Circular Economy Rebound

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Keywords:

circular economy
closed looprecycling
economics
industrial ecology
reuse
rebound effect

Summary

The so-called circular economy—the concept of closing material loops to preserve products, parts, and materials in the industrial system and extract their maximum utility—has recently started gaining momentum. The idea of substituting lower-impact secondary production for environmentally intensive primary production gives the circular economy a strong intuitive environmental appeal. However, proponents of the circular economy have tended to look at the world purely as an engineering system and have overlooked the economic part of the circular *economy*. Recent research has started to question the core of the circular economy—namely, whether closing material and product loops does, in fact, prevent primary production. In this article, we argue that circular economy activities can increase overall production, which can partially or fully offset their benefits. Because there is a strong parallel in this respect to energy efficiency rebound, we have termed this effect "circular economy rebound." Circular economy rebound occurs when circular economy activities, which have lower per-unit-production impacts, also cause increased levels of production, reducing their benefit. We describe the mechanisms that cause circular economy rebound, which include the limited ability of secondary products to substitute for primary products, and price effects. We then offer some potential strategies for avoiding circular economy rebound. However, these strategies are unlikely to be attractive to for-profit firms, so we caution that simply encouraging private firms to find profitable opportunities in the circular economy is likely to cause rebound and lower or eliminate the potential environmental benefits.

Introduction

The concept of the "circular economy" has gained significant traction since its introduction a half century ago (Boulding 1966). Scholars, practitioners, governments, and nongovernmental organizations have recognized the apparent appeal of closing material loops, reusing and recycling industrial "nutrients" to extract their maximum value with minimum waste (Ellen MacArthur Foundation 2016; Frosch and Gallopoulos 1989; Yuan et al. 2006). There are many "schools of thought" regarding the circular economy that share a central theme, but differ in their intended outcomes and optimal implementations (Ellen MacArthur Foundation 2016). Some of these concentrate on minimizing waste and resource extraction (EC 2016a; Nansai et al. 2014), others focus on economic growth potential (Ellen MacArthur Foundation 2015; McKinsey & Company 2014; Morgan and Mitchell 2015), and others on environmental impact reduction (e.g., Allwood 2014). As this special issue of the *Journal of Industrial Ecology* illustrates, the field of industrial ecology (IE) is one such school of thought that focuses on the latter. Indeed, IE takes as its central metaphor an ecological cycling of matter and energy applied to industrial systems. For this reason, this article will focus primarily on the environmental outcomes of the circular economy.

Conflict of interest statement: The authors have no conflict to declare.

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DOI: 10.1111/jiec.12545

Editor managing review: Elsa Olivetti

Volume 21, Number 3

Despite the differences between schools of thought, in practical terms, the core of the circular economy refers to three activities: reuse at the product level (such as "repair" or "refurbishment"); reuse at the component level (e.g., "remanufacturing"); and reuse at the material level ("recycling"). For simplicity, we will refer to all these activities as "secondary production."[1]

There is an intuitive environmental appeal to the circular economy. Extracting and processing raw materials is energy and material intensive and creates significant environmental damage. Reprocessing used products and materials by repair, creative reuse, refurbishment, or recycling typically creates less (but non-negligible) environmental damage. To the extent that secondary production actually prevents primary production, the environmental benefit is the difference between incurred impacts of reprocessing and avoided impacts of primary production.[2] Additionally, if primary production is reduced, scarce resources are preserved for future use and landfills are filled less quickly. However, it is widely recognized that the benefits of avoiding primary production impacts typically outweigh both of these ancillary benefits (The Economist 2007; UNEP 2010).

Much of the scholarly, practitioner, and legislative efforts in the circular economy have therefore been spent trying to find and implement the best ways to increase secondary production, and to properly account for it in measurement methodologies such as life cycle assessment (LCA) (e.g., Atherton 2007; Ekvall and Finnveden 2001; Weidema 2003). The European Commission (EC) has actively embraced the concept and has already committed over 6 billion euros to helping businesses transition to a circular economy (EC 2016b). The EC's position is that the circular economy transition will be driven by private firms and consumers, with regulatory agencies actively promoting the concept by creating regulatory frameworks, sending economic signals such as recovery targets and quotas, and providing economic incentives and assistance, including preferential governmental procurement programs. The EC hopes that this will drive businesses and consumers to "develop a sustainable, low carbon, resource efficient and competitive economy" (EC 2016a, 2). Since 2002, China has also aggressively pursued circular economy strategies with the dual goals of economic growth and environmental sustainability (Mathews and Tan 2016; Su et al. 2013; Yuan et al. 2006).

Recently, however, the circular economy has faced some criticism. Allwood (2014, 446) discussed its limits and questioned the desirability of the circular economy in a reality with growing demand. He stated that trying to "meet human needs while minimizing environmental impact" would be a better goal than material circularity. The central tenet behind the environmental merits of the circular economy is whether secondary production activities *actually* reduce, or "displace," primary production. If so, the intuitive promise of the circular economy is achieved; if not, we are left with the impacts of increased secondary production *in addition to* the impacts of primary production. Further, without displacement, landfilling of materials is merely delayed rather than reduced and resource extraction is unaffected or even increased.

Typically, IE scholars have implicitly taken for granted that displacement occurs on a 1:1 basis (i.e., each kilogram [kg] of secondary production reduces primary production by 1 kg) (e.g., Atherton 2007; Ekvall and Finnveden 2001; Mathews and Tan 2016). However, displacement is governed primarily by market forces (McMillan et al. 2012), and there is no inherent reason to believe that these market forces would conspire to create full displacement. For example, secondary materials may displace material of a different kind or may lower prices and increase overall demand (Ekvall 2000; Zink et al. 2016). Therefore, a central question surrounding the circular economy is whether and to what extent secondary production displaces primary production.

Recent studies have started to clarify and answer this question. In a review of allocation in LCA, Ekvall and Finnveden (2001) ventured that increased recycling may fail to displace virgin material of the same kind if there is no market willing or able to absorb the increased material; the material may instead displace recycled material from other sources, resulting in increased landfilling and/or incineration. Ekvall and Weidema (2004) stated that recycled material can also displace completely different types of material, or no material at all. Thomas (2003) found that consumers' value perceptions of secondhand goods determine whether used products will displace new products; the study concludes that partial displacement is possible in reuse cases, and in some instances, secondhand markets may actually increase demand for new goods.

Zink and colleagues (2016) developed economic mechanisms of displacement after increased recycling and proposed a partial equilibrium framework for estimating primary production displacement from increased recycling. The researchers found that, for most materials, the prospect of 1:1 displacement is unlikely, but that zero displacement is possible and even likely for materials that are poor substitutes. For instance, Zink and colleagues (2014) and Geyer and Doctori Blass (2010) argued that displacement of new smartphones by refurbished ones is likely to be low given that refurbished phones are typically sold in developing countries where the alternative is no phone at all. These studies suggest that environmental assessments that assume a 1:1 displacement ratio for recycled materials systematically underestimate the environmental impacts of the product system.

Geyer and colleagues (2016) reiterated the importance of displacement in the environmental benefit of recycling and further demonstrated that there is no important difference between so-called closed loop and open loop recycling; the benefit of either depends entirely on the type and quantity of material displaced and there is no a priori reason to assume closed loop is superior. Therefore, contrary to circular economy mantra, there is no inherent disadvantage to dissipative reuse relative to circular reuse—the only relevant considerations are the (1) relative impacts of reprocessing vis à vis displaced production and (2) extent to which that production is, in fact, displaced. This insight can have important implications in areas such as handling of used motor oil (Geyer et al. 2013) or used cooking oil (Talens Peiro et al. 2010).

The common theme in these recent articles is the idea that simply connecting waste streams from one process to inputs in another does not automatically assure reductions in environmental impact. In other words, there is nothing intrinsically "green" about the circular economy (or about any product or activity, for that matter [Zink and Geyer 2016]). Instead, it is necessary to look at the net consequences of increased secondary production. Looking at all possible causal chains, does increased metals recycling, cell phone refurbishment, or reuse of glass bottles (for example) result in a net increase or a net decrease in environmental impacts? Answering that question alone can tell us if and when bolstering the circular economy is environmentally worthwhile.

The effects of increased secondary production are fundamentally economic in nature and cannot be predicted by engineering models alone. The studies mentioned above identified several different mechanisms by which the circular economy can go wrong. This article generalizes these concepts into an overarching phenomenon we call "circular economy rebound." The goal of this article is to define circular economy rebound, explain the mechanisms that drive it, and propose suggestions for avoiding rebound so that the promise of the circular economy can be fulfilled. Additionally, a goal of this article is to encourage the establishment of a body of research on circular economy rebound and partial displacement more generally. Such literature is currently lacking. The articles reviewed above were found due to our familiarity with recycling literature and by searching a variety of terms related to partial displacement. Unfortunately, this field of study is nascent, and no established set of search terms of keywords has been established. We hope that providing uniform terminology for this topic will help coalesce past and future research into a searchable body of literature.

Circular Economy Rebound

One way the circular economy can backfire is by increasing overall production and use of products and therefore environmental impact. There is a strong parallel to energy efficiency rebound (Berkhout et al. 2000; Hertwich 2005; Sorrell and Dimitropoulos 2008), so it is worth briefly reviewing some highlights from the energy efficiency literature.

Energy Efficiency Rebound

In energy efficiency literature, the rebound effect describes the phenomenon where increased efficiency makes consumption of some good (e.g., energy or transportation) relatively cheaper and, as a result, people consume more of it. This increased use decreases the environmental benefit of the efficiency increase, and can even lead to "backfire," where the increase in use is proportionally larger than the efficiency increase, leading to higher net impacts.

In the past two decades, scholars have developed a large body of literature on the rebound effect. Many review articles about energy efficiency rebound have been compiled, Greening and colleagues (2000) being the most cited. The review by Greening and colleagues (2000) led to a four-part typology of rebound, describing the nature and scope of the effect: (1) direct rebound, which is the immediate increase in consumer demand attributed to lower prices from increased efficiency; (2) secondary effects, which are the increases in demand of other goods attributed to consumers spending some of the energy savings elsewhere; (3) economy-wide effects, which refer to larger, largely unpredictable effects that increased efficiency has on prices and demand of other goods; and (4) transformational effects, referring to the potential of energy efficiency increases to change consumer preferences, societal institutions, technological advances, regulation, or other large-scale effects. Originally, rebound referred to production-side efficiency improvements that lowered production costs and therefore prices, but has been expanded to include efficiency upgrades by the end-use consumer (Borenstein 2013).

Borenstein (2013) provided a useful framework for energy efficiency rebound using the microeconomic concepts of price effect and substitution effect. Borenstein argued that investing in efficient products makes consumers effectively wealthier by lowering the amount they must spend on energy. This can have two broad effects. First, it may cause the consumer to use more of the product in question (leave lights on, drive more, etc.), commonly called "direct rebound." It also may cause the consumer to spend some of that savings on other goods, commonly called "indirect rebound." These collectively refer to an income effect—the change in levels of consumption attributed to a perceived wealth increase. The increased consumption of these goods (both the upgraded product and all other goods) increases energy consumption. The second effect, known as the substitution effect, is that the efficiency investment can change consumption choices due to the fact that the price of using the newly upgraded product is now lower relative to all other goods than it was before the upgrade. Thus, the consumer will use more of it—not just due to his or her increased income (the income effect), but because it is now more attractive compared to other goods. Said another way, as the consumer uses the upgraded product more, that expense necessarily reduces consumption of some other good for which the additional income could have been used. This consumption shift is governed by the consumer's cross-price responses—how willing he or she is to substitute consumption of the upgraded good for all other goods. On an economy-wide scale, these concepts can explain why, for instance, investments in efficient alternative energy do not fully displace fossil fuels (York 2012).

Much of the rebound research has focused on its mechanisms (Borenstein 2013) and the size of the effect (Sorrell et al. 2009), which has varied widely. The effect has been examined in a wide variety of arenas, including transportation (de Haan et al. 2007; Greening et al. 2000; Spielmann et al. 2008), lighting (Fouquet and Pearson 2012; Saunders and Tsao 2012), and even non-energy-related goods (Chalmers et al. 2015; Thiesen et al. 2008).

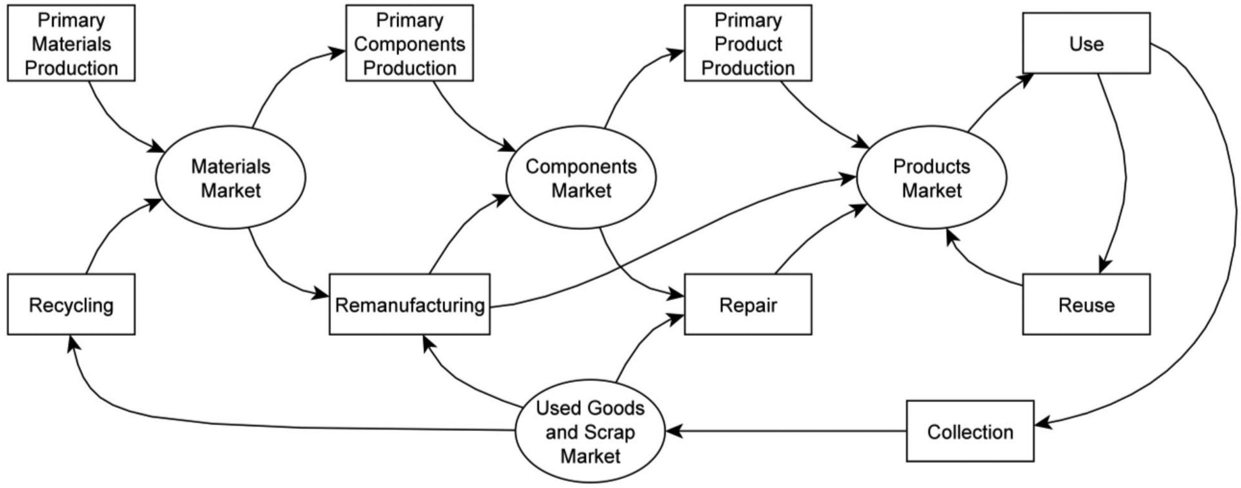

Figure 1 The circular economy as a system of interconnected markets. The diagram is typically drawn without the market ovals and therefore misses the key interactions between economic agents in the circular economy. Including the markets makes the outcomes of the circular economy harder to predict. Adapted from Ellen MacArthur Foundation (2016).

Circular Economy as a System of Markets

A close parallel can be drawn to the circular economy. Energy rebound occurs when increases in use-phase efficiency are offset by increased use; circular economy rebound occurs when increases in production or consumption efficiency are offset by increased levels of production and consumption.

To see how this happens, a shift in perspective is required. Too often, discussions of the circular economy view the world as an engineering model with flows seemingly traveling directly from consumer to collector to secondary processor to manufacturer back to the consumer (the "Circular Economy System Diagram" from the Ellen MacArthur Foundation being a prime example). The trouble with this view is that it ignores the fundamentally economic nature of the circular *economy*. In fact, between nearly every step in the circular economy there exists a market—a market for final goods, end-of-life (EoL) goods, unprocessed scrap, semiprocessed scrap, recycled materials, refurbished products, secondhand repaired products, and so on. This is important because in each of these markets, secondary goods compete directly with primary goods. The competition of primary and secondary goods in markets is what makes the circular economy promising in the first place—it creates the hope that secondary goods and materials might compete with and reduce the production of primary goods and materials. However, it also makes the interactions between primary and secondary goods more difficult to predict than an engineering schematic would suggest. Figure 1 shows a more accurate schematic of the circular economy that incorporates markets.

Circular Economy Rebound

In the diagram without markets, a flow, say, from consumer to recycler to manufacturer implies 1:1 displacement—that every kg recycled prevents 1 kg of production from raw materials. The environmental benefit of recycling is then simply calculated as shown by equation (1):

$$E_{net} = (e_r - e_p)\, Q_r \tag{1}$$

with e_r and e_p being the environmental impact of producing one unit of secondary and primary material, respectively, and Q_r the amount of secondary material being produced. For ease of exposition, environmental impact is here measured using a one-dimensional impact indicator. In this engineering view, recycling generates environmental benefits as soon as $e_r/e_p < 1$, a condition met for many recycling activities.

When the market is included between consumer and recycler, and between recycler and manufacturer, the outcome is more difficult to predict. The net environmental impact of an increase in circular economy activity is now (equation 2):

$$E_{net} = e_r \Delta Q_r + e_p \Delta Q_p \tag{2}$$

with ΔQ_r being the change in secondary production and ΔQ_p the resulting, market-mediated change in primary production. Recycling now reduces environmental impacts only if $\Delta Q_p < 0$ and $e_r/e_p < |\Delta Q_p|/\Delta Q_r$. In analogy to energy efficiency rebound, any circular economy activity with $\Delta Prod = \Delta Q_r + \Delta Q_p > 0$ is deemed to experience circular economy rebound. Comparing equation (1) with equation (2) shows that the engineering view implicitly assumes that $\Delta Q_p = -\Delta Q_r$.

Circular economy activities other than recycling that are likely to meet the condition $e_r/e_p < 1$ are product repair, for example, of garments, and product refurbishment, for example, of smartphones. In fact, there is a considerable body of research quantifying the environmental impacts e_r of many different recycling, refurbishment, and repair activities. In stark contrast, the impact of those activities on primary material and product production, ΔQ_p, is largely unknown. There is some theoretical and anecdotal evidence that many recycling

		Change in production impacts	
		$e_r < e_p$	$e_r > e_p$
Change in production quantities	$\Delta Prod > 0$	**Q1: Circular Economy Rebound** Video on demand, recycling, service-based floor covering, recoverable rocketry, refurbished phones	**Q2: Higher net impact**
	$\Delta Prod \leq 0$	**Q4: Lower net impact** Smartphone parking meter Product lifetime extension (*ceteris paribus*)	**Q3: Potential shortfall** Reusable bottle Reusable grocery bag

Figure 2 Framework of potential environmental outcomes of circular economy activities based on changes production quantities and differences in production impacts. Activities in Q1 represent circular economy rebound.

and refurbishment activities are likely to increase total production and consumption, that is, $\Delta Prod > 0$ (Thomas 2003; Zink et al. 2014, 2016). Another circular economy activity, which is espoused by the Ellen MacArthur Foundation, but may also increase consumption, is virtualization. For instance, video-on-demand, which is a virtualization of media delivery, often has lower per-use impacts than physical video delivery, that is, $e_r/e_p < 1$ (Shehabi et al. 2014; Weber et al. 2008). However, video-on-demand has also increased consumption of video content (Walgrove 2015). Recoverable rocketry, such as that being pioneered by SpaceX and Virgin Galactic, has lower per-launch and per-rocket material and energy requirements, but also makes rocketry cheaper and therefore may increase the number of launches.

Realistic examples for $\Delta Q_p = -\Delta Q_r$ are difficult to find. As one potential example, Zink and colleagues (2014) analyzed the impacts of repurposing a smartphone as an in-car parking meter and found that it had lower production impacts than primary production and was highly likely to lower consumption of primary production parking meters. Another example may be product life-span extension given that there is no income effect as a result. Cooper (2005) suggested that increasing product life spans through repair, quality production, and material selection may overcome the rebound effect while also bolstering job creation. For instance, recent efforts by Patagonia, Inc. to encourage garment repair and reuse may generate net environmental benefits attributed to the low environmental impacts of garment repair and its potential to decrease new garment production. However, Cooper also cautioned that convincing consumers to extend product life spans can be difficult due to stigmas about owning outdated products and the fact that consumers may lack the care and attention required to maintain and repair products. The rise of "fast fashion" since the publication of Cooper's article seems to support this point.

Equation (2) also covers circular economy activities for which $e_r/e_p > 1$, such as production of multiple-use products such as reusable shopping bags, bottles, or mugs (Lewis et al. 2010; Nestlé Waters North America 2010). The conditions $\Delta Q_p < 0$ and $e_r/e_p < |\Delta Q_p|/\Delta Q_r$ still apply, and the latter provides a first-order quantification of the number of single-use products that need to be displaced by the reusable one in order to generate net environmental benefits. If the reusable product fails to reach this mark, it fails to result in net environmental benefit, an effect we have termed *shortfall*.

Equation (2) shows that the net environmental impact of circular economy activities depends on their combined effects on production impacts and production quantities. One fundamental distinction is whether a circular economy activity has lower or higher unit impacts, e_r, than the primary production activity it is competing with. The other distinction is whether the circular economy activity increases overall production and consumption, that is, $\Delta Prod > 0$, or not. This can be summarized in a 2 × 2 matrix, shown in figure 2.

Activities in Q2 will always increase net environmental impact, whereas activities in Q4 will always decrease net environmental impact. Activities in Q3 may not decrease primary production activities enough in order to reduce overall environmental impact and thus suffer from the aforementioned *shortfall*. Activities in Q1 also have the potential to reduce overall environmental impact, but experience circular economy rebound, that is, $\Delta Prod > 0$. In the best case, this increase in total production and consumption only reduces the net environmental benefits, E_{net}, but does not reverse its sign (see figure 3). In the worst case, net environmental impact increases, resulting in circular economy *backfire*.

Mechanisms of Circular Economy Rebound

There are at least two general mechanisms by which secondary production can lead to rebound. The first has to do with the substitutability of secondary goods; the second has to do with the effect of secondary goods on market prices.

Rebound Attributed to Insufficient Substitutability

Secondary goods may be insufficient substitutes for primary goods because they are of inferior quality or are otherwise less desirable to users. For example, recycled plastics and papers rarely compete directly with primary materials due to degradation in the quality of the polymer and shortening of fiber lengths during use, collection, and reprocessing (Allwood 2014). Recycled metals such as aluminum are contaminated with alloying materials, reducing their utility and value (Nakajima et al. 2010). This means that recycled plastics,

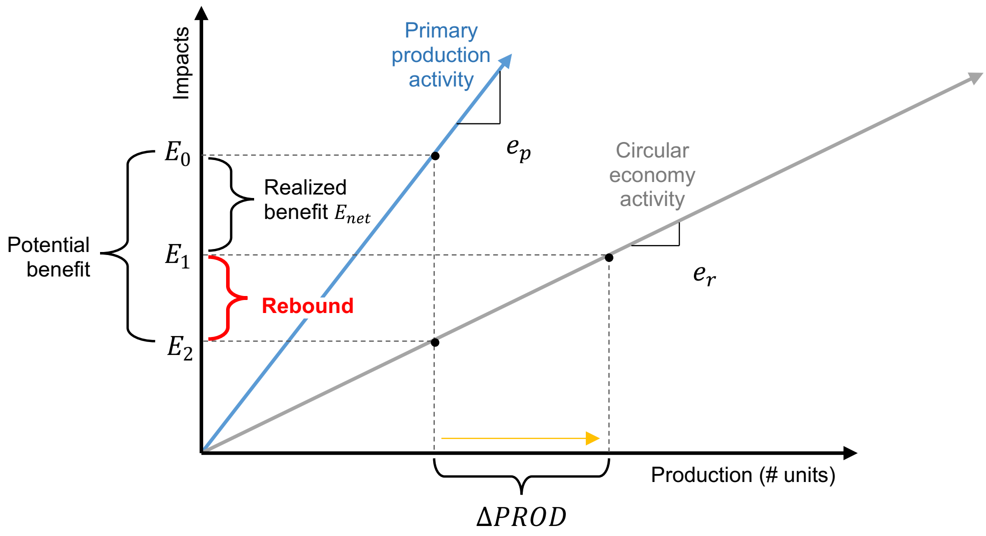

Figure 3 Circular economy rebound attributed to increased production. If no rebound occurs, the potential benefit is realized and impacts fall from E_0 to E_2. However, $\Delta Prod > 0$ reduces the net benefit by $E_1 - E_2$, termed circular economy rebound. If rebound is sufficiently large, the benefit is eliminated entirely (i.e., $E_0 - E_2 = 0$), or backfire can occur (i.e., $E_0 - E_2 < 0$).

papers, and some metals are likely to be produced in addition to, rather than instead of, primary materials, and the potential benefits of recycling will be reduced.

Refurbished smartphones also rarely compete in the same market with primary smartphones (Geyer and Doctori Blass 2010; Skerlos et al. 2003). Instead, these secondhand phones are sold to consumers in developing countries who would not be able to afford a primary phone. Therefore, the appropriate comparison in this case is not between the impacts of refurbishing vs. primary production, but of refurbishing vs. no phone at all.[3] Used phones are refurbished in addition to, rather than instead of, new phones, and the smartphone circular economy (how it is currently practiced) necessarily leads to rebound. The same is true for many used goods where technology changes too rapidly to support a secondhand market (Allwood 2014); in these cases, refurbishment or resale of used goods will necessarily increase net production and consumption.

Rebound Attributed to Price Effects

The second general mechanism for circular economy rebound happens when increased secondary production activity impacts prices. To see how this happens, consider again that some circular economy goods are lower quality than their primary production counterparts (recycled papers and plastics are a good example). In order to entice buyers to purchase lower-grade materials, sellers offer them at a discount relative to primary materials. Downstream producers that choose to substitute with secondary material are now comparatively wealthier (the income effect) and can purchase more material and use it to make more products than they could before. It is likely that these products will also be of lower quality and will need to be sold to end users at a discount, multiplying the income effect. As a result of increased paper and plastic recycling, more goods are now produced, sold, and used.[4]

However, problem deepens because it is not necessary for the secondary good to be cheaper in order for it to impact prices and therefore lead to rebound. To see this, consider that increasing circular economy activities has the effect of increasing the supply of secondary goods (products, components, and materials) to markets. The secondary goods compete in these markets as substitutes for primary goods. Basic economic principles suggest that as supply of a good increases, both its price and the price of substitute goods will fall as suppliers compete for buyers and buyers of substitute goods switch to the cheaper good. This price decrease will cause demand for both the good and its substitutes to increase as consumers perceive themselves to be comparatively wealthier (the income effect) and make consumption decisions about all other goods in relation to the cheaper good (the substitution effect). Fringe buyers who were previously priced out of the good (or its substitutes) may also start to purchase the good. These demand increases will then increase prices, and these opposing forces will balance at a new equilibrium price and quantity. However, assuming a competitive market and normal goods, the new equilibrium price will necessarily be lower than the original price and the quantity consumed will be higher. Additionally, given that secondary production lowers cost and raises apparent income, the excess wealth will be spent elsewhere, with unpredictable results (Allwood 2014).

The income and substitution effects are likely to be even more prominent in developing economies. Although the circular economy has been touted as a way for developing economies to "leapfrog" less efficient technologies (Geng and Doberstein 2008), consumers in developing economies tend to increase their consumption of consumer products proportionally more than those in developed economies when their income increases

(UN 2013). Additionally, often the "benchmark" product in developing economies is no product at all (as in the case of refurbished cell phones), so no real displacement of primary production is even possible. Therefore, increasing the supply of products, components, and materials in these economies will result in a comparatively larger increase in consumption and therefore higher environmental impacts relative to developed economies.

The result is that increasing the circular economy may prevent some primary production, but it may not prevent it on a one-to-one basis. Zink and colleagues (2016) demonstrated this in the context of recycling; the case is no different in the other circular economy activities of reuse, repair, or refurbishment—the only difference is the market being supplied. In the case of recycling, Zink and colleagues (2016) found that the primary factors determining displacement rate were the price responses of buyers and sellers of primary and recycled material and buyers' willingness to substitute between them. For repair or refurbishment, the determining factors will be the price responses of buyers and sellers to increased supply of repaired or refurbished goods, the pricing response of sellers to lowered demand attributed to reused goods, and buyers' willingness to substitute between new and secondary goods (e.g., Thomas 2003). These responses cannot be known in advance and therefore the net impact of increased circular economy activities is, at best, uncertain, but is likely to be lower than what 1:1 displacement would predict.

Broader Circular Economy Rebound

We have focused primarily on rebound attributed to income and substitution effects—what Greening and colleagues (2000) would call direct and secondary rebound effects. However, economy-wide and transformational effects are also possible, though necessarily more speculative. Increased refillable bottle use, for instance, could lead to increased production and operation of refilling stations; increased emphasis on recycling could lead consumers to purchase more disposable products, believing they can erase their impact at the recycling bin; availability of cheaper materials attributed to increased recycling may change consumer tastes (e.g., the perceived value of Apple products made from aluminum rather than plastic); repair occupations that have systematically disappeared over the past century may start to re-emerge with unpredictable effects on employment, affluence, immigration, and overall consumption levels and patterns. A study commissioned by the Ellen MacArthur Foundation found that the circular economy would enable Europe to increase resource productivity by up to 3% annually, which would translate to a gross domestic product (GDP) increase of up to 7% by 2030 relative to the current development scenario (Ellen MacArthur Foundation 2015). Whereas the study heralds this as a competitive opportunity for the European economy, the clear implication is that the circular economy will create growth—growth means the rebound effect and a reduction in expected environmental benefits.

Avoiding Circular Economy Rebound

Circular economy rebound could be a serious obstacle to creating meaningful environmental improvement. How, then, can we work to avoid rebound so that the promise of the circular economy is realized? From the preceding discussion, several necessary conditions emerge for avoiding circular economy rebound.

First, it is necessary that circular economy activities produce products and materials that truly are substitutes for primary production alternatives. Products or materials that are poor substitutes attributable to differences in quality, price, or target market cannot compete with primary alternatives and are nearly guaranteed to result in rebound. As a result, strategies that market secondary goods as specialized products sold either to niche markets or at vastly different price points are likely to be ineffective at creating meaningful environmental benefit. Instead, companies must market secondary goods in the same way as primary goods—using similar channels, touting similar benefits, and reaching similar customers. This may include educating the public to overcome stigmas (for instance, about the quality of secondary goods such as used motor oil [Geyer et al. 2013]) or convincing buyers of the value proposition of higher-quality, longer-lasting goods relative to lower-quality throwaway goods.

Second, it is necessary that circular economy activities either have no effect on or decrease aggregate demand for goods. This is to say that they either must target areas with fairly satiable demand (i.e., markets where buyers' price sensitivity is low), or they must ensure that increased secondary production does not significantly affect overall prices. The first alternative may be more likely than the second. Certain types of goods tend to have more satiable demand than others (e.g., demand for furniture or vehicles may be more satiable than for electronics). Companies that focus their circular economy activities in these low-price-response areas are less likely to create rebound. On the other hand, it is not immediately clear how a single company could prevent a market-wide price effect from increased supply; in free markets, individual suppliers are unlikely to be able to control market-wide behavior. There may be certain industries with mono- or oligopolistic traits where this type of control might be possible.

Third, if the first two conditions are met, it is also necessary that the circular economy activity *actually* draws consumers away from primary production. In other words, substitution from primary to secondary goods must actually occur. This is a substantial hurdle given that the two primary tools that a marketer might use to draw away customers—lowering prices or finding niche markets—are off limits in order for the circular economy to avoid rebound.

Unfortunately, due to the unpredictable nature of highly complex systems, such as the system of markets involved in the circular economy, it is likely impossible to derive any meaningful conditions that are both necessary *and* sufficient. Unforeseen consequences may mean that a well-intentioned circular economy activity nonetheless results in rebound.

Conclusions

The basic concepts of the circular economy have a strong intuitive appeal. Closing material loops, extending product lifecycles, and virtualizing products all hold great promise for reducing environmental damage. However, just as increased use can reduce the environmental benefits of light-emitting diodes or hybrid cars, increased production and consumption, which we have termed circular economy rebound, can reduce the benefits of the circular economy.

A key insight of this article has been that the *economy* part of the circular economy tends to be overlooked. The circular economy is typically conceptualized as a pure engineering system, a worldview that leads to implicit unfounded assumptions about the impact of the circular economy on primary production. When these complex socioeconomic factors are included, the environmental outcome of the circular economy becomes ambiguous. It turns out that simply closing material loops is not enough to guarantee environmental improvement.

Circular economy activities can lead to rebound by either failing to compete effectively with primary production or by lowering prices and therefore increasing and shifting consumption. Pricing reused products and recycled materials lower to make up for real or perceived technical deficiencies is very likely to produce rebound. Even if secondary products are not discounted, their increased production can depress their own price and that of all substitutes, leading to rebound. Secondary products that compete in either low-end or high-end niches simply grow the "pie" rather than taking slices from primary production and also result in rebound.

Suggestions for avoiding circular economy rebound include ensuring that products are good substitutes for benchmark alternatives and focusing on markets where buyer price sensitivity is low. Contrary to circular economy mantra, managerial focus should *not* be on simply closing material and product loops, but on causing *displacement* of primary production. What happens at the end of the product life cycle is relatively unimportant on its own—what is utterly important are the downstream consequences caused by the chosen EoL treatment. Similarly, and again contrary to the mantra, the focus should *not* be on maximizing the "utility" of the product or material, but on maximizing the *displacement potential* of EoL goods (Zink et al. 2014).

Unfortunately for environmental proponents of the circular economy, our suggestions are unlikely to be attractive to most for-profit companies and are probably impossible for publicly owned corporations. As mentioned, not all proponents of the circular economy intend for it to be environmentally beneficial. For instance, the consulting firm McKinsey & Company views the circular economy as an opportunity not for environmentalism, but for arbitrage. McKinsey & Company explicitly advise their clients that marketing secondary products, components, and materials in a way that *does not* cannibalize existing sales (i.e., does not displace primary production) will create the largest profits (McKinsey & Company 2014).This means that simply introducing the circular economy concept to free markets and profit-maximizing firms (as the EC has actively done) is very likely to result in rebound. As Julian Allwood phrased it, "a circular economy could be achieved if global demand for both the volume and composition of products stabilized. That 12-word condition describes an environmental nirvana that defies all imagination in current growth-driven economies . . . " (Allwood 2014, 446). What is truly required to reduce environmental impact is less production and less consumption. The circular economy promises this outcome, but, once economic realities are considered, may fail to deliver on its potential.

Acknowledgments

We appreciate the helpful feedback of three anonymous reviewers. Naturally, any remaining errors are our own.

Funding Information

This research was funded by National Science Foundation (NSF) Chemical, Bioengineering, Environmental and Transport Systems (CBET) grant #1335478.

Notes

1. Proponents of the circular economy also include other aspects, such as the sharing economy, servicizing products, or redistribution of resources. However, when talking about the "circular" nature of the circular economy, the core concept is using waste streams—used products, components, and materials—as industrial inputs. For this reason, we constrain our discussion to the core activities of reuse, refurbishment, and recycling.
2. Throughout this article, we will refer to environmental "impacts." There are, of course, many types of impacts ranging from emissions of greenhouse gases and toxins to deforestation and habitat destruction. There are some examples where the general pattern that secondary production creates lower impacts does not hold for certain products and impact categories, and trade-offs between categories can exist. However, such cases serve to strengthen rather than weaken our overall argument that caution is required when implementing circular economy activities. Therefore, for the sake of exposition, we will simplify the panoply of impacts into the term "environmental impacts."
3. Note that there may be significant welfare benefits to increased connectivity in the developing world; this article focuses on the potential environmental rebound of the circular economy and therefore ignores these welfare concerns.
4. Again, this may be welfare increasing or decreasing, considerations that are out of scope of this article.

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