. An influential document that brought environmental issues into the world political agenda was the Limits to Growth report (LTG) (Meadows et al., 1972). The LTG report used system dynamics modelling and challenged the idea of endless growth which was the mantra of capitalist economics at the time. It argued that maintaining the level of human activities and welfare of an exponentially increasing population that is expected to peak in mid 21st century, cannot go on for ever on a finite planet. If left unchecked, environmental degradation would overcome any further progress.

While at the time it was received as an outlandish proposal, the idea of a finite planet with finite, vital natural resources that humans consume at unprecedented rates to cater for their needs, slowly took hold (Aleklett et al., 2010). Overlaying historical data against LTG scenarios, shows that historical trends follow the business-as-usual or ''standard run'' scenario (Turner, 2008). In the updates of LTG (Meadows et al., 1992; 2004) the authors reaffirmed their initial concept of limits to growth and they provided links to the concepts of the Brundtland report (WCED, 1987), which introduced the concept of sustainable development to a broad audience.

The Brundtland report acknowledged the existence of physical limits on human activity, but it rejected the idea that there were fixed environmental limits to growth (Kirkby et al., 1995). It conceptualized sustainable development in terms of four interrelated strategies (Shrivastava, 1995): (i) management of population impact on ecosystems, (ii) ensuring world wide food security, (ii) managing ecosystem resources, and (iv) creating sustainable economies.

The implications of the line of thinking, reach at the core of manufacturing operations. This activity, is inextricably linked to our own existence and welfare, and consists in transforming some form of material input along with an appropriate energy input to some form of functional technological output that caters for a human need. The range of products is stupendous and reflects the breadth and complex nature of human ingenuity. The current manufacturing paradigm, the outcome of the industrial revolutions of the past, reflects these very qualities.

However, the environmental impact of this paradigm also implies that corporations cannot support expanding consumer societies indefinitely. The latter have to alter their patterns of material consumption and consumers have to adjust their lifestyles as well. Furthermore, it is evident that the dominant market model that manufacturing serves, has also contributed to some long term problems with incentive systems that encourage waste and environmental degradation and overexploitation of natural resources (Dunphy and Griffiths, 1998). In order to set the context for the rest of the chapter, the following section presents some characteristics of the evolution of manufacturing.

2.2 Manufacturing: The Current Paradigm

2.2.1 The Rise of Manufacturing

The evolution of manufacturing has evidently been influenced by the evolution of product design. Over the past decades due to the trend of reduction in material costs relative to labour costs, products or components were designed to be used once and then thrown away. In the event of a breakdown, the faulty part was simply replaced. Hence, the focus of manufacturing was in producing sufficient quantities in order to meet the strategic objectives of the firm, to which manufacturing was just a supporting function.

The fundamental shift that took place in the 1980s was the introduction of TQM and JIT in manufacturing. Their adoption improved business processes and performance, and lowered operating costs. Eventually, the ensemble of process management principles, and the advent of information and communication technologies became part of the management tool set for manufacturing and supply chain operations (Kleindorfer et al., 2005).

The broad adoption of TQM and JIT, illustrated how manufacturing could contribute to customer retainment and profit. This transformed the perception of operations and manufacturing from a function supporting marketing and finance, to a core function of value creation in a firm. Subsequently manufacturing processes rose to prominence as a pillar of firm strategy rather just a cost center that had to be managed (Hayes et al., 1988; Hayes and Pisano, 1992; Wheelwright and Bowen, 1996). A lot of related research, and practical applications aimed at improving the efficiency and quality of the operations function in isolation from external influences, including the natural environment. When the natural environment was taken into account, it was typically treated as an external constraint to the operations function (Srivastava, 2007). If this assumption is relaxed and the environment is not treated as a constraint but environmental issues are seen as integral to the manufacturing process, then manufacturing and operations more broadly, can potentially contribute significantly to firm environmental performance.

2.2.2 Threats to Sustainability

The wide adoption of quality principles in operations, transformed the manufacturing paradigm just as the pressures for environmental responsibility did. Firms engaged in a never ending quest for eliminating waste from their production processes. However, this has not changed the dominant way of thinking. Improved product and process quality resulted in less reworking, less process waste, and even more smooth and efficient operations. However, the overall paradigm has remained one where products are to be used only once or replaced in the event of breakdown, and then disposed of. What has proved to be a major cause of continued deterioration of the global environment is the unsustainable pattern of consumption and production, particularly in industrialised countries (Pogutz and Micale, 2011).

Broad recognition that operations, however efficient and flawless they may be, have a considerable impact on the natural environment which is evident, lead to an awareness that profits are only one element in the long-term success of companies and the economies (Hay et al., 2005). A further indispensable consideration is that firms and people run their operations drawing on resources and services of the natural environment (Lovins et al., 1999). Thus, the welfare of the people, the condition of planet earth as a whole, and company profits have to be considered (an exemplary approach is that of Odum and Odum, 2001).

Because of these growing concerns, firms are under strong pressure to adjust their operations and their strategies accordingly so that they moderate their impact on the environment. Operations management is thus increasingly connected to sustainability, and it encompasses both the operational drivers of profitability and their relationship to people and the planet. This entails adjustments and modifications to the production and transportation of their products, the introduction of recycling and remanufacturing operations, and the design of products that are suitable for such reverse supply chain operations to a considerably wider scale than at present (Kleindorfer et al., 2005).

2.2.3 Issues & Influences on The Manufacturing Paradigm

Environmental pollution, the diminishing availability and the rising price volatility of natural resources, and pressure from customers, public and private organisations compel manufacturers to reconsider the environmental impact of their production, delivery, and final disposal of their products (Kovacs, 2008). Clearly, strategies that integrate such concerns are meaningful and sustainable only if they are in alignment with business strategies (Porter and Reinhardt, 2007).

Recycling and remanufacturing are strategies towards this direction, and are carried out in accordance with national and international environmental legislation. In most EU countries, there is legislation in force that attributes extended producer responsibility for the full product life cycle (Fleischmann, 1997; Tibben-Lembke, 2002). For example, the

European Parliament issued directives (Extended Producer Responsibility (EPR) program for end-of-life vehicles and Waste Electronics and Electrical Equipment WEEE) which were intended to reduce the impact of waste streams of durable goods and electronic and electrical equipment. EPR is defined in Lindhqvist (2000, p v) as "a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts involved in the entire life cycle of the product, and especially to the take-back, recycling and final disposal of the product".

EPR and life cycle assessment extend the purview of corporate social responsibility upstream and downstream of the focal company in the supply chain (Kovacs, 2008). As stated in a European Commission green paper (European Commission, 2001, p14): "Corporate social responsibility extends beyond the doors of the company into the local community and involves a wide range of stakeholders in addition to employees and shareholders: business partners and suppliers, customers, public authorities and NGOs representing local communities, as well as the environment". Consequently, the issue of incorporating EPR is not only related to manufacturing decision processes. Due to the prominence that the manufacturing function has risen to, issues such as this can be explored from a competitive perspective as well (Spicer and Johnson, 2004).

Apart from legislation, consumer interest and environmental concerns have put further pressure on companies to adopt EPR (Blumberg, 1999). Many companies, anticipating these concerns, act proactively with regard to the evolution of environmental performance requirements. For example, manufacturers of durable goods are setting up systems for remanufacturing of used products alongside with the manufacturing of new ones, in an economically viable way (Savaskan et al., 2004). In many cases, the supporting reverse logistics networks are not set up independently, but are intertwined with existing logistics structures (Srivastava, 2008).

Product recovery is the first step in a wide range of activities namely, reconditioning, repairing, remanufacturing, recycling or reuse, (King and Lennox, 2001; Thierry et al., 1995), where the aim is to regain the potential value built in a used product (Guide et al., 2005; Ferrer and Whybark, 2000,2001; Guide and van Wassenhove, 2003). This involves the physical transportation of used products from the end user back to a producer-remanufacturer. A necessary condition for these activities is that the products considered for remanufacturing should offer sufficient savings in production costs compared to the value difference between new and recovered products. Furthermore, there are risks and uncertainties associated with the timing, quality, quantity and variety of returns, as well as with coordination processes along the reverse channel and related operational costs (Shrivastava, 2008). The supply of used products that can be remanufactured depends on volumes of past product sales and their level of remanufacturability (Ferrer and Swaminathan, 2006; Fleischmann et al., 2000).

It is also contingent on the manufacturer's decision of whether it chooses to collect used products directly from consumers (as in the case of Xerox, and Hewlett Packard), or prefers to allocate the reverse channel responsibility to the retailers (as in the case of Kodak) and manage collection indirectly via the retailers (Savaskan and Wassenhove, 2006). The example of Xerox, illustrates how a company has saved hundreds of millions of dollars through asset recovery and remanufacturing programs, while having a significant positive effect on the environmental bottom line (Kerr and Ryan, 2001). The case of Xerox has proved that remanufacturing can be both environmentally efficient and profitable (Ferrer and Whybark, 2000; Guide, 2000; Kerr and Ryan, 2001; Dowlatshahi, 2005).

Frequently, though, in a closed loop supply chain there is a conflict of interest between upstream and downstream partners, resulting in a competitive situation (Majumder and Groenevelt, 2001). Upstream partners, which are usually the manufacturers of products, want to project an environmental - friendly firm image by remanufacturing some of the used products, as well as recapture some of the value in the product. For these reasons, they build facilities and collection capacity. However, downstream partners can also build remanufacturing capacity to take advantage of their proximity to the market and their close relations with customers (sales and collection).

Demand management by regulating supply to retailers, is an apparent strategy response for the upstream partners to make the operations of those that depend on them (downstream) uneconomical. However, the manufacturer cannot always maintain control over the entire supply chain. Downstream partners may respond by over-ordering to overcome the rationing of the manufacturers, or wholesalers. This results in a gaming situation similar to the rationing and shortage game (Lee et al., 1997), whose long-term results are not easily visible and may be undesirable for all the partners in the supply chain. The situation may be more complicated if market entry barriers are low. Product recovery opportunities may attract specialized third parties, in activities such as tyre retreading (Ferrer, 1997b) or recovery of toner cartridges even when an OEM has not initiated product recovery (Majumder and Groenevelt, 2001).

Success though, is not always straightforward to achieve as product recovery and remanufacturing are operations of increased complexity compared to production and distribution of new products. The negotiations between retailers and suppliers are more complicated compared to cases involving new products because the quality of the products is not uniform and potential buyers may want to inspect the product before making an offer (Tibben-Lembke, 2002). Another potential factor of complexity is that since the recovery activity (repair, remanufacturing) requires (and reveals) intimate knowledge about the products, it is necessary to be carried out by the OEM only (Ferrer, 1997a; Thierry, 1997). A further factor of complexity is customers (Min and Ko, 2008). Direct shipment from customers back to OEMs is more costly than indirect shipments despite this being the preferred mode of product return for customers. Customers do not want to go into the trouble of making shipping arrangements. Instead, they prefer to drop off products for return at facilities located in their area.

Consequently, while it is possible to reduce the environmental impact of industrial production, the breadth and depth of changes that are required to do so is considerable. It constitutes nothing short of a paradigm shift, where simple and straightforward end-of-pipe control gives way to environmental strategies and practices that are considered instrumental for sustainable economic profit and sustainability (Srivastava, 2007).

2.3 Potential Change Directions

Companies have begun to address sustainability issues by developing and implementing innovative strategies (Shrivastava, 1995; Hart, 1995). Among the several motivations cited in the literature, for doing this, are competitiveness, legitimation, and ecological responsibility. Its long being argued that environmental and economic firm performance are positively linked and more so in growth industries (Russo and Fouts, 1997; Klassen and McLaughlin, 1996).

Some firm strategies can be described as small scale because of the scope of operations they encompass and their potential in influencing the broader environmental impact of manufacturing operations. Small scale innovation involves new technologies and practices regarding pollution prevention and product stewardship that have considerably reduced the operating costs of companies (Hart, 1995; Sarkis, 2001). The first, pollution prevention, involves firm compliance with regulations and pollution abatement through "end of pipe" approaches. The second, emphasizes the reduction of raw materials and process innovation for improved efficiency. Evidently there are inherent limits to the environmental performance that each approach can achieve, hence further improvements require large scale innovation, a concept that goes beyond firm centric operations.

2.3.1 Small Scale Innovation

Pollution Control & Prevention

Firms can implement pollution reducing strategies through: (i) controlling or capturing the emissions and storing them or treating them (an often cited example is carbon capture and sequestration), (ii) preventing emissions through process innovation or substitution (Hart, 1995; Sarkis, 2001). The difference between the two is that the former requires adding emission capturing equipment to the manufacturing process, while the latter requires modifications to the process itself, and focuses on new capability building in production and operations.

Depending on the strategy the firm chooses, the resources and capabilities required to implement it vary considerably. Pollution control strategies, concern only physical asset resources, the manufacturing technology, and the raw materials the firm uses. Compliance with regulations, is achieved by adding on pollution removing, or filtering equipment to the existing assets that is acquired from the market. Consequently, the firm does not develop additional internal capabilities except in operating it. Thus no competitive advantage accrues from this strategy (Kemp, 1993).

Prevention, in contrast, involves extensive employee participation and effort to continuously improve the emission performance of the firm, instead of buying off the shelf and implementing "end of pipe" technologies (Porter and Van der Linde, 1995b; Sarkis et al., 2010). It requires changes in the human resources and organizational capabilities of the firm. Pollution prevention strategies can thus strengthen the competitive advantage of the firm since their implementation involves developing the required intrafirm skills which are harder to copy than ready made technical solutions (Sarkis, 2001). Furthermore, they have positive synergies with other objectives of competitive advantage such as cost, speed and flexibility (Klassen and Whybark, 1999). Hence, pollution prevention is a more comprehensive and socially complex process than compliance, since it necessitates employee involvement, cross disciplinary coordination and integration and a forward thinking management style.

Preventing emissions, can result in significant benefits for firms and a cost advantage relative to competitors as it foregoes the cost of installing and operating additional equipment (Smart, 1992). Benefits to firms also accrue due to better utilization of inputs and corresponding lower material procurement costs and waste disposal. This can be achieved by removing wasteful, unnecessary steps in the production or reducing cycle times (Hammer and Champy, 1993). Pollution prevention enables a firm to advance beyond compliance to regulatory initiatives, and thus avoid further costly adjustments to its emissions performance at a later time. Inevitably though, given a specific production architecture and technology, there are inherent limits to the potential for environmental improvements. Continuous reductions in emissions progressively become harder to achieve and require more capital or broader concurrent changes in product design and technology (Walley and Whitehead, 1994). In short, there are limits to what the firm can achieve on its own.

There are other reasons for extending the search of environmental improvements beyond the boundaries of the firm to its institutional environment. Corporate social responsibility is a notion that has grown in legitimacy over the past decade. It is a result of local communities and external stakeholders demanding that corporate practices become more visible, transparent, and responsible towards the communities that their operations affect (Benn et al., 2009; Kovacs, 2008; Mathis, 2007). Therefore companies find themselves compelled to greater social accountability than before, that goes well beyond the immediate effect of their manufacturing processes.

The example of the computer industry is a case in point: the highly toxic materials used in circuits have been an increasing source of worry and growing awareness. This fact is reflected in the legitimacy of consumers asking who is currently the greenest manufacturer (Zhou et al., 2011). This shift in corporate accountability is evident in other industries as well, and it consists in pollution prevention strategies moving from being an exclusively internally developed process and a source of competitive advantage, to an externally oriented activity that can influence the legitimacy of other firms operations (Spekman and Davis, 2004). Product stewardship represents the next step in a firm's commitment to its social milieu.

Product Stewardship

This step is broader in scope than pollution prevention. It lies on the fact that there are opportunities for reduced environmental impact at every stage and process of the value chain of a product namely: raw material access, production processes and disposal of used products. A stimulus for this, is the internalization of environmental costs, something that was anticipated 30 years ago (Constanza, 1991) and has been since implemented with the introduction of regulations reflecting the polluter pays principle. This brought forth anticipated changes in the design of products and processes with the integration of stakeholder perspectives and expectations (Markley and Davis, 2007) and the widespread adoption of life cycle analysis (LCA) into the overall product development process.

At present, firms make an active effort to minimize the environmental impact of their products over their life cycle and simultaneously reduce their costs. In this way they can create new business, reduce the impact of their product lines, and develop new, novel products that exhibit lower life cycle costs. A life cycle perspective requires that firms: (i) reduce the use of raw materials extracted, (ii) avoid using hazardous or non biodegradable materials, and (iii) use renewable resources where possible, in line with their replenishment rate. This inevitably requires that firms engage in collaboration with their material and parts suppliers, marketing and customers, in order to minimize the environmental impact of the entire supply chain that the product goes through in its life cycle (Corbett and DeCroix, 2001; Vachon and Klassen, 2008). This should increase ease of collection and reuse, remanufacturing or recycling at the end of the product's useful life (Shrivastava and Hart, 1995).

There are several factors that are implicated in green product and process development (Kleindorfer et al., 2005): (i) uncertainty on the success of such development efforts having to do with lead times and the establishment of regulation, (ii) acquiring a first mover advantage with the development of manufacturing capabilities (an example is Toyota Prius which with its introduction opened up a considerable market for hybrid cars and forced competitors to follow) and (iii) designing products that require less material for their manufacturing and more efficient manufacturing processes.

Consequently, by implementing product stewardship, firms develop an ability in coordinating intra-organizational, disparate, functional groups and at the same time integrating the perspectives of key external stakeholders: community leaders, the media, regulators into decisions on product design and development (Vachon and Klassen, 2008). This ability contributes to the firm's competitive advantage since it rests on the accumulation of socially complex resources, establishing communication channels across organizational functions, and boundaries.

There appears to be a threshold with a product stewardship strategy. It can obviously contribute to building and sustaining a firm's competitive advantage, along with LCA and design for environment approaches. Seeking further advances to operations performance inevitably leads firms to place demands to their suppliers for minimizing their environmental impact as well. The example of the package printing industry is characteristic (Vachon and Klassen, 2006). It is only in this way, going beyond firm boundaries, that this strategy may appear as legitimate, be adopted by others, and allow for a wider impact (Bansal and Roth, 2000; Darnal et al., 2008). Furthermore, a proactive approach such as product stewardship, can lead to the development of knowledge integration capabilities across the supply chain, including absorptive capacity (Bowen et al. 2001; Cohen and Levinthal, 1990).

Thus, the next level of broadening the environmental strategy scope, involves engaging stakeholders external to the firm. Over time the product stewardship strategy will need to be aligned with those as well (Sarkis, 2001; Sarkis, 2010). This kind of perspective is illustrated in the sustainable operations management that integrates a firm profit and efficiency focus with broader considerations of stakeholders and environmental impact in three areas (Kleindorfer et al., 2005): (i) green product and process development, (ii) lean and green operations management, and (iii) remanufacturing and closed-loop supply chains.

Closed Loop Supply Chains

Organizations move towards green supply chain practices for a range of reasons including: (i) a response to governmental incentives and legislation, pressure from social groups, or (ii) a conscious policy for influencing their competitive environment (Seuring and Muller, 2008a, 2008b). The establishment of closed loop supply chains involves integrating and managing forward and reverse supply streams and an array of activities: used-product collection, reverse logistics (moving to reprocessing facilities), and inspection and separation i.e. deciding on whether to repair, remanufacture, or recycle (Guide and Van Wassenhove, 2001). Firms engaging in these activities must deal with the timing of returns, their quantity and quality, in order to extract the residual value of collected products and integrate them back in the forward supply stream.

Consequently, the focus of academic research has shifted towards green supply chain management and the creation of additional value instead of minimizing costs (Seuring and Muller, 2008a; Srivastava, 2007). Collecting used products means that their design becomes even more important, as are the processes that they go through (Debo et al. 2005; Blackburn et al. 2004). Operating a profitable closed loop supply chain requires balancing an ensemble of issues beyond those of product collection (Guide et al., 2003), reverse logistics and remarketing decisions (Geyer et al., 2005; Savaskan et al., 2004).

It is supported by research and evidenced through practice, that closed loop supply chains foster sustainability. They reduce the environmental impact of operations, the demand of raw materials and logistics, through product collection and reuse. They contribute to a firm's profit and its environmental performance simultaneously (Kleindorfer et al., 2005). However, their impact can have wider and less obvious implications. For example, operations involved in reverse supply chains are typically labour intensive, and can improve employment rates. Furthermore, the adoption of closed loop supply operations ushered in an increasing trend of leasing and installed based management, instead of manufacturing and selling products. As a result, firm competition is beginning to shift towards competition between supply chains acting as quasi meta – organizations (Hult et al., 2007; Gold et al., 2010).

Consequently, purely internal competitive approaches may prove inadequate due to external (social) legitimacy, reputation and stakeholder issues (Henriques and Sadorsky, 1999; Sarkis et al., 2010; Shah, 2011). Indeed, the role of social legitimacy for a firm's competitive advantage has been recognised long ago (Bozeman, 1987; DiMaggio and Powell, 1983). Therefore, in addressing the issue of sustainability, pollution control and prevention are only part of the picture. They are strategies that concern firm processes and are thus situated at the firm level. Hence, there is a need to address these issues at the supply chain and industrial system levels (Figure 2.1). This is because there is an indirect element to the environmental impact of firms through the use of products by consumers. Reducing their impact, involves the development of new technologies, and while this is part of what firms do, it is also bounded by the wider context in which they operate (Kemp, 1994). Therefore while it is necessary to seek further progress at the firm level with pollution control and prevention, at some point it becomes of little value. The context in which the industrial production system operates will have to be addressed at the macro level along with changes at the micro level, for example through legislation and Emission Trading Schemes (ETS) in order to render environmental strategies more effective (Chaabane et al., 2012). At this level the appropriate theoretical lens is sustainable development.

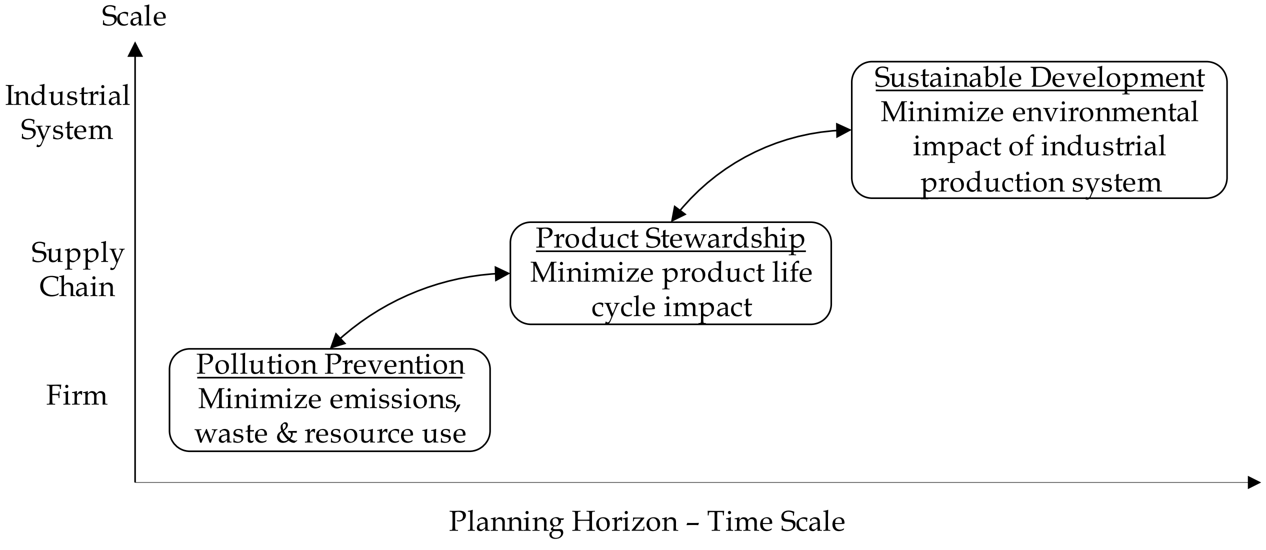

Figure 2.1: Levels of firm environmental engagement

2.3.2 Large Scale Innovation

Sustainable development is put forward as the *shared* vision of the future. Hence, although firms that adopt sustainable development strategies will inevitably develop new technologies and competencies, sustainability cannot be tackled at a firm level alone. It has to be addressed at a larger collective scale if the impact of economy on the environment is to be mitigated (UNEP, 2011). This requires taking a step from the firm to the industrial system (Figure 2.1). Sustainable industrial production involves (Shrivastava, 1995): (i) using cleaner and more efficient production technologies in order to reduce the impact of production systems on the environment, (ii) reducing pollution, toxic and solid wastes through recycling, remanufacturing and reusing materials. In this way, fundamental changes can dramatically improve the productivity of natural resources at a profit for firms (Lovins et al., 1999). Sustainable development hence, provides an opportunity for firms to acquire and sustain a competitive advantage through accumulation of resources and competences relating to these. However, it involves a shared future vision of new technology and competency development that extends beyond them.

The use of new technologies, discussed in previous sections, requires the development of new labour skills, new management styles, and even institutional changes such as regulation about the market and industry. It is also necessary to overcome the vested interests of firms and whole industrial sectors in order to promote the adoption of new technologies at the firm level, and the growth of new technological systems at a larger scale. The user side of such systems must also be considered, as consumer lifestyles and preferences coevolve with, and constitute part of the social context in which technologies are embedded. They are shaped by perceptions of technology, its adoption and use. Furthermore, there is considerable inertia and financial interests involved in radically changing consumer habits and restructuring firms. Consumers in industrialized world are accustomed to unsustainable patterns of consumption and it is not in the immediate interest of firms to change that, nor they have the capabilities to do so (Shrivastava, 1995). For example, the widespread use of cars in the Western world has irreversibly changed the lifestyle of people in many respects and not just the way they commute everyday (Shove and Walker, 2010). At present, more people live in cities than in rural areas (Dye, 2008) and this is partly due to the availability of technologies and infrastructure and all the complementary technologies and products that enable their convenient use, that have made possible such a concentration of people in confined spaces. Thus technology and people's social behaviour and lifestyle are intertwined in many ways, by enabling new behaviours and activities (Kemp, 1994, p1032): “Technological change and socioeconomic trends co-evolve and interact.”

2.4 Factors of Change in Manufacturing

There are several factors, both internal and external, that influence the environmental strategies that firms adopt (Hassini et al., 2012). External forces (Figure 2.2) include consumers and retailers, that may demand products manufactured in an environmentally friendly way. Firm shareholders and stakeholders, may also require that the firm follows sustainable practices in line with industry standards. Finally, offering green products may become just another market entry requirement in the future.

Other external factors include policy and regulations that introduce environmental standards such as ISO 14001. These require that firms invest in environmental management practices (Klassen and Vachon, 2003). Consequently, they usually involve some R&D, in house or outsourced, in order to develop materials and processes that are less harmful to the environment (science and technology). They try to capitalise on this, by launching the appropriate marketing and public relations campaigns and educating their customers in order to create the desired level of awareness for their products and processes. NGOs and social groups are further sources of external pressure. They can boycott or launch adverse publicity campaigns towards a company's misconduct and harmful products. For example, Greenpeace has produced a list of the computer brands whose manufacturing operations are least harmful to the environment (HBR, 2012).

Internal factors include the firm's product and process development, for example designing for recycling/remanufacturing or using biodegradable materials. If these materials are procured, then their suppliers must also be prepared to adapt their processes to be more environmentally friendly. Developing manufacturing processes may involve improving the existing ones in terms of energy efficiency, energy sources used and greenhouse gas emissions. In addition, they have to be able to absorb returned or used products. Hence, significant changes to the firm's logistics are required to support these increased flows of materials and products moving in the supply chain and in the firm.

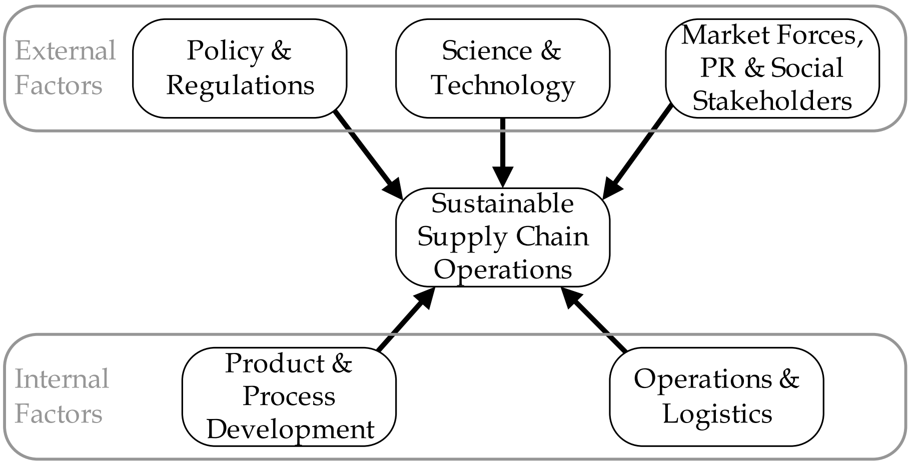

Figure 2.2: Factors in sustainable supply chain practices (adopted from Hassini et al., 2012)

2.4.1 The Role of Regulation

Early recognition of the role of regulation, documented the fact that the same policies that internalized negative environmental costs for firms, can also lead them to enhanced environmental performance (Russo and Fouts, 1997). It can spur firms to overcome organizational inertia and innovate, point towards harmful inefficiencies, and ensure that product and process innovations will be environmentally friendly (Porter and Van der Linde, 1995b). A related consideration to firms implementing environmental policies is the management of their reputation in accordance with regulation. For example, some product categories are required to indicate their energy efficiency class. This offers an opportunity for firms to enhance their market advantage building on an overall reputation for product quality.

Furthermore, in considering regulatory changes, another organizational asset may be brought to bear. Firms employing pollution prevention strategies, can be proactive with regard to regulation and at the same time they can also act in order to influence it directly. They can actively employ technology to improve their environmental performance beyond compliance levels and thus raise the bar for the rest of the competition. Hence, the implementation of environmental strategies has a political as well as a technical component. It can be a source of competitive advantage against firms that follow a compliance strategy and often resort to lobbying against fast paced changes to environmental legislation.

The role of government regulation and policies though, is broader than just setting environmental performance goals. By implementing science and technology policies it steers the development of knowledge and education and consequently the range of competencies available in the market (for example the REVLOG project[1]). Furthermore, development policies through the provision of large transport and communication infrastructure, provide a vital complementary component to the functionality of many technologies and services. Finally, with their fiscal policies, they can directly influence whole industrial sectors in important ways, for example in the energy sector (Van den Bergh, 2012). In either case the implementation of policies requires time, because it is often the case that relevant research and planning has to be conducted and people need to be educated.

Policy making has also a central role in promoting new, or protecting mature technologies and industries against the challenges that firms and new technologies mount. It seems though, that the policy apparatus and its related socioeconomic system usually favour the status quo. Consequently, those technologies that can be integrated easily into it, will promptly diffuse. In contrast, those that require substantial change in the wider socioeconomic environment, the skills involved, different production and consumption patterns and regulation, will diffuse slowly or stagnate. A logical repercussion of this is

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[1] http://www.fbk.eur.nl/OZ/REVLOG/welcome.html (accessed on 29 – 5 – 2012)

that government policy (R&D subsidies, science policies, taxation, environmental regulation) influences the direction of R&D firm activities towards the direction of foreseeable profits and this usually implies a short to medium term focus. This has also a direct impact on technology selection because it modulates the wider selection environment in which it is embedded.

There is a range of technologies available from which to choose at any time. There are several reasons for this (Kemp, 1994): (i) scientific progress opens up new possibilities, (ii) new needs and therefore new markets and demand for technologies emerge, (iii) there is no clear superior choice, (iv) there is uncertainty as to how the new needs and demand for technology will evolve, (v) different organizations carry a different endowment of resources and capabilities and therefore respond by developing different technological solutions. Therefore it is important that technology policy attends to the specific context, the competitive advantage and sustainable behaviour of firms (Zhu and Sarkis, 2007).

The question then for policy becomes, how to facilitate in the best way possible, the development of relevant technologies that can transform the current manufacturing system. Picking early winners, could result in suboptimal choices as it is not always obvious how technological opportunities and user needs will coevolve. Instead policies should aim at providing the context in which organizations develop, innovate and continuously improve technologies and provide a match to human needs (Porter and Van der Linde, 1995b). This is important since the viability of technologies is contingent on the underlying socioeconomic context which depends strongly on government policy.

Thus, the development of short and long term technological solutions, must be nurtured through public policy, away from short term pressures of corporate growth. This can be accomplished in niches (Schot and Geels, 2007; Schot and Geels, 2008; Caniels and Romijn, 2008). These are an important stepping stone for further developing radically new technologies and practices towards alternative more sustainable industrial production systems that can replace the current one (Figure 2.3). They also provide the space for exploring and learning about user needs, allow critical problems to surface, and derive lessons for wider scale application. Finally, they constitute a scaled technology experiment for learning about particular technologies and social practices with the potential to transform the industrial production system. They involve potential suppliers and users of technologies, and public authorities that want to effect wider system changes.

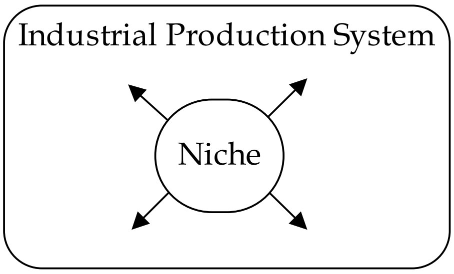

Figure 2.3: Niches of sustainable industrial production

2.4.2 The Role of Technology

An often cited equation for the environmental impact of societies is I = PxAxT (Ehrlich and Holdren, 1971) where I is the environmental impact, P is the population size, A is the economic affluence and T is the technology which indicates the amount of pollution per unit of GDP. Since population and affluence are relatively difficult to constrain, the logical inference is that technology offers the most promising solution to reducing society's impact (Pogutz and Micale, 2011). Hence, in any perspective on sustainable development, and in any view on the change required, technology policies have a prominent role.

The development and diffusion of environmentally benign technology is generally considered as imperative. There is considerable research and ongoing debate on which technologies should be given priority, which should be abandoned and which development path should be followed in order to achieve this. However, the dominant view on technology sees it as an instrument to use, in order to achieve a goal. Therefore only its use is debated.

There is considerable literature investigating which technologies should be further promoted for sustainability. For example technology has a prominent role in mitigating and adapting to climate change in all IPCC reports (for example IPCC, 2007). However, the literature on sustainable development does not address the effect technology has on society, the changes it can initiate and their repercussions on sustainable development. There is very little consideration on the nature of technology itself and its implications for a sustainable society (Johnson and Wetmore, 2009; Paredis, 2010).

In fact, if the direction of technology innovation and development is to be influenced, its relationship to society must be understood (Kemp, 1994; Bijker, 2010). Hence the current discourse on sustainability and technology must be informed by the understanding of the relation between social, technological and environmental sustainability and how they are interrelated (Udo and Jansson, 2009). Otherwise, sustainable development practitioners and policy makers, working with ill informed conceptions of technology, are likely to arrive at erroneous conclusions about how to use technology for sustainable development. This will inevitably have social and environmental repercussions.

In light of this, insights from the philosophy and the field of science, technology and society studies (STS) on the coevolution of society and technology, should be considered in the sustainable development debate (Johnson and Wetmore, 2009). Their importance lies in providing a range of perspectives on how technologies are integrated in larger evolving technical and social systems and producing useful knowledge to the politics of technology and consequently of sustainable development (Kemp, 1994; Bijker, 2004). Empirical studies of technology have demonstrated that society and technology dynamically interact and influence each other and its development is influenced by social groups (engineers, firms, consumers, users, policy making institutions).

Technologies are not developed and chosen solely on performance criteria (technological determinism) but their adoption is also based on the alignment of certain normative values. This is how people are motivated to consider, promote and adopt technologies. In other words, technology is enmeshed into a value laden social network (Johnson and

Wetmore, 2009). Thus the introduction of new technologies becomes an issue of technical selection as well as of social and institutional compatibility. Due to the interaction of technological and socioeconomic change, those technologies that can easily become part of the wider sociotechnical system and integrated into people's daily life, will diffuse more easily than technologies that require considerable changes and adjustments and thus constitute a break with the way things are done. This view has important implications for influencing technology development since (Feenberg, 1999; Achterhuis, 2001): (i) it is not autonomous, (ii) it is not determined solely by efficiency criteria but by a social process, (iii) it is not about fulfilling human needs but defining them in a certain cultural context, and (iv) competing technology definitions reflect the visions of modern society that drive technology choice processes.

The role of technology then is twofold: it influences the society-technology duality and the natural environment. Technological limits, manifesting in diminishing environmental performance gains, can either result in a search for alternatives and innovation (the technology) or a redefinition of human needs (the society). In both cases technology utilised by organizations can result in significant changes.

2.4.3 The Role of Organizations

Firms producing goods and services are situated at the core of technological progress and influence its trajectory. They are the intermediaries between technology and society. They translate user needs, or create new ones, and use natural resources to produce goods and services that meet them. Therefore, firm environmental strategies have a social, and a technical – economic aspect (Jimenez and Lorente, 2001). They can have a significant contribution to preserving natural resources. The implementation of appropriate operations strategies, for example total quality environmental management (TQEM), can also contribute positively to the triple bottom line of firms (Gimenez et al., 2012).

TQEM employs life cycle analysis in order to link the organizations design for environment and deign for disassembly strategies to its natural environment (Sarkis, 2001). It thus encompasses all aspects of product development, production processes, use and disposal, and identifies the ecological impact of inputs, throughputs, and outputs for the entire product life cycle (Linton et al., 2007). Product and process technologies are the main environmental and cost variables. They determine the types of raw materials used, workers, health and safety, ecological risk, materials efficiency, waste generated and disposal treatment (Sarkis, 1995). Inevitably the implementation of environmental strategies also concerns purchasing policies and supplier management (Simpson and Power, 2005).

The aim of TQEM is to minimize the life cycle costs without compromising the quality of products and services. This is done through (Shrivastava, 1995): (i) minimizing the energy and raw materials used in products, (ii) using renewable materials where possible, (iii) offsetting the consumed, natural resources and emissions, and (iv) implementing environmentally responsive purchasing policies and inventory management systems. The integration of environmental stewardship with continuous improvement, a major tenet of TQM efforts, is reflected in the ISO certification standards. The rational being that by reducing waste, efficiencies tend to increase, and result in win-win-win situations for business, the environment and society (Sarkis, 2001).

There are several benefits that accrue to firms pursuing environmental strategies and TQEM (Shrivastava, 1995):

i. The reduced use of energy, materials and life cycle costs, drives down operating costs.
ii. They can be a source of competitive advantage as there are growing market segments of consumers that are drawn to companies implementing sustainable practices.
iii. Firms can create unique and inimitable environmental strategies, and thus attain a leading status in their industry. They may also preempt or influence regulations through setting the example.
iv. The improved environmental performance of the firm is an asset for its public relations, corporate image and social legitimacy.
v. They can contribute to management of long term risks having to do with resource

depletion, waste management and the rise of energy costs. They can also contribute to reducing health risk and thus liability in the community the firm operates.

There are of course certain limits to this. Firms have limited knowledge and resources and as a result their competences lie mostly within the markets they operate (Hult et al., 2006). This knowledge base involves technological know how (tacit and codified) about products and services, an understanding of customer needs and their perception of the technologies used, a broad knowledge of how the market is structured, and managerial skills. It is one of several factors that shapes the response of firms to pressures (regulatory and stakeholder) for improving environmental performance and engaging in remanufacturing and recycling (Simpson, 2012). Thus in addition to the acquisition of new knowledge, the development of products for, and their integration to recycling and remanufacturing processes, may require significant investment in technology (Sarkis, 2001).

This ensemble of resources along with the capital stock of the firm impose limits on what the firm can achieve in the short and long term, and to its profitability. Its capabilities, are a result of the history of the firm, and consequently limit the level and scope of its competition (Garud and Karnoe, 2001). Furthermore, as the competitive environment changes, firms have to adjust their capabilities in order to maintain their advantage (Helfat, 2007). The implication for industries where firms face the same constraints and a similar scope of competition is that a single firm may be incapable to overcome some of the limitations it faces since firms tend to adopt similar competitive strategies in response to institutional changes they face (Hoffman, 1997). It may be sensible to seek change at a higher organizational level that involves the totality of actors implicated in the development and use of certain technologies (Rip and Kemp, 1998). This is largely the case in every industry.

However, there is a problem with small and large scale innovation, including remanufacturing and recycling operations, which has at least two aspects: (i) the appropriability of benefits i.e. whether the innovating firm can reap the benefits of the innovation and (ii) whether participation in or adoption of innovations is done on a voluntary or compliance basis.

Appropriability

Appropriability consists in the opportunity for the developer of an innovation to capture the benefits from its inception and introduction, and prevent other firms from doing so (Nelson, 1987). There is an obvious difficulty in securing this with systemic innovations, that by their very nature are of broad scope and involve interactions between actors that contribute complementary assets (Teece, 1986). Their success may depend on technical advances in complementary technologies that lie outside the innovating firm (or industry) and may need the construction of physical infrastructure. An alternative can be to involve all the potential beneficiaries in the development phases of the innovation, and share the benefits, in order to secure the widest possible support and commitment, technical and financial from relevant actors (other firms, and government agencies).

In this way it is possible to infuse the innovation with the required momentum in order to have an impact against established technologies (Schot and Geels, 2008). Probably even more important for the take-off of the new innovation is that, an early market niche may be found for its application. A further consideration is whether the benefits of the innovation become evident in its early stages of implementation as it competes against well established technologies.

These issues are relevant for environmental innovations because, as discussed in section 2.3, firms can reduce their environmental impact by adopting innovations at the firm level but also others that need to be introduced at a more aggregate level and are thus systemic. For example, the concept of Extended Producer Responsibility requires original equipment manufacturers (OEMs) to take back used products in order to reduce disposal and land filling. The initiation of reverse flow of products involve a range of actors, including the consumers. The products must also incorporate characteristics that render them suitable for processing (remanufacturing or recycling) after their use, or even more durable for reuse. Thus extended producer responsibility is two fold: (i) it extends OEMs responsibility beyond their products reaching the market, and (ii) it involves actors that are related to the technologies and materials that the product incorporates and the operations of the reverse supply chain (Dowlatshahi, 2005).

The issue is, whether involvement in systemic innovations really involves a trade off between cost and benefits of environmental regulations because of appropriability. The early view on this, was that there were trade-offs between innovations for sustainability and economic competitiveness. This view was challenged from a number of authors (Porter, 1991; Makeower, 1993; Lovins et al., 1999). It is argued that it is possible for environmental regulation and standards to trigger innovation and have a positive effect on the environmental and economic performance of firms (Porter and van der Linde 1995a, 1995b).

An important qualification in this view is that, environmental strategies ranging from conformance, to regulations and standard industry practices, to voluntary actions for environmental preservation are contingent on managerial interpretations of environmental issues as threats or opportunities (Sharma and Vredenburg, 1998). Uncertainty and risk involved in seeking innovative environmental technologies and systems, depend on managers perceiving them as opportunities to be explored rather than threats to be averted. For example if remanufacturing and recycling are perceived as opportunities, the result will be an open search for solutions (Nutt, 1984). In the opposite event, i.e. if they are perceived as threats, then it is most likely that they will evoke a risk averse managerial behaviour that will seek to minimize losses rather than maximize gains (Kahneman and Tversky, 1979; Kahneman, 2011).

These managerial interpretations can be influenced by factors such as the organizational context, the legitimacy of environmental issues for enhancing corporate identity, the potential organizational slack of managers for creative problem solving, integrating business, and natural environment considerations (Dutton and Duncan, 1987; Sharma, 2000). The implication of this is that in order to engage firm managers in developing and employing technologies for reducing ecological impact, a suitable context should be provided in which they perceive environmental issues as opportunities. In this way firms will actively seek environmental innovations, cogent with their organizational identity and context, rather than complying to regulation with investments in pollution control (Porter, 1991; Porter and Van der Linde, 1995a). Hence, policy makers in considering the role of organizations, must facilitate the construction of a competitive context in which sustainable processes, product redesign for material and energy substitution are valued.

Conformance vs Voluntary Strategies

Research on organizations has identified four motives for implementing environmental strategies. Placed in order of descending importance these are (Bansal and Roth, 2000): legislation, stakeholder pressures, economic opportunities, and ethical motives. Evidently legislation is important in bringing about a desired corporate through penalties and costs (Lawrence and Morell, 1995; Post, 1994). The rest of the drivers, in addition to compelling a firm to comply with regulation, can cause it to become proactive by keeping ahead of legislation.

Firms that adopt pollution control strategies as a response to regulation, usually invest in "end-of-pipe" solutions that are already available. Therefore this strategy does not require the development or acquisition of skills regarding new technologies and processes (Russo and Fouts, 1997). Conformance to regulation involves adopting industry standards and industry association practices or even responding to pressure groups and industry stakeholders. Thus there is no competitive advantage to be gained by this (King and Lennox, 2000).

Firms that voluntarily adopt proactive pollution prevention strategies, inevitably venture into a path that is "less travelled". It requires learning and developing organizational capabilities that may contribute to competitive advantage (Russo and Fouts, 1997; Sharma and Vredenburg, 1998). It represents a distinct pattern of actions taken to improve the environmental performance of operations, and not simply to comply with environmental regulations. In this way they can avoid having to incur the costs of adjusting their environmental performance by buying “off the shelf” technology.

Furthermore by being proactive, firms can actively create opportunities to lower their costs and environmental impact (Porter and van der Linde, 1995b; Vachon and Klassen, 2008). There are a number of ways to do this. For example, green marketing, selling, remanufacturing or recycling, instead of disposing waste products, and outsourcing their environmental expertise. Hence, firms can benefit by appropriately managing and developing resources such as such as corporate reputation (Russo and Fouts, 1997), learning capabilities (Hart, 1995), and product quality (Shrivastava, 1995).

Stakeholders can also have some influence on corporate environmental strategies (Lawrence and Morell, 1995). Customers, local communities, environmental interest groups, can encourage or pressure firms to consider the impact of their strategies (Berry and Rondinelli, 1998). By responding to them, managers are able to avert negative publicity, build corporate identity and secure stakeholder support.

2.5 Synthesis: Why Change in Both Scales is Necessary

There are two arguments for supporting the approach of change on both scales. The first has to do with technology adoption by firms. The second concerns the embeddedness of technology in society.

First, there are certain limits to what a firm can achieve on its own by technology adoption. Furthermore, while regulation compliance is a way of forcing the issue, it is certainly slow because, on occasion, it involves overcoming the resistance of firms to stricter emissions regulation. Those firms that voluntarily go beyond compliance of course influence things but not every firm can follow at the same pace, or respond strategically to the same opportunities in a similar manner.

Nevertheless, proactive firms that take initiatives for pollution prevention without alterations in the wider context in which they operate face significantly higher risks because in effect they venture beyond regulation. For example, investing in redesigning and replacing existing products with easy to remanufacture products, and committing to making the corresponding adjustments to processes in a competitive environment, requires significant financial resources and involves substantial risk. For example instead of appropriating the value of investments a manufacturer can find that 3rd party by remanufacturing can reap the benefits of such efforts.

The decision to adopt clean technologies and to incur additional costs is even more risky for three reasons. First early in their life cycles, technologies and processes that are on the cutting edge of source reduction may cost more and may be of lower quality than when they become off the shelf technologies. Thus firms can risk their brand image. Second, the viability of new, clean technologies and the economic consequences of their use, can be largely unknown (Russo and Fouts, 1997). Third, the response of users, while it tends to be favourable, is uncertain because green products are usually more expensive. This is related to the second argument of the social embedding of technology.

The second argument has to do with those elements of the social context in which the firm is embedded, that lie outside its immediate control. A firm cannot directly affect the skills and competences of potential employees in the market. It also does not carry fundamental research on its own, even in the case of biotechnologies and pharmaceuticals. This is mostly carried in universities. Furthermore, it has limited scope in influencing regulation through industry associations. All these lie out of its sphere of immediate influence and can thus aggravate or alleviate the risk and complexity that the firm faces in its competitive environment. Their effect is also likely to condition the response of the firm towards competitor moves.

Obviously, industry associations and groups of firms have more leverage in effecting change. However, it may not be possible even for industry to influence developments according to its will. Indeed, social intervention through governmental regulation or public pressure, has occasionally kept corporations from engaging in much more destructive practices. Consequently it is imperative that government and society be considered as well in the adoption and use of environmental technologies is apparent.

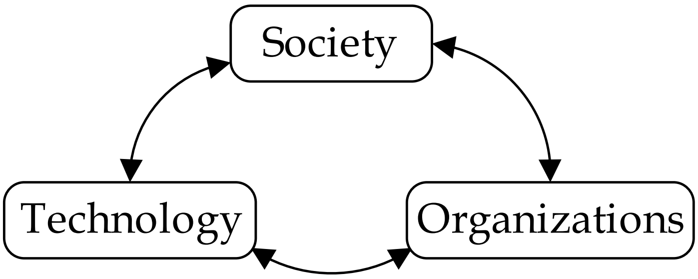

Figure 2.4: Society, technology and organizations

2.6 Thesis Proposal

Drawing on the description of the issues pertinent to the industrial production system, the following chapters explore the implications of environmental operations (recycling and remanufacturing) at the level of the supply chain (chapter 3). System dynamics modelling investigate the limited leverage of a single firm and thus the limits to the economic and environmental performance that it can achieve. It also demonstrates that being environmentally proactive in an unregulated environment exposes it to risk of competition. Chapter 4, follows on the argument of addressing environmental performance issues at a macro scale when changes at the regulation and consumer sides facilitate a different institutional environment that allows for a different mode of competition (state 2). Simulation results show how the same operations can result in overall improvements and win win situations for the firms, and the environment.

2.7 Summary

This chapter has presented an overview of aspects of the industrial production system, its current paradigm and its influence on the environment. It has argued that because its current mode is unsustainable it has to change and, that this is necessary to take place at two levels: the micro level of firms and macro level of the industrial production system. Implementing these changes for improving environmental performance is not only a burden that firms have to bear but also harbours opportunities for furthering their competitive advantage and profitability. Thus they can improve their triple bottom line, by being profitable, being responsive to environmental problems and responsible to the society.

Chapter 3 Remanufacturing Operations Strategies in the Current Institutional Environment

3.1 Introduction

This chapter analyses in detail the case of a particular supply chain, in industrial production. In its current institutional state 1, the supply chain has an input output configuration, which is unsustainable as discussed in chapter 2. A number of reasons that apply generally to the production of goods and services, exacerbate the situation: population trends, the growth impetus in the economy which is not decoupled from manufacturing goods, increasing energy demand, and the cultural trend of consumerism which continues unabated. Therefore a transition from its current state to one where outputs feed back to it as inputs is necessary (Figure 3.1). The question is: "when and how big will the impact be and how fast will the transition be?" (Kleindorfer et al., 2005, p 489). This transition involves, and therefore its study should also include, a simultaneous consideration of a number of factors including environmental, health and safety concerns, green-product design, lean and green operations, and closed-loop supply chains.

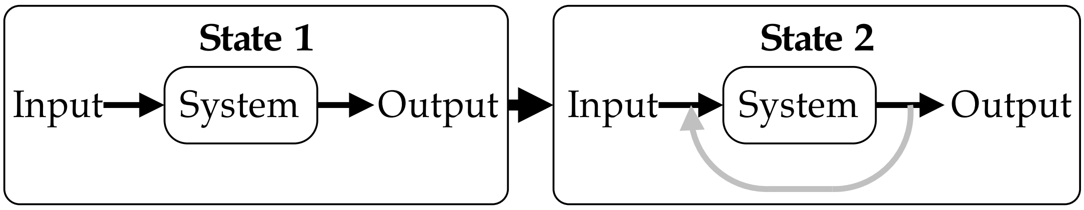

Figure 3.1: Current and prospective states of the manufacturing system

However, in such all encompassing processes as transitions, change is not straightforward. It requires small and large scale change as discussed in chapter 2. The present chapter addresses the issue at the small scale in order to illustrate that under "business as usual" small scale changes only are possible but are not sufficient. The starting point is a particular case of manufacturing supply chain which motivates the development and use of a system dynamics model is developed to quantify the competitive and environmental effects of operations strategies of actors in a closed loop supply chain. The results show that competition between supply chain partners impedes a reduction in the environmental impact of the entire chain and a market shift away from brand new products.

3.2 Issues in Closed Supply Chains

The responses of firms to the pressure for change, have taken different directions, with a varying degree of commitment to the protection of the environment (Jermier and Forbes, 2003). Given the very nature of these profit-seeking organisations, their environmental strategies are meaningful and sustainable only if they are aligned to their business (Hart, 1995; Porter and Reinhardt, 2007) and operations (Kleindorfer et al., 2005) strategies.

Recycling and remanufacturing of used products are strategies in this direction. They are frequently driven by national and international environmental legislation. For example the EU has developed regulations including the End-of-life Vehicles Directive (ELV), Waste Electrical and Electronic Equipment Directive (WEEE), Restriction of Use of certain Hazardous Substances Directive (RoHS), and the Packaging and Packaging Waste Directive for the full product life cycle (Fleischman et al., 1997; Tibben-Lembke, 2002).

Conformance with legislation or "*regulatory greening*" (Jermier and Forbes, 2003) is only a reactive approach to environmental strategy and cannot be seriously considered as a source of sustainable competitive advantage (Hart, 1995; Hunt and Auster, 1990). Therefore in firms that adopt this reactive attitude, the strategic contribution of remanufacturing and recycling is usually sought in the improved environmental-friendly image of the firm, "*ceremonial greening*" (Jermier and Forbes, 2003)) rather than in operational gains. However, there are manufacturing firms, of both durable and nondurable goods, that set up closed-loop supply chains with remanufacturing and/or recycling nodes (Savaskan et al., 2004) for gaining real operational benefits, in addition to those of marketing and communication. These include: (i) the reduction of manufacturing activity and thus environmental pollution, (ii) the reduction of the quantity of natural resources required for production, (iii) the reduction of after-use products disposal in the environment, and (iv) the opportunity of recapturing some of the residual value built of used products (Guide et al., 2005; Ferrer and Whybark, 2000; 2003). These benefits can be captured provided that remanufacturing and/or recycling (Heese et al., 2005) are in full alignment with an organisation's manufacturing/operations strategy (Sarkis, 1995;

Newman and Hanna, 1996; Burgos and Céspedes, 2001).

The fact that firms in manufacturing supply chains will be engaged in forward and reverse channels simultaneously, complicates things as they have to conform to legislation and adopt strategies aligned to one another. Original Equipment Manufacturers (OEM) cooperate with retailers in the forward supply chain but the proximity of the latter to consumers, confers an advantage in the collection of used products. In the context of the transition of the industrial production system from institutional environment state 1 to state 2 this has two implications: (i) it is easier for the retailer to close the loop back to a secondary market segment and thus threaten to cannibalize the OEM's sales and (ii) it places the OEM in situation where it has to defend the forward supply chain operations against it. This is orthogonal to the overall desirable transition direction of the system where the objective is to change the input – output architecture of the system. It thus may impede rapid progress despite the best intentions of the OEM since this is a matter of sustaining its business and survival.

Engagement in recycling and/or remanufacturing operations introduces new forms of competition, not only among Original Equipment Manufacturers (OEMs) involved in remanufacturing products that compete with new ones in low-level market segments, but also between OEMs and local remanufacturers (Matsumoto, 2009). This explains the involvement of OEMs in remanufacturing as a reaction to the market competition of other OEMs or third party re-furbishers, including (their own) resellers and retailers, rather than as a proactive environmental strategic move.

Engaged in such a situation, an OEM, apparently, has six options to follow (Atasu et al., 2008; Atasu at al., 2009; Toffel, 2004): (i) *do nothing*, i.e. ignore competition with other OEMs or local remanufacturers (ii) *remanufacture and compete on prices* with other OEMs that offer remanufactured products, or other products that can be considered as substitutes to remanufactured, (iii) *co-operate* with third party (local) remanufacturers to ensure that the quality standards of the OEM's products and services are met by them, (iv) *pre-empt* the entry of third party (local) remanufacturers by using contractual means, such as leasing, provision of payback incentives, etc., and possibly launch a remanufacturing operation, (v) *launch a collection operation* so that used products never reach third party remanufacturers (and possibly launch a remanufacturing operation), or (vi) *directly compete* with local remanufacturers at the level of operations, trying to make the purchase of new products more attractive to customers than that of the remanufactured ones. These alternatives, except from options (i) and (vi), have been the subject of extensive academic research. However, as discussed in the following section, the focus has been put solely on economic performance and environmental issues have received little attention. This chapter focuses on the last option (option vi), and investigates both the economic and environmental effects of competition between OEMs and local remanufacturers, when the latter are also resellers, or retailers, of the OEMs.

In some industries and specific business environments, OEMs choose to compete directly with their resellers/retailers-turned-remanufacturers (the term retailer is used to include also distributors, resellers, etc. who are usually engaged in commercial activity and who are close to the end customers). In these cases, OEMs and retailers-turned-remanufacturers are cooperating partners with mutual interests and benefits in the forward supply chain, and competitors in the reverse. This means that, while OEMs and retailers-turned-remanufacturers are cooperating partners with mutual interests and benefits in the forward link of the supply chain, in the reverse (after product use), they are competitors (the term retailer is used for all firms engaged in commercial activity, distributors, resellers, etc.). This is an exemplary case of co-opetition (Nalebuff and Brandenburger, 1996), especially when the OEMs decide not to engage themselves in remanufacturing operations.

Obviously, there may be additional benefits for the OEM beyond environmental and economic ones, such as securing spare parts supply and warranty, as well as market share, brand protection and customer orientation (Seitz, 2007). However in reality, the OEM is limited to a passive role, because its remanufacturing cost structure, which includes additional transportation costs, may favour direct competition, instead of cooperation, with retailers acting as remanufacturers in the market of remanufactured products. Retailers can draw on a variety of possible seller-customer relationships (Őstlin et al., 2008) and, directly or indirectly, exclude the OEM from the collection market. In such a situation, where the new and remanufactured product market segments interact, the competitive advantage for OEMs and retailers does not lie only on different market positions (brand products and non-brand products), but rather on idiosyncratic resources, capabilities and their accumulation process dynamics regulated by operations-level decisions (Porter and Reinhardt, 2007; Barney, 1986; Wernefelt, 1984; Dierickx and Cool, 1989; Warren, 2008).

In certain industries, this internal competition in the supply chain may improve the environmental performance of individual firms and of the supply chain as a whole, as competitive moves result in increased product durability and product multi-cycles (Kumar and Putnam, 2008; Atasu et al., 2009). However, this is only one dimension of environmental performance in closed loop supply chains. Frequently, there are additional logistic and industrial activities (remanufacturing, recycling) which also have considerable environmental impact (e.g. product dismantling). In addition, co-opetition in the forward and reverse supply chain is dynamic. It is multi faceted and evolves in action-reaction patterns with complex resource accumulation dynamics. It is difficult to determine a priori and generalise the long term business and environmental effects of competitive moves involving remanufacturing, even within very specific industries.

The assessment of the efficiency and effectiveness of such dynamic management processes is clearly a complex task due to the interdependence of the resource stocks and the associated flows (Morecroft, 2002). There is a corresponding difficulty in assessing the environmental impact of remanufacturing in this context of competition. In many cases, remanufacturing is associated with additional operations-strategy-dependent industrial and logistical activities, which have a considerable negative environmental impact.

A way of overcoming these difficulties is the use of dynamic models of resource-based competition (Großler, 2007; Mollona, 2002; Morecroft, 2002). In this chapter, drawing on this stream of strategy research, a system dynamics model of resource-based competition is used to conduct this explorative study, as it is the most appropriate means to artificially represent the context and capture the dynamics of resource stock accumulations (Mollona, 2002; Morecroft, 2007; Warren, 2008). It is the first time, that a dynamic perspective is adopted to examine the effect of patterns of operations-level strategic decisions related to the development of brand awareness, the accumulation of production experience. This perspective is also applied to tactical moves, such as order quantity rationing, on the financial, operational and environmental performance of the competitors (an OEM and a retailer acting also as remanufacturer). The research presented in this chapter concerns primarily sectors of functionality-seeking customers, such as the industrial equipment sector. Nevertheless, the results obtained are valid for other sectors with similar characteristics, which may have greater economic and environmental impact. In order to position the research a brief overview of the related literature of internal competition in manufacturing/remanufacturing supply chains is given in the following section.

3.3 Competition in Supply Chains

The environmentally benign supply chain, as a distinct supply chain research area has increasingly attracted the interest of many researchers over the last years (Seuring and Müller, 2008; Sarkis et al., 2011). In particular, there is considerable research in closed-loop supply chains and reverse logistics. Qualitative and quantitative methodologies have been used in addressing issues of network design and operations, assuming OEM's ownership of the reverse chain, or cooperating partners (e.g. Atasu et al., 2009; Blumberg, 2002; Carter and Ellram, 1998; Dowlatshahi, 2000; El korchi and Millet, 2011; Fleischmann et al., 2000; Guide et al., 2000; Heese et al., 2005; Jaber and El Saadany, 2009; Kumar and Putnam, 2008; Nenes at al., 2010; Őstlin et al., 2008; Robotis et al., 2004; Seitz, 2007; Srivastava, 2007; Thierry et al., 1995).

In quantitative studies, a variety of deterministic and stochastic models have been employed (De Brito and Dekker, 2003; Fleischmann et al., 1997; Fleischmann et al., 2001; Gharbi et al., 2008; Jayaraman et al., 1999; 2003; Savaskan et al., 2004; Tang and Grubbström, 2005), including system dynamics models which, however, have been built mainly for investigating purely operational issues (e.g. Georgiadis and Besiou, 2008; Spengler and Schroter, 2003; Vlachos et al., 2007).

Nevertheless, competition in remanufacturing supply chains has received very little attention, particularly in cases that involve firms that are partners in the forward supply chain (Atasu et al., 2008; Toffel, 2004). The majority of investigations in this area are concerned with the determination, or the justification, of the incentives of the OEMs for reclaiming materials and equipment (Kumar and Putnam, 2008; Seitz, 2007; Debo et al., 2005), as well as with their strategies of pre-empting the entry of third parties in the secondary (remanufactured items) market. In this line, Debo et al. (2005) examined the effect of incentives connected to the manufacturability of products, Őstlin et al. (2009) analysed the effect of product type on competition, Robotis et al. (2006) have considered different quality levels in secondary markets and Majumder and Groenevelt (2001) develop a two-period gaming model and show that an OEM and an independent remanufacturer should cooperate in keeping the return incentives for customers low in order to have profitable operations.

Building on Majumder and Groenevelt's, Ferguson and Toktay (2006) analysed the OEM's dilemma: remanufacture or launch a collection programme and pre-empt local remanufacturers. In their model, it is assumed that when the OEM does remanufacture, local remanufacturers are excluded, and that the OEM's new and remanufactured products, as well as those of the local remanufacturer, are distinguishable. They concluded that both strategies are viable depending on the specific cost structures. Extending the above research, Debo et al. (2006) considered competition among OEMs and showed that remanufacturing is more profitable for slowly diffusing products, while high sales of new and remanufactured products make the availability of flexible capacity more valuable.
In the same line, Richey et al. (2004), adopting a resource based view of competition, and

using an empirical methodology, investigated the importance of timing and resource commitment in introducing reverse logistics programmes, on the competitiveness of an OEM. They concluded that both have a positive effect. Finally, Atasu et al. (2008), using a model of a two-segment market (normal and "green") showed that remanufacturing can become an effective marketing strategy for an OEM, although there are cases where remanufactured products can cannibalise new product sales (especially when the OEM acts as remanufacturer).

Issue	Reference
Business strategy	Hart, 1995; Porter and Reinhardt, 2007; Jermier and Forbes, 2003; Matsumoto, 2009; Atasu et al., 2008; Atasu at al., 2009; Toffel, 2004; Debo et al., 2005; Őstlin et al., 2009
Operations strategy	Kleindorfer et al., 2005; Klassen, R.D., Vachon, S., 2003; Klassen, R.D., McLaughlin, C.P., 1996; Heese et al., 2005; Sarkis, 1995; Newman and Hanna, 1996; Burgos and Céspedes, 2001; Robotis et al., 2006
Closed loop supply chain and reverse logistics	Tibben-Lembke, 2002; Savaskan, C.R., Van Wassenhove, L.N., 2006; Savaskan et al., 2004; Seitz, 2007; Kumar and Putnam, 2008; Seuring and Müller, 2008a, b; Guide et al., 2005; Ferrer and Whybark, 2000; 2003
Supply chain operations research with system dynamics	Georgiadis and Besiou, 2008; Spengler and Schroter, 2003; Vlachos et al., 2007
Deterministic and Stochastic models	De Brito and Dekker, 2003; Fleischmann et al., 1997; Fleischmann et al., 2001; Ghabri et al., 2008; Jayaraman et al., 1999; 2003; Savaskan et al., 2004; Tang and Grubbström, 2005
Competition between OEMs	Majumder and Groenevelt (2001); Ferguson and Toktay (2006); Debo et al. (2006); Richey et al. (2004); Atasu et al. (2008)

3.1: Table: A selection of relevant strategy and operations literature

The literature review presented is summarized in Table 3.1. It indicates clearly that the case of competition between an OEM that recycles but does not remanufacture, and local remanufacturers, who are also retailers of the OEM's products, has not been considered yet. As it will be discussed in more detail in the following section, the distinct strategic feature of this case of co-opetition, in a resource-based perspective, is that competition concerns the *imitability* of existing resources, rather than the *development* of idiosyncratic new ones. Inevitably, the focus is on operations strategies for the management of the existing resources. In previous research, operations have been overlooked as a milieu of interventions, mainly because competition has been assumed to be market-based. In addition, markets and market segments have been defined statically (there was no flow of customers between market segments). Most importantly, the above survey indicates that, in previous research, no explicit consideration has been given to the effects of competition on the natural environment. After all, has been widely assumed to be the principal motivator for remanufacturing.

3.4 Dynamic resource-based co-opetition in supply chains with remanufacturing activities: Case presentation and research questions

The case used in this chapter, concerns supply-chain co-opetition which is frequently met in the suppliers of agribusiness industries, more specifically in the market of stainless steel tank-like equipment (fermenters, stabilisers, vinificators, oil and milk vats, etc.), which are mainly used in the food and alcoholic beverages industries (Adamides et al., 2008). In addition to the main storing barrel-like stainless steel tanks, these equipments include motors and electro-mechanical components, such as valves, shakers, sensors, etc., as well as heating and cooling jackets. The major producers in the market serve, through local distributors and retailers, customers of different scale, involved in different but related industrial activities (wineries, breweries, cooking oil producers, milk-processing cooperatives, etc).

Stainless Steel Tanks (SST) S.A. is one of these firms. It is based in Greece and is one of the largest manufacturers of stainless steel industrial equipment in the South East of Europe. (name is withheld for confidentiality). In addition to its standard range of fifty products, the firm undertakes the development and production of customised products and turn-key projects for the food and alcoholic beverages industries, as well as for other more demanding, including pharmaceuticals. These custom products (mainly breweries and micro-breweries) are built to order, and their components are forwarded and installed under the SST’s own responsibility. Other standard products are supplied and serviced by the retailing firms. The core production facility of SST is located at a distance of about 300 km from the capital city of Athens. The firm's downstream supply network includes a distribution centre/warehouse for supporting sales in the Athens metropolitan region, four regional distributors, as well as retailers all over Greece, and agents/resellers in five other nearby countries.

Fifteen years ago, the firm started a collection and recycling programme for large products for customers who wanted to renew their equipment. The actual collection and recycling was undertaken by a third party steel producer who was also the supplier of SST. Gradually, one of the SST's distributors located abroad, started remanufacturing small tanks (washing, treating oxidized areas, galvanizing, and replacing electro-mechanical parts) after collecting them from the retailers when customers renewed their equipment. Collecting small tanks, assessing their condition, transporting them to its manufacturing facilities and eventually remanufacturing has always been considered a very costly enterprise for SST, especially for foreign markets. However, as more customers were looking for more economic solutions, the reseller-turned-remanufacturer built up capacity for remanufacturing larger tanks. This constituted in effect a new supply channel of collected and reconditioned/remanufactured equipment parallel to the one used for recycling.

Although the OEM had initially set up the collection activity for economic and environmental reasons, at present, the reverse chain is mainly controlled by two distributors and a small number of large retailers situated near industrial districts, who remanufacture mainly small tanks (motivated by purely economic reasons) received in a repairable condition. The brand name of the OEM per se is not strong enough to attract customers seeking primarily functionality from remanufactured equipment offered at lower prices, and/or with higher availability (Atasu et al., 2009). It is often the case that brand name attractiveness and consumer trust are outweighed by the proximate, sometimes personal, relationships and the trust built between distributors/retailers, that also function as the sole remanufacturers that serve particular geographic areas. In addition, close customer-retailer relationships reinforce market segment boundaries among competing OEMs, therefore customers rarely switch from one brand to another.

The SST case is a typical situation of internal competition in a remanufacturing supply chain, in an industry characterised by functionality-seeking customers. In this context, there are no other plausible options for SST than competing on operations. The operations strategy of the OEM cannot deviate from the objectives of quality, cost, and dependability (on-time delivery), while similar objectives drive the retailers' remanufacturing-related strategic decisions. In addition, the OEM desires to adhere to its initial environmental goal of collecting used products by reviewing its competitive moves against environmental performance metrics. Nevertheless, the environmental performance of the entire supply chain is of interest to a broader audience of policy makers and regulators, when justification or review of incentives and restrictions to business activity are of concern.

3.5 Strategic analysis of the case – development of research questions

Clearly, in situations that resemble the case of SST, the strategies of local remanufacturers are directed towards achieving market performance which is comparable with, or superior to, that of the OEM, as far as product cost/price, on-time delivery, and proof of good functionality are concerned. The achievement of these performance objectives depends on OEMs resources and activities and on the levels of the resource stocks that the remanufacturers own. These resources are: remanufacturing capacity, trust (trust is a matter of geographic proximity and frequent face-to-face interaction), and market segment size. The last two have a mutually reinforcing relationship, so that the size of customer base accounts as a performance metric for both.

To protect their market position, OEMs are obliged to manage the levels of their resource stocks which are responsible for the performance of their products as far as cost/price, availability and image-of-functionality are concerned (Dierickx and Cool, 1989). The OEMs resources include manufacturing capacity, production know-how, and product technology. The stock levels of the last two resources are determinants of the OEM's product brand name, which may be assumed to be equivalent to, and measured by, the level of the resource stock customers/sales. Recycling technology and recycling capacity are also resources of OEMs. (In the SST case, the OEM recycles when local manufacturers do not absorb all used products.)

The levels of the resource stocks associated with processing capacity contribute to the operations objectives of cost (due to economies of scale) and dependability (on time delivery). The production know-how resource (more specifically, its "improved production" dimension) also contributes to cost reduction through the learning effects exhibited in both competitors. Speed and flexibility are of less importance in this particular case, while quality can be linked to the production know-how resource stock which increases with cumulative production. Since quality is not a direct order winning criterion (Hill, 2000), the net effect of the operations-related quality improvement (error-free processing) with cumulative production is mirrored in the reduced product unit cost, through its direct association with the resource stock of production know-how. Hence, effectively, both competitors compete by managing their capacity to improve dependability and costs, and by additionally improving production know-how and production efficiency to attain even lower costs. Customer base is a resource that also contributes to their competitiveness, however it depends on product cost/price and availability and develops gradually, just following the historical evolution of the other two performance metrics.

To manage its resource stocks, an OEM needs to manage its resource accumulation processes. It can adjust its resource flows instantaneously but the it takes time for the flow to have an effect on the firm's stocks (Dierickx and Cool, 1989). Therefore, competition on resource stock levels concerns the management of these flows. In every case, it is only through certain patterns of flows that stocks can achieve desired levels. Preventing a competitor to achieve the same, or higher, levels of resource stocks is possible by either accelerating the flow of resources owned, or slowing down those of the competitor/imitator (if possible), or both.

In this context, the management of tangible and intangible resource stocks (Wernerfelt, 1984) associated with the specific objectives of both co-opetitors is accomplished at the level of operations by regulating the associated resource flows through decision making in four broad operations strategy areas (Slack and Lewis, 2002): (i) capacity management decisions for regulating the capacity development rates for the production of OEM's new products, for OEM recycling, and for remanufacturing by the retailers, respectively, (ii) supply chain and logistics management decisions which concern the flow of products (new and used) in the supply chain, and the way capacity is being used, (iii) organisational learning and operational improvement decisions which concern the rate of improvement of manufacturing, remanufacturing, and recycling operations and, consequently, the rate of accumulation of the production know-how resource stock, and (iv) decisions on the rate of acquisition and use of product and process technology. Nevertheless, in this last option, both competitors have equal access to product and process technology factor markets, and products are not technologically complex. Hence, technology cannot be considered as a distinctive strategic decision area which contributes significantly to any operations strategic objective.

In the Dierickx and Cool (1989) perspective on competition, there are certain characteristics of accumulation processes which are important for the strategic behaviour (decision making) of competitors in the case considered in this thesis. The characteristic of time compression diseconomies (very difficult to achieve the same level of stock in much less time) suggests the adoption of an operations strategy of pre-emptive resource development by the OEMs, and the development of faster accumulation processes by the imitators (remanufacturers). The same pre-emptive strategy seems appropriate when OEMs aim at taking advantage of asset mass efficiencies (adding increments to an existing stock is facilitated by already possessing high levels of the stock), while, the interconnectedness of resource stocks that determines the dynamics of accumulation in the forward channel of the supply chain, when managed appropriately, may reinforce or slow down the accumulation of the resource stocks of both co-opetitors (Dierickx and Cool, 1989).

In theory, production improvement programmes that rely on learning-by-doing tend to increase the efficiency of production and reduce costs with cumulative production. Thus competitors can take advantage of the time compression diseconomies associated with them. However, in the case studied, the OEMs cannot rely on time compression diseconomies. This is based on the fact that while they have been manufacturing for a long time before retailers started remanufacturing, the latter can easily reach the same effective level of production efficiency as they have a relatively simpler manufacturing task. Hence, remanufacturers will be in a superior position, as far as cost and dependability are concerned, and it will be the OEMs that will have to improve their efficiency.

Anticipating this situation, the OEMs can either (i) manage strategically their production capacity and know-how by pre-emptively developing recycling capacity and/or accelerating their learning (improvement of production), so that more used products are processed, and recycling contributes more to the cost reduction of brand products (asset mass efficiency), and/or (ii) taking advantage of the dependence of the retailers on them, and intentionally rationing on their orders, at regular or irregular time intervals. In this way, the regulation of new products flow to the market, creates a delayed oversupply or undersupply of used products and disrupts the retailer's remanufacturing operations. Thus, it is anticipated that co-operating retailers will be either short of capacity, have order backlogs and will be forced to reduce their collection effort and forward the products collected for recycling to the OEMs, or will suffer capacity underutilisation and lower competitiveness from higher costs. The effectiveness of these strategies is investigated in the following sections, where answers are provided to the following questions:

i. Does early recycling capacity development by the OEMs make their operations more competitive or environmentally benign?
ii. Does order rationing by the OEMs result in the retailers experiencing remanufacturing overcapacity or/and undercapacity? Does it improve the environmental performance of the supply chain?
iii. Do more intense production improvement efforts by the OEMs increase their competitiveness in comparison to that of the retailers? Do they improve the environmental performance of the supply chain?

3.6 Relevant Methodologies

In order to investigate the above research questions, a system dynamics simulation model based on the resource based view (RBV) was developed with two co-opetitors, the OEM and one retailer-remanufacturer. The theory of RBV and system dynamics methodology are briefly discussed in the following sections, before presenting the model and results.

3.6.1 The Resource Based View

The Resource Based View (RBV) is one of the most influential theoretical frameworks for understanding strategic management about the firm and its operation in a competitive environment (Barney et al., 2001). Firms are viewed as heterogeneous, complex ensembles of resources, and the framework is used to investigate how superior firm performance and competitive advantage emerges from these unique configurations of resources (Morecroft 2002). The RBV has been extended to include natural resources (Hart, 1995) and dynamic capabilities (Helfat and Peteraf, 2003; Helfat et al., 2007).

In the RBV the fundamental determinants of firm performance are firm specific capabilities and assets, and the existence of isolating mechanisms (Rumelt, 1984; Teece, 1984; Wernerfelt, 1984). Competitive advantage stems from the firm's idiosyncratic resources (Teece et al., 1997). Resources that are scarce, immobile, inimitable and unsubstitutable, durable, and complementary are thought to contribute to the firm's competitive advantage. This is supported by empirical evidence showing that intra-industry differences in profits are greater than inter-industry differences, which strongly suggests the importance of firm specific factors and the relative unimportance of industry effects (Rumelt, 1991; Hansen and Wernerfelt, 1989).

The RBV attempts to explain how all the resources that are owned by, or are available to a firm, contribute to its operations. A thorough understanding of a firm's resources can then be translated into specific and concrete operations strategy decisions that guide the accumulation of firm capabilities (Slack and Lewis, 2002). This is required as firms, at least in the short run, are to some extent stuck with the resources they have. The reason for this is that firms lack the organizational capacity to develop new competences quickly and some assets are simply not readily tradeable, for example tacit know how and reputation (Dierickx and Cool, 1989). Rents thus tend to flow not just from the asset structure of the firm and their characteristics but also by the firm's ability to reconfigure and transform (Teece et al., 1997). Consequently, the resource based perspective also invites consideration of managerial strategies for developing new capabilities. If economic profits come from the control of scarce resources, then it follows that issues such as skill acquisition, the management of knowledge and learning become fundamental strategic issues (Shuen, 1994).

Another interesting contribution of the resource-based view relates to the issue of "trade-offs" in operations strategy (Gagnon, 1999). Using a "market-based" view of strategy, decisions such as "factory focus" are used to help firms select one or two key competitive dimensions, and then ask operations management to meet the appropriate order winners and qualifiers, assuming a fairly stable competitive environment (Skinner, 1976). However, Schroeder and Pesch (1994) have shown that this kind of trade-offs cannot be sustained for a long time, since as soon as a firm has mastered some focus, changes in the environment can reduce its relevance rapidly. This marked the entry of operations strategy into the hyper-competition era, where strategies and capabilities will inevitably become short-lived in global industries (D'Aveni, 1994). As Corbett and Wassenhoff (1994) argue, the only way to keep operations strategy relevant under hyper-competition is to forget trade-offs.

3.6.2 System Dynamics

System dynamics was developed in mid 1950s originally for understanding industrial processes (Forrester, 1961) and policy analysis and design (Forrester, 1969). Its scope of application has broadened considerably, and includes business, supply chain and other issues (Morecroft, 2007). System dynamics is part of systems theory and provides a tool for understanding the dynamic behaviour of complex systems. Its core tenet is that the structure of the system under study, which includes interactions between system elements and delays, is just as crucial in determining system behaviour with the system elements themselves. The system dynamics methodology, enables the construction of models for analysing complex problems that involve such interactions between the variables of a system(Sterman, 2000). It provides a way of formalizing them, even when they are initially expressed in qualitative terms, and analysing their influence on the behaviour of the system.

3.7 Dynamic resource-based co-opetition in supply chains with remanufacturing activities: Research approach and assumptions

In order to investigate the four research questions outlined in section 3.5, a system dynamics simulation model of two co-opetitors (OEM and retailer-remanufacturer) has been developed. The operational characteristics and the assumptions of this model were based on the case of forward and reverse channels of the supply chain of the industrial equipment sector mentioned in section 3.5, and appropriate modifications were introduced to widen its generality. Hence, the model represents a single product, two-segment (primary and secondary) market, served by a retailer that sells the brand name product of the OEM, as well as its own non-branded remanufactured product. Competition among OEMs is excluded from the model.

The retailer sells used products after collecting and reconditioning/remanufacturing OEM used products from the market. The retailer is assumed to serve a geographically-bounded market in which there is no competition with other retailers – a realistic assumption for this industrial equipment case. The forward supply chain is assumed to operate in a pull mode, i.e. orders are placed to the OEM and shipments are made in a lot-for-lot basis. The fraction of used products which is collected by the retailer (the rest is assumed to be disposed of to the environment) does not depend on the type of product or other factors (Majumder and Groenevelt, 2001), but is restricted to the total re-processing capacity of the system (retailer remanufacturing and OEM recycling).

It is assumed that the retailer is the sole collector of after use products as the volume and bulkiness of the products makes their collection by the OEM uneconomic. Although the acquisition cost of after-use products is the same for both competitors, the OEM prefers to recycle than to remanufacture aiming at shrinking the secondary market. Hence, collected used products are either remanufactured by the retailer, when it has the required capability and capacity, or, forwarded to the OEM for recycling. The materials recycled are then used in the production of new products. The retailer does not recycle.

The primary market consists of customers that are willing to pay a premium for brand name products and are willing to wait for them if they are not readily available. The secondary market is formed by customers who are indifferent to the brand name. They equally value price and availability, and thus, under specific conditions, buy remanufactured products. The sizes of the two segments are not fixed, i.e. there is a bidirectional flow of customers between segments according to the difference in the attractiveness of new and remanufactured products. Product attractiveness is an aggregate measure that combines brand strength, price and availability. Operationally, it depends on the level of the resources of co-opetitors. Brand strength is proportional to the firm's customer base, and price and availability are a function of production capacity. The strength of the brand of remanufactured products increases with sales volume as customers gradually trust the products of the retailer. It is assumed that, initially, the secondary market is only a small fraction of the entire market, but it grows slowly at the cost of the brand new products market as more remanufactured products are available. The entire market grows annually at a fixed percentage rate.

If there was no remanufacturing, the retailer and the OEM would be fully cooperating partners in the forward supply chain. Even when involved in remanufacturing, the retailer has an incentive to fully satisfy the demand of the primary market (with OEM’s brand new products) for mark up collection, and for augmenting its prestige and customer loyalty. Due to the retailer's proximity to the market, it is more sensitive to signals regarding the potential of the secondary market. On the basis of these signals, it initiates the development of remanufacturing operations/capacity with a certain level of commitment and risk. Clearly, the degree of commitment depends on the size of the secondary market relative to the primary one. By committing more resources, the retailer improves its operations and becomes more efficient in collecting and processing after-use products. Hence, it is assumed that the collection effort of the retailer is directly proportional to the commitment with which its proprietary remanufacturing operations are initiated. The effort it undertakes leads to an increase in the collection rate of used products, and triggers demand for remanufacturing capacity. The retailer reviews its capacity every financial quarter and then decides whether to expand it or not, based on remanufactured product sales, inventory coverage, and existing capacity.

The OEM follows a similar capacity management policy but it can build recycling capacity faster than the retailer. Initially, the remanufactured products are assumed to be sold at a lower price compared to new ones. Product pricing is dynamic and costs are influenced by improvement initiatives and learning in the manufacturing, remanufacturing and recycling processes. For example, in a base scenario, the retailer’s initial unit remanufacturing cost is assumed to be half the unit production cost of the OEM, while it further decreases as the remanufacturing activity increases. In addition, the OEM’s production cost is assumed to reduce with the amount of used products recycled, as recycled materials substitute new ones. This is based on the realistic assumption that, on average, the costs of used products, their collection and remanufacturing are roughly equal to the corresponding costs for recycling by the OEM (recycling costs include much higher transportation costs).

The system's causal loop diagram of the conceptual model is presented in Figure 3.2. The systems endogenous dynamics are governed by the reinforcing (plus sign) and balancing relationships (minus sign) among its elements and the structure of its loops. The “Pricing policy” and “Capacity for new” are assumed to be endogenous variables, which do not contribute to the OEM’s operations strategies repertoire. Its decision making includes variables for the learning effort, initial recycling capacity and rationing to the retailer. The OEM aims at increasing the demand for its branded products and reducing that of the secondary market. This entails increasing the returned used products of retailers for recycling. This can be done by: (i) accelerating its learning loop (LL), (ii) by taking advantage of the delay between sales of brand new products and used products available for remanufacturing and/or recycling (top of diagram), (iii) by preempting the retailer and having early recycling capacity that will enable its operations to create economies of scale and more attractive products. Figure 3.2 shows that the environmental impact that different strategies (different decision variables settings) have on the entire supply chain can be assessed by measuring the amount of recycled and (re)used materials, the additional industrial activity (pollution) introduced into the system, and the additional transportation and warehousing that is required for recycling and remanufacturing.

The causal loop diagram of Figure 3.2 has been implemented in a system dynamics model which is described in the following section. It was used to explore the effectiveness and efficiency of the intended operations strategies of the OEM, as well as the effect that these have on the environment.

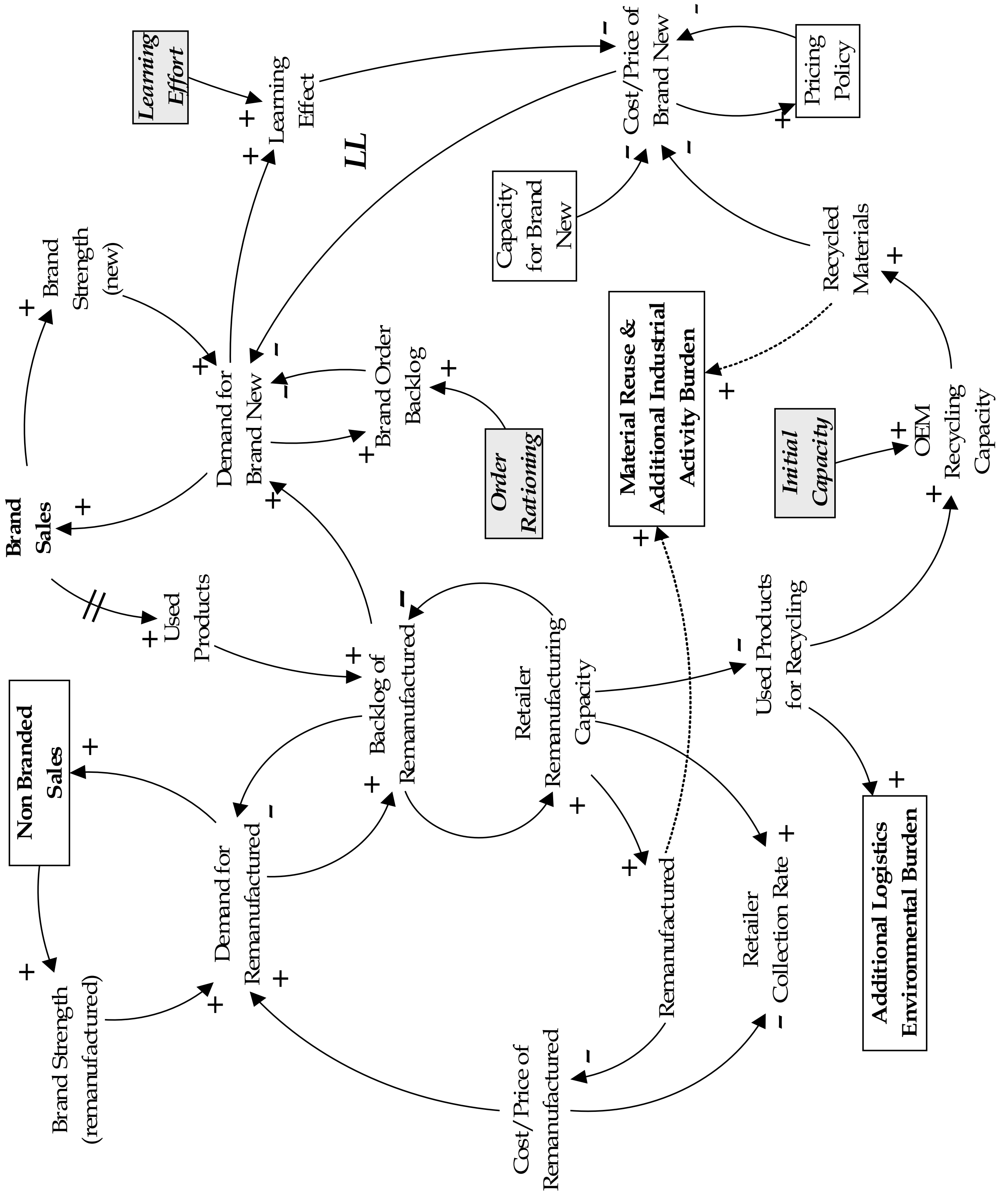

Figure 3.2: Causal loop diagram of the model

3.8 The System Dynamics Model: State 1

The core stock and flow structure of the system dynamics model developed is presented in Figure 3.3. In the symbolic language of system dynamics models, resources are modelled as stocks and resource accumulation and depletion processes as flows (Morecroft, 2007). Usually, the rates of activity (or process) execution are regulated by other variables, as well as by the levels of resource stocks.

In the model, the flow of customers between the two market segments is bidirectional and is regulated by the *Market_Shift* which depends on the relative attractiveness of the two segments (*Retailer_Attractiveness* and *OEM_Attractiveness*). Clearly, the attractiveness of the products of each co-opetitor reflects its set of resources, as well as the level of their utilisation (where appropriate). Both variables are a function of price and availability, and in each case the price is linearly related to the unit product cost, which is a function of cumulative production learning (learning – experience negative exponential function). More specifically,

$$\mathit{OEM\ Brand\ Attractiveness} = \frac{\mathit{Retailer\ Order\ Backlog}}{\mathit{Total\ Demand}}\, x\, \frac{\mathit{Retailer\ Unit\ Price}}{\mathit{OEM\ Unit\ Price}} \qquad (1)$$

$$\mathit{Retailer\ Attractiveness} = \frac{\mathit{Brand\ Order\ Backlog}}{\mathit{Total\ Demand}}\, x\, \frac{\mathit{OEM\ Unit\ Price}}{\mathit{Retailer\ Unit\ Price}} \qquad (2)$$

$$\mathit{Market\ Shift\ Magnitude} = \frac{\max(\mathit{Retailer\ Attract} - \mathit{OEM\ Attract}, \mathit{OEM\ Attract} - \mathit{Retailer\ Attract})}{\mathit{OEM\ Attractiveness} + \mathit{Retailer\ Attract}} \qquad (3)$$

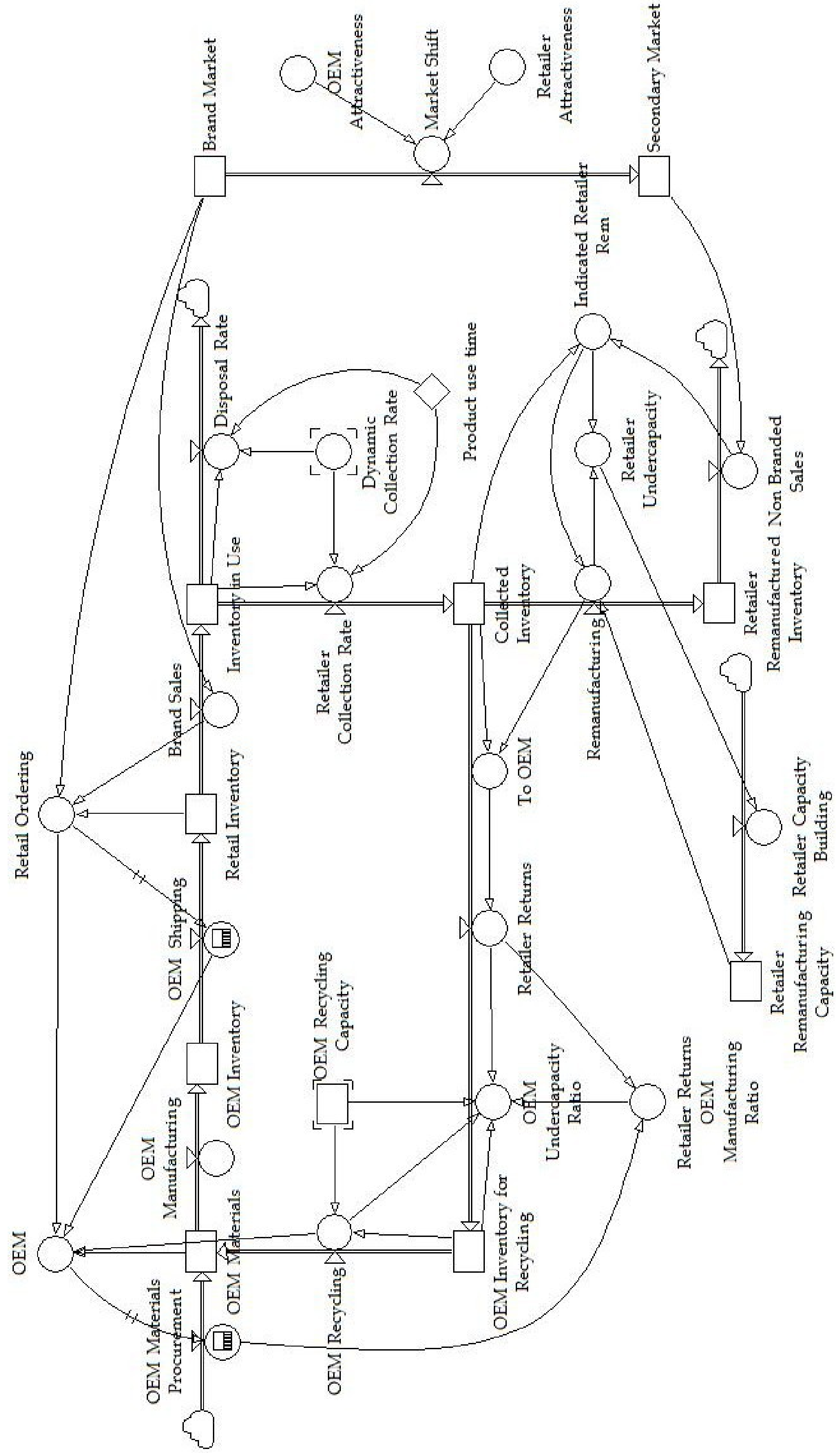

Figure 3.3: Stock and flow structure of the supply chain model in state 1

The market shift direction depends on the attractiveness differential. The total demand is the sum of demand for brand new and remanufactured products. The process of building remanufacturing capacity (product units per year) is connected to the operational processes of end-of-life product collection, remanufacturing, and/or forwarding to the OEM (lower part in Figure 3.3). In the model, the retailer is assumed to collect all used products which are stored temporarily (*Collected_Inventory*) before remanufacturing them (*Remanufacturing*). Remanufactured products are stored before being absorbed in the market (*Retailer_Remanufactured_Inventory*). If the retailer lacks remanufacturing capacity, collected products are forwarded to the OEM for recycling (first stored in *OEM_Inventory_for_Recycling* and then through to *OEM_Recycling* Figure 3.3). The OEM's recycling operations are also constrained by capacity. Hence, when both co-opetitors lack capacity, used products are disposed of and exit the system.

In the model, the retailer adds remanufacturing capacity according to its *Retailer_Undercapacity* which is given by:

$$Retailer\,Undercapacity \;=\; Retailer\;Indicated\;Remanufacturing - Prospective\,Capacity \qquad (4)$$

Prospective_Capacity is the capacity planned by the retailer, which becomes available/effective with a certain delay. The *Retailer_Indicated_Remanufacturing* is the capacity required for supplying demand provided that the collection rate is sufficiently high. It is the level of production activity the retailer must maintain in order to keep up with the demand for non-branded products, assuming a constant collection rate. As indicated in the description of the conceptual model above, the level of capacity of the retailer is sampled quarterly, and a decision for adding (or not) capacity is taken on the basis of the annual average requirements. The *Remanufacturing* variable is the same activity, subject to collected inventory and/or capacity constraints.

In modelling the OEM's operations, the OEM adds recycling capacity based on the rate of used products forwarded by the retailer (*Retailer_Returns*), current capacity

(*OEM_Recycling_Capacity*), and the potential that the returns represent. The latter is modelled by the variable *Retailer_Returns_OEM_Manufacturing_Ratio*, which is the ratio of the rate of product returns to the OEM, over the rate of products being manufactured. Operationally, recycling reduces the amount of required materials and production activity, as well as the environmental impact of new product production by 30% per product manufactured. Similarly, the environmental burden of the remanufacturing activity is assumed to be in the region of 30% of that of the normal production activity required for producing brand new products. The forward supply chain (upper part of model of Figure 3.3) operates in a 'quasi-pull' mode. The product use period is assumed to be three years, and the initial values for the price of brand and remanufactured products were set to 1.3 and 0.8 monetary units. In addition, initially, the secondary market is assumed to be 10% of the primary one, which is initially set at 900 units per year. Both markets grow at a rate of 7% annually.

In calculating the environmental effect of transportation in the model, based on the case described in Section 3.4, the distances between the market and the retailer, and the market and the OEM were set to 60 Km and 300 Km (Figure 3.4). Component suppliers are assumed to be at a distance of 60 Km for both co-opetitors. It is further assumed that the average product unit volume is 1000 lt, while the average part volume required for remanufacturing is 30 lt. In both cases, the environmental impact is calculated on a volume x distance basis.

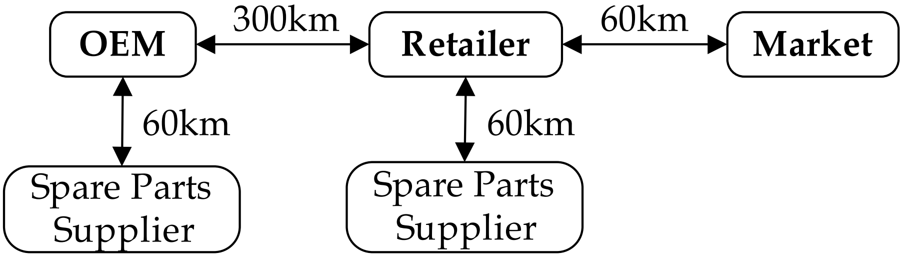

Figure 3.4: Supply chain topology

The behavioural and structural validity of the model was tested against the behaviour and the structure of SST's supply chain (reproduction of selected behaviours), after scaling parameters appropriately. In addition, a variety of methods, such as the dimensional consistency test and the extreme value test, were used for validating and verifying the model (Sterman, 2000).

3.9 The Competitive and Environmental Effects of Operations Strategies

To investigate the competitive and environmental effects of the operations strategies of the OEM, a simulation study of the model described above was conducted. The simulation time horizon was set to 6 years with a time step of 0.5 weeks. The research aim was to investigate the effect that pre-emption in recycling capacity management, order rationing in supply chain relations, and investments in learning and improvement initiatives have on the economic and environmental performance of the OEM and the supply chain.

The OEM decision variables that were used for implementing strategies in the model (the decision variables, otherwise) were: (i) *Initial_OEM_Recycling_Capacity* (level of pre-emptive capacity) with values ranging from 1 to 120 product units per year, (ii) *Rationing_Level* with values ranging from 0% to 60% of the order placed by the retailer, and (iii) *OEM_Learning_Exponent* (the exponent's value in the negative exponential learning function) having values in the range 0.005 to 0.035.

Simulations in every case were executed for sizes of initial brand product demand ranging from 300 to 900 units per year. The effect of each of the three potential strategic moves implied in the research questions of Section 3.5 was assessed by running the appropriate simulations and by observing the behaviour of the output variables listed in Table 3.2. In each case, the environmental effects are also assessed. Table 3.3 lists the formulae of output variables.

Variable Name	Description	Units
1. *Total_Brand_Sales*	Total units sold in forward supply chain	Scalar
2. *Total_Remanufactured_Quantity*	Total units remanufactured by the retailer	Scalar
3. *OEM_Competitiveness*	Retailer REM Unit price / OEM Unit price	Dimensionless
4. *Retailer_Competitiveness*	OEM Unit Price / Retailer REM Unit price	Dimensionless
5. *Remanufacturing_Capacity*	Retailer Remanufacturing Capacity	Product units/year
6. *Remanufacturing_Capacity_Utilization*	Average Capacity Utilization	Percentage
7. *Total_Production_Activity_ Environmental_ Impact*	The environmental effect of brand production, recycling and remanufacturing.	Average product unit production equivalent in Kg
8. *Total_Material_Use*	Total material quantity used in brand production, recycling and remanufacturing	Average product unit equivalent mass in Kg
9.*Total_Material_Disposed*	Used products, and disposed materials in brand production, recycling and remanufacturing	Average product unit equivalent mass in Kg
10. *Environmental_Impact_of_OEM_ Logistics*	Impact of OEM logistics of recycling operations.	litres x km
11. *Environmental_Impact_of_Retailer_ Logistics*	Impact of retailer logistics of remanufacturing operations.	litres x km

Table 3.2: The system dynamics model output variables

Variable Name	Calculation
1. *Total_Production_Activity_ Environmental_Impact*	*OEM_mfg* x *Contribution_of_New_Products_to_Activity* + *Contribution_of_Recycled_Product_to_Activity* x *OEM_ Recycling* + *Contribution_of_Remanufactured_Products_to_ Activity* x *Retailer Remanufacturing*
2. *Total_Material_Use (at any processing activity)*	*OEM_Materials_Procurement* x *Production_Materials* + *OEM_Recycling* x *Recycling_Materials* + *Retailer_Remanufacturing* x *Remanufacturing_Materials*
3. *Total_Disposed_Material*	*Disposal_Rate* + *OEM_Recycling* x *Recycling_Disposed_Material* + *Retailer_Remanufacturing* x *Remanufacturing_Disposed_ Material*
4. *Environmental_Impact_of_OEM_ Logistics*	*Dist_Supplier_OEM* x *OEM_Recycling* x *Vol_Spares* + *(Dist_OEM_Retailer* + *Dist_User_Retailer)* x *OEM_Recycling* x *Vol_Reverse*
5. *Environmental_Impact_of_Retailer_ Logistics*	*(Dist_OEM_Retailer* + *Dist_Supplier_OEM)* x *Retailer_ Remanufacturing* x *Vol_Spares* + *Vol_Reverse* x *Dist_User_Retailer* x *Retailer_Collection_Rate*

Table 3.3: Environmental impact functions

OEM_Competitiveness and *Retailer_Competitivess* were chosen as the two most indicative variables to measure the performance of the OEM and that of the retailer. Although both are economics-oriented measures, they are directly related to operational performance, as, in the model, competitiveness and price are directly related to cost. Cost is calculated from operations variables, the latter being directly influenced by the strategies of the OEM (the strategy of the retailer-remanufacturer is constant). The unit prices of the OEM's products depend on the overall production cost. This is directly related to the performance of recycling, and to the cost of production of new products. The more used products are recycled, the less the production cost becomes, because recycling becomes cheaper (learning effects) and more materials are used in the production of new products whose unit cost is a function of the cumulative production. The greater the cumulative production of OEM is, the lower the amount of remanufactured products sold (the OEM has a pull production system) and the higher the cost of remanufactured products (Figure 3.2).

A variety of tests have been carried out in order to verify and validate the model (Sterman, 2000). A fundamental test was verifying that the time step chosen for the simulation was adequate in terms of minimizing the integration errors in the model. The choice of the time step was informed by the shipment delay with a value of 1 week which was the smallest delay in the model. Furthermore there are no point decisions implemented in the model with "if … then" functions. The Euler method of integration was chosen because the dynamics of interest in the model are slow relative to the time step. Production and remanufacturing as more other flows concern annual rates. Thus along with the check for integration errors the time step was set at 1/8 week.

The test for validity of the model involved several tests. Among those used were the dimensional consistency test and extreme value test where the model's behaviour was tested under high or zero forcing. For example with no collection effort on the part of the retailer there is no inventory flowing back through the reverse supply chain and no extra capacity is being built apart from that already in place. With zero materials procurement on the part of the OEM - producer, the production flow in the forward supply chain is sustained only by the recycling of collected materials and stocks are considerably lower.

Another test that was carried out was to implement complete rationing on the part of the OEM which eliminates the inventory in the supply chain. Further tests were implemented to ensure that there were no negative orders, shipments, manufacturing, remanufacturing or recycling activities and that mass is conserved in every instance. Care was taken to implement functions that use decision information readily available to managers in real situations (the "Baker criterion", Sterman, 2000, p 516).

3.10 The Effect of Rationing

In the base scenario it is assumed that the OEM rations the shipments to the retailer for a period of six months. Setting different rationing frequencies and rationing duration did not significantly affect the behaviour of the model. Simulations of scenarios indicated that, order rationing seems to have a decreasing effect on the total (6 year) sales of brand products, irrespective of the relation of the size of the brand market to that of the remanufactured products market. Figure 3.5a below shows the effect of rationing on total brand product sales for large (900 units) and small (300 units) initial brand product markets, for stable and growing markets. As expected, the total sales of new products are greater in larger brand markets. The total quantity of remanufactured products is not affected by rationing when the size of the secondary market is only a small fraction (1/9th) of the brand market. Rationing begins to have an effect when the initial size of the brand market is reduced from 900 to 300 units for both stable and growing markets (Figure 3.5b). This is because this strategy of the OEM succeeds in starving the new products market and subsequently, after some time, the remanufactured products market.

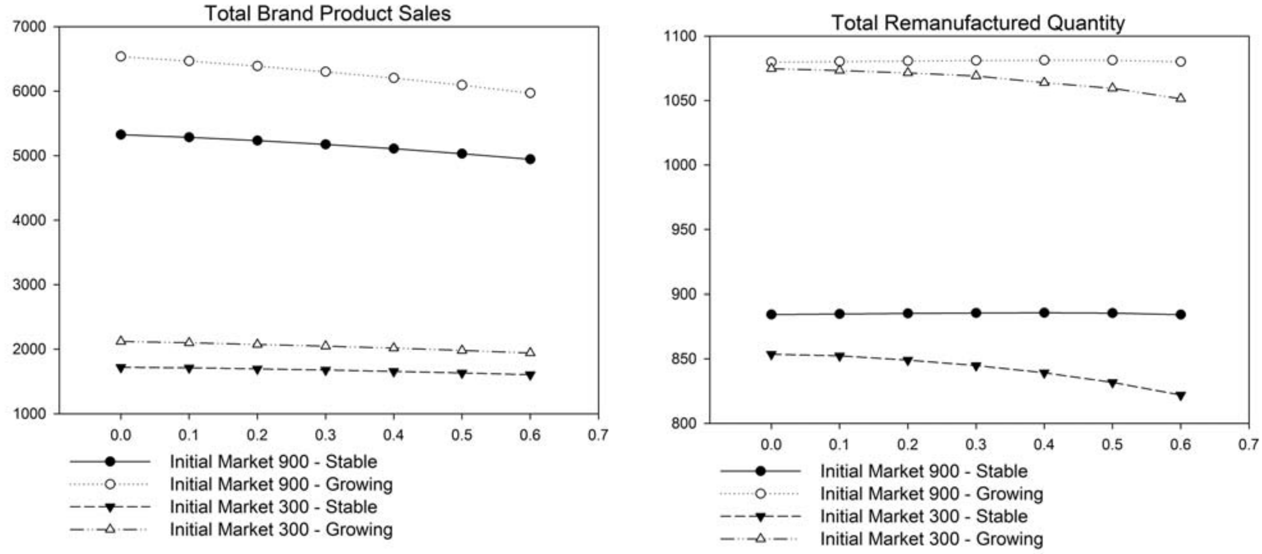

Figure 3.5: The effect of rationing (% of quantity shipped) on a) the total brand product sales, and b) the total quantity of remanufactured products in small and large initial markets, both stable and growing

The price-based competitive performance of the OEM decreases with rationing (and initial market size) because backlogs build up, the production of brand new products is slowed down and learning effects are reduced. Lower production levels result in slightly higher brand product prices and the OEM is more competitive in stable markets than in growing ones (Figure 3.6a). This makes sense as the expanding market provides an increased stream of used products (even when the OEM is rationing) and thus offers to the retailer/remanufacturer a better business opportunity. When the remanufactured products market is a large fraction (1/3rd) of the brand products market, the OEM's scale of production provides him with a small comparative learning advantage to the retailer. This is because both markets are assumed to grow at 7% annually, and it takes some time for the difference in their size to have a discernible effect in cumulative production and remanufacturing levels.

Regarding the effect of rationing on the remanufacturer's capacity utilisation, when the OEM is not rationing, capacity utilisation ranges from 70% for a large initial market (900 product units) to 85% for a small one (300 product units). This trend holds for both stable and growing markets. Rationing seems to have a small impact on capacity utilisation only in small (stable or growing) markets (Figure 3.7). Utilization increases because the retailer actually builds less capacity. In these settings rationing can starve the brand market and thus it has a delayed impact on the collection rate of the retailer. As a result, there is less remanufacturing activity in settings of small brand markets.

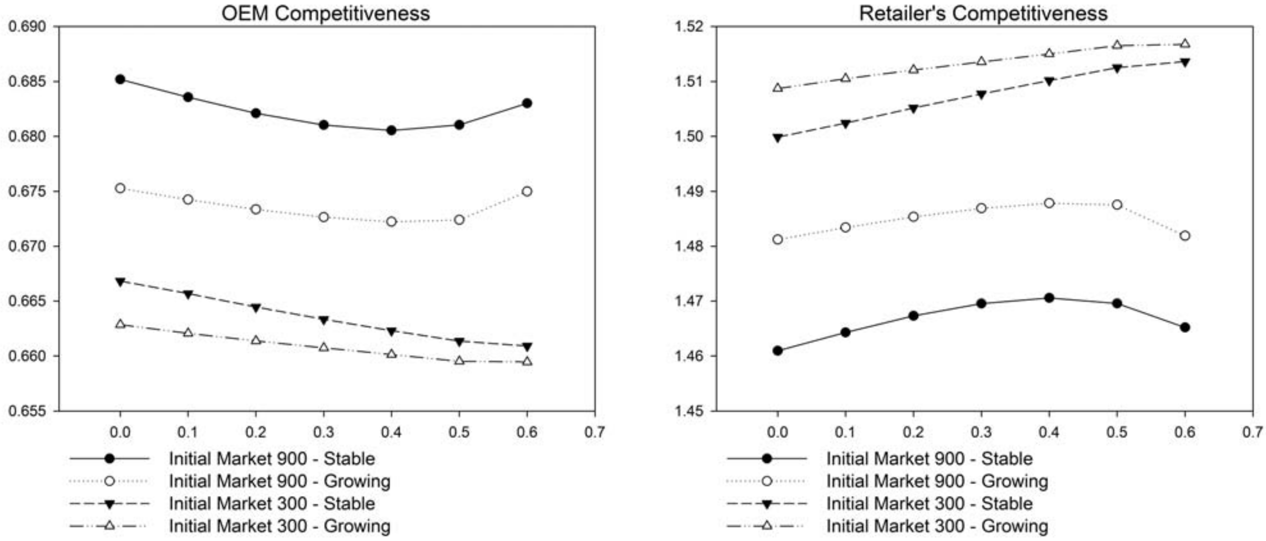

Figure 3.6 The effect of order rationing on the competitiveness of a) the OEM and b) the retailer/remanufacturer, in small and large initial markets, both stable and growing

Regarding the environmental effects of rationing strategies, there is a marginal improvement of the environmental performance of the supply chain as the percentage of

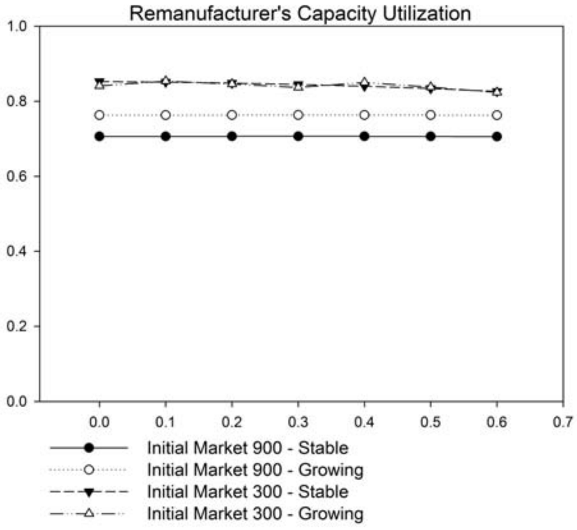

Figure 3.7: The effect of order rationing on the remanufacturer's capacity utilization, in small and large initial markets, both stable and growing

rationing increases (less production and consequently less environmental effects) (Figure 3.8). This improvement is more pronounced in large brand markets. Market size per se is a more important factor as it is directly connected to production activity, use of materials and quantities disposed.

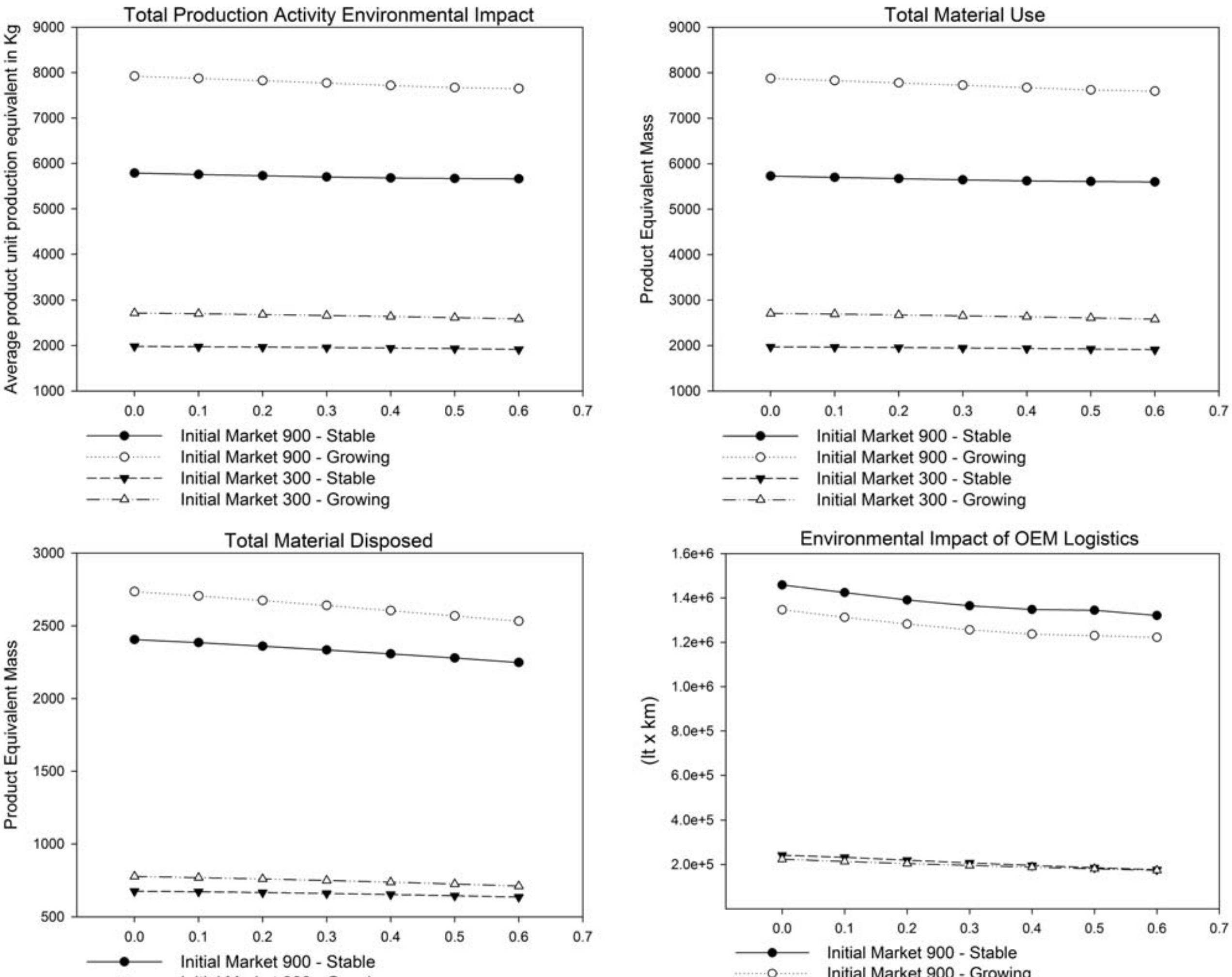

Figure 3.8: Supply chain environmental indicators with rationing

3.11 The Effect of Initial Recycling Capacity

Varying the OEM's initial (pre-emptive) recycling capacity only, the competitiveness of the OEM is higher in large brand markets, while that of the retailer is higher in small ones (Figure 3.9). Increasing the initial recycling capacity increases the OEM's competitiveness and reduces that of the retailer. This is because the use of the recycled materials contributes to the reduction of the production costs of new brand products. Figure 3.9 presents the values of competitiveness at the end of the 6-year simulation period. In this six year period, the early availability of recycling capacity locks the OEM in a situation where inventory for recycling takes time to build up. As capacity is added according to the inventory of the used products forwarded by the retailer, more recycling capacity is needed towards the end of the 6-year period. Thus while early recycling capacity increases the OEM's competitiveness temporarily, in the end the OEM is worse than in the case of no initial capacity.

Early recycling capacity reduces the OEM's average recycling capacity utilization (it also reduces with market size). This is because the retailer's shipments of used products result in underutilised recycling capacity, as the retailer first keeps the quantities it requires and builds capacity accordingly and then ships the remaining quantities to the OEM. So the retailer remains unaffected by the OEM's initial capacity. The remanufacturing capacity utilization remains relatively high because the retailer adjusts its capacity development to brand products market size. That is, in small brand markets it develops less capacity and remanufactures smaller quantities.

The environmental performance is presented in Figure 3.10. Clearly, increasing the initial recycling capacity has the opposite effect than rationing. The OEM becomes more competitive at the expense of the retailer and delivers more products in the market as demand is greater for brand new products than for remanufactured (the retailer "struggles" to develop capacity for remanufacturing). As a result, the remanufacturing loop weakens and more used products are transported for recycling. In addition, the results of the simulation experiments indicate that the initial recycling capacity does not affect the retailer's remanufacturing capacity, total remanufactured quantity, and capacity utilisation. Thus its remanufacturing operations remain unaffected.

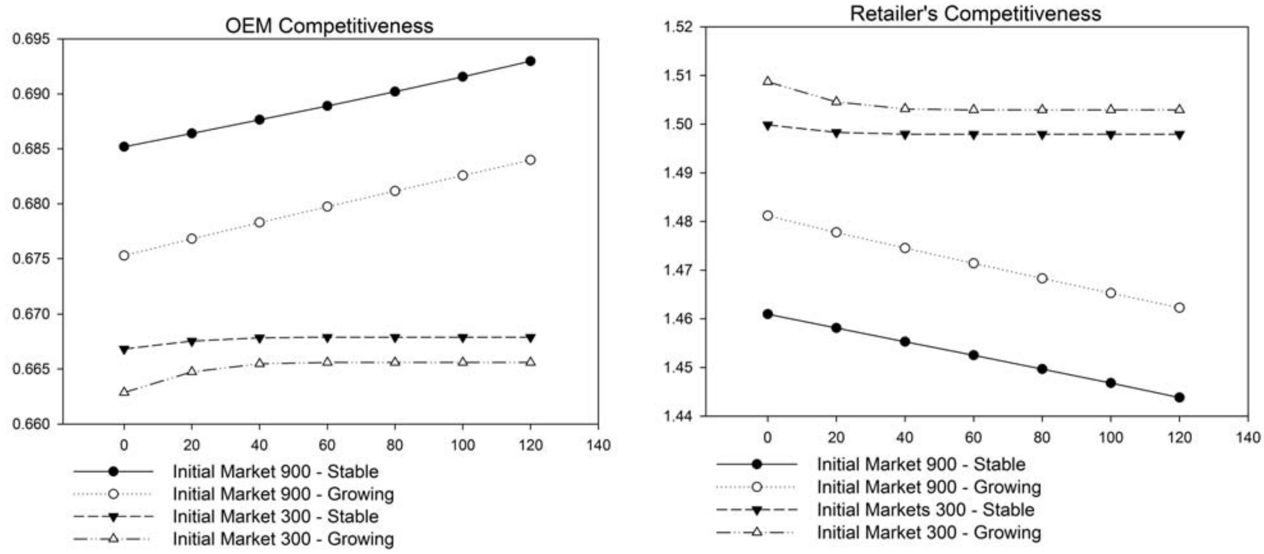

Figure 3.9: The effect of initial recycling capacity on the competitiveness of the OEM and the retailer for small and large markets, stable and growing

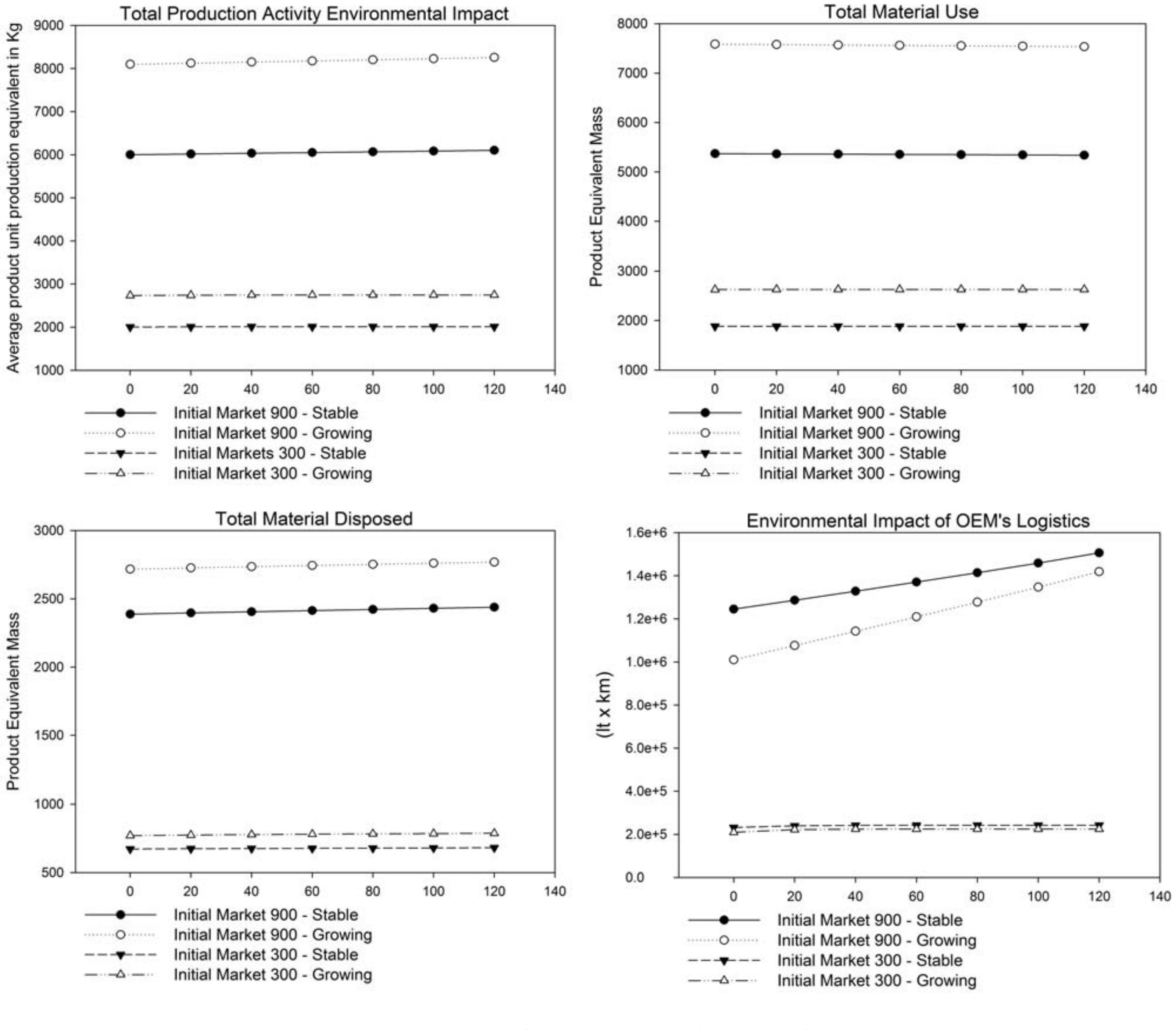

Figure 3.10: Environmental impact of the supply chain with OEM recycling capacity

3.12 The Effect of OEM Learning Pace

The simulations executed showed that by increasing the coefficient of the production learning function the competitive situation for the OEM is improved at the expense of that of the retailer (Figure 3.11). However, the OEM can only approach, at best, the competitiveness of the retailer. It cannot surpass it under any operations strategy.

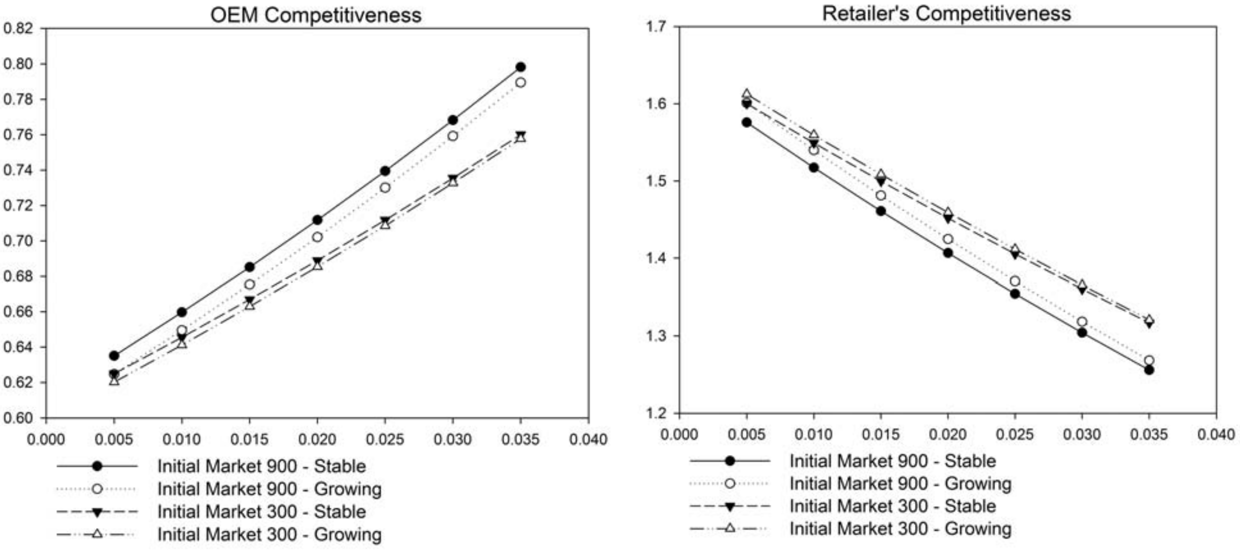

Figure 3.11: The effect of the OEM's production learning on the competitiveness a) of the OEM, and b) of the remanufacturer (small and large markets, stable and growing

In addition, the pace of learning in production has some effect on the remanufacturing operations of the retailer. It slightly decreases the remanufacturing capacity and the quantity of remanufactured in stable or growing markets, small or large (Figure 3.12). Overall capacity utilization is lower in large brand markets and higher in small.

Finally, as shown in Figure 3.13, the pace of learning does not influence the environmental impact of production activity, the total material used, and the total material disposed, in stable or growing markets, for any initial brand market size. It only reduces the amount of parts used by the retailer in remanufactured products. This is apparent in the environmental impact of its logistics operations.

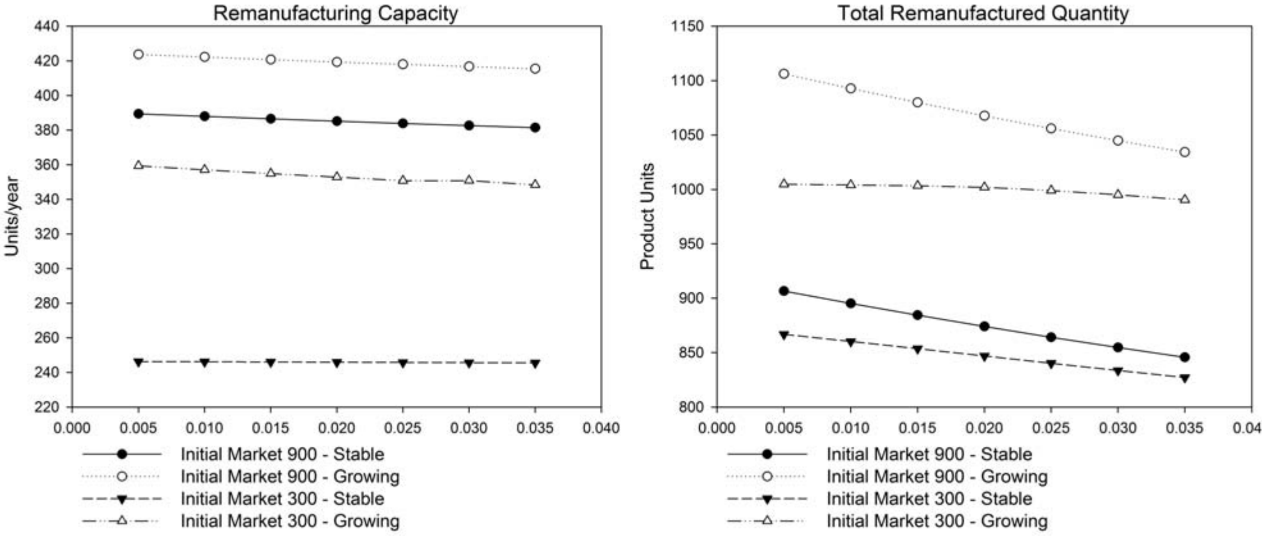

Figure 3.12: The effect of the OEM's production learning pace on a) remanufacturing capacity built, b) total quantity of used products remanufactured (in small and large initial markets, stable and growing)

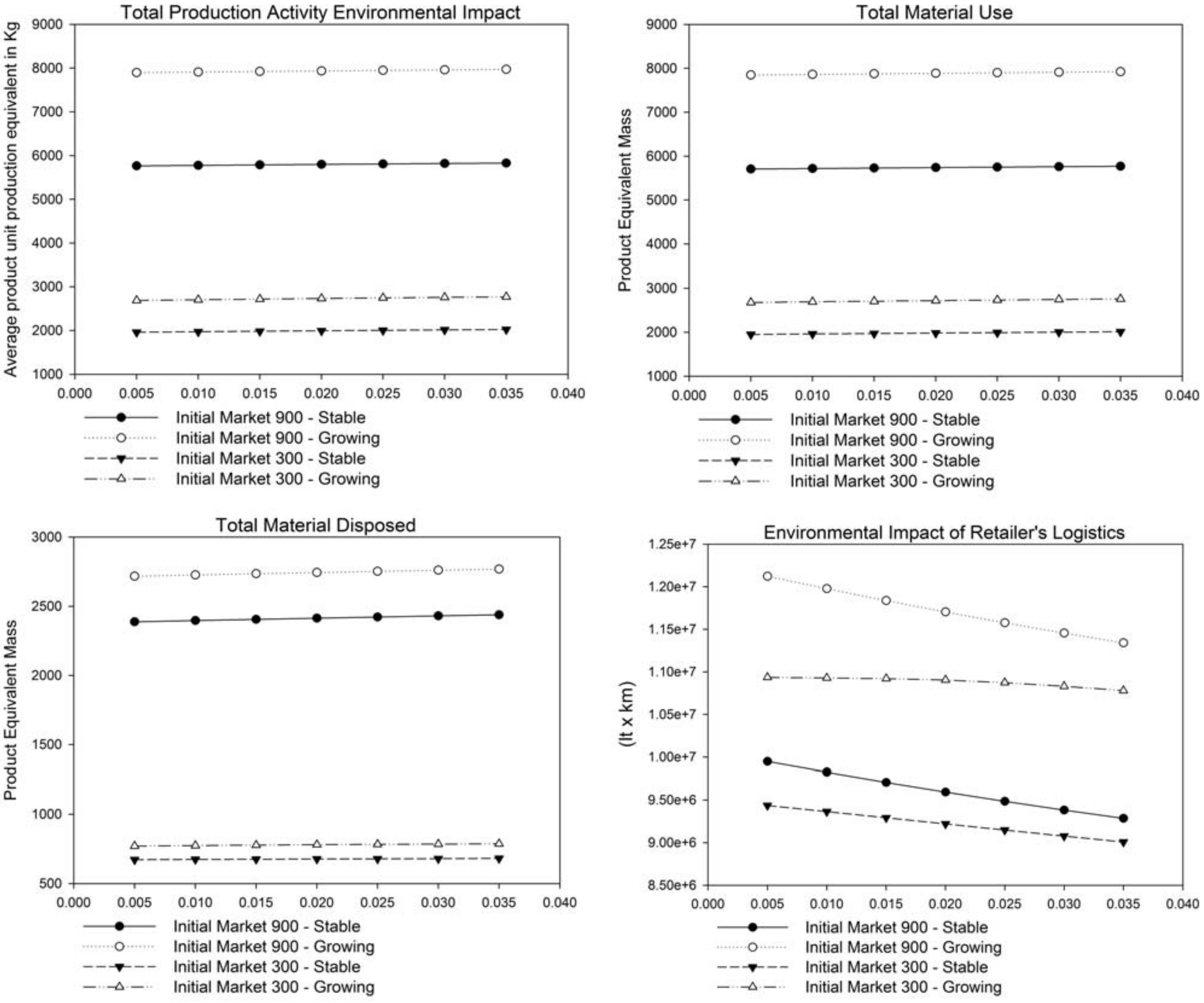

Figure 3.13: The effect of the pace of production learning on the environmental performance of the supply chain (for small and large initial markets, stable and growing)

3.13 Sensitivity Analysis

Sensitivity analysis was carried out to assess the dependence of the model's behaviours described above on model's parameter settings. The parameters chosen to carry out the analysis were:

i. Market shift delay (speed at which customers switch between primary and secondary markets and vice-versa) (2 to 6 months)
ii. Recycling contribution to OEM unit cost (how much the cost of brand new products is reduced by using recycled materials) (10% to 50%)
iii. Retailer's capacity building lead time (time between the decision to increase capacity and the moment the capacity is available) (6 to 18 months)
iv. Initial remanufacturing unit cost (variation from 0.1 to 0.9 monetary units)

Sensitivity analysis was carried for each of these variable with respect to the three OEM strategy variables: initial recycling capacity building, percentage rationing on retailer's orders, and rate of production learning and Table 3.4 presents the results observed. A total of 36 simulations were executed (3 strategy variables x 4 sensitivity parameters x 3 settings each). Table 3.4 presents in a compact qualitative form the results obtained for the four sensitivity-analysis variable that seemed to have an impact on the most important (aggregate) output variables.

The speed at which customers switch between primary and secondary markets and vice-versa has no impact on the competitiveness of the two co-opetitors, but it increases the non-logistic environmental performance variables of the supply chain. Market segments change with order backlogs and sales lead to more production of both new and remanufactured products. As expected, there is a decrease in the environmental effects of logistics, as fewer used products are forwarded to the OEM for recycling. On the other hand, as recycling materials contribute more to the production of new products, the competitiveness of the OEM increases at the expense of the retailer. Similarly, the logistics-related environmental performance of the OEM is improved as (relatively) fewer used products enter the reverse link of the supply chain because the reduced competitiveness of the retailer affects its collection effort.

Sensitivity Variable Name	OEM Competitiveness	Retailer Competitiveness	Total Production Environmental Impact	Total Materials Use	Disposed Material	Environmental Impact of logistics OEM	Environmental Impact of logistics Retailer
Market shift time (increase)	No effect -	No effect -	Increase↑	Increase↑	Increase↑	Decrease↓	Decrease↓
Recycling contribution to OEM unit cost (increase)	Increase↑	Decrease↓	No discernible effect	No discernible effect	No discernible effect	No effect	Decrease↓
Retailer capacity building time (increase)	Increase↑	Decrease↓	Increase↑	Decrease↓	Increase↑	Increase↑	Increase↑
Initial Remanufacturing unit cost (increase)	Increase↑	Decrease↓	Increase↑	Increase↑	Increase↑	Decrease↓	Decrease↓

Table 3.3: Sensitivity analysis

Increasing the retailer's capacity-building lead time reduces its competitiveness. Overall the environmental performance of the supply chain deteriorates, because the retailer remanufactures less. Finally, increasing the initial retailer's unit cost, effectively, takes the retailer out of the reverse supply chain (less competitive and, consequently, reduced collection effort) and the environmental gains of remanufacturing are lost (there is only an improvement of logistic metrics because not many products are moved in the reverse supply chain). Overall, sensitivity analysis stressed the importance of the retailer's remanufacturing operational performance on the environmental performance of the entire supply chain.

3.14 Discussion and Concluding Remarks

The previous sections detailed the results of the investigation of a closed-loop remanufacturing supply-chain from a business and environmental perspective given the decision of a retailer to establish remanufacturing operations. Frequently, a decision to enter a market is not taken solely on financial grounds and extensive quantitative analysis.

It is also based on subjective evaluations of intangible resources such as trust, reputation, etc. and results in complex dynamics of competition and cooperation, and resource accumulation flows that require appropriate methods of analysis. In order to explore this situation, system dynamics modelling and simulation was used. The model developed was based on a case from the industrial equipment industry. Its scope was broadened subsequently so that the results apply to a class of similar cases in the same or similar industrial sectors. Simulations were employed to explore the strategic space of an OEM engaged in internal supply-chain co-opetition, rather than to predict performance and to prescribe strategies.

The results of simulations showed that OEM order rationing does not increase its relative competitiveness in large markets as it does in small ones. Rationing improves the environmental performance of the entire supply chain as less material is moved in the entire chain, while a competitive retailer absorbs an increased number of used products. This is more evident in large markets where the competitiveness of the retailer is higher. Large initial (pre-emptive) recycling capacity improves the competitiveness of the OEM in large markets significantly, at the expense of the retailer's competitiveness. The environmental effects of this strategy are significant only for OEM's logistics (reducing environmental performance), as the reduced competitiveness of the retailer/manufacturer increases the level of recycling by the OEM. Faster learning and improvement in production seems to be a more effective strategy but its environmental performance is limited. Experimenting with initial conditions and/or different modelling assumptions confirmed the importance of the retailer's operational characteristics on the environmental performance of the entire supply chain.

The clear message of the study is that the involvement of the retailer as a remanufacturer in the supply system, results in a need for improved competitive performance and additional environmental-performance-oriented resource commitments on the part of the OEM. Within the context of this simulation study, it seems that there are not many actions the OEM can undertake to mitigate the effect of the retailer's remanufacturing. At the same time their actions under the competitive frame assumed, affect the environmental performance of the whole system. More specifically, as the OEM commits to building large amounts of capacity pre-emptively, the after-use products absorbed in the reverse supply-chain raise its competitiveness and thus the sales of new products. Under any of the options available to him the environmental impact of the supply chain does not vary significantly.

Overall, model simulation and meta-analysis of the results at an aggregate level suggest that consistent strategic behaviour with respect to the environment and the chosen strategies of competition and cooperation result in higher benefits than nervous and opportunistic ones. Comparing the resource-based operations strategies of the OEM, pre-emptive capacity seems more effective when it comes to reducing the average competitiveness of the retailer. On the other hand, rationing has the opposite effect and reduces at the same time the environmental impact of the OEM. Obviously, this strategy has a serious impact on the profitability of the OEM as well. Accelerated learning and efficient improvement programmes improve the competitive performance of the OEM. However, overall, there is no single overarching strategy which the OEM can adopt in order to confront the onslaught of the retailer, given that technology and contractual means cannot be employed as competitive weapons.

The OEM in defending its competitive advantage, increases the demand for new products and thus the inflow of material to the supply chain. If it is not successful, then the retailer stands to gain at its expense, improving simultaneously the environmental performance of the supply chain. However this is possible only up to a point. Sustained remanufacturing operations require a constant inflow of used products and thus some sort of consideration for the growth of the used products market relative to the brand product market. This presents the two actors with a conundrum as they cooperate in the forward supply chain and compete for the secondary market. Thus in this case the supply chain remains in a state with little scope in improving its environmental performance.

What is required is a different strategy for the OEM's operations and cooperation with the retailer, so that product flows in the forward chain are sufficient to sustain the remanufacturing and recycling operations in the reverse chain and that the survival of the OEM is ensured. This does not require any change in the architecture of the supply chain as shown in Figure 3.3. However, while the OEM can extend its operations to reach product users, there is nothing to prevent supply chain retailers or third parties from establishing their own remanufacturing operations, thus putting the OEM back into a competitive defensive frame. The kind of change required cannot easily be brought about endogenously. Some form of intervention, regulatory or otherwise is required in order to shift the system from its current state to a new one with lower environmental impact. Chapter 4 makes the case for the difficulties that arise in organizational settings and propose two forms of intervention to OEM – retailer supply chain systems. It then presents a modified supply chain that operates in a new state whereby the two supply chain actors collaborate and it exhibits an improved environmental performance with relatively comparable profits to that of state 1.

Chapter 3 Contents

Chapter 3 List of Figures & Tables

Chapter 4 Closed Loop Operations Strategies in a Transformed Institutional Environment

4.1 Introduction

In chapter 3 the competitive situation that the OEM faces was presented, and arguably continuing with business as usual, is not going to improve its position vis a vis the retailer, nor the environmental performance of the supply chain. In competing with the retailer, the OEM can have some moderate success but it also makes a commitment to a strategy of operations that excludes the prospect of significant improvements in the environmental performance of the supply chain because it draws consumers towards purchasing new products. It thus excludes other forms of growth (Barnett and Sorenson, 2002). However, even if the OEM succeeds in this, there is always the possibility of third parties engaging in remanufacturing activities, that will further erode its market share.

The OEM's managers are in a position where decisions have to be taken about the utilization of firm resources for exploitation or exploration. This chapter uses arguments from the literature to support the view that managers are most likely to take decisions that will lead the OEM further into a lock – in into its current position of competition with the retailer. The particular environmental – institutional arrangements in which actors operate, impose a particular set of corporate and operations strategies that render the achievement of both competitive and environmental objectives unattainable. Hence, to achieve the environmental objectives, given that competitive objectives are in the very existence of firms, a different institutional configuration should be put in place. Only then will remanufacturing be effective.

Two arguments will be made to support this, drawing broadly on: (i) the allocation of resources and the balance of exploration and exploitation activities in a firm, and (ii) the effect that organizational complexity has on firm performance and attainment of goals. More specifically the arguments that will be developed in section 4.2 are: (i) the suppression of risky exploration activities in the face of adverse financial outcomes, that affect the allocation of resources and potentially lead the firm to escalate its commitment into exploitation activities, and (ii) the increased risk and complexity that firms face when taking environmental performance (as in the supply chain case presented in chapter 3) into consideration and the implications for decision making and its outcomes.

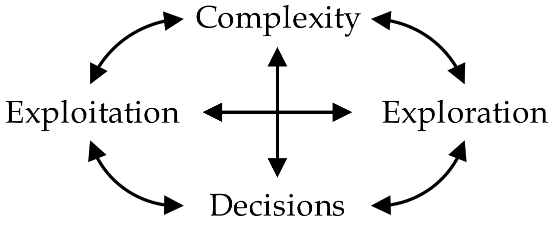

Figure 4.1: Interaction among complexity and organization decisions for exploration and exploitation

Based on these arguments, two propositions for the case of the OEM are made and elaborated at the end of the chapter: (i) regulatory action is required to reduce the complexity that the OEM faces, so that it can innovate and effectively protect its proprietary assets (Teece, 1986), and (ii) a third party intervention is required in order to facilitate the transfer and use of new knowledge. These should lead each actor and the system as a whole, to a transition from their current situation of mediocre environmental performance as illustrated in chapter 3 (state 1 hereforth) to one of superior performance (state 2 hereforth) without compromising the viability either of the OEM or the retailer. In order to demonstrate this possibility, the model presented in chapter 3 has been modified appropriately. Simulation results from the model support the thesis put forward.

4.2 Firm Adaptation: The Suppression of Exploration Under Adverse Performance

Firms strive to achieve and maintain a desired balance in the use of organizational resources allocated to exploration (innovation) and exploitation (generating returns on investment) activities (Lavie et al., 2010; Gupta et al., 2006; March, 1991). Organizations engage in both types of activities for organizational learning and development (Tushman and O'Reilly, 1996). In the long run, particularly when experiencing prolonged success, firms tend to give resource and competence exploitation activities precedence over exploration activities (Helfat et al., 2007). This has been documented in many industries, for example in semiconductor and biotech (Sorensen and Stuart, 2000). It places firms in a precarious position, as exogenous developments are likely to disrupt their continuous success.

The firms response to this, is likely to be one of intensifying exploitation efforts, further exacerbating the situation they face. In effect they find themselves caught in a success trap of their own doing, that stops them from investing and engaging in exploration activities in order to adapt to their environment (at the very least this is not their first response) (Leonard-Barton, 1992; Levinthal and March, 1993). This kind of behaviour has been documented in several cases (see for example Tripsas and Gavetti, 2000; Helfat et al., 2007). It consists in management's failure to detect and respond appropriately by taking the necessary decisions and adjusting firm strategy. This stems from the cognitive processes of managers that constrain their ability to effect strategic change when it is most required and can eventually lead to organizational decline (Mellahi and Wilkinson, 2004; Sheppard and Chowdhury, 2005).

The literature on organizational failure is considerable (see Whetten, 1980; McKinley, 1993; Mellahi and Wilkinson, 2004). There are two distinct established approaches developed for understanding management reactions to organizational decline: (i) the ‘invention perspective’ where managers respond by exploration activities when they perceive the declining performance of the firm (see Miles and Cameron, 1982; Mone et al., 1998), and (ii) the ‘rigidity perspective’ where managers respond to declining performance by focusing on efficiency, and further commitment to exploitation of the firm's existing resources and competences.

The latter will most likely cause the organization to fail to adapt. The exploitation strategy might lead to a temporary improvement, but to further decline in the long term (see Staw et al., 1981; Cameron et al., 1987; D’Aveni and MacMillan, 1990; D’Aunno and Sutton, 1992). What is required in such situations where markets change and the kind of learning required is radically different, is an enlargement of the organization's inputs and diversity of responses (Weick, 1979; Aldrich, 1979). From the two approaches, the rigidity approach has gained considerable acceptance in the exploitation – exploration literature (Gupta et al., 2006; Lavie et al., 2010), and its consequences have been documented in the organizational decline literature (McKinley, 1993; Rosenblatt et al., 1993; Latham and Braun, 2009).

In this research stream, Walrave et al. (2011) following the rigidity perspective, have built a system dynamics model drawing on earlier theoretical work on self justification theory (Staw, 1981; Brockner, 1992), where they explore the 'success trap', i.e. the underlying mechanisms that suppress the firm's exploration activities in the face of changes in the competitive environment that produce negative outcomes. If the organization has a culture in which: (i) people are unwilling to admit failure or (ii) consistency in behaviour is highly valued, (Staw and Ross, 1987), then it is more likely that escalation of commitment to failing endeavours will occur (Kahneman, 2011). Their model is in agreement with theoretical and empirical observations suggesting that managers can sometimes become trapped in persisting with a course of action driven by sunk costs or by external demands for success (Garland and Newport, 1991). This may marginalize experimentation as a provisional form of management behaviour. Based on their model, Walrave et al. (2011) develop a process theory that explains how the interaction of managers, stakeholders and firm exploitation and exploration activities, can keep or delay the firm from engaging in substantial exploration activities.

The implication of this strand of literature, for the case presented in chapter 3, are straightforward. While the OEM does not necessarily face a complete decline, it will certainly engage in strategic behaviour that will suppress exploration activities. In terms of the range of strategies explored in chapter 3, this corresponds to the OEM competitive-preemptive strategies that were simulated. The underlying logic for this is presented in the following section.

4.2.1 The Dynamics of Exploration Suppression

The dynamics of the exploration suppression have been captured by Walrave et al. (2011) in a causal loop diagram (Figure 4.2). It consists of three main loops. First, the *Stick to exploitation* loop reinforces resource investments in exploitation activities owing to the firm's alignment to the broader stable and favourable competitive context. Consequently, no additional investments are made for exploration and the firm focuses on exploitation. However, if the competitive environment changes, then the alignment decreases, and the perceived need to explore increases after a certain delay. The second loop, *Balancing external pressure,* goes through the operating results of exploration investments, and determines the effect that the perceived need to explore has on exploration investments. It is assumed that the shareholders of the firm, are mainly driven by firm financial returns. Hence, if operating results are satisfactory, then the pressure to exploit is reduced and this creates the necessary organizational slack for exploitation and exploration activities. On the contrary, negative results increase the pressure to exploit. The third loop, *Attempt to explore*, represents the effect of investments on exploration. When these are aligned with the competitive environment in which the firm operates, they improve operational results, albeit with a certain delay. This reduces the pressure to exploit and allows for further exploration investments. An important detail is that the implementation of new strategies and routines in explorative ventures, takes more time and effort than in the case of exploitative ones. Hence they require long term planning (Burgelman et al., 2004).

Changes in the *Environmental competitiveness and dynamics*, have repercussions for the optimum exploitation – exploration balance. They affect the allocation of resources and the anticipated operating results (Romme et al., 2010). The balancing act that management performs, consists in allocating a limited amount of resources (that come from operating results) to firm activities. *Environmental competitiveness and dynamics* incorporates two components (Figure 4.2). *Environmental dynamism* relates to the pace and unpredictability with which the broader context in which the firm operates undergoes change (Dess and Beard, 1984).

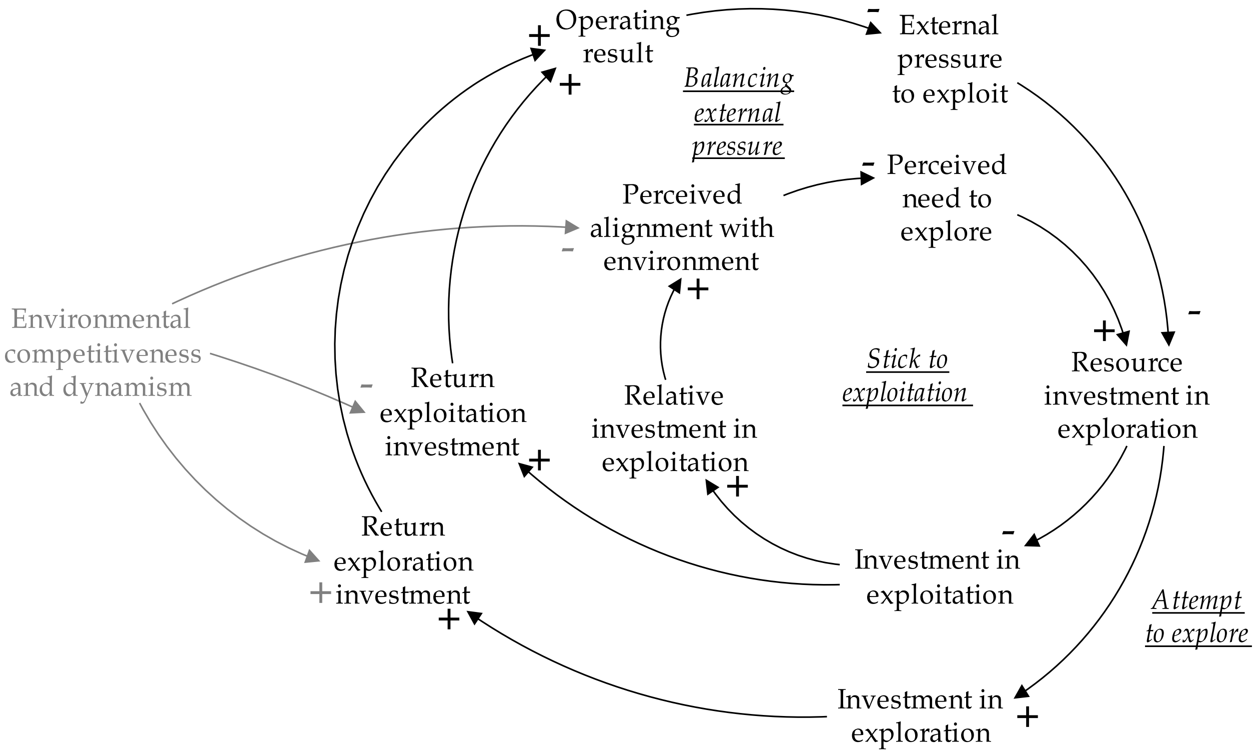

Figure 4.2: Causal loop diagram: The suppression of exploration (adapted from Walrave et al., 2011)

Contributing factors to this include: competence-destroying changes (Tushman and Anderson, 1986), periodic shifts in market preferences (Christensen et al., 1998), and fluctuations in product/service demand (Jansen et al., 2006). The literature provides evidence that at higher levels of environmental dynamism returns to investment are higher for exploration than exploitation, and vice versa (Uotila et al., 2009). A rapidly changing environment where perceptions of customers and competitors fluctuate, is likely to result in the devaluation of available products, which creates the need to widen the search for new alternatives. Therefore, a commitment to exploitation strategies, risks being effective in the short term, and facing a declining market in the medium to long term.

Environmental competitiveness is linked to the level and intensity of competition (Jansen et al., 2006). Two variables contribute to this: the number of firms in a market and their relative market share (Boyd, 1990; Porter, 1980). Industrial settings with high competitiveness involve a large number of firms operating with high efficiency and possessing approximately equal market shares, thus competing on price. In this situation firms have low profit margins, and scarcely any organizational slack for exploration (Zahra, 1996). Hence, their operations strategy is likely to focus on improving and expanding the existing line of products further. This strategy is essentially one of exploitation, similar in nature to those presented in chapter 3, where the OEM faces the remanufacturing operations the retailer has engaged in.

4.2.2 Implications for the Remanufacturing Case

In the remanufacturing case of chapter 3, simulation results show that the OEM can respond relatively successfully by intensifying the competition with the retailer in the short term. However, this creates a path dependent situation where exploitation leads to success in the short term, but also to less exploration, and can potentially disrupt its alignment with the environment, in the long term. The OEM's strategic behaviour, can lead to an undesirable downward performance spiral from which it can recover with great delay and at the risk of loosing new emerging markets. This also carries undesirable effects for the wider public.

Persisting with its exploitation strategy, i.e. intensifying the competition to the retailer, does not improve the environmental performance of the OEM and the supply chain. Consequently, the OEM behaviour works against developments that can lead to more sustainable supply chain operations. What is required, in order to re-establish its alignment with the environment, is exploration. However, because of the success trap it is likely to engage in more exploitation. Furthermore, engaging in exploration and adopting early clean technologies for example, is risky because as with any technology, it may cost more to obtain and use, and is also of unknown quality (see chapter 2 section 2.4) (Russo and Fouts, 1997).

In summary, the OEM, faced with new competition is more likely to employ an exploitation strategy, at least in the short term, which is detrimental to the environment and operates at the expense of the general public. What is required is a fundamental shift of the exploitation – exploration towards exploration. However, there are additional impediments that are likely to prevent this change from taking place endogenously in the system, as discussed in the following section. Consequently, external influences and interventions should be sought. A likely escape from the vicious circle of detrimental exploitation decisions can come from outsiders (Staw et al., 1981), i.e. individuals that are not subject to commitments to the organization, or do not need to justify their actions in the way that managers have to.

4.3 Impediments to Organizational Performance Improvements

The previous section explained how managers may engage in decisions that lead to an escalation of committing the firm's resources to exploitation activities. This section focuses on the difficulties that managers face if they try to escape the success trap and explore further the options that are available to them by altering their strategy. In doing so they should: (i) not lock the firm early on the first set of good choices that they come across, (ii) stop their search efforts and stabilize their decisions once a really good set of choices is found, and (iii) not attempt to uncritically imitate the strategies of other competitors.

The difficulties in every case, lie in the interdependency of decisions that has been shown to affect the adaptation of the firm to its environment. This subject has been explored in the literature in a series of papers that utilised and extended the NK model in numerous ways in order to address a variety of subjects (Levinthal, 1997; McKelvey, 1999; Rivkin, 2000; Rivkin and Siggelkow, 2003; 2007; Ethiraj and Levinthal, 2004; 2009; Lenox et al., 2006). Furthermore, it has been applied to manufacturing strategy formulation by viewing manufacturing organisations and supply networks as complex adaptive systems (CAS) (McCarthy, 2004; McCarthy and Tan, 2000; Choi et al., 2001).

This perspective assumes that each capability of manufacturing firms contributes to the level of fitness of the strategies they implement which is defined as (McCarthy, 2004, p142): "The capability to survive in one or more populations, imitate and/or innovate combinations of capabilities, which will satisfy corporate objectives and market needs, and be desirable to competing firms."

The implications of this strand of literature, are directly relevant to the case analysed in chapter 3. They are explored drawing on three models of organizational change that address issues of: (i) organizational fitness and adaptation (Levinthal, 1997), (ii) the pursuit of multiple goals under decision interdependencies (Rivkin and Siggelkow, 2007), and (iii) the complexity barrier to imitating successful strategies (Rivkin, 2000).

4.3.1 The NK Model of Organizational Adaptation

The issue of firm adaptation to its environment has been studied by using concepts originating in biology, such as the fitness landscape (Wright, 1931). It is original form, this is a multidimensional space where each dimension corresponds to one gene (attribute) of a living organism. An additional dimension indicates the fitness level of the organism as a whole. This concept has been operationalised in order to demonstrate how the fitness of an organism relative to its environment, is determined by the interdependence of the genes of the organism, what population geneticists refer to as epistatic effects (Smith, 1989).

The NK model (Kauffman, 1993) represents these epistatic interactions. In this, an entity, or organization, consists of N attributes that each takes two values. The contribution of each attribute to the overall fitness of the organization depends on the number of interactions of each attribute specified by K. Hence, if K is zero, the contribution of each attribute is independent of all the others and in this case, the organization is said to be loosely coupled. If K equals N-1 then each attribute affects every other attribute of the organization. The magnitude of K, therefore, determines the topology i.e. the number of peaks of the fitness landscape (Figure 4.3 is a conceptual representation). If K equals zero, then the fitness landscape is smooth with a single peak (maximum fitness point) as each attribute is independent of the others. As K increases, the landscape becomes more rugged with many peaks and troughs. This is because as K grows, changes in a single attribute affect other attributes and thus adjacent points in the fitness landscape can have varying levels of fitness. Thus organizations navigate through this landscape by identifying in their immediate vicinity points with a higher level of fitness and then modifying some of their N attributes in order to attain that level of fitness. Long "jumps" in the landscape are costly and time consuming and thus are less frequently attempted. The problem is that peaks with significantly higher fitness level, are not in the organization's immediate vicinity. Consequently, it must traverse a trough in order to get to a higher peak (Figure 4.3). This kind of behaviour in systems theory is known as the "worse before better" behaviour (Sterman, 2000).

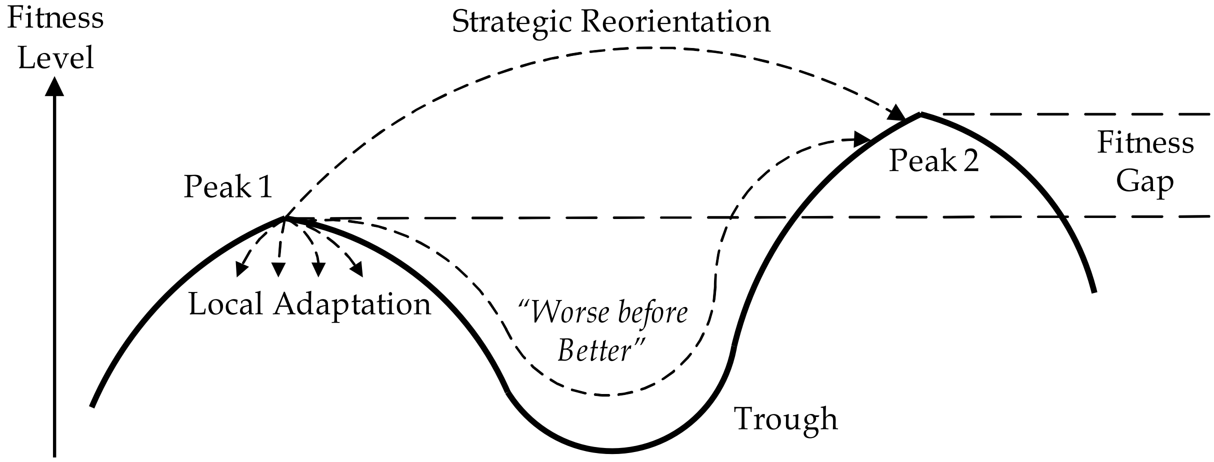

Figure 4.3: Conceptual representation of NK landscape

4.3.2 Adaptation on Rugged Landscapes

Levinthal (1997) developed one of the early applications of the NK model. His model explores the interrelationship of processes of organizational change and broader population selection forces in changing environments. Rivkin and Siggelkow (2007) confirmed the results of Levinthal (1997) and went a step further in exploring the implications that the pattern of decision interdependencies (K) has on organizational performance. In this case as well though, several general insights relevant to the case presented in the thesis hold. The results of organizational adaptation for fixed landscapes indicate that (Levinthal, 1997):

i. In a rugged fitness landscape (K is high), where multiple local optima exist, a single dominant organizational form will not emerge from a process of adaptation. After a brief period where considerable variety is generated, there is a steady convergence to a small set of forms that correspond to the local peaks in the landscape.

ii. Organizations with different founding attributes, are lead to adopt distinct organizational forms. Thus, local search for organizational adaptation in a multi peak landscape is path dependent.

iii. The survival probability of an organization is determined by the relationship between its fitness and the maximum fitness of the population of organizations. As K increases, the landscape becomes more rugged and, as a result, the expected value of the maximum fitness level increases. Therefore, the intensity of selection pressures increases at higher K values, resulting in a steep decline in the number of alternative organizational forms over time.

iv. The process of local adaptation reduces the number of organizational forms, much more quickly than selection forces in the population. Adaptation thus generates the set of dominant organizational forms. Then, selection pressures operate over time, and change their frequency distribution.

The results of the model for changing fitness landscapes indicate that (Levinhtal, 1997):

v. For a low K value, the organization faces a fitness landscape where adjacent fitness values are highly correlated. Therefore it is able to adapt locally with ease. However for high K values, (a more tightly coupled organization) organizational changes are more difficult. Thus in general, a more rugged landscape i.e. when organizational decisions are highly interdependent, tends to induce organizational inertia.

vi. Searching for solutions by local adaptation, is not an effective response to changes in the fitness landscape for the organization. Consequently, the remaining option at high K values, when the organization is tightly coupled, is a successful long jump or strategic reorientation (Figure 4.3).

vii. For low K values, there is low correlation of reorientation and organizational survival. For high K values there is a strong positive correlation of strategic reorientation and survival rate. This result is robust even when noise is applied to represent error in the evaluation of alternative peaks by the organization.

4.3.3 Implications for the Remanufacturing Case

The implications of Levinthal (1997) in terms of the case are clear. The OEM tries to respond to the competitive threat of remanufacturing. It is plausible to assume a high K value in this case, because the decisions the OEM faces on engaging in recycling and working out the implications of rationing, add to the complexity of its normal mode of competition. In this context the simulations that were conducted in chapter 3, constitute a detailed local adaptation search on a landscape of high K, for alternative competitive strategies with corresponding fitness levels. However, as stated in point (vi) above, a local adaptation behaviour is not an effective response to changes in the competitive environment. If the fitness of the organization i.e. the OEM in the case, is to be considerably improved, then a strategic reorientation is required (Figure 4.3). While the environmental considerations of the OEM operations do not influence customer choice, this is unlikely to remain so in the future. Incorporating environmental impact considerations effectively raises the K value of the OEM organization further. Thus it faces a more rugged fitness landscape (see point v). In this situation, local adaptation is not effective, and it is linked to organizational decline as Levinthal has shown (see point vii). Instead a strategic reorientation that will take the OEM away from its current place in the fitness landscape, enhances its long term survival prospects, which is what is required.

4.3.4 Complex Organizations and Multiple Goals

Ethiraj and Levinthal (2009) have explored the implications of organizations pursuing multiple performance goals. The authors argue that multiple goals are the result of two factors: (i) the fact that every managerial decision cannot be directly linked to a global goal and thus it necessitates the use of intermediary ones, and (ii) the effect of single decisions on multiple goals complicates managerial decisions. Thus multiple goals can exist independently of manager's individual preferences. The research questions these authors addressed concern, the implications of pursuing multiple performance goals, and whether the prioritization of local over global goals is effective in addressing multiple goals. They make two fundamental assumptions in order to answer them: (i) managers are boundedly rational individuals and (ii) each decision affects multiple goals.

The results of their model on organizations pursuing multiple goals indicate that:

i. Overall, multiple performance goals imposed in simple and complex organizations with loose (low K) or tightly coupled (high K) structures, present severe coordination challenges. Consequently, exploring the fitness landscape and discovering high fitness peaks is difficult.
ii. Organizations face two coordination challenges in addressing many goals: (i) the coordination of interdependent decisions (illustrated also by Levinthal, 1997) and (ii) the coordination of decisions in relation to goals especially when each one affects multiple goals.
iii. In pursuing many weakly correlated goals at once, the organization gets locked into the status quo. Managers are not able to take decisions that enhance organizational performance across the range of goals. This problem increases as organizational interdependencies (K) increase.

4.3.5 Implications for the Remanufacturing Case

The results of the Ethiraj and Levinthal (2009) model are in agreement with Walgrave et al. (2011) and the stream of literature they followed, that illustrates how decisions lead the firm to an exploitation path. In particular point (iii), is also in agreement with empirical evidence that strategic decisions in forward and reverse supply chains are indeed weakly correlated (Kocabasoglu et al., 2007). Hence, the situation in which the organization finds itself is one where a decision may improve one performance goal but can simultaneously undermine others. This is evident in the case of remanufacturing presented in chapter 3, where if the OEM competes successfully the demand for brand products increases. This has a high environmental impact as the production of new products is increased. In contrast, scenarios with low environmental impact (high levels of remanufacturing and recycling or rationing) result in low competitiveness and prospects of survival for the OEM.

Thus, the critical managerial challenge in addressing multiple goals is to design effective strategies and organizational structures. However, what compounds the difficulties of the

OEM, is that engaging in remanufacturing operations, requires constant monitoring of product life cycles which is also disrupted by the competitive behaviour of the retailer – remanufacturer (Atasu et al., 2008). Ethiraj and Levinthal (2009) suggest that in such cases, an effective strategy is to provide incomplete directives to action i.e. a subset of the underlying set of goals in order to direct and coordinate behaviour. This kind of reduction in the number of goals pursued, provides a degree of clarity for strategy making because it effectively reduces K. This is possible through regulation, or some form of exogenous third party intervention that fixes some of the decision variables for all organizations and in effect provides organizations with a broad direction for exploration. This is explored further in section 4.4 by modifying the model of chapter 3 appropriately.

4.3.6 Imitation of Complex Strategies

The fundamental question that Rivkin (2000) sought to answer is what prevents the imitation of well known winning strategies. The simulation model he developed, follows the NK logic, and explains why some successful winning strategies cannot be imitated readily even when they are open to public scrutiny. A logical repercussion is that certain ensembles of organizational practices diffuse slowly even though they lead to superior performance and therefore the business strategies that incorporate them, yield superior returns even after many of their critical ingredients are adopted by competitors (e.g. the Toyota production system). The complexity of a strategy, coupled with limits on what managers know about their rivals and can implement, raises a barrier to imitation. The simulation results indicate that when the decisions involved in a strategy are numerous and tightly linked to one another, this effectively insulates the firm against imitation in three ways (Rivkin, 2000):

i. Tracing all the interactions among the decisions involved in strategy formulation and implementation is an intractable problem. The number of decisions, and time consuming strategy evaluation, preclude a purely analytical approach in imitating a competitor's high performing strategy.
ii. Following an incremental approach to imitation, leads to the competitors being

entangled in a web of conflicting constraints and requirements.

iii. Following a strategy where imitation is a one off attempt to match the high performance, will also likely fail. This is because of the likelihood of oversight on the part of the potential imitator. The overall strategy then, consisting of a set of interdependent decisions, is likely to fail as well. The implication is that the adoption of successful organizational practices is delayed.

4.3.7 Implications for the Remanufacturing Case

The implication of Rivkin's (2000) results, in terms of the remanufacturing case of this thesis, is that the OEM cannot simply imitate the successful strategy of another manufacturer in order to overcome the difficulties it is faced with and improve its performance. Instead, the barriers to successful strategy imitation provide a further motive for crafting a novel supply chain strategy which, by incorporating environmental considerations will be more complex, and thus more difficult to imitate (Hart, 1995; Carter and Rogers, 2008). In this way the OEM raises the K value of its strategy and thus makes it even harder for its competitors to copy its strategy. In a nutshell, the way to improved organizational performance is contingent on avoiding local adaptation, a suggestion also supported by Ethiraj and Levinthal (2009).

Summarizing the insights of sections 4.3.2 to 4.3.7 for the remanufacturing case, it is evident that OEM in its competition with the retailer it faces the possibility of becoming ensnared in a competitive trap that jeopardizes its ability to adapt to a changing competitive environment in the long term. It is obvious that it must invest in the discovery of new knowledge and market opportunities in order to secure future economic gains. What is required, is a more fundamental strategy reorientation. This is unlikely to be successful if the OEM simply tries to imitate the strategy of another successful manufacturer (assuming that there is one). In effect the OEM needs to engage in exploration in order to move from its current position. This is bound to change to a certain extent its organizational knowledge base and skills.

Such a shift would involve new technical skills, market expertise, or external relationships (Lavie and Rosenkopf, 2006; Smith and Tushman, 2005). The OEM, in moving away from its position in the fitness landscape, needs to consider both competition and the environmental impact of the supply chain i.e. a complex array of goals, in order to enhance its competitive advantage. The overarching argument made in section 4.3 is that the best course of action for the OEM is to come up with its own strategy for the circumstances it faces by developing or utilising knowledge that is internal or external to the organization.

However, the literature stresses the managerial preference for outside knowledge (Menon and Pfeffer, 2003) and its potential for radical innovation (Kemp, 1994). Thus even in the case that managers inside the OEM have some good idea about how to respond it is unlikely that it will be adopted. Managers tend to learn from competitors out of fear of being out competed in the marketplace. Furthermore, this kind of learning does not jeopardize their status inside the firm, since they do not validate the knowledge of another manager with whom they compete for career prospects. Managers actually gain status by using external contacts and knowledge (Burt, 1992). This is in part because external knowledge is often overvalued, it requires more time, effort, and cost to acquire, compared to endogenous knowledge that is more readily available. Consequently, managers tend to be more committed in realising its potential in order to justify the costs they incurred (Cialdini, 2001).

Furthermore, external knowledge, despite its cost and lower detail has certain benefits compared to internal knowledge: (i) it comes from a variety of sources and (ii) due to its heterogeneity, it deviates from the path dependent knowledge that has been developed within the organization (Ingram and Baum, 1997; Haleblian and Finkelstein, 1999). It thus has the potential required to move the firm off its vicious circle local adaptation. Based on the arguments developed about the role of complexity and knowledge preferences, there are two policy propositions for the case of the OEM:

i. Regulatory action in order to reduce complexity so that the OEM can innovate and effectively protect its proprietary assets (Teece, 1986).
ii. A third party intervention in order to facilitate the transfer and use of new knowledge.

The policy propositions have been built so far on observations drawn from the organizations literature. The following section provides support for these propositions by drawing on the remanufacturing literature. Overall, it presents 3rd party remanufacturers as having a damaging effect for OEMs and makes the case for preemptive remanufacturing on the part of the OEM (Agrawal et al., 2010).

4.3.8 Social & Technical Factors in Inducing Remanufacturing Regulation

Kumar and Putnam (2008) argue that extended producer responsibility regulation, is a move towards a more holistic approach to supply chain management that includes other actors of the supply chain and the users. This should result in a different kind of competitive advantage for manufacturers where they view their products as vehicles for other business models, such as unique services (leasing or renting equipment). However, this has not been the case so far i.e. firms still engage in local adaptation strategies.

For example, the appliance industry traditionally has not taken a systems approach in integrating environmental management with metals recycling. This is partly due to the fact that it is hard to rationalize and make investments for better design, if manufacturers cannot capture the value added in the manufacturing process. This is something that has to be dealt with regulation. As shown by Jacobs and Subramanian (2012), it is in the interest of supply chain actors to share the responsibility of product recovery. Appropriate incentives should be aimed at OEM designing products for ease of reuse and remanufacture instead of adopting a defensive approach towards it (Matsumoto, 2009).

Majumder and Groenvelt (2001) document examples in the printer industry where, in addition to legal restrictions on 3rd party remanufacturing, some OEMs may also use technology to achieve similar objectives. However, this keeps the OEM in essentially the same defensive strategic behaviour of local adaptation. The results of the model point towards counterproductive OEM strategies that increase the remanufacturing costs for local remanufacturers. The authors also highlight the fact that because the flows of used products depend on new products sales, remanufacturers actually have an interest in cooperating in order to reduce the remanufacturing cost for the OEM, so that it will initially produce more new products in the first period, thus reinforcing consumer attitudes towards brand products. This also depends on the product life cycle (Ostlin et al., 2009).

Kaya, (2010) explores several different supply chain settings with centralized and decentralized product collection. His results corroborate the results of the model in chapter 3. Remanufacturing activity increases as the gap between manufactured and remanufactured product cost increases and as the gap between their prices decreases. The author also explores the extent to which government incentives can increase remanufacturing. His results corroborate those of Mitra and Webster (2008) and Webster and Mitra (2007), whose analysis suggest that by allocating subsidies to remanufacturers and OEMs, the latter have an incentive to design products for remanufacturability, and collaborate in increasing product return rates. This is in support of the first proposition made for implementing regulation for the OEM retailer dyad.

The significance of regulation however, extends beyond capturing product value. While the OEM has several options in securing the return of used products, several antitrust and economic questions arise. For example in the use of prebates that prevent other companies besides the OEM from refurbishing its products (Toffel, 2004). As long as this and similar issues, are not sufficiently addressed with regulation, the controversy surrounding the issues will prevent full commitment of firms to such practices. In a global trade world, product take-back regulations also raise concerns about international treaty obligations such as the General Agreement on Tariffs and Trade and the World Trade Organization's Agreement on Technical Barriers to Trade.

Market

The establishment of regulation, is not the only development that could cause a shift of strategic focus. There are resource limits that might require certain industries (automotive, consumer appliances and electronics) to shift their strategies from "cradle-to-grave" to "cradle to cradle" and thus to more sustainable trajectories that economize on raw material consumption (Ferrer and Ayres, 2000). Automotive manufacturing is a case in point. Legislation has never been a reason for automotive OEMs to undertake remanufacturing operations (Seitz, 2007). For example in the US and Europe the growth of the remanufacturing sector preceded environmental legislation and was due to material scarcity during the Depression and the Second World War and demands from the racing industry. Regulation thus is not a panacea. Motives of automotive OEM for remanufacturing include equally significant issues such as the securing of spare parts over the whole car life cycle, as well as market share and brand protection (Seitz, 2007). While most vehicle manufacturers do not consider remanufacturing a core activity, they see it as necessary in order to defend against competition and secure a supply of spare parts. The fact that profitability is not considered to be a driving force is a reflection of the prevailing strategic mindset in the industry.

Robotis et al., (2004) note that the process of adopting remanufacturing is also being driven by demand and consumer preferences. A particular difficulty that arises from this with respect to firms escaping local adaptation, is that it involves changing the dominant consumer mindset. Customers expect that as technology continuously improves, it will be made readily available to them integrated in new products. The example of the automotive industry is a case in point, as it has always focused on the making and distribution of new products thus shaping consumer expectations. Consequently, the whole industry is structured to suit the needs of new parts production and distribution. The return and recovery of used products was not anticipated to be a part of this structure. Remanufacturing is seen as less influential in shaping customer perceptions than the distribution of new cars and may even result in negative brand image.

The results of Debo et al., (2005) support this view. The consumer profile is a crucial element in determining the potential for remanufacturing and the optimal remanufacturability level. (here there is a trade off as the reuse of products constitutes environmentally conscious behaviour but also slows down the diffusion of products that incorporate new more energy efficient technologies.) Therefore, before remanufacturing is universally accepted, economic factors and regulatory pressures are likely to increase and consumer attitudes will have to be changed so that they value remanufactured goods more.

A significant factor in this respect is likely to be the onset of online markets for remanufactured products. These are likely to have two effects (Subramaniam and Subramanyam, 2009): (i) inform consumers about the quality of remanufactured products either through companies or the users themselves, and (ii) allow the companies to test various combinations of products and prices relatively quickly within the space of a single product life cycle. Ferguson and Toktay (2006) comment that, the relative advantage of adopting a remanufacturing strategy increases with market acceptance of such products, thus pointing towards a more holistic consideration of manufacturing practices, their implications and ways of stimulating change. Market acceptance of the remanufactured product increases the legitimacy of a remanufacturing strategy. Remanufacturing becomes more valuable both in its own right and as a competitor deterrent strategy. It thus achieves both goals of sustainable advantage and environmentally conscious manufacturing.

In the automotive industry, two potential motives for remanufacturing are brand name protection and market share protection (Seitz, 2007; Ferguson and Toktay, 2006). This is due to the fact that brand name management and awareness have always been perceived as key components to success. Therefore in order to protect brand name, OEMs seek to collect all used products (particularly engines) so that remanufacturing takes place only at their plants. This also provides a valuable source of spare parts and warranty replacements. Furthermore, brand and market share protection, as well as customer orientation towards brand products, are seen as dominant reasons for engaging in recovery operations.

Consequently, remanufacturing is undertaken by the OEMs for defensive reasons under their current frame of competition. Moral and ethical producer responsibility has a low degree of influence on the decision to remanufacture (Seitz, 2007; Ferrer and Guide, 2002). However, the strategy of simply collecting cores in order to deter the remanufacturer's entry is simply not desirable. Even in the case of these cores being used for the production of new products, the whole situation just reinforces the regime of new product manufacturing since there is no scope for actually reducing the quantities of manufactured products. This is the direction that a transition of the manufacturing system would take.

In conclusion, changes in supply chains operations strategy are likely to come through factors that are hard for firms to influence and thus are usually considered to be exogenous to the competitive environment in which they operate. The end result of the vast array of factors involved in remanufacturing, is that they are excluded from operations research models as they increase the level of complexity and render analytical solutions intractable. This leads managers searching for tools to help them, to the use of rules of thump which are nowhere near close to being a holistic approach to the issue (Atasu et al., 2008) and are more likely than not, to induce local adaptation behaviour. The result is that the competitive strategies that are examined are predominantly directed towards fending off the onslaught of competitive remanufacturing operations from other OEMs or 3rd parties.

4.3.9 The Complexity of Decisions Making

Obviously a complete shift towards remanufacturing is not possible as a certain quantity of new products is desirable for balancing supply and demand in the remanufacturing industry. This is an issue directly linked to the product life cycle. Ostlin et al. (2009) emphasize the need for collaboration between OEM and other supply chain actors, in identifying the potential products and timing for remanufacturing. Competition can be a major limitation in this regard as the success of remanufacturing is dependent on the relationship between the remanufacturer and the customer, since the customer acts as a supplier and a customer to the remanufacturing company (Ostlin et al., 2008). Closer cooperation between the OEM, remanufacturing actors and potential customers has certain advantages:

i. The early identification and supply of markets for remanufactured products can result in increased product remanufacturing.
ii. It provides a first mover advantage to other similar competitive product offerings and a low cost alternative to the competitions brand offerings (Heese et al., 2005).
iii. It facilitates adherence to OEM quality standards for remanufactured products.
iv. It results in the establishment of channels for acquiring used products for remanufacturing.

Atasu et al. (2008) show that the profitability of a remanufacturing system strongly depends on factors such as: the existence of green market segments, competition between manufacturers and product life cycles, as well as their interactions. They show that for a monopolist facing competition, remanufacturing becomes an effective marketing strategy that allows the manufacturer to defend its market share through price discrimination. When competition is high and cannibalization is low, it is better to start using remanufactured products early in the life cycle. In contrast, when competition is low and cannibalization is high it is better to delay remanufacturing towards the end of the product life cycle.

The work of Atasu et al. (2008) reveals the complexity of the issues involved in remanufacturing and thus it supports the argument made in section 4.3.1 – 4.3.7 about complexity and the fact that profitability of remanufacturing lies on consideration of these factors. The key word is that there are interactions among these issues. Atasu et al. (2008) demonstrate the complexity of decisions and their stochastic character in the case of Bosch electronics. This firm utilises a simple heuristic for deciding whether to remanufacture a certain product. They remanufacture it only if its market share is small and there is a substantial price gap to new products introduced in the market. This is due to the fact that the influence of remanufactured products on overall firm profitability is hard to establish. This strategy in effect is indicative of the dominant mindset. It does away with the complexity of the issue and simply intends to prevent cannibalisation of new product sales. On the issue of strategic planning for remanufacturing in the automotive sector, Subramoniam et al. (2010) propose a decision making framework that reflects the complexity and holistic nature of the problem. It consists of the following factors:

1. Economic, environmental and social impact of remanufacturing,
2. Design for remanufacturing and product life cycle cost
3. Intellectual property
4. Product recovery value
5. Product specifications from the OEM customers
6. Product disposal cost
7. The core management process
8. Brand erosion
9. Remanufacturing as a green initiative
10. Local remanufacturing operations
11. Organizational alignment between aftermarket and OEM divisions
12. Governmental regulations

The authors argue that there are several other factors that influence and are influenced by these, and therefore they must be considered in conjunction, some of them are: the broader impact of the remanufactured product on society and the environment and consumer awareness of it, its performance and price compared to the original product, its availability and its impact on employment conditions.

Therefore, the combination of complexity and reluctance on the part of the OEM to engage in remanufacturing, driven by the fear that it may cannibalize the primary product sales, pose a limitation or lead to remanufactured product not being offered at all. Other contributing factors to complexity are the markets in which the OEM is involved which entail different legal and competitive environments. In effect Subramoniam et al. (2010), make the case for the need to develop tools to aid decision making and the need to reduce complexity through regulation.

Atasu et al. (2008; 2009) observe that the dominant mindset of managers equates maximizing new product sales to maximizing profits which is simply not true. It may be possible for a product portfolio that includes remanufactured products to be profitable, reach additional market segments and help block new low priced competition and independent 3rd party remanufacturing. Internal resistance to remanufactured products from sales and marketing groups can, and often does impede efforts to create additional profits (the suppression of exploration effect) despite the fact that remanufacturing is technically feasible. Managers who understand the composition of their markets (functional users, new product users, and green customers), the proper use of pricing strategies, the competition and the supply of remanufacturable products over the product life cycle, should be able to minimize the potential for cannibalization and create additional profits. What compounds the difficulties they face though is that engaging in remanufacturing operations, requires constant monitoring of product life cycles (Atasu et al., 2008). Remanufacturing is not a one off decision, it needs to be reevaluated over the entire product life cycle. This highlights the need for a different management mindset.

4.4 The Link to Sociotechnical Transitions

Section 4.3 so far, discussed the observations and results from the remanufacturing and operations literature, and the insights from the exploration exploitation and NK organizational models literature, and established that they are in alignment. These provide support for the two propositions of regulation and outsider intervention. Since the NK models used in order to make the case for the two propositions are based on the simulation results of a population of firms, the propositions also hold for the class of firms that the OEM belongs to. This population of manufacturers constitutes a distinct organizational field. Going from one firm to many, involves an ontological step to the level at which transitions take place (Geels and Schot, 2007). Instead of a single firm, it is plausible to consider the population of OEMs, that engage in path dependent competition and face the complexity of remanufacturing decisions. Their response to 3rd party remanufacturing is likely to be similar to the ones outlined in chapter 3 for reasons already discussed in the current chapter.

The ontological step from a single OEM to the population of OEMs, requires consideration of the wider institutional environment, that conditions to an extent the set of strategies available to them. This institutional perspective requires that additional social groups, relevant to manufacturing processes must be considered. In order to complete the ontological step from a single OEM and supply chain to the level of sociotechnical regime, other relevant social groups to manufacturing need to be considered. Inevitably this requires the adoption of an appropriate framework on the evolution of technology. The following sections make a brief reference to the most prominent among.

Large Technical Systems (LTS)

The Large Technical Systems framework (LTS) is concerned with technologies that involve infrastructures. For example electricity networks, railroad networks, communication systems and the internet, which constitute the unit of analysis for the framework which looks at socio-technical ‘seamless webs’ and system builders (Hughes, 1983, 1986). They are constructed by system builders that traverse social, economic, political, technological, applied scientific research domains. Therefore, the notion of a “seamless web of technology and society” is testimony to the fact that technical and non technical factors are implicated in technology development and hence required for its understanding.

The components of LTS include technological artefacts and organisations (manufacturing, financing, research and development), natural resources, scientific elements, legislative artefacts and university teaching programs. Consequently, it is necessary to attend to all of the interacting elements of a large technical system, the physical artifacts, the institutions, and broader integrative technical, social, economic and political facets. It is also required to include the enabling and abating factors of the system, what are called “reverse salients” and ”critical problems”, in order to explain the delays and paths not taken during technological development.

Sectoral Systems of Innovation (SSI)

Sectoral systems of innovation are defined as (Malerba, 2004, p 16): "a set of new and established products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products". In this, a sector is a set of activities which are unified by some linked product-groups for a given or emerging demand and which share some common knowledge. This definition acknowledges the often intrinsic ties between production and innovation activities.

The basic elements of a sectoral system are (Malerba, 2002): (i) products, (ii) organisations (e.g. universities), financial institutions, central government, local authorities and firms, (iii) knowledge and learning processes: the knowledge base of innovative and production activities differ across sectors and greatly affect the innovative activities, the organisation and the behaviour of firms and other agents within a sector, (iv) basic technologies, inputs, demands, and the related links and complementarities. The links and complementarities between technologies, inputs and demand, maybe dynamic and also be related to other sectors, converging products from other industries, or emerging new demands. These complementarities and linkages define the boundaries of a sectoral system.

Technological Innovation Systems (TIS)

Technological innovation systems concern agents that interact in a specific technology area. Institutions facilitate the development, diffusion and use of technology. These systems are dynamic and the key consideration is how knowledge and competence flows develop in them. The TIS framework and its latest development, the functions of innovation systems framework, focus on the most important processes required for technology development and diffusion and how potential obstacles can be removed. Consequently, the TIS framework aims at understanding the creation of technology along with its diffusion and utilisation (Hekkert et al., 2007; Bergek et al., 2008).

The Social Construction of Technology

The social construction of technology (SCOT) inspired by the sociology of scientific knowledge (Bijker et al., 1987; Bijker, 1995) applies its insights to study of technology. Knowledge in the sociology of science is viewed as being socially constructed rather than derived by observation from Nature. Observations are merely a tool and their results are thus subject to multiple interpretations. Consequently, knowledge is not created by scientists but it is socially constructed. The proponents of SCOT argue that technologies and technological practices follow a similar process of social construction and deliberation by relevant actors.

The Multi Level Perspective

Finally, the Multi Level Perspective, focuses on a different, more aggregate level, of societal functions like transportation, communication, housing, energy supply, recreation and health care (Geels, 2004; Geels and Schot, 2007). Technology is implicated in the fulfilment of these functions, for example by vehicles in transportation and digital devices in communication. Technological artifacts embedded in larger social structures, and organizations fulfil societal functions driven by human agency. Thus technological artifacts are analysed in a particular context which has both social and technical aspects. It includes technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and production systems that come to constitute a sociotechnical system. In such systems changes, or transitions, are the result of the timing and nature of interactions of their elements with niches and exogenous landscape pressures. Finally, a more recent and growing consideration in the literature has been the issue of sustainable development and system transitions towards sustainability (Kemp and Van Lente, 2011; Geels, 2011; Smith et al., 2005).

These frameworks all consider to a lesser or greater extent the role of the market - consumers, and regulation - policy makers. The Multi Level Perspective is adopted for the rest of the discussion, in the context of remanufacturing.

The implication of taking a higher level view on changes in supply chains is that a system wide change towards remanufacturing and sustainability, necessitates changes social and technical in order to be established. For example, it requires changes in the mindset of engineers and managers if products are to be designed for remanufacturability. There are different goals involved in designing for remanufacturability and management goals other than short term profit implicated. Therefore, it is imperative that engineering and management attitudes and education changes as well. Consequently, it is the combination of changes at the sociotechnical regime level that include science, technology, industry, policy, user preferences and culture that will enable a transition or abate it.

In the opposite event, for example as long as the population of firms continues to operate in local adaptation mode, the sociotechnical regime will proceed along a reproduction trajectory, and the dominant, established practices in supply chains will persist, thus impeding rapid and radical improvements to their environmental impact. Escaping from local adaptation behaviour, or innovating, requires the utilisation of external knowledge which is more conducive to facilitating the strategic reorientation of a single firm. This holds for each firm in the population of manufacturers. Therefore, since all manufacturing firms are engaged in path dependent competition, knowledge external to the population of these firms, is knowledge external to the sociotechnical regime they are members of, i.e. knowledge that is carried by regime outsiders. They in turn are members to one or more sociotechnical regimes as shown in Figure 4.4.

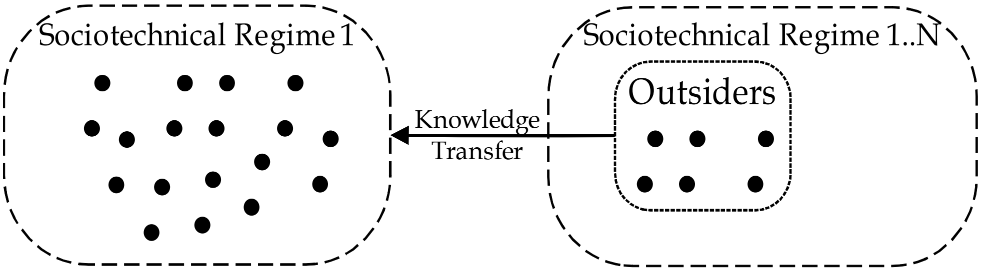

Figure 4.4: Outsider knowledge transfer in sociotechnical regimes

4.4.1 System Wide Propositions

The issues discussed in the previous section have further implications in the context of sociotechnical transitions. If new manufacturing practices and operations strategies are to replace existing ones and become the norm, they have to diffuse quickly and be adopted. This requires some degree of imitation, or that goals and knowledge are codified so that interdependencies are reduced (lower K value). This entails a paradox in that the advantage of the first mover must be dissipated by codifying knowledge in order to replicate it both internally and externally by other firms. Clearly this is not a practice that any firm would willingly engage in, thus it cannot be done on a purely competitive context but rather in niches as discussed in chapter 2 section 2.4.1. Regulation is required in order to provide incentives for first movers and for firms to utilise external knowledge in order to innovate and allow for new strategies to emerge (Mintzberg et al., 2009). Taking stock of the issues and insights drawn so far, the propositions presented in section 4.3.7 are elaborated with the aim to set the industrial production system on a desirable transition path towards sustainability:

i. Regulation is required in order to reduce complexity and allow supply chain actors to innovate, share the responsibility and gains. This entails sharing reverse flows of used products as well the internalised environmental costs. The reduction in complexity is also required to allow these practices to be imitated and diffuse promptly.
ii. A reduction in complexity also entails that competitive 3rd party remanufacturing is prevented, and that the OEM is allowed to choose partners for its reverse supply chain operations.
iii. Third party intervention is required in order to facilitate the transfer and use of new knowledge in products design for ease of reuse and remanufacture and educating – influencing consumers to change their product preferences and their behaviour towards returning used products.

The following section, discusses how these propositions were implemented as assumptions in the model of chapter 3 as well as other necessary adjustments in order to assess their effectiveness.

4.5 The System Dynamics Model: State 2

Modifications to the model of chapter 3 made to set up the model for institutional state 2, reflect two points: (i) the propositions of regulatory action and outsider intervention and (ii) the scope of changes involved in a sociotechnical regime transition. Drawing on point (i), regulation is assumed to govern the reverse flows in the supply chain and specifically the ratio of products that the retailer gets to remanufacture and those the OEM gets to recycle. It is assumed that supply chain actors share the responsibility for product collection and thus also share the volume of collected products (Jacobs and Subramanian, 2012). It is assumed that appropriate incentives are provided to the OEM in order to design remanufacturable and recyclable products and to the retailer to diligently collect all used products from the market. Outsider intervention is assumed necessary to change the strategic mindset of the two actors and bring them to cooperate.

Drawing on point (ii), it is assumed that engineers and managers are educated on the virtues of designing for remanufacturing and foregoing short term profits in favour of long term market development and overall performance that includes externalised environmental costs (Hart, 1995). It is also assumed that consumer preferences have changed and that they don't consider the product in terms of its properties but in terms of the function it provides. Hence new and remanufactured products are perceived as substitutable subject only to availability. This allows decoupling OEM revenue from sales. Finally, aided by regulation, a different consumer culture favours product returns instead of product disposal. The model assumptions in state 2, compared against those of state 1 are listed in table 4.1.

Supply Chain State 2	Supply Chain State 2
Product offering	Service offering
Competition	Collaboration
Unregulated return flows	Regulated return flows
Remanufactured products cannibalize market	Remanufactured products supply market
Products are portrayed as different	Products are substitutable
Some products are disposed	No products are disposed (ideally)
Revenue coupled to sales	Revenue decoupled from sales

Table 4.1 State 1 vs State 2 assumptions

Modifications to the model structure have been made as shown in Figure 4.5. The overall flow structure has been kept identical. A change to the structure of the model concerns the flows into the *Inventory in Use.* This is fed by *Brand Sales* and *Non Branded Sales*, in order to reflect the assumption of substitutable products. A coefficient has been added (*Return Flow Coefficient*) in order to allow testing for different ratios of return flows to the retailer and the OEM, assuming that the actual value is set by regulation. Finally reflecting the assumption of product substitutability, *OEM Attractiveness* and *Retailer Attractiveness* are no longer contingent on price but only on backlog. Changes have been made to some flow governing equations, particularly *OEM Returns* and *Retailer Collection Rate* as shown below:

$$OEM\ Returns = Return\ Flow\ Coefficient\ x\ Collected\ inventory$$

The Dynamic Collection Rate has been changed to Collection Rate because it is assumed that the retailer does not initiate product collection. Instead this activity is part of a supply chain system that is closed and thus product collection is regulated and is part of the wider scope of operations. Consequently it is considered to be an exogenous constant.

$$Retailer\ Collection\ Rate = Inventory\ on\ Use\ /\ Product\ Use\ Time\ x\ Collection\ Rate$$

It is also assumed that consumer preferences are different and thus keeping the total market of 1000 users constant across states, the ratio of initial new products demand to remanufactured is 3/7 compared to state 1 set up which is 9/1.

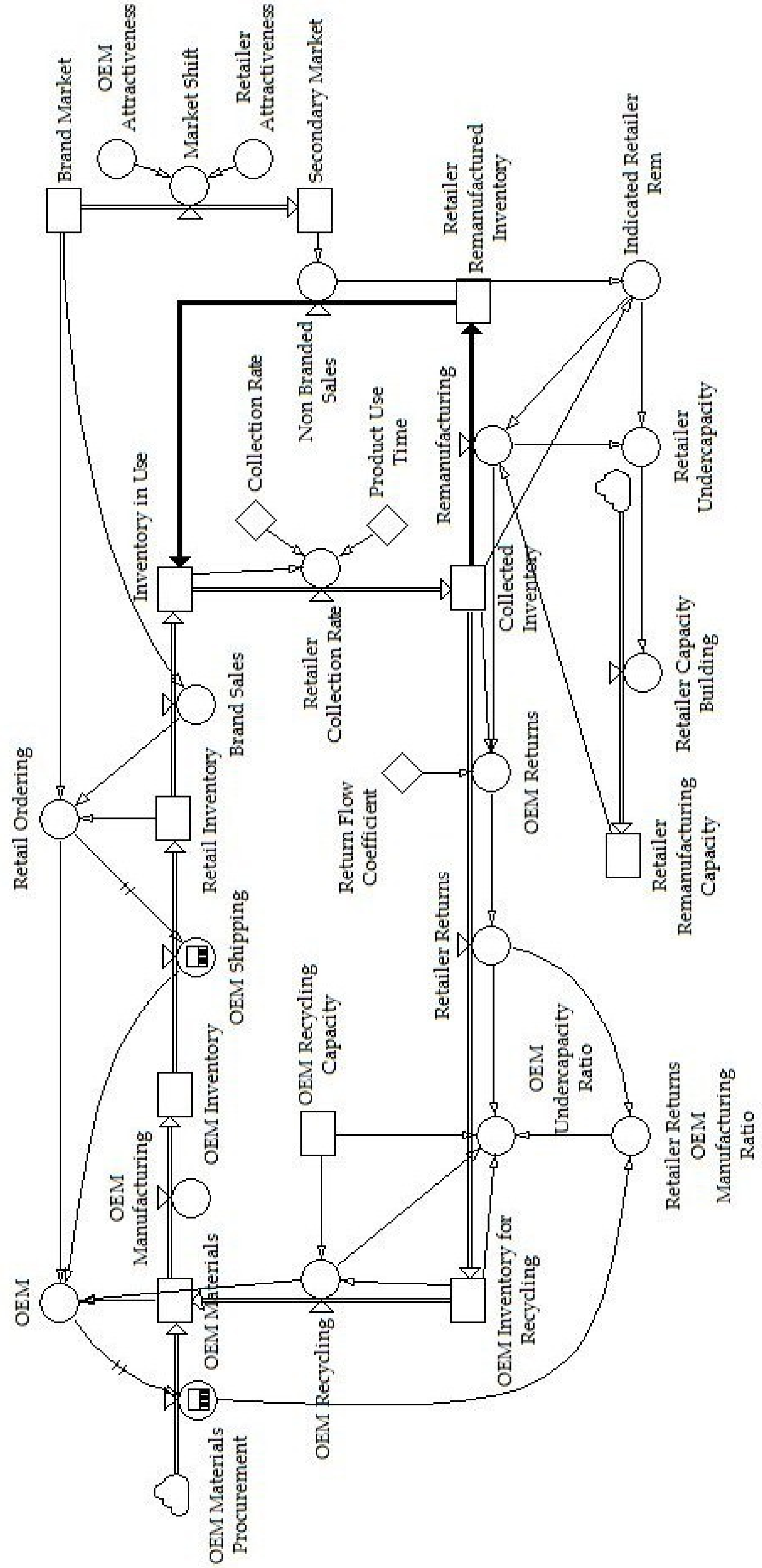

Figure 4.5: Stock and flow diagram of state 2 model

4.6 Results

Comparative results for state 1 (reference run, 50% rationing, preemptive capacity of 500 units per year, and learning scenarios) and state 2 in stable and growth markets (7% annual rate) are shown in Tables 4.2 and 4.3. Results overall show that environmental performance of the supply chain in state 2 is superior to 1, and there is less material inflow, use and disposal from the system. While state 2 appears to be less profitable compared to state 1 this is because profitability does not include external environmental costs in state 1 or 2. The OEM in state 1 has double the profits of state 2 but with environmental performance that is four times less. A regulatory framework that penalises low environmental performance would limit its profitability and thus narrow or even reverse the situation compared to state 2.

	State 1: Competition				State 2: Closed
	Reference	Rationing 50%	Recycling capacity	Learning	Supply chain
OEM environmental performance	0.05	0.05	0.08	0.07	0.36
Retailer environmental performance	0.04	0.04	0.04	0.04	0.12
OEM production activity	103.56	117.85	169.31	160.79	779.63
Retailer remanufacturing activity	441.74	441.07	444.06	466.58	1325
Total OEM recycled quantity	345.21	392.84	564.37	535.97	2598.77
Total retailer remanufactured quantity	631.06	630.1	634.37	666.54	1892.86
Total material inflow to the system	4311.79	4075.65	4089.49	4082.23	204.37
Disposed Material	2263.02	2203.12	2281.41	2524.62	827.73
Total Material Use	4742.76	4539.66	4674.87	4657.37	2591.37
OEM profit with 20% margin	880.04	840.81	879.52	874.39	393.83
Retailer profit with 20% margin	6080.11	5800.6	6080.96	6090.35	4846.69
Total profit	6960.15	6641.41	6960.48	6964.74	5240.52

Table 4.2: Comparative results for stable markets

	State 1: Competition				State 2: Closed
	Reference	Rationing 50%	Recycling capacity	Learning	Supply chain
OEM environmental performance	0.07	0.07	0.1	0.07	0.37
Retailer environmental performance	0.05	0.05	0.05	0.05	0.13
OEM production activity	140.99	153.56	222.61	141.53	794.92
Retailer remanufacturing activity	550.03	549.85	552.92	578.27	1390.76
Total OEM recycled quantity	469.96	511.88	742.03	471.78	2649.73
Total retailer remanufactured quantity	785.76	785.49	789.89	826.1	1986.8
Total material inflow to the system	5898.54	5585.31	5622.46	5852.65	538.88
Disposed Material	2874.76	2773.72	2897.46	2832.72	861.01
Total Material Use	6463.23	6179.27	6378.85	6430.73	2989.73
OEM profit with 20% margin	1131.74	1077.04	1131.1	1125.38	507.62
Retailer profit with 20% margin	7352.45	6973.4	7353.46	7363.89	5407.66
Total profit	8484.19	8050.44	8484.56	8489.27	5915.28

Table 4.3: Comparative results with 7% annual market growth rate

Further simulations were carried out in order to compare the operation of the supply chain in states 1 and 2. Overall the environmental performance of the supply chain in state 2 (S_2) is superior than state 1 (S_1). S_1 in stable market has the worse performance. Figure 4.6 illustrates three points. First, that S_2 has superior environmental performance than S_1 for any market set up. Second, that the benefits of higher collection rates do not diminish as in state 1. Finally, it is evident that the gains increase with collection rates, there are no diminishing returns, hence this is a motivation to increase the collection rate to 100%. This is where regulations and incentives can be influential irrespective of whether they concern stable (mature), or growing (new markets).

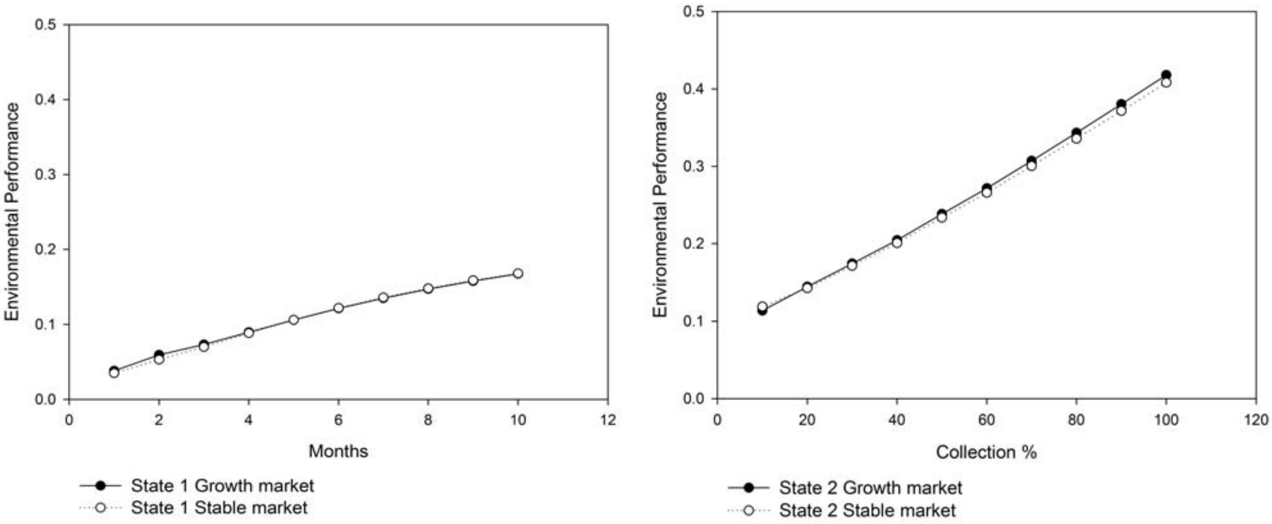

Figure 4.6: Supply chain environmental performance in state 1 (left) and state 2 (right)

Figure 4.7 compares S_1 and S_2 in terms of raw material inflow into the system. The total inflow is given by the sum of materials used in new product production, in recycling, and remanufacturing. S_2 has lower materials requirements and thus preserves valuable natural resources. S_1 requires more material in growth and stable markets, because of the market segmentation with high brand demand that requires a significant quantity of new products. Figure 4.7 illustrates an interesting point, consumer attitudes can have a significant effect on material flows in the system. Hence, in addition to regulation, engineering and management changes that shift supply chains from S_1 to S_2, a cultural change on the part of consumers, is required in order to curb the growth of demand. This has two aspects, consumption patterns have to stop growing and consumers have to perceive remanufactured products as perfect substitutes for new ones.

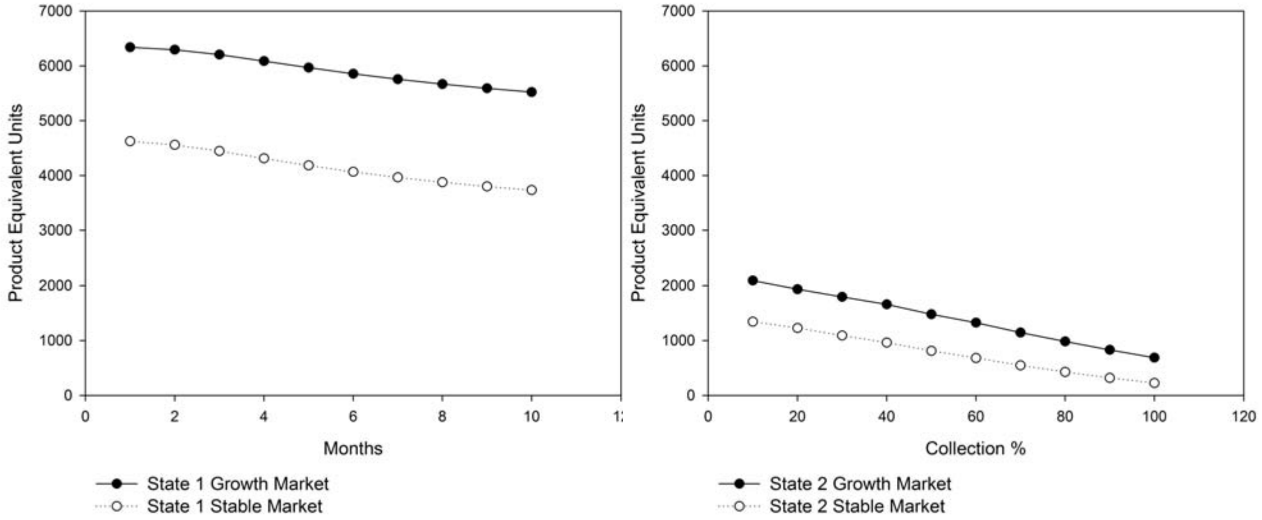

Figure 4.7: Total inflow to the system in growth (left) and stable (right) markets

Figure 4.8 shows that less material is disposed off in S_2 than S_1 at collection rates greater than 60%. Total disposed material includes, disposed used products, and materials used and disposed in remanufacturing and recycling operations. Figure 4.8 reinforces the point about the impact that qualitative attributes of consumer demand can have. In state 1 stable markets, there is a considerable reduction in disposed material.

Figure 4.9 shows that the operation of the supply chain in S_2 is less profitable. This result is in line with Jacobs and Subramanian (2012). Reduced profitability is more pronounced in growth markets than stable ones. It is an illustration of the difficulties involved in going from S_1 to S_2 as the companies apparently have to forego some of their profitability. It also illustrates a fundamental difference between the two states, as in state 2 increasing cooperation pays off more though it does not make up for the loss in profitability.

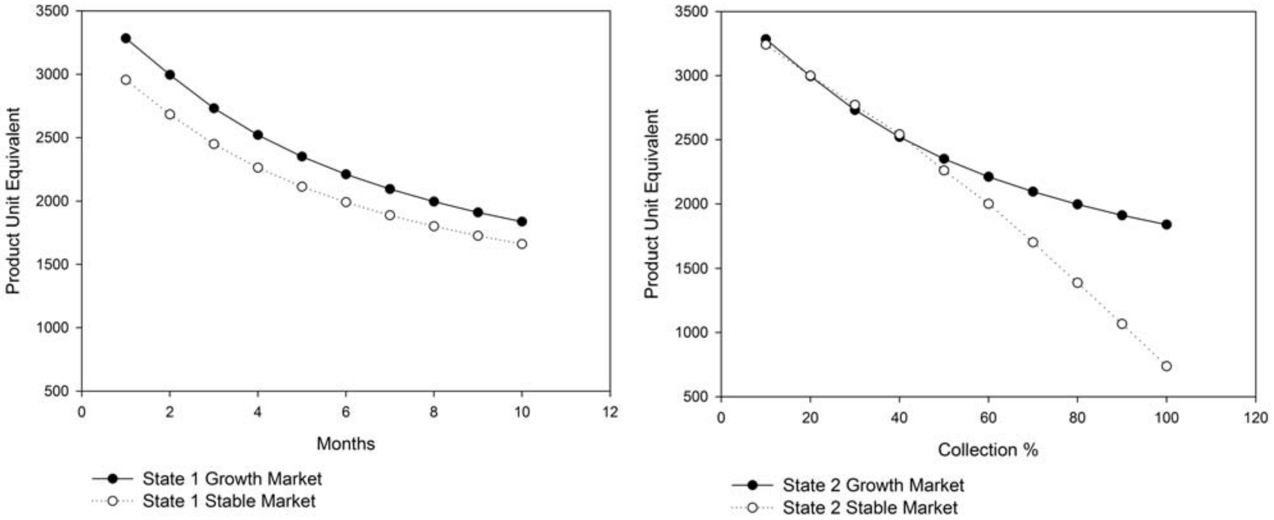

Figure 4.8: Total supply chain disposed material in State 1 (left) and state 2 (right)

The gap in profitability comes from the way profit is calculated. There are two aspects to it: (i) the OEM in S_2 leases products to consumers instead of selling them and this requires a different pricing altogether, and (ii) environmental costs are not integrated in profit calculations. Therefore, in state 2 the OEM benefits from increased consumer loyalty, and the reduced use of raw materials insulates it from market price volatility and supply risks thus facilitating growth. At the same time consumers also benefit from the reduction of environmental impact.

The actual calculation of external environmental costs is beyond the scope of the thesis and it is difficult to conduct on any kind of manufacturing system as a whole at the present level of knowledge. Calculating the value of the services that the natural environment provides for the support of human activities is a complicated and contested issue and is the subject of ecological economics discipline (Van den Bergh, 2010). Nevertheless, cost internalization with the polluter pays principle has been the trend for considerable time now, and is certainly going to continue in the future (Costanza, 1991).

Therefore, when the increased quantities of disposed materials are taken into account (Figure 4.8) the profitability gap is much less in situations where the remanufacturer incurs the disposal costs (Extended Producer Responsibility). In fact as S_2 requires much lower inflows (Figure 4.7) than S_1, it has lower procurement costs as well and thus is in agreement with Russo and Fouts (1997) hypothesis that firms are more likely to reap benefits from increased social performance when they are in high growth industries than low growth industries.

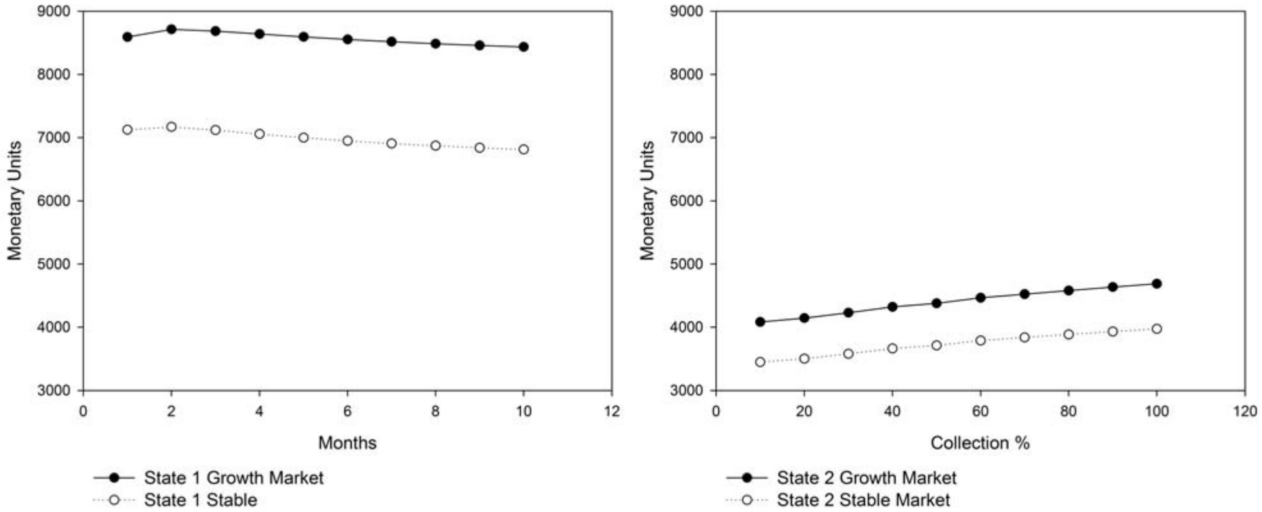

Figure 4.9: Total supply chain profit in state 1 (left) and state 2 (right)

Figures 4.10 and 4.11 show that the magnitude of the profit that the OEM and the retailer have to forego if external costs are neglected, is approximately 50% in each case. This provides also a starting point for sharing the burden of changing the supply chain operations from S_1 to S_2. If only one of the two stood to gain or loose this would definitely result in greater resistance to change and a much more complicated regulatory task.

Finally, the simulation results illustrate that investments in sustainable practices (S_2) have a higher return in growth markets than in low growth markets even against more profligate resource use (S_1). This is evident when comparing in Figures 4.9, 4.10 and 4.11 the plots with 7% annual growth market and zero growth market. The simulation results thus corroborate the empirical findings of Russo and Fouts (1997), where they conclude that industry growth has a modulating effect on economic and environmental performance.

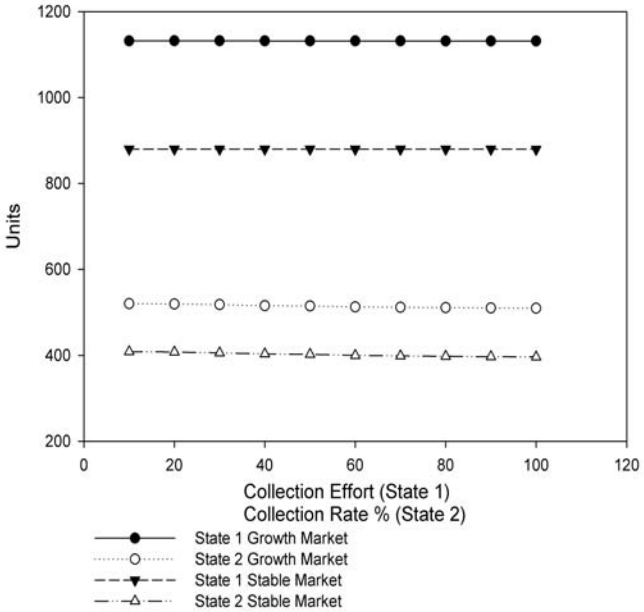

Figure 4.10: OEM profit in growth (left) and stable (right) markets

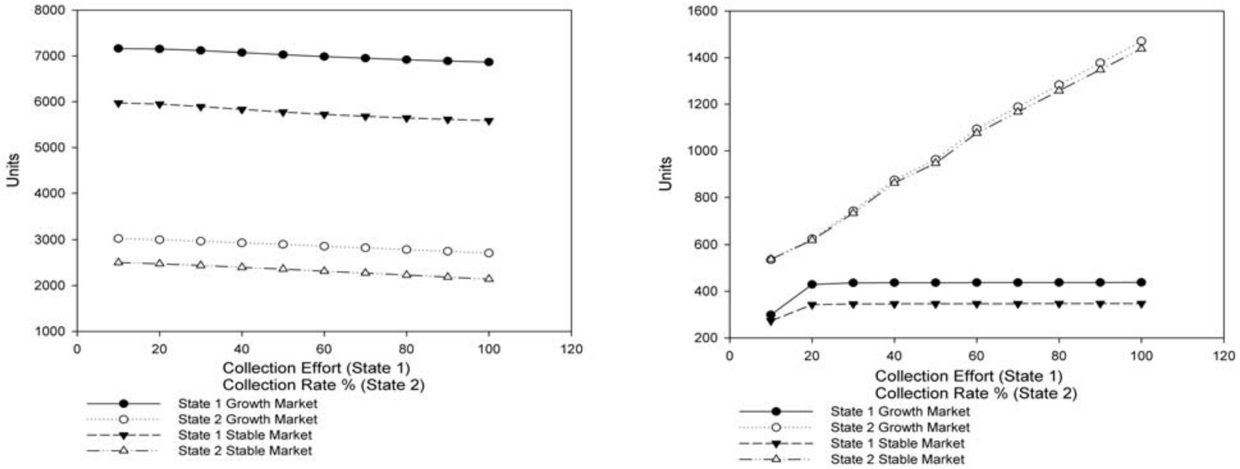

Figure 4.11: Total retailer profit from brand (left) and remanufactured products (right)

Investigation of the environmental performance of the supply chain in state 2 for stable markets, over the range of collection % and proportion of collected products shipped to the OEM (Figure 4.12), shows that the highest performance is achieved with high collection performances and high returns to the OEM.

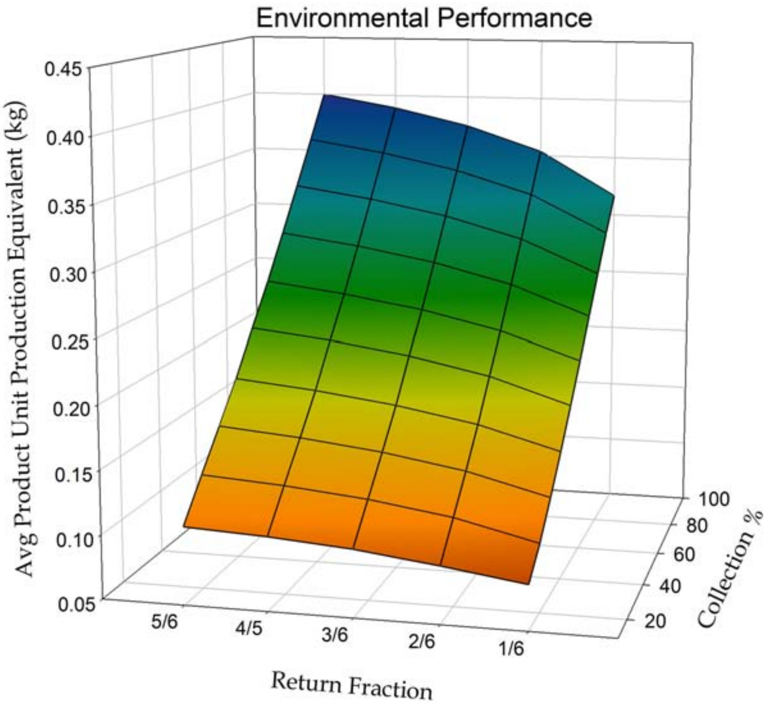

Figure 4.12: Environmental performance in state 2 with collection % and returns to OEM

Figures 4.13 shows the total material inflow to the system in state 2, for stable markets, as a function of the collection % of used products and the proportion of the stream of collected products that the OEM gets to remanufacture. As expected, total inflow is minimum when all brand products are collected and the majority is shipped back to the OEM for recycling, thus minimizing procurement of raw materials for its manufacturing processes.

Figure 4.14 shows the total disposed material of the system in state 2, for stable markets, as a function of the collection % of used products and the proportion of the stream of collected products that the OEM gets to remanufacture. As expected, this is minimum when all brand products are collected and the majority is shipped back to the OEM for recycling, thus minimizing procurement of raw materials for its manufacturing processes.

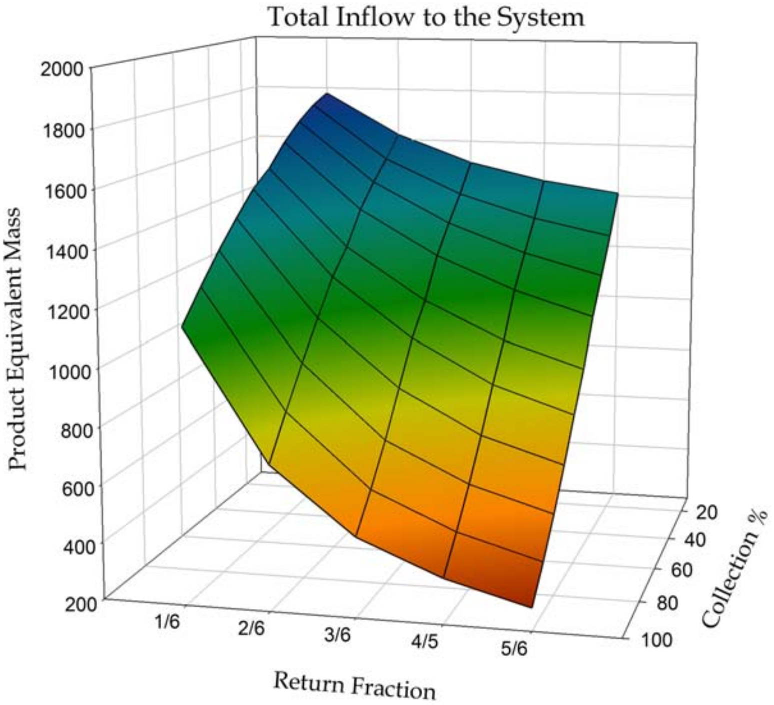

Figure 4.13: Total system inflow in state 2 with collection % & returns to OEM

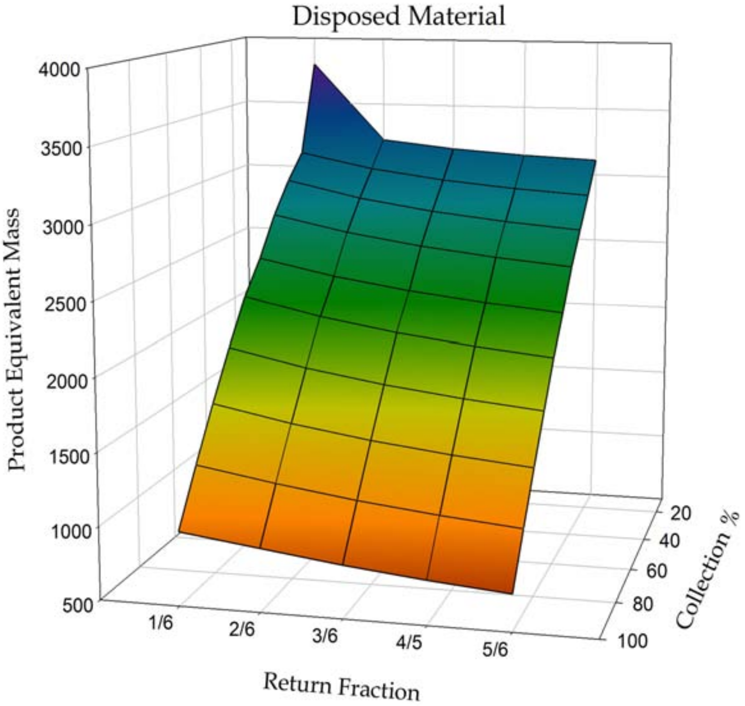

Figure 4.14: Figure Total disposed material in state 2 with collection % & returns to OEM

4.7 Conclusions

Chapter 4 has built on the insights and suggestions of chapters 2 and 3. It applied them in the simulation model and demonstrated that a different supply chain system could perform better. Chapter 4 argued based on the NK model of organisational change literature, the exploration – exploitation literature and the manufacturing literature that the complexity that supply chain actors face in state 1 keeps them in a local adaptation mode from which they are unlikely to escape by themselves. Even if they did though, the market characteristics would prevent them from ripping the benefits of the strategic shift they would undergo. The implication of this is that a wider system change is required at the sociotechnical level instead of the micro level of the supply chain. Such a change will encompass science, technology, industry, policy, user preferences and culture i.e. it constitutes a system transition from regime state 1 to regime state 2 that will carry with it supply chains as well. In order to drive such a process, regulation and outsider interventions are assumed to reduce the complexity that supply chain actors face and facilitate a change in their strategic focus towards state 2. In this context, simulations of the model in state 2 were intended to show the effect of regulation and outsider interventions on the supply chain.

The simulation results highlighted several fundamental points:

i. The effect of consumption patterns (growth or stasis) in driving flows in and out of the system and consequently driving its environmental performance.
ii. The effects of changes in consumer preferences where remanufactured products are perfect substitutes for new ones.
iii. The effect of collaboration in reverse supply chain operations.
iv. The effect of regulation in structuring reverse supply chain operations.
v. The effect of internalising external costs in profitability measures.

In conclusion, supply chain operations in state 2 have superior environmental performance. The apparent lower profitability, which could be taken to be a downside and thus inhibit progress is due to the fact that environmental costs have always been considered external. This is an assumption that if applied to models of state 1 and 2, it portrays state 1 as superior. However, if a systemic perspective or “cradle to cradle” approach is taken, then the end result of the supply chain operation needs to be considered. To the extent that it has an effect on the natural environment and its capacity to provide services vital to the human species, it is necessary to internalise it. Maintaining this capacity is part of sustainable development and is critical to our own survival. Coherent and coordinated actions need to be taken in order to take the first step towards this, abandon local adaptation and truly adapt.

5 Summary & Conclusions

5.1 Summary

This chapter provides an overview and summary of the main points of the thesis and outlines possible future research directions. The subject of interest of the thesis was the integration of environmental considerations in the operations strategy of supply chain actors and the case of internal competition in particular. In order to explore the hypothesis and answer the research questions set in chapter 1, analysis proceeded in two scales.

At the micro scale of individual firms, an analysis of interaction strategies between supply chain actors was carried out based on a case of industrial equipment remanufacturing. In order to explore this hypothesis, the Resource Based View of competition (RBV) was adopted as a framework for analyzing the case. A system dynamics model was developed that was broadened in scope so that it could represent the class of supply chains in which the case belonged to. The model represented a supply chain with an Original Equipment Manufacturer (OEM) that recycled, and a retailer that remanufactured used products. It represented a situation where OEMs and retailers cooperated in the forward supply channel and competed in the reverse. Additional model assumptions were implemented to represent the current state (S_1) of the sociotechnical system and its actors i.e. the institutional environment and consumer behaviour where the supply chain is embedded. For example, it is assumed that there is competition for collected used products in reverse supply chain flow and consumer market is segmented in branded and non branded (remanufactured) products. Subsequently, a set of strategic choices for the supply chain actors was explored through simulations.

Their results showed that under its modus operandi the OEM faced choices that can improve its competitiveness vis a vis its downstream remanufacturers and partners, or can improve the environmental performance of the supply chain at the expense of its own market share and thus its long term prospects. With regard to question 1 set in chapter 1, about the available strategic responses of the OEM and their effectiveness, the results of the simulations showed the complex trade offs that Original Equipment Manufacturers (OEM) face in devising effective strategic responses to supply chain remanufacturing operations undertaken by retailers. The simulation results provided a measure of the environmental impact that each actor had. The responses of the OEM are sufficient but not successful in addressing simultaneously competitive and environmental performance objectives. The key insight derived is that there are inherent trade offs imposed by the institutional environment on the configuration of the interactions in the supply chain, when trying to successfully integrate competitive and environmental considerations in the OEM operations strategy.

Hence, with regard to question 2 on the possibility of addressing simultaneously competitive and environmental performance objectives, it is concluded that the OEM strategies are moderately effective in improving its competitive position or the environmental performance of the supply chain. However, it is impossible to attain both when the supply chain is in state 1 configuration. A macro scale change is necessary that will allow the strategic reorientation of the OEM at the micro scale. The argument on the difficulty in changing the organizational decision making in general and operations strategy in particular, was developed in chapter 4. When applied to the modelled case of industrial equipment production, it suggests that the actors of the supply chain will most likely engage in incremental strategic search. This is effectively a local adaptation logic to the competitive environment, which is hard for the supply chain actors to extricate themselves from, since their mode of interaction is conditioned by the broader institutional environment in which they operate.

The fundamental insight is that strategic change is not likely to materialize or persist and diffuse without macro scale change as well. It will remain local and focused solely at the micro scale. In order for the actors to find their way out of their predicament, the fundamental assumptions under which the system operates in state 1 have to change. This was considered by adopting a macro scale perspective through the Multi Level Perspective framework (Geels, 2004; Geels and Schot, 2007).

Change at this scale constitutes a sociotechnical system transition to a new state (S_2). With regard to question 3 of chapter 1, about the possibility of supply chain configurations that exhibit superior competitive and environmental performance, the alternative assumptions for this state S_2 (outlined in chapter 4) allowed a different set of strategies for the supply chain actors at the micro scale. This enabled the emergence and diffusion of alternative supply chain configurations such as the one explored in chapter 4. The emergence of remanufacturing (RMFG) was conceptualised as a niche of OEMs that engage in such activities initially under the industrial production system in state S_1. The emergence of this niche was considered as a necessary step in shifting the entire industrial production system (IPS) towards a more sustainable operation with remanufacturing and recycling (RMFG).

Its further development though, requires a simultaneous change at the macro – system level from S_1 to S_2. In order to articulate the altered assumptions of state $S_{2,}$ the change from S_1 to S_2 was conceptualised as a system transition using a sociotechnical approach and in particular the Multi Level Perspective (MLP). These new assumptions constitute the end result of the industrial production system transition process from state S_1 to S_2, which would bring about the strategic reorientation of OEMs and allow niches of sustainable operations to form, persist and develop. Subsequently, the new transformed system will be in a better position to respond to the pressures of population, affluence and consumption trends that impact the natural environment.

The first assumption made is that the complexity the actors face in state 1 has been reduced through regulation. This allowed the evolution of their strategies from competition to cooperation in the reverse channel, and institutionalisation of a ratio of controlled reverse product flows to the retailer and the OEM. In effect reducing the complexity should enable the actors to explore more bold strategic moves, and escape the local adaptation logic. The second assumption was that new knowledge has been transferred and utilised in the supply chain system and the sociotechnical system at large. It is assumed that it influences the practice of engineering, product design and product life cycle management issues. It enables the adoption of different perspectives on strategic issues that involve core business competences, competitive positioning in the market, and issues of long and short term profitability. It also shifts the consumer's perception of remanufactured products to being perfect substitutes of new products, in effect unifying the market segments of new and remanufactured products. Thus, system state 2 represents changes to the production and consumption elements, i.e. the technical and the social aspects of the sociotechnical industrial production system.

In order to illustrate the impact of these assumptions on supply chains at the micro scale, and assess their implications, they were implemented in the system dynamics model used in chapter 3 by modifying its structure and assumptions appropriately. In its new configuration, the model demonstrated how the supply chain would operate in an altered state within a transformed sociotechnical system. The results of the simulations showed that the supply chain can operate with a lower environmental impact. The analysis highlights:

i. The effect of consumption patterns (growth or stasis) in driving flows in and out of the system and consequently driving its environmental performance. Specifically, the tests of the model in state 2 illustrated the improved environmental performance of the supply chain, but they also indicated the significant role of exponentially increasing vs stable markets. The implication is that changing the configuration of the supply chain is just as important as curbing further demand growth.
ii. The effects of changes in consumer preferences where remanufactured products are perfect substitutes for new ones. This different consumer attitude allows a significantly different market structure to persist in state 2. Hence, the remanufactured to brand products user ratio is 7/3 in state 2 compared to 1/9 in state 1.
iii. The effect of actor collaboration in reverse supply chain operations. Instead of engaging in detrimental competition for controlling reverse flows, collaboration among actors enables sharing the gains and thus higher utilisation of resources dedicated to remanufacturing and recycling.
iv. The effect of regulation in facilitating and structuring reverse supply chain operations. Regulation reduces complexity and business uncertainty, and thus is conducive to

exploration of different alternatives and bold investment by supply chain partners instead of local adaptation competitive moves.

v. Regulation is also instrumental in changing the framework of supply chain performance evaluation by internalising external costs when measuring profitability. Changing what is measured, alters the framework under which supply chain performance is evaluated and at the same time enables setting new priorities. This is illustrated by comparing the profitability of supply chain in states 1 and 2. Calculation of profit in the conventional way with external costs, renders state 1 as clearly superior.

vi. The role of policy making at the macro level should not be narrowly focused on efficiency improvements on the current state of the system. Instead, it should promote environmentally benign collaboration and open new avenues for firm strategy making.

vii. The role of introducing new knowledge into the system. Endogenous change is usually incremental because it tends to come up against self imposed path dependent obstacles and mental frames. It relies on knowledge that displays the same characteristics. By contrast, knowledge which is external to the system of reference, originates in a variety of sources, it is heterogeneous, and it deviates from the path dependent knowledge that has been accumulating within the system. It therefore carries with it the potential to disrupt the patterns of thinking, decision making and behaviour, and eventually the direction towards which actions are taken.

5.2 Insights At The Micro Scale: Supply Chain Actors

The analysis of the situation in the supply chain, based on the literature, has assumed that the actors cannot endogenously change the situation by themselves. This eventuality is unlikely but not impossible. However, it is not possible to use the same models to offer insights for the decision makers at the micro scale of the supply chain, because they represent the structures of the supply chain as unchanging or exogenously fixed. Inevitably they lead to the conclusion that someone external to the situation must change the structure (Ostrom, 1990). Nevertheless, assuming that the actors are willing to explore different cooperative strategies there are some options that could potentially improve their situation and result in mutual benefit.

The OEM and the retailer in state 1 are in a competitive situation, where the presence of a reverse supply channel complicates things in a number of ways. The availability of used products from the market, sets a capacity constraint for the remanufacturing operations of the retailer and an upper limit for the market share of remanufactured products. It is not possible to become successful to the point where there are not sufficient brand new products to supply the reverse supply channel. In parallel, the OEM faces competition to which it is difficult to respond with resounding success as the simulation results in chapter 3 have shown. In addition, the OEM risks potential future losses if it leaves the retailer unchecked and the retailer also risks future losses in a war of attrition with the OEM.

Drawing on prospect theory that suggests that individuals weigh more future losses than future gains, we can expect if the two actors are made aware of their situation to turn to cooperation rather than competition. This is the case in the supply chain since either of the actors is constrained (retailer), or unable (OEM) in its attempt to counter the strategy of the other, the logical alternative is for the actors to explore strategies of cooperation if they are made aware of their situation (In the event that the retailer has not yet established remanufacturing operations then the OEM can attempt to preempt its move by collecting the cores directly from the market).

The OEM and the retailer could cooperate in order to ensure that remanufactured products do not cannibalize the market for brand products which is the main concern of the OEM. This would include ensuring that the quality standards of the brand products are met by the remanufactured products of the retailer, without the latter promoting them as an alternative to brand products as it currently does. It is possible to differentiate the products by offering service related incentives or offering a discount for new products to users that promptly return their used ones. This could be connected to an agreed ratio of collected products flow to the retailer and the OEM, so that lower production costs allow for brand product discounts. In this way the market share of the OEM is consolidated and the retailer does not have to invest as much in collection effort.

5.3 Insights At The Macro Scale: Policy Makers

The simulation results in chapter 4 demonstrated that the supply chain system could achieve higher environmental performance under a different configuration designated as state 2. The logic in distinguishing between two states is that the complexity the supply chain actors face in state 1 keeps them in a local adaptation mode from which they are unlikely to escape by themselves. Even if they did though, market characteristics would prevent them from ripping the benefits of the strategic shift they would undergo. The implication is that a broader system change is required at the sociotechnical level (macro scale) instead of the micro scale of the supply chain. Such a change will encompass science, technology, industry, policy, user preferences and culture i.e. it constitutes a sociotechnical system transition from regime state 1 to regime state 2 that inevitably changes supply chain configurations as well. In order to facilitate and/or guide such a process, policy interventions are required to reduce the complexity that supply chain actors face and facilitate a change in their strategic focus towards state 2. In this context, simulations of the model in state 2 showed the potential influence of regulation and outsider interventions could have in a number of areas of the sociotechnical system that around the supply chain:

i. The consumption patterns (growth or stasis) that drive flows in and out of the system and consequently drive its environmental performance.
ii. The consumer preferences (remanufactured products are perfect substitutes for new ones).
iii. Collaboration between actors in reverse supply chain operations.
iv. Provide a regulatory apparatus for reverse supply chain operations.
v. Internalise external environmental costs of production.

While it is not possible to determine or produce the desired outcome through policies alone, it is possible to use them in order to facilitate these kind of effects on the system. Therefore, policies designed to curb demand growth, facilitate the move towards collaborative closed loop supply chains and internalising environmental/external costs in product cost structures are particularly conducive towards this.

5.4 Future Research Outlook

Building on the current thesis, the research outlook consists of a number of ideas that can be implemented relatively easily and complement the work of the current thesis, and others that constitute long term aims. The first possible extension to the model is to examine cases where supply chain actors engage in remanufacturing or in recycling only. Working with the model developed in chapter 3, it would be possible to compare different configurations:

i. Competitive recycling between the OEM and the retailer or a third party which intercepts reverse supply chain flows.
ii. Competitive remanufacturing between the OEM and the retailer or a third party which intercepts reverse supply chain flows
iii. Explore points i and ii and the model of chapter 3 for various levels of product remanufacturability and recyclability. The question that could be answered is how each operation performs in terms of eroding the competitive advantage of the OEM, and in terms of their environmental impact.

A concomitant step would be to conduct an exploration of the supply chain configuration in the same way done in chapter 3 in order to see whether there are any win – win strategies. In the case that there are none, this would strengthen the argument the thesis makes on the value of collaboration in reverse supply chains. Subsequently, it would be interesting to modify the models produced in order to examine possible alternative collaborative supply chain configurations. An additional research line would be to use the models to explore closed loop supply chain dynamics, product life cycle management, product diffusion issues, and OEM competition. For example study the impact of the diffusion rate and the number of repeat purchases, or the length of the product life cycle on the environmental impact of the supply chain.

A more comprehensive and ambitious modelling endeavour would be to expand the model to represent several supply chains. This would enable an exploration of competitive situations where any combination of recycling and remanufacturing is undertaken by supply chain actors. It would provide some insight into the conditions under which an OEM can, or cannot, respond against competing OEMs that undertake recycling and/or remanufacturing operations. This would complement the work of the present thesis that explored how the OEM can respond its position against retailer remanufacturing operations.

Modelling work at the macro scale could be undertaken in order to study the transition of the supply chain from state 1 to state 2 and thus complement the work of this thesis that has explored only the initial and the final states of the supply chain. This requires an expansion of the model in order to represent a complete sociotechnical system instead of the supply chain only. Through this, it would be possible to conduct a longitudinal examination of how changes in the institutional context can influence the managerial interpretations of environmental issues and thus accelerate the incorporation of environmental elements in corporate strategy.

Drawing on this kind of work would enable a more nuanced and detailed exploration on the effect of regulation, its timing and intensity, as well as the role of outsider intervention. It would be possible to experiment with different kinds of interventions at different points in the system and study if and when the system does transition to a new state. The added benefit of doing so would be to identify the sources of resistance to change in the system and devise different interventions in order to overcome it. It would be possible to get some sense of which interventions tilt the system towards the desirable effect and which should be avoided altogether.

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Appendix 1 Model variables grouped in model modules

OEM manufacturing

Variable name	Unit	Description
OEM manufacturing	da^-1	Rate of brand product manufacturing
OEM policy		Variable generating the rationing policy profile of the OEM towards the retailer
OEM inventory		
OEM production data review		Contribution of recycled products in OEM manufacturing
OEM shipping	da^-1	Ratio of OEM shipments to retailer
OEM unit cost		Variable of OEM unit cost based on manufacturing experience
OEM unit price		OEM unit price based on cost and margin
OEM recycled unit cost		OEM unit cost for recycled products based on recycling learning

Retailing Operations

Variable name	Unit	Description
Brand Order Backlog		
Brand Order Fill Rate	da^-1	Rate of orders filled per day
Retail Inventory		
Retail Ordering		Retailer orders for brand products based on brand demand and backlog, brand product inventory and sales
Brand Sales	da^-1	Rate of brand sales subject to inventory coverage

Market dynamics

Variable name	Unit	Description
Brand attractiveness		Brand attractiveness based on brand backlog and product unit price
Brand Customer Orders	da^-1	Rate of customer orders directly proportional to drand demand
Brand demand increase	yr^-1	Annual brand demand increase directly proportional to brand demand level.
Brand demand total		Sum of brand demand and backlog orders
Brand differential		Difference between OEM brand image and Non branded image
Check brand demand		Check implemented for zero values
Check non branded demand		Check implemented for zero values
Market shift	mo^-1	Rate of customers shifting from brand to remanufactured products and vice versa based on product attractiveness
Retailer attractiveness		Retailer attractiveness based on brand backlog and product unit price

Appendix 1 Model variables grouped in model modules

Variable name	Unit	Description
Collected inventory		
Collected inventory coverage	da	Inventory coverage based on required rate of remanufacturing in order to cover total demand
Collection effort		
Collection effort deterioration	mo^-1	Rate at which the effect of collection effort is depleted
Disposal rate	da^-1	Rate of used product disposal
Dynamic collection rate		Amount of collection effort that actually has an effect on collection rate
Remanufactured demand increase	yr^-1	Rate of annual demand for remanufactured products
Remanufactured demand total		Sum of demand and backlog for remanufactured products
Retailer collection	da^-1	Rate of collection of used products by the retailer
Remanufacturing	da^-1	Retailer remanufacturing rate based on retailer capacity and remanufacturing inventory coverage
Remanufacturing customer orders	da^-1	Rate of orders for remanufactured products
Remanufactured order backlog		
Remanufactured order fill rate	da^-1	Rate of order fulfilment for remanufactured products demand
Retailer remanufacturing	da^-1	Rate of retailer remanufacturing not subject to capacity constraints, based on collection rate, remanufactured sales
Retailer capacity being built	da^-2	Rate of order of remanufacturing capacity based on collected inventory, capacity on line, remanufacturing capacity coverage
Retailer REM capacity increase	da^-2	Rate at which the remanufacturing capacity ordered becomes operational
Retailer remanufacturing capacity	da^-1	
Retailer remanufactured inventory		
Remanufactured sales	da^-1	Rate of sales of remanufactured products
Retailer returns OEM manufacturing ratio		Ratio of retailer returns to the OEM over the OEM manufacturing rate
Remanufacturing undercapacity ratio		Ratio of actual remanufacturing capacity over the required capacity
Retailer remanufactured unit cost		Remanufactured product cost based on learning achieved in remanufacturing
Retailer remanufactured price		Remanufactured product unit price
Remanufactured sales collection rate ratio		Rate of remanufactured products sales to used product collection rate
Retailer returns	wk^-1	Rate of used product returns to OEM
Retailer trust		
Retailer brand		Level of status the retailer has achieved as remanufacturer
Retailer trust decrease	yr^-1	Rate at which customers lose trust in the retailer's remanufactured products
Retailer trust increase	mo^-1	Rate at which the retailer wins over customers trust in remanufactured products
Total retailer remanufactured quantity		

Appendix 1 Model variables grouped in model modules

OEM's recycling resources

Variable name	Unit	Description
OEM capacity increase	da^-2	Rate at which recycling capacity comes on line
OEM recycling	da^-1	OEM recycling rate subject to capacity constraints
OEM recycling %		Recycled products by the OEM as percentage of total processed products (manufactured and recycled)
OEM recycling capacity being built	da^-2	Rate at which recycling capacity is being ordered
OEM recycling capacity built	da^-1	Capacity not online
OEM recycling capacity	da^-1	Initial OEM REC capacity
OEM recycling inventory		Initial REM inventory
OEM recycling brand inventory ratio		Ratio of inventory for recycling to brand inventory
OEM recycling manufacturing ratio		Ratio of OEM recycling to manufacturing ratio
Retailer returns OEM manufacturing ratio		Ratio of rate of returns of used products over manufacturing rate, used to assess the significance of the return stream for the OEM
OEM undercapacity ratio		Ratio of actual to required recycling OEM capacity
Total OEM recycled quantity		

Appendix 2 Modifications of State 1 for State 2 model

1. Product attractiveness is contingent only on order backlog. Products are substitutable.
2. Returns to OEM equation changed to 1/5 x Collected inventory
3. Non brand sales flow is connected to Inventory in use thus closing the loop.
4. There is no product disposal to the environment.
5. Dynamic collection rate has been set to 100%.
6. Product life cycle from 3 years to 2.

Appendix 3 Model Equation Listing

Name	Definition
OEM avg mfg	SLIDINGAVERAGE('OEM mfg',1<<yr>>,'OEM Materials Procurement')
Backlog effect	1
Brand attractiveness	MAX('Retailer unit REM price'/'Retailer unit price', SLIDINGAVERAGE('Retailer Backlog Demand Ratio','Market Backlog Perception Time','Retailer Backlog Demand Ratio') *'Retailer unit REM price'/'Retailer unit price'*'Backlog effect')
Brand Customer Orders	Brand demand'/1<<yr>>
Brand demand	Initial Demand'
Brand demand increase	Brand demand'*'Fractional demand increase'
Brand demand total	Switch Linear - Periodic Demand'*'Brand demand'+'Brand Order Backlog'
Brand differential	OEM brand image'-'No name image'
Brand Order Backlog	0
Brand Order Fill Rate	Retail Sales'*MAX(0,MIN(1, FLOOR('Brand Order Backlog')))
Brand profit	'Brand demand total'*'OEM margin'
Check brand demand	MIN('Brand demand'/(ABS('Attractiveness differential'.'Attractiveness differential')),1)
Check brand inventory	MIN('Retail Inventory'/'Brand demand total',1)
Check collection effort	1-MIN('Collection effort'/'Maximum Collection Effort',1)
Check no name demand	MAX(0,MIN(ROUND('Non branded demand',0.01)/ABS('Attractiveness differential'.'Attractiveness differential'),1))
Check OEM inventory	MIN(MAX('OEM inventory'/'Retail Ordering',0),1)
Check REM inventory	MIN(FLOOR('Retailer REM inventory',0.1)DIVZ0 NUMBER('REM demand total'),1)
Check retailer brand image	1-MIN('No name image' DIVZ0 'Target retailer image',1)
Check System R capacity	NUMBER(MIN(1/1<<yr>>,MAX('OEM Recycling capacity','REM capacity being built','Retailer REM capacity')))
Check trust	1-MIN('Retailer trust'/'Maximum Retailer Trust',1)
Collected inventory	'Initial REM inventory'
Collected inventory coverage	MIN('Collected inventory'/MAX('Indicated Retailer Remanufacturing',1/1<<yr>>),1<<yr>>)
Collection effort	0
Collection effort deterioration	Collection effort'/'Retailer Collection Effort Depletion'
Contribution of new products to activity	1
Contribution of Recycled product to activity	0.8
Contribution of recycled products to activity	-0.3
Contribution of remanufactured products to activity	0.3
OEM capacity becomes available	MAX('OEM capacity being built'/'OEM recycling capacity lead time',0/'OEM recycling capacity lead time'^2)
Delay in effect of effort	6<<mo>>
Disposal rate	MAX('Inventory on use'/(NUMBER('Product use time Sensi Var'))/1<<yr>>,0/1<<yr>>)*(1-'Dynamic collection rate')
Disposed Material	0
Dist OEM Retailer	300
Dist Supplier OEM	60
Dist User Retailer	60
Dynamic collection rate	MAX(ROUND((MIN('Effective collection effort',1)),0.001),0)
Effective collection effort	SLIDINGAVERAGE('Collection effort','Delay in effect of effort')
EI Production Activity	0
EI Spare Retailer	0
EI Spares OEM	0
Environmental performance	OEM Env Perf'+'Retailer Env Perf'
Final retailer REM Sales ratio	MAX(SLIDINGAVERAGE('Retailer REM Retail sales ratio',1<<mo>>,0),0)
Forward OEM capacity	1000/1<<yr>>
Fractional demand increase	0.07/1<<yr>>
Frequency period	1<<mo>>
Increase in collection effort	MAX(NUMBER('No name total demand ratio'),0)/'Time to increase Retailer Collection Effort'*'Check collection effort'*'Check System R capacity'
Increase OEM REC	'OEM Recycling'
Increase retailer REM	'Retailer Remanufacturing'
Indicated Retailer Remanufacturing	MAX('Non Brand Sales','REM demand total'/1<<yr>>,0/1<<yr>>)*'Retailer collection sales ratio'
Inflow Outflow Collected Inventory	'Retailer Collection Rate'-'Returns to OEM'/1<<yr>>-'Retailer Remanufacturing'

Appendix 3 Model Equation Listing

Name	Definition
Initial Demand	1000
Initial inventory	1000
Initial Non Branded Demand	10
Initial OEM margin Sensi Var	0.3
Initial OEM REC capacity	0/1<<yr>>
Initial OEM unit cost	1
Initial REM inventory	0
Initial REM unit cost	0.5
Initial Shipments	1000
Inventory on use	Initial Demand'
Manufacturing Retail sales ratio	'OEM Materials Procurement'/MAX('Retail Sales',1/1<<wk>>)
Manufacturing Retailer REM ratio	'OEM mfg'/MAX('Retailer Remanufacturing',1/1<<wk>>)
Margin reduction	0.5
Market Backlog Perception Time	1<<mo>>
Market shift	('Attractiveness differential'.'Attractiveness differential'*'Market shift Brand-Price spectrum based behaviour' +IF ('Attractiveness differential'.'Market shift direction'=1,MIN('Brand differential',1),MIN(1,1-'Brand differential')) *(1-'Market shift Brand-Price spectrum based behaviour'))*'Check no name demand' /'Market shift time'
Market shift Brand-Price spectrum based behaviour	0.7
Market shift time	1<<mo>>
Maximum Collection Effort	1
Maximum Retailer Trust	1
Multiperiod switch	0
No name brand demand ratio	'Non branded demand'/'Brand demand'
No name image	0
No name image increase	('Non Brand Sales' DIVZ0 'Retail Sales'-DELAYINF('Non Brand Sales' DIVZ0 'Retail Sales','Time to change retailer brand image',1,'Non Brand Sales' DIVZ0 'Retail Sales'))/'Time to change retailer brand image'*'Check retailer brand image'
No name total demand ratio	'Non branded demand'/'Total Demand'
Non Brand Demand Increase	Non branded demand'*'Fractional demand increase'
Non Brand Sales	'REM demand total'*'Check REM inventory'/1<<yr>>
Non branded attractiveness	MAX('Retailer unit price'/'Retailer unit REM price', SLIDINGAVERAGE('OEM Backlog Demand Ratio','Market Backlog Perception Time','OEM Backlog Demand Ratio') *'Retailer unit price'/'Retailer unit REM price'*'Backlog effect')
Non branded demand	'Initial Non Branded Demand'
OEM production decisions	MAX(0,(NUMBER('Retail Ordering'*'OEM No Cooperation - Rationing') -'OEM inventory')+NUMBER('OEM shipping'))
OEM Backlog Demand Ratio	('Brand Order Backlog'/'Total Demand')}[INDEX('Relative Backlog Effect Set up')]
OEM brand image	1
OEM brand production	OEM mfg'
OEM Brand production percentage	MAX(1,'Total OEM brand production')/MAX(1,'Total OEM Brand & REC production')
OEM capacity being built	0/1<<yr>>
OEM capacity increase	OEM undercapacity ratio'*MAX(1/1<<yr>>,'OEM Recycling capacity'+'OEM capacity being built') /1<<yr>>
OEM Comp Perf	RUNAVERAGE('Retailer unit REM price'/'OEM unit price to retailer')
OEM cost exponent	-0.015
OEM Env Perf	('Total OEM REC quantity' *'OEM production Activity')DIVZ0('EI Spares OEM')
OEM inventory	Initial Demand'
OEM inventory for recycling	Initial REM inventory'
OEM manufacturing remanufacturing ratio	MIN('OEM mfg'/'Retailer returns',100)
OEM margin	'OEM unit price to retailer'-'OEM unit cost'
OEM Materials Procurement	MAX(0/1<<yr>>,DELAYMTR('OEM production decision','Shipping delay Sensi Var',1,NUMBER('Initial Demand'))/1<<yr>> -'OEM Recycling')
OEM mfg	DELAYMTR('OEM production decision','Shipping delay Sensi Var',1,NUMBER('Initial Demand'))/1<<yr>>
OEM No Cooperation - Rationing	IF ('Rationing Pattern'<1,1-'Rationing Level OEM',1)
OEM price response switch	0
OEM production	'OEM mfg' +'OEM Recycling'
OEM production Activity	0
OEM profit	0
OEM Raw Material	'Initial Demand'

Appendix 3 Model Equation Listing

Name	Definition
OEM REC %	'Total OEM REC quantity'/'Total OEM Brand & REC production'
OEM REC avg Capacity utiliz	RUNAVERAGE('OEM REC capacity utilization')
OEM REC capacity utilization	'OEM Recycling' DIVZ0 'OEM Recycling capacity'
OEM REC manufacturing ratio	DELAYINF('OEM Recycling'/MAX(1/1<<yr>>,'OEM avg mfg'),1<<qtr>>,1, 'OEM Recycling'/MAX(1/1<<yr>>,'OEM avg mfg'))
OEM REC Retail sales ratio	'Retailer returns'/'Retail Sales'
OEM Recycling	MIN(FLOOR('OEM inventory for recycling',0.01)/1<<yr>>,'OEM Recycling capacity')
OEM Recycling capacity	Initial OEM REC capacity'
OEM recycling capacity lead time	0.5<<yr>>
OEM REM brand inventory ratio	'OEM inventory for recycling'/'OEM inventory'
OEM shipping	DELAYMTR('Retail Ordering','Shipping delay Sensi Var',1,NUMBER('Initial Demand'))/1<<yr>>
OEM undercapacity ratio	IF ('OEM inventory for recycling'>NUMBER('OEM Recycling capacity'), NUMBER(MAX('Retailer returns'-'OEM Recycling capacity' +'OEM inventory for recycling'/1<<yr>>-('OEM Recycling capacity'+'OEM capacity being built') ,0/1<<wk>>) /MAX(1,NUMBER('OEM Recycling capacity'+'OEM capacity being built'))) *'REM returns OEM manufacturing ratio',0)
OEM unit cost	(('Initial OEM unit cost'*(1-'Weight of REC in price setting') +(1-MIN(1,'Production data review'))*'Weight of REC in price setting')) *MIN('Total OEM Brand & REC production'^'OEM cost exponent',1)
OEM unit price to retailer	'OEM unit cost'+'Initial OEM margin Sensi Var'
OEM unit REC cost	MIN('Total OEM REC quantity'^'OEM cost exponent',1)
Pricing policy	IF (SLIDINGAVERAGE('Retail Sales',1<<mo>>,'Retail Sales')<900/1<<yr>>,1-'OEM price response switch',1)
Product use time Sensi Var	3<<yr>>
Production activity new	'Contribution of new products to activity'*'OEM mfg' +'Contribution of recycled products to activity'*MIN('OEM mfg','OEM Recycling')
Production activity remanufactured	'Contribution of remanufactured products to activity'*'Retailer Remanufacturing'
Production data review	SLIDINGAVERAGE('OEM REC manufacturing ratio','Production data review delay')
Production data review delay	6<<mo>>
Production Materials	1
Prospective capacity	0
Prospective capacity built up	'Retailer capacity increase'*1<<yr>>
REM capacity becomes available	MAX('REM capacity being built'/'Retailer REM Capacity lead time',0/'Retailer REM Capacity lead time'/1<<yr>>)
Total activity increase	'Total activity'
Retailer production activity increase	'Retailer Remanufacturing'*(1-'Contribution of remanufactured products to activity')
EI production activity increase	'OEM mfg'*'Contribution of new products to activity' +'Contribution of Recycled product to activity'*'OEM Recycling' +'Contribution of remanufactured products to activity'*'Retailer Remanufacturing'
Total materials use increase	'OEM Materials Procurement'*'Production Materials' +'OEM Recycling'*'Recycling Materials' +'Retailer Remanufacturing'*'Remanufaturing Materials'
Disposed material increase	'Disposal rate' +'OEM Recycling'*'Recycling Disposed Material' +'Retailer Remanufacturing'*'Remanfuacturing Disposed material'
OEM profit increase	('OEM margin'-0.01)*'OEM shipping'
Retailer profit increase	'Retailer margin'*('Non Brand Sales'+'Retail Sales')
EI OEM spares increase	Dist Supplier OEM'*'OEM Recycling'*'Vol Spares' +('Dist OEM Retailer'+'Dist User Retailer')*'OEM Recycling'*'Vol Reverse' /1000
EI Retailer spares increase	('Dist OEM Retailer'+'Dist Supplier OEM')*'Retailer Remanufacturing'*'Vol Spares' +'Vol Reverse'*'Dist User Retailer'*'Retailer Collection Rate' /1000
Material inflow to system	'OEM Materials Procurement'
OEM production activity increase	OEM Recycling'*(-'Contribution of recycled products to activity')
Total REM & REC increase	'Total production'
Total collected inventory increase	'Retailer Collection Rate'
Total brand sales increase	'Retail Sales'
Total REM sales increase	'Non Brand Sales'
Ratio of recycling to materials procurement	MIN(1, 'OEM Recycling'/'OEM Materials Procurement')
Rationing Level OEM	0.9
Rationing Pattern	(1-(STEP('Rationing Level OEM',STARTTIME+'Rationing Policy Start')))*(1-'Multiperiod switch')+ MIN((NUMBER(SINWAVE(-'Rationing Level OEM',2*'Frequency period',-2*'Frequency period'))) *STEP(1,STARTTIME+'Rationing Policy Start') +1,1)*'Multiperiod switch'

Appendix 3 Model Equation Listing

Name	Definition
Rationing Policy Start	0<<yr>>
REC & REM units as % of Total sales	('Total OEM REC quantity'+'Total retailer REM quantity')/MAX(1,('Total Brand sales'+'Total retailer REM sales'))
Recycling Disposed Material	0.1
Recycling Materials	0.7
Relative Attractiveness	'Non branded attractiveness'/ ('Brand attractiveness'+'Non branded attractiveness')
Relative Backlog Effect Set up	1
REM & REC Brand Ratio	('Total retailer REM quantity'+'Total OEM REC quantity') DIVZ0'Total OEM brand production'
REM avg Capacity utiliz	RUNAVERAGE('REM Capacity utilization')
REM Backlog Demand Ratio	'REM Order Backlog'/MAX(1,'Non branded demand')
REM Brand profit ratio	'REM profit'/'Brand profit'
REM Brand Ratio Sales	'Total retailer REM sales' DIVZ0 'Total Brand sales'
REM capacity average utilization	RUNAVERAGE('REM Capacity utilization')
REM capacity being built	0/1<<yr>>
REM Capacity utilization	Retailer Remanufacturing' DIVZ0 'Retailer REM capacity'
REM Customer Orders	Switch Linear - Periodic Demand'*'Non branded demand'/1<<yr>>
REM demand total	MAX('REM Order Backlog'+'Switch Linear - Periodic Demand'*'Non branded demand',0)
REM in Use	0
REM inventory coverage	FLOOR('Retailer REM inventory',0.01)/'REM demand total'//,0.01)
REM Order Backlog	0
REM Order Fill Rate	Non Brand Sales'*MAX(0,MIN(1, FLOOR('REM Order Backlog')))
REM profit	'REM demand total'*'Retailer margin Sensi Var'
REM profit average	RUNAVERAGE('REM profit')
REM profit STDEV	RUNSTDEV('REM profit')
REM REC Ratio	'Total retailer REM quantity' DIVZ0'Total OEM REC quantity'
REM returns OEM manufacturing ratio	SLIDINGAVERAGE(MIN('Retailer returns'/MAX('OEM mfg',1/1<<yr>>),1),1<<mo>>)
REM sales total sales ratio	'Non Brand Sales'/('Retail Sales'+'Non Brand Sales')
REM Switch	1
REM undercapacity ratio	REM Switch'*MAX(0,(NUMBER('Indicated Retailer Remanufacturing')-MAX(1,'Prospective capacity'+NUMBER('Retailer REM capacity'))))
Remanfuacturing Disposed material	0.3
Remanufaturing Materials	0.3
Retail Inventory	Initial Demand'
Retail Ordering	MAX(0,((NUMBER('Brand demand total')-'Retail Inventory')))
Retail Sales	'Brand demand total'*'Check brand inventory'/1<<yr>>
Retailer Average Collection Rate	RUNAVERAGE('Retailer Collection Rate')
Retailer Backlog Demand Ratio	('REM Order Backlog'/'Total Demand')}[INDEX('Relative Backlog Effect Set up')]
Retailer Capacity Expansion Decision Frequency	6 mo
Retailer capacity increase	'Decision module'.Decision
Retailer Collection Effort Depletion	4 mo
Retailer Collection Rate	MAX('Inventory on use'/(NUMBER('Product use time Sensi Var')/3)/1<<yr>>,0/1<<yr>>) *MAX('Dynamic collection rate',0)
Retailer collection sales ratio	MIN('Retailer Collection Rate' DIVZ1'Non Brand Sales',1)
Retailer Comp Perf	RUNAVERAGE('OEM unit price to retailer'/'Retailer unit REM price')
Retailer cost exponent	-0.015
Retailer Env Perf	('Total retailer REM quantity' *'Retailer Production Activity') DIVZ0'EI Retailer spares'
Retailer margin	1.2
Retailer margin Sensi Var	0.3
Retailer Production Activity	0
Retailer profit	0
Retailer profit brand sales	'Total Brand sales'*'Retailer unit price'
Retailer profit rem sales	'Total retailer REM sales'*'Retailer unit REM price'
Retailer REM capacity	0/1<<yr>>
Retailer REM Capacity lead time	1<<yr>>
Retailer REM inventory	'Initial REM inventory'
Retailer REM OEM total manufacturing ratio	SLIDINGAVERAGE('Retailer Remanufacturing'/MAX(('OEM mfg'+'Retailer returns'),1/1<<wk>>),1<<mo>>,0)
Retailer REM Retail sales ratio	'Retailer Remanufacturing'/'Retail Sales'
Retailer Remanufacturing	REM Switch'*MIN('Retailer REM capacity','Indicated Retailer Remanufacturing' *MIN('Collected inventory coverage'/1<<yr>>,1))
Retailer returns	DELAYMTR('Returns to OEM','Shipping delay Sensi Var',1,0)/1<<yr>>

Appendix 3 Model Equation Listing

Name	Definition
Retailer Sensitivity to Undercapacity	0.5
Retailer trust	0
Retailer trust decrease	'Retailer trust'/'Time for trust depletion'
Retailer trust increase	MAX(0,'Collection effort'-'Retailer trust')/'Time to Increase Retailer Trust'*'Check trust'
Retailer unit price	'Retailer margin'*'OEM unit price to retailer'
Retailer unit REM cost	Initial REM unit cost'*MIN('Total retailer REM quantity'^'Retailer cost exponent',1)
Retailer unit REM price	'Retailer unit REM cost'+'Retailer margin Sensi Var'
Returns to OEM	MAX(ROUND('Collected inventory',0.1)-NUMBER('Retailer Remanufacturing'),0)
Shipping delay Sensi Var	2<<wk>>
Switch Linear - Periodic Demand	1
Target retailer image	1
Test Dynamic Collection Rate	0
Threshold capacity	0/1<<yr>>
Time for trust depletion	3<<yr>>
Time to change retailer brand image	3<<mo>>
Time to increase Retailer Collection Effort	1<<mo>>
Time to Increase Retailer Trust	9<<mo>>
Total activity	'Production activity new'+'Production activity remanufactured'
Total Backlog	'REM Order Backlog'+'Brand Order Backlog'
Total Brand & REM Sales	'Total Brand sales'+'Total retailer REM sales'
Total Brand REM & REC production activity	0
Total Brand sales	0
Total collected inventory	0
Total Collected Inventory Total Brand & REM sales Ratio	'Total collected inventory'/'Total Brand & REM Sales'
Total Demand	'Brand demand'+'Non branded demand'
Total Inflow to the System	0
Total Materials Use	0
Total OEM Brand & REC production	0
Total OEM brand production	0
Total OEM REC quantity	0
Total Outflows from Collected Inventory	'Retailer Remanufacturing'+'Returns to OEM'/1<<yr>>
Total production	('OEM Recycling'+0.3*'Retailer Remanufacturing'+0.3*'OEM mfg')
Total production REM & REC	0
Total REM & REC	'Total OEM REC quantity'+'Total retailer REM quantity'
Total Remanufacturing Retail sales ratio	SLIDINGAVERAGE(('Retailer returns'+'Retailer Remanufacturing')/MAX('Retail Sales', 1/1<<wk>>),1<<mo>>,0)
Total retailer REM quantity	0
Total retailer REM sales	0
Undercap Ratio & Decision Start	1<<mo>>
Vol Reverse	1000
Vol Spares	30
Weight of REC in price setting	0.2

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