

# Chapter 7

## Stocks and Flows in the Performance Economy

Walter R. Stahel and Roland Clift

**Abstract** The performance economy is a concept which goes beyond most interpretations of a “circular economy”: the focus is on the maintenance and exploitation of stock (mainly manufactured capital) rather than linear or circular flows of materials or energy. The performance economy represents a full shift to servicisation, with revenue obtained from providing services rather than selling goods. While the form of industrial economy which has dominated the industrialised countries since the industrial revolution is arguably appropriate to overcome scarcities in a developing economy, the performance model is applicable in economies close to saturation, when the quantities of new goods entering use are similar to the quantities of goods being scrapped at the end of life.

Key elements of the performance economy are re-use and re-manufacturing, to maintain the quality of stock and extend its service life by reducing material intensity, i.e. the material flow required to create and maintain the stock. Because material flows represent costs which reduce the revenue from service provision, business models inherent in the performance economy support the macro-level objective of extending service life and thereby minimising material intensity. Product life in the performance economy is limited by technological improvements in the efficiency of manufactured capital rather than by damage, wear or fashion.

Re-use and re-manufacturing tend to be more labour-intensive and less capital-intensive than virgin material production or primary manufacturing. This enables re-use and remanufacturing to be economically viable at smaller scales. It also enables these activities to substitute labour for energy, reversing the trend which has characterised industrial economies and offering ways to alleviate current environmental, economic and global challenges; i.e. to make the economy more sustainable. However, there are significant barriers to adoption of the performance economy model, partly because economic and business models generally focus on flows (GDP or added value) rather than prioritising the quality, value and use of stock. Promoting the performance model may require a complete re-think of public policy,

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away from subsidising to taxing use of non-renewable resources and away from taxing the use of renewable resources, of which labour is possibly the most important. Recent analyses of the social costs of unemployment and potential social benefits of a more resource efficient performance economy provide some of the evidence supporting a shift from flow to stock management.

**Keywords** Circular economy • Flows • Goods as services • Manufactured capital • Molecules as services • Performance economy • Re-use • Recycling • Remanufacturing • Reprocessing • Service life • Stocks

## 1 Introduction

Economic activities, particularly trade, are usually characterised in terms of flows of goods, energy and services. Many areas of industrial ecology focus on flows, and concepts such as the “circular economy” are framed in terms of recycling and re-use flows. However, wealth itself is a stock, not a flow: the wealth of societies is based on their stocks of goods and capital. Arguably, the quality of life in a developed society depends more on the quantity and quality (Q&Q) of its stock than on the flows through the economy. Stocks represent accumulated flows. Therefore, the flows needed to develop and maintain capital stocks are important, particularly in developing economies; the relationship between flows and stocks is explored in Chap. 6. But this chapter explores some of the insights revealed by focussing on managing and using the stocks themselves rather than flows. This is one of the central principles in the concept of the “performance economy” (Stahel 2010).

Various authors (e.g. Forum for the Future 2015) have proposed categorisations of the stocks available to a society. Most categorisations propose five forms of capital; for example, in the context of this chapter:

- Natural capital
- Cultural capital
- Human capital
- Manufactured capital
- Financial capital.

*Natural capital* can be treated as a Global Commons, using a stock management approach, such as sustainable fishing and forestry. If a flow maximisation approach is applied instead, natural capital will inevitably be degraded, repeating the “Tragedy of the Commons”; obvious examples are over-fishing, loss of biodiversity and accumulation of foreign substances such as toxins, salts and plastic debris.

Maintaining quality with its associated tensions is also a widespread concern for *Cultural capital*; the UNESCO world heritage programme is regularly faced with the dilemma of balancing protecting sites against their economic exploitation.

Cultural capital includes immaterial stocks such as music and local traditions; these can be shared but commercialised sharing may lead to loss of quality through dilution.

*Human capital* is intrinsically linked with intangible *acquired capital*; i.e. *skills and capabilities*. Human capital is the only resource whose quality can be improved through education and training. Developing and maintaining human capital as a renewable resource is one of the issues explored in this chapter.

### **The Role of Incentives in Flow Versus Stock Management – The Case of Reforestation**

If the wealth of societies is based on the quantity *and* quality (Q&Q) of capital or stocks, a delicate balance is necessary to maintain stock quantity without compromising stock quality. Growth can be defined as increase in Q&Q of stock rather than flow. To achieve this, policy measures need to shift from a flow to a stock approach: witness reforestation programmes in countries like Nepal, which are directed and financed by Western organisations.

Local people are paid to grow seedlings, plant them on barren slopes, water them regularly and protect them by fences - a typical production-driven flow approach. Local people respond in a flow-focused way by minimising their work load, which means reforesting slopes near villages rather than the slopes presenting the biggest hazards (the stock approach). As villagers have conflicting priorities, such as feeding their goats and cattle and working as tourist guides, they will often neglect the maintenance of the fences, and goats will eat the young trees. A new reforestation programme will follow, financed by well-meaning sponsors.

In a stock management approach, the villagers are instead paid a modest fee for each tree on the village property. The driver for reforestation is then villagers looking for a higher donor income by increasing their stock of trees, which includes protecting young trees from being eaten by animals as much as planting new trees. The barrier is that donors, including the World Bank, generally do not pay for stock management but only for flow. The same applies to preventive measures versus post-disaster repairs.

The focus in this chapter is on *manufactured capital*: i.e. material goods and fixed assets. This includes infrastructure (for energy distribution, communications, transport, and water and other services), buildings (industrial, commercial, institutional and domestic), equipment (both “productive” and appliances used by “consumers”) and durable consumer goods (including, for example, furniture and garments). Focussing on the stock brings out the importance of something which is often overlooked: durability or service life of manufactured capital. This is explored later in this chapter.

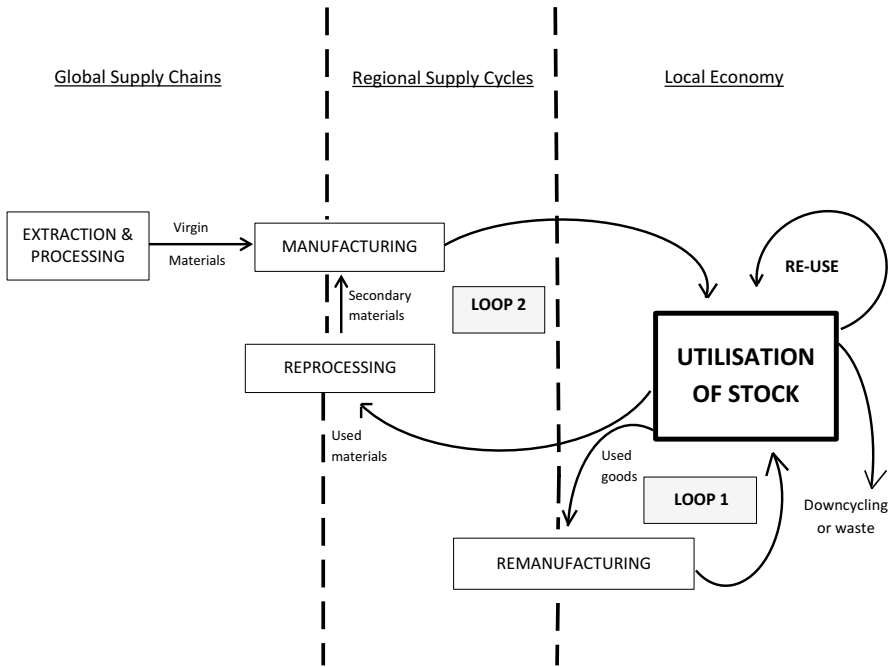
## 2 The Circular Economy – “Loop”, “Lake” and “Performance” Models

Distinguishing between capital stock and flows opens up useful perspectives on the idea of a “circular economy” which aspires to replace the linear “once through” *industrial economy* which has dominated business in the industrialised countries since the industrial revolution. In the linear economy, the focus is on management of throughput flows. On the macro-economic level, the performance of the industrial economy is judged by measuring the sum of all flows (GDP); on the micro-economic level, by calculating the value added to the flows. Its optimisation stops at the point of sale where the responsibility for operating and disposing of the goods is passed to the buyer.

Arguably, the industrial economy is the best strategy to increase stock and expand economic activity to overcome scarcities of food, housing, infrastructure and/or equipment, as they exist in many developing countries. However, in markets near saturation, so that the number of new goods is similar to the number of scrapped goods, the relevance of the paradigm of economic growth has been questioned (e.g. Jackson 2009); in the absence of quantum leap innovation, the circular economy is a more viable business model than the industrial economy with regard to environmental, economic and social factors. Even where technology quantum leaps do take place through rapid innovation, the circular economy will complement the industrial economy.

The *circular economy* is based on value preservation, not value added. The basic elements are shown schematically in Fig. 7.1. *The Reuse Loop* includes second-hand markets (from garage sales and flea markets to eBay) as well as commercial and private reuse of goods (e.g. refilling of beverage containers, reuse and resale of garments). These activities are usually carried out locally. *Loop 1*, labelled *Remanufacturing*, includes repair, remanufacturing and “upgrading” to meet new technological standards or to meet new fashion expectations (Smith and Keoleian 2004). Remanufacturing may be a local activity (e.g. refurbishing of domestic appliances or cars) or may be carried out via regional service centres. *Loop 2* represents *recycling* in which, rather than repairing or re-using manufactured goods and components, the product is reprocessed to recover secondary materials for return to the same use. *Reprocessing* may be a regional activity or may be part of a global supply system. Reprocessing includes operations such as recycling of paper and plastics, re-refining of fluids such as lubrication oils (Clift 2001) and, where practical, depolymerisation of polymers (Clift 1997). Some end-of-life goods and materials may go to other uses, such as export for re-use in other locations or “cascading” into lower specification applications (*downcycling*) including energy recovery, or may leak from the economic system as *waste*.

Different interpretations of the circular economy place different emphasis on the elements in Fig. 7.1. At its simplest (but also least profitable and materially efficient), the circular economy takes the form of the *Loop* economy, focussed on recycling (loop 2 in Fig. 7.1) in which the material of the product is not lost as waste but



**Fig. 7.1** The basic loops of a circular economy (Adapted from Stahel and Reday-Mulvey 1976)

is reprocessed for return to the same use. This is the interpretation embodied in China’s “Circular Economy” laws, for example. In the Loop Economy, ownership changes with each loop, each owner aiming to achieve the highest profit when passing on material goods.

The “Loop” or “cradle-to-cradle” concept is still framed in terms of flows and therefore overlooks ways to optimise the physical and economic performance of the economy based on optimising the use of the stock. An example of good stock management is provided by the 2008 EU Waste Directive, which appropriately calls for the reuse and service-life extension of goods as priorities, putting waste prevention before waste management. The *Lake* economy uses the same loops as the Loop economy, but with a focus on value preservation through stewardship and without changes in ownership: The main economic actors in such an economy are here termed “fleet managers”: they operate a fleet of similar goods, such as the vehicles of haulage or transport companies, and maintain their components (e.g. engines and tyres in the case of road vehicles). These owners may have their goods repaired or remanufactured by independent service companies. The focus is on managing the stock rather than the flows: “fleet managers” maintain ownership of their stock and therefore profit from the economic advantages of re-use and remanufacturing strategies.

If economic actors are selling performance, through business models such as “goods as services” or “molecules as services”, which means earning revenue and

profits from stocks instead of flows, they shift from the Lake Economy, with its focus on maintaining the stock, to the *Performance* Economy which focuses on maximising the value obtained from using the stock. The Performance Economy demands an internalisation of the costs of waste and of risk over the full service-life of goods, which in turn are substantial financial incentives to include waste prevention and loss prevention at all stages in the product cycle from design to decommissioning.

The Performance Economy is primarily driven by competitiveness, the Lake Economy by long-term operation and maintenance cost optimisation and the Loop Economy by (environmental) legislation. Some of the business implications of the shift to the Performance model are explored by Stahel (2010) and in Sect. 4 of this chapter.

The stock perspective is routine for infrastructure and buildings but less familiar for other forms of manufactured capital. The shift from a flow to a stock perspective is enabled when economic actors (companies, consumers and public entities) assume longer-term ownership or stewardship of, for example, fleets of vehicles or goods, changing their business approach from the bigger-better-faster-safer model of an industrial flow economy to the functional view of goods of a Lake Economy. The motivation for commercial actors is usually to reduce operating costs (for example, retreading truck tyres by haulage companies, remanufacturing diesel engines), whereas public actors (armed forces and public administrations like railways, NASA) seek to reduce long-term system costs (mothballing of warships, “cemeteries” of aircraft for access to spare parts). For consumers, the motivation may be a personal relationship with goods (the “teddy bear” effect which leads individuals to keep personal souvenirs such as watches or pens, or family heritage objects such as paintings or vintage cars). By retaining the ownership of the goods and their embodied resources, fleet managers gain a resource security with regard to both future availability of resources and commodity prices. Expected scarcity of some critical materials therefore provides another driver to take the stock perspective.

If loops involve professional services, transaction costs occur, adding to the costs and often influencing the choice of the next owner: for example, sales such as buildings, domestic premises and artworks require fees to individuals or specialist dealers. However, some OEMs take back their own goods, disassemble them and reuse components as service parts, a strategy pursued by many IT manufacturers, or remanufacture and remarket them in exchange for faulty products. Such service exchange systems are used by some European car manufacturers: damaged car engines and gearboxes which cannot be repaired locally are returned to the OEM in exchange for an OEM-remanufactured product<sup>1</sup>; Sony Computer Entertainment Europe offers a remanufactured exchanged product when customers return a faulty product for repair, in order to reduce the time a customer is without the product. Further illustrative examples are discussed in later sections.

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<sup>1</sup> VW annually remanufactures 50,000 engines and the same number of gearboxes in a dedicated plant located in Kassel.

### 3 Remanufacturing, Reprocessing and Product Life

#### 3.1 Material Intensity and Product-Service Intensity

To understand the importance of the quality and durability of stock, it is convenient to use a formulation introduced by the IPCC in the 5th Assessment Report (2014).<sup>2</sup> For a sector producing materials and products for stocks that deliver quantifiable services, the energy use ( $e_p$ ) and associated GHG emissions ( $g_p$ ) over a specified accounting period (for example, GJ per year and tonnes CO<sub>2</sub>e per year) can be broken down in a form of Kaya (1990) relationship as:

$$e_p = (e/p) \times (p/S) \times (S/d) \times d \quad (7.1)$$

$$g_p = (g/e) \times e_p = (g/e) \times (e/p) \times (p/S) \times (S/d) \times d \quad (7.2)$$

where  $e$  represents the energy input to manufacturing and processing,  $e_p$  is the energy used specifically to produce the flow  $p$  of materials and products (e.g. tonnes per year) needed to maintain the stock  $S$  of the relevant manufactured capital (e.g. tonnes) and  $d$  is the quantity of service delivered in the time period through use of that capital (e.g. passenger-km per year for the personal transport sector).

These expressions are conceptual, but they reveal the significance of the different terms:

$(g/e)$  is the *emission intensity* of the sector expressed as a ratio of GHG emissions to energy used. The emissions arise largely from energy use (directly from combusting fossil fuels, and indirectly through purchasing electricity and steam) and therefore depend most critically on the emission intensity of the background energy system of the economy where the goods in question are made. However, emissions also arise from industrial chemical reactions; in particular, producing cement, chemicals and non-ferrous metals leads to release of significant “process emissions” regardless of background energy sources.

$(e/p)$  is the *energy intensity of production*. Approximately three quarters of industrial energy use worldwide is required to create materials from ores, oil or biomass, with the remaining quarter used in the downstream manufacturing and construction sectors that convert materials to products (IPCC 2014). In some cases, particularly for metals,  $e/p$  can be reduced by production from reused components or recycled material (see below) and can be further reduced by exchange of waste heat and/or by-products between sectors through industrial symbiosis.

$(p/S)$  is the *material intensity* of the sector: the material flow required to create and maintain the stock.

<sup>2</sup> A form of this equation is given in IPCC (2014: 746) but the explanation and interpretation given here differs from that in IPCC (2014). In the notation used here, upper case letters denote stocks and lower case denote flows.

( $S/d$ ) is the *product-service intensity*; i.e. the quantity of stock required to deliver the required service.

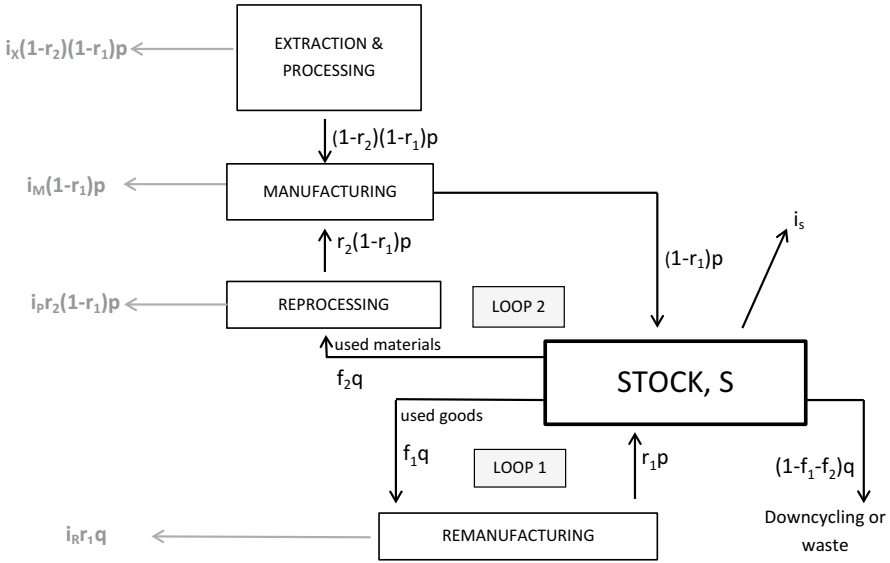
Equation 7.1 has a number of important implications, underpinning the specific business strategies explored in Sect. 4. The emission intensity term, ( $g/e$ ), depends primarily on the fuel mix used in the extractive, processing and manufacturing operations and the background economies in which they are located. The energy intensity of production, ( $e/p$ ), which is the usual target of industrial improvement and innovation, is also obviously important. These terms underlie concerns over the “carbon leakage” resulting from the potential migration of primary manufacturing to economies with high carbon intensity and possibly lax environmental standards (see for example Clift et al. 2013) but the scope for reducing ( $e/p$ ) is limited by technological and thermodynamic constraints (Allwood et al. 2012). We therefore concentrate here on the other terms in Eq. 7.1 which are key for the circular and performance economies: material intensity, ( $p/S$ ), and product-service intensity, ( $S/d$ ). These parameters are measures of the efficiency and quality of the stock: low values indicate good system performance. Reducing the product-service intensity means using capital goods more intensively, for example through “pooled” use of vehicles or appliances. Material intensity can be reduced by design measures such as “lightweighting” and, importantly but less obviously, is also dependent on product life, re-use, remanufacturing and recycling.

### 3.2 Remanufacturing and Reprocessing

To reveal the significance of material and product-service intensities and product life, we explore the flows needed to maintain the stock of manufactured capital,  $S$ , as shown in Fig. 7.2. The “Re-use” loop (see Fig. 7.1) is treated here as an activity needed to keep the stock in use; it is therefore not shown in Fig. 7.2 because inputs to and losses from re-use are included in  $i_s$  (see below). Of the flow of goods into stock,  $p$  (as in Eqs. 7.1 and 7.2), a fraction  $r_1$  is remanufactured and the balance is newly manufactured goods incorporating a fraction  $r_2$  of recycled material. The input of primary material to the product system is therefore  $(1-r_2)(1-r_1)p$ . Unsurprisingly, increase in  $r_1$  or  $r_2$  reduces the need for primary material.

More interesting insights emerge from examining other relationships within the service system, illustrated by Fig. 7.2. The outflow from stock at the end of its (first) service life is denoted by  $q$ . A fraction  $f_1$  is routed to remanufacturing, a fraction  $f_2$  to recycling and the balance leaves the product system as downcycled goods or materials or as waste. Material losses, degradation and/or contamination in remanufacturing and reprocessing are thermodynamically inevitable and also occur in the associated logistics, so that  $r_1p < f_1q$  and  $r_2(1-r_1)p < f_2q$ . The relatively high population density in urban areas makes the logistics of collection easier and therefore supports the development of a circular economy (see, for example van Berkel et al. 2009; Kennedy et al. 2011). The main losses and degradation usually occur in





**Fig. 7.2** Remanufacturing and recycling to maintain manufactured stock (adapted from Clift et al. 2009 and Clift and Allwood 2011). Interventions per unit of output from operations:  $i_R$  remanufacturing,  $i_M$  manufacturing,  $i_P$  reprocessing/recycling,  $i_X$  extraction and primary processing

reprocessing. It follows that the economics of the circular economy depend on using the shorter, more local and less dissipative loops (i.e. re-use and remanufacturing) and keeping materials separate to minimise contamination.

As well as the material flows within the system, Fig. 7.2 shows the interventions: i.e. the exchanges across the system boundary. These interventions may be emissions from the system (for example of greenhouse gases or waste material) but the analysis also applies to inputs (energy or labour, for example) or costs. They are associated with the operations shown in Fig. 7.2, expressed in proportion to the quantity of material produced. Interventions,  $i_S$ , are also associated with use of the stock to deliver the service. For the whole service system, the total interventions,  $i_T$ , are:

$$i_T = [i_R r_1 + (1-r_1)\{i_M + r_2 i_P + (1-r_2)i_X\}] p + i_S \tag{7.3}$$

We focus initially on the first term in Eq. 7.3, i.e. the interventions associated with the material flows. If the objective is to reduce  $i_T$ , the single most important action is to reduce the material throughput,  $p$ ; this is explored below. For some materials, the energy use, emissions, material degradation and/or costs of reprocessing may be prohibitive (see, for example, Allenby 1999; Allwood 2014). Reprocessing is then undesirable on cost or environmental grounds, representing a limit to the circular economy in any of its forms. More commonly, and particularly for manufactured

goods, the energy use and emissions are least for remanufacturing and greatest for primary material production; i.e.

$$i_R < i_P < i_X \quad (7.4)$$

while labour input is in the reverse rank order. This underlines the business models for the performance economy explored in Sect. 4: whilst reprocessing is commonly (but not universally) beneficial compared to primary production, remanufacturing is to be preferred over reprocessing. In addition to energy and resource efficiency, remanufacturing has the benefit of substituting labour input for energy input.

### 3.3 Product Life

It was noted above that the circular economy model is most appropriate for a mature economy, with markets near saturation, where the stock of manufactured capital has already been built up. Under these circumstances the change of stock over time is relatively small, so that  $dS/dt \approx 0$  and  $p \approx q$ . This approximation also applies to personal property, for example clothing (where the stock is limited by storage space) and furniture (limited by living area). The throughput of material to maintain stock with long life is then:

$$p = q = S / T \quad (7.5)$$

where  $T$  is the average service life of the stock. As noted above, the priority is to reduce  $p$ . From Eqs. 7.3, 7.4, and 7.5, the options for reducing energy use and associated emissions are, in priority order:

1. Extend service life,  $T$ , to reduce throughput,  $p$
2. Intensify use to reduce stock needed,  $S$
3. Increase the proportion of post-use products remanufactured,  $f_1$
4. Increase the proportion of post-use products reprocessed,  $f_2$
5. Reduce the inputs required for manufacturing,  $i_M$
6. Reduce the inputs required for reprocessing,  $i_P$
7. Reduce the inputs required for remanufacturing,  $i_R$
8. Reduce the inputs required for primary material production,  $i_X$ .

This rank order underlines why focussing on stock leads to the priorities which underpin the performance economy model (see Sect. 4 below) but which are overlooked in many policy measures. It also leads to useful insights into sustainable consumption concerning the importance of durable quality goods rather than disposable purchases (Clift et al. 2013).

For products with a short service life, such as beverage containers, the priority is on the efficiency of loop 2; i.e. on reprocessing/recycling rather than remanufacturing. Figure 7.3 shows a simple recycling loop. The fraction of material returned to

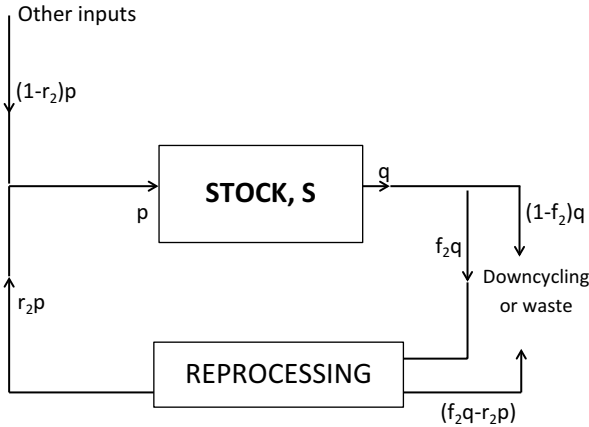


Fig. 7.3 Simple recycling loop

use after each loop is  $r_2$ . After  $n$  loops, the fraction remaining in use is  $r_2^n$ , which reduces rapidly even when  $r_2$  is relatively high. The average life of the material leaving use in terms of number of uses,  $\tilde{n}$ , is:<sup>3</sup>

$$\tilde{n} = 1 / (1 - r_2) \tag{7.6}$$

For paper, recycling damages the fibres so that, to keep  $\tilde{n}$  from becoming too high,  $r_2$  is limited and a minimum introduction of new material is needed to maintain the paper properties (Hart et al. 2005). Even for such a valuable material as nickel, used in many alloys but also in items such as fashion jewellery, only 55 % returns around the loop (i.e.  $r_2 = 0.55$ ) so that 30 % remains after two loops and only 17 % after three. In this particular case, about 2/3 of the losses arise from dissipative use ( $(1-f_2)q$  in Fig. 7.3) and the remaining 1/3 from losses during reprocessing, mainly of alloy bars used to reinforce concrete structures (Bihoux, quoted in Levy and Aurez (2014)). For beverage cans, which typically have a life of 3 weeks from canning plant to disposal, even with a high recycling rate of 75 % half the stock is lost after 6 months in use and effectively all is lost after a year. Even with a highly optimistic recycling rate of 90 %, the metal stock is effectively lost in less than 2 years of use. By contrast, and emphasising the importance of re-use to extend service life ( $T$ ), refillable glass bottles are typically refilled 27 times before reprocessing, so that the first recycling occurs after about 1 year and a half (Stahel 2010).

In addition to the interventions required to produce and maintain the material stock, Eq. 7.3 includes those needed to operate it:

$$i_s = (i / d) \times d \tag{7.7}$$

<sup>3</sup>For a more complete analysis, specific to paper recycling allowing for inputs from other sources, see Göttching and Pakarinen 2000: 394 and Hart et al. 2005.

where  $(i/d)$  is the input or emission per unit of service delivered; e.g. the energy or labour intensity of the service, providing a further measure of the efficiency or quality of the stock. Technological improvements usually mean that  $(i/d)$  decreases over time. The balance between the interventions needed to operate and to replace the stock leads to a systematic approach to defining optimal service life (Kim et al. 2003; Keoleian 2013). Combining Eqs. 7.1 and 7.7, the ratio of operating energy ( $e_s$ ) to production energy ( $e_p$ ) is:

$$e_s / e_p = (e_s / d) / [(e_p / p) \times (p / S) \times (S / d)] \quad (7.8)$$

Operating energy is thus more significant, and therefore the optimal service life is shorter, when the material intensity ( $p/S$ ) and product-service intensity ( $S/d$ ) are low; i.e. when the manufactured capital is well designed and efficiently used.

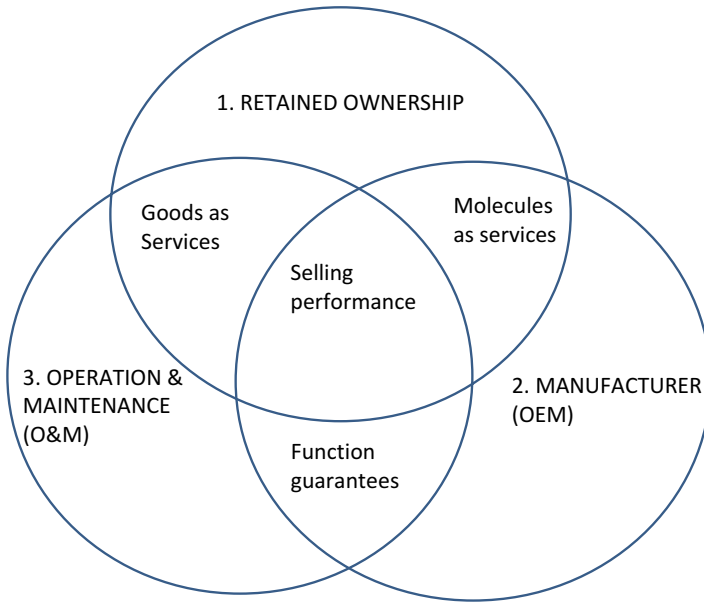
## 4 Economic and Social Implications

The principal of stock management is caring (stewardship) to maintain the quantity and quality of stock. This applies to most stocks, including natural, human and manufactured capital, and is radically different from the bigger-better-faster-safer (fashion) thinking underpinning the industrial economy. The throughput (flow) optimisation of production in global supply chains is replaced by asset (stock) management in the circular economy; the economic concept of value added is replaced by the objective of value preservation. What is of interest to investors is the fact that the return on investment (ROI) of a remanufacturing plant is usually many times that of a plant manufacturing the same goods from scratch, due to lower capital cost. On the other hand, the operating costs, notably labour, are typically much higher. These differences have a number of important implications.

### 4.1 Business Models in the Performance Economy

The essence of the performance economy lies in producing, selling and managing performance over time (Stahel 2010). Stock management lies at the heart of the business model because each flow (repair or stock loss) represents a cost. The three essential components and actors in the performance economy are shown schematically in Fig. 7.4:

1. Retained ownership of goods and their embodied resources by a manufacturer or fleet manager; this supports objectives (1) and (2) of the priority list developed in Sect. 3;
2. The skills and powers of an original equipment manufacturer (OEM), to support objectives (3) to (8);



**Fig. 7.4** The business models of the performance economy

3. The skills of an economic actor responsible for the operation and maintenance (O & M) of a fleet of goods, to support objectives (3) and (7).

Successful operation in the performance economy incorporates all three components. Selling performance (or “servicisation”) entails internalising the costs of risk and waste over the full service life of the manufactured capital. As a result, different ways have emerged to combine the roles of the three different types of actor to increase stock life, quality and performance and reduce transaction costs. They are illustrated by the specific examples shown in Fig. 7.4 and itemised in the text box. Manufacturers exercising the O & M of their goods through service contracts give their customers a function guarantee; this provides reassurance of quality and encourages users to retain the stock. This also encourages modular design to facilitate upgrading rather than complete replacement; for example, some lift manufacturers adapt existing elevators by replacing single doors with modern double door sets; devices with electric motors can be equipped with electronic speed control to improve energy efficiency; office equipment companies (e.g. Xerox) use modular system design with standardised components across different product lines. Retaining ownership encourages management of end-of-life goods. Performance monitoring of stock in use and preventive maintenance to guarantee uninterrupted performance are essential, where possible using maintenance strategies which minimise or eliminate the need to stock spares.

As indicated in Fig. 7.1, the performance economy entails intelligent decentralisation, with generally more localisation of economic activity than in the industrial

economy. This provides further opportunities for the development of industrial symbioses (see Chap. 5). Re-use is inherently local. The geographic scale of Loop 1 activities (remanufacturing) is determined by the mobility of goods, the extent of standardisation of goods and the batch size necessary to reach a competitive remanufacturing volume. For immobile goods, such as infrastructure and buildings, service-life extension activities require mobile labour and mobile workshops. For stand-alone goods, such as engines of tractors, buses, ambulances and vintage vehicles, local remanufacturing workshops may be optimal because the remanufacturing costs are secondary to the clients' wish to continue operating the vehicle. In textile leasing (hotel or hospital textiles, which have to be washed or sterilised daily), the optimal transport distance is about 100 km (Stahel 1995: 249); franchising can therefore be a better business model than centralised treatment. The geographic scale of Loop 2 activities (reprocessing) is determined by the technology used; many metallurgical processes, associated with high capital cost, need to be operated at large scale to be competitive with primary production. However, the dominance of labour and logistic costs, rather than capital, in re-use and remanufacturing reduce the economies of scale and are therefore consistent with smaller scale, decentralised operations.

### **Examples of Business Activities in the Performance Economy (Figure 7.4)**

#### **(1) RETAINED OWNERSHIP + (2) OEM + (3) O&M**

##### **Selling Performance**

- tyre use by the mile (e.g. Michelin)
- power by the hour (e.g. Rolls-Royce turbines)
- illumination: “pay per lux” ( e.g. Philips)
- office equipment: “pay per copy” (e.g. Xerox)

#### **(1) RETAINED OWNERSHIP + (2) OEM**

##### **Molecules as Services**

- chemical leasing: “rent a molecule” (e.g. lubricants, cleaning solvents)
- mining: nation state grants “licence to operate” but retains ownership of the output (WEF 2015)

#### **(2) OEM + (3) O&M**

##### **Function Guarantee**

- commercial and service equipment (e.g. freezers, elevators)
- chemical management systems
- integrated crop management

(continued)

### (3) O&M + (1) RETAINED OWNERSHIP

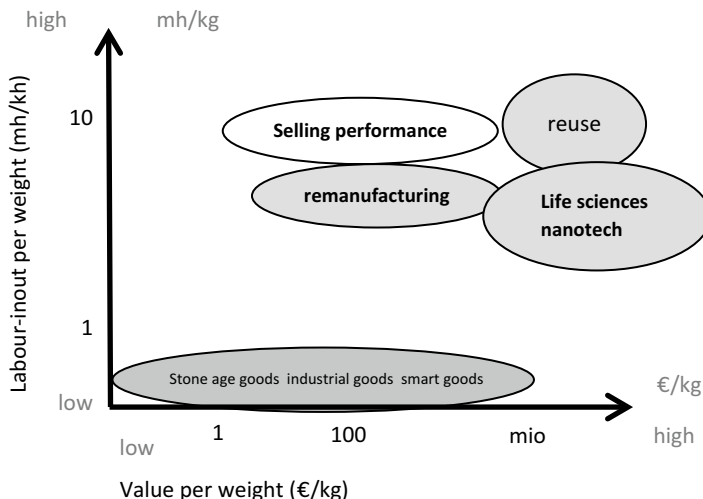
#### Goods as Services

- transport (e.g. shipping, buses, containers)
- “wet” leasing of aircraft: aircraft plus crew plus fuel
- real estate (e.g. hotels, time-shares)
- short-term equipment rental (e.g. vehicles, tools)

## 4.2 Employment

What was probably the first research report to articulate the idea of a circular economy set out to identify the potential for substituting manpower for energy (Stahel and Reday 1976). It found that on a macro-economic level, three quarters of energy is used in mining activities and basic material production, while one quarter is used in manufacturing goods from basic material; the same estimates are reported by IPCC (2014). For manpower, the proportions are reversed: three quarters of the labour input into finished products is in the manufacturing of goods, with only one quarter in resource exploitation and primary production. Service-life extension focuses on activities which are kin to manufacturing before automation and are the most labour intensive. As noted in Sects. 2 and 3, end-of-life goods must be collected using non-destructive and non-diluting collection processes (rather than compactor lorries); the collected goods must be disassembled into components and materials (instead of being shredded); the components and materials must be screened to separate parts to preserve value (using skills and experience) so that components can be repaired or remanufactured and materials can be sorted to be recycled in the purest form and kept separate to minimise contamination. Each of these steps is more labour-intensive and resource saving than in the linear make-use-waste approach.

Macro-economic analyses of the impact of service life extension are scarce, although a recent study by Skanberg for the Club of Rome (2015) has used input/output analysis to explore the effect on the Swedish economy of increased resource efficiency. At the micro-economic level, numerous case studies exist (see text box) on the manpower intensity of reuse, repair and remanufacturing. All confirm the conclusion that service-life extension activities substitute manpower for energy and materials, when compared to manufacturing equivalent new goods. This is exemplified by Fig. 7.5, which shows the results of an analysis of different sectors (Product-Life Institute 2015) with regards to value per weight at the point of sale (€/kg) and labour input per weight (mh/kg; i.e. the labour components of  $i_M$  and  $i_R$  in the terms of Fig. 7.2) associated with manufacturing or remanufacturing: the key activities of the performance economy are comparable to life-sciences and nanotechnologies, and a far distance from manufacturing (Product-Life Institute 2015).



**Fig. 7.5** Comparison of different sectors by value per weight (€/kg) and labour input per weight (mh/kg) (Source: Product-Life Institute 2015)

### Examples of the Manpower Intensity of Re-use, Repair and Remanufacture (Stahel 2010)

An analysis of the running costs of a 30-year-old automobile (Toyota Corona Mk II of 1969) reveals that the share of labour costs as a percentage of accumulated total costs increases from 18 % after 10 years to 34 % after 20 years to reach 48 % after 30 years (Buhrow et al. 1999).

The remanufacture of a Jaguar XJ6 engine necessitated 120 h of labour and new parts of a total weight of 20 kg; the labour-input per weight ratio of 6 man-hour/kg material input is 240 times that of manufacturing a new car engine (pp. 198/9).

The Eiffel Tower in Paris is completely repainted every 7 years; 25 painters spend more than 12 months to apply 60 tonnes of paint on 250,000 m<sup>2</sup> of iron elements; the labour input per weight ratio is 0.7 man-hours per kg (p. 191).

The remanufacture of the gearbox of a Lorry needs 59 h of manpower if parts are individually repaired, at a cost of CHF 10,400; or 23.5 h at a cost of CHF 16,000 if damaged parts are replaced by new ones. (p. 220).

Medieval cathedrals have teams of masons spending a lifetime repairing the stonework to check decay and prevent the eventual collapse of the landmark buildings. A similar workshop exists for the Golden Gate Bridge in San Francisco. (p. 208).



The biggest potential for creating jobs and developing skills lies in repairing and remanufacturing standardised goods, such as infrastructure, buildings and stand-alone mobile and immobile goods, preferably in local workshops using and developing the human capital represented by skilled labour. They thus contribute to preserving the “industrial commons” – an industrial network of customers, skilled labour and subcontractors which is an essential knowledge base for innovation and the emergence of new industries (Pisano and Shih 2012). Some companies active in repair, maintenance and remanufacturing activities acquire sufficient knowledge to move upstream into manufacturing innovative new products in their field of activity (see box).

### **The Hidden Innovation Potential of Operation and Maintenance Services**

Some companies active in repair, maintenance and remanufacturing activities acquire sufficient knowledge to move upstream into manufacturing innovative new products in their field of activity. Witness Israeli Aircraft Industries (IAI), which started as maintenance service provider before assembling fighter planes and today is a leading manufacturer of drones (pilot-less remotely controlled aircraft); and Stadler Rail in Switzerland, moving from a local maintenance service provider for rolling stock (railways) to become a major European manufacturer of regional trains.

## **4.3 Fiscal Policy**

By reducing dependence on primary resources and energy and providing skilled employment, the performance economy has the potential to alleviate many current economic, environmental and social problems, i.e. to contribute to improved sustainability. However, promoting and developing this economic model requires a comprehensive re-examination of public policies, moving away from the fragmented policies of most public administrations. The “whole system” approach of industrial ecology, which provides the background to the idea of the performance economy, reveals the inconsistencies between policies to preserve stocks (natural and cultural capital, for example), to tax flows (levies like Value Added Tax) and stocks (human and financial capital) and to subsidise consumption of stock (such as fossil fuels).

These inconsistencies are exemplified by the 2012 “cash for clunkers” policy followed in 22 countries, which had the ambitions of stimulating national economies by increasing the demand for new cars (i.e. the flow of new goods) and simultaneously reducing GHG emissions from vehicles in use. The policy ignored the GHG emissions resulting from recycling old cars (i.e. the ‘clunkers’) and manufacturing their replacements. In many countries, the cars bought were imports; in some

cases, “clunkers” were not destroyed but exported and sold abroad (Ashok et al. 2012; Antoniadou 2013). In a circular economy perspective, the same payments could have been offered to remanufacture/retrofit stock, e.g. to remanufacture the car engines and convert them to compressed natural gas. As this job is best done in local workshops, it would have created local jobs. It would have avoided the GHG emissions from recycling the clunkers and manufacturing their replacements, and substantially reduced emissions in use.

Most current policies promoting a circular economy focus on environmental performance or resource efficiency, exemplified by:

- OECD Guidance (2015b): due diligence guidance for responsible supply chains of minerals from conflict-affected and high-risk areas (“Guidance”);
- Rules of the U.S. Securities and Exchange Commission on Disclosure of Payments by Resource Extraction Issuers (US SEC 2012);
- UN (2013) Mercury agreement, designed to reduce emissions and ensure an efficient utilisation of stocks of resources;
- EU (2008) waste directive to foster waste prevention through reuse and service-life extension of goods (see Chap. 14).

To promote sustainable development, a new approach should be more holistic, defining policies which are simple, convincing and cross-cutting with the objective of preserving stock. The full societal cost of not working has generally been underestimated, but a recent OECD study has shown a strong link between mental health and employment (OECD 2015a). Both health and acquired capital of unused workers (e.g. sub-employed or unemployed people and non-active retirees) can deteriorate rapidly and even lead to a high risk of developing mental problems (Coulmas 2012). On the other hand, just as for poorly maintained manufactured capital, overuse of human capital can also lead to a loss of the stock through, for instance, burn-out. In general, to promote sustainable development, policies are needed which promote economic sectors that intelligently use and also preserve all forms of stocks or capitals. As these activities are more labour and considerably less resource intensive than manufacturing, sustainable taxation emerges as a key lever to promote change to a low-carbon resource-efficient society (Stahel 2013). Examples of a different approach to taxation include:

- Do not tax renewable resources, noting that human labour is renewable, but exclusively tax non-renewable resources, wastes and emissions;
- Do not levy value added tax (VAT) on the value preservation of stock (such as reuse and service-life extension activities);
- Give carbon credits to carbon emission prevention (smart stock management) at the same rate as to carbon emission reductions (cleaner flow).

It must be emphasised that the proposal here is for a shift in the tax base rather than an increase in tax levels. A fiscal policy of sustainable taxation could make many subsidy policies redundant; taxing non-renewable resources instead of labour would give clear incentives to economic actors to shift from flow to stock business models. In addition, it would make all stock management activities (looking after

people's health, looking after natural and cultural capital) more competitive. In the USA, eleven States do not tax labour (human capital) but flow of non-renewable resources (for example, the construction industry in Florida, the oil and gas industry in Texas). In Canada, the move in British Columbia towards taxing GHG emissions (B.C. 2013) appears to be having effects which are both environmentally and economically beneficial (Elgie and Clay 2013). Not levying value-added tax (VAT) on value preservation activities would give goods in the circular economy a substantial cost advantage over new goods (around 20 % in most EU countries), again giving economic actors a clear incentive to change from flow to stock management.

## 5 Industrial Ecology and the Performance Economy

The idea of the performance economy has developed separately from developments in industrial ecology (Stahel 2010). One of the main objectives of this chapter is to show how thinking on the performance economy embodies the idea of an industrial ecosystem articulated by Frosch and Gallopoulos (1989), so that the performance economy is underpinned by and applies industrial ecology concepts and tools including life cycle management, accounting of material flows and stocks, resource efficiency, urban metabolism, servicisation and dematerialisation. Localisation of re-use, remanufacturing and some reprocessing can open up new opportunities for symbiosis between industrial activities. Although the drivers for the performance economy are primarily economic (or could be primarily economic under an appropriate fiscal regime), the model has the potential to alleviate the same environmental, economic and social challenges which industrial ecology seeks to address.

The performance economy represents industrial ecology in action.

### Notation

- d Quantity of service delivered in specified time period (e.g. passenger-km per year for personal transport)
- e Energy use (e.g. GJ/year)
- $e_p$  Energy input to a sector producing material products (e.g. GJ/year)
- $e_s$  Energy input to using manufactured stock (e.g. GJ/year)
- $f_1$  Fraction of  $q$  routed to remanufacturing
- $f_2$  Fraction of  $q$  routed to recycling/reprocessing
- $g$  GHG emissions from energy sector (e.g. tonnes CO<sub>2e</sub> per year)
- $g_p$  GHG emissions associated with a sector producing material products (e.g. tonnes CO<sub>2e</sub> per year)
- i Interventions (i.e. exchanges across the system boundary) associated with operations and activities, per unit of output; i.e. inputs (e.g. energy or labour or financial costs) or outputs (e.g. emissions or wastes)
- p Flow of materials or products into use (e.g. tonnes/year)
- q Outflow of materials or products from use phase (e.g. tonnes/year)

- $r_1$  Fraction remanufactured goods in flow  $p$   
 $r_2$  Fraction recycled material in newly manufactured goods  
 $S$  Stock of manufactured capital (e.g. tonnes)

#### Subscripts Indicate Operation or Activity

- M Manufacturing  
 P Reprocessing  
 R Remanufacturing  
 S Use of stock to deliver services  
 T Total  
 X Extraction and primary processing

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