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Don Fullerton

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Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
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Abstract

Research about the circular economy is dominated by engineers, architects, and social scientists in fields other than economics. The concepts they study can be useful in economic models of policies – to reduce virgin materials extraction, to encourage green design, and to make better use of products in ways that reduce waste. This essay attempts to discuss circular economy in economists' language about market failures, distributional equity, and policies that can raise economic welfare by making the appropriate tradeoffs between fixing those market failures and achieving other social goals.

JEL-Codes: H230, Q380, Q520, Q530.

Keywords: disposal, dumping, environment, extraction, litter, policy, product design, recycling, remanufacturing, repair, reuse, social justice, sustainability.

Don Fullerton
University of Illinois at Urbana-Champaign / USA
dfullert@illinois.edu

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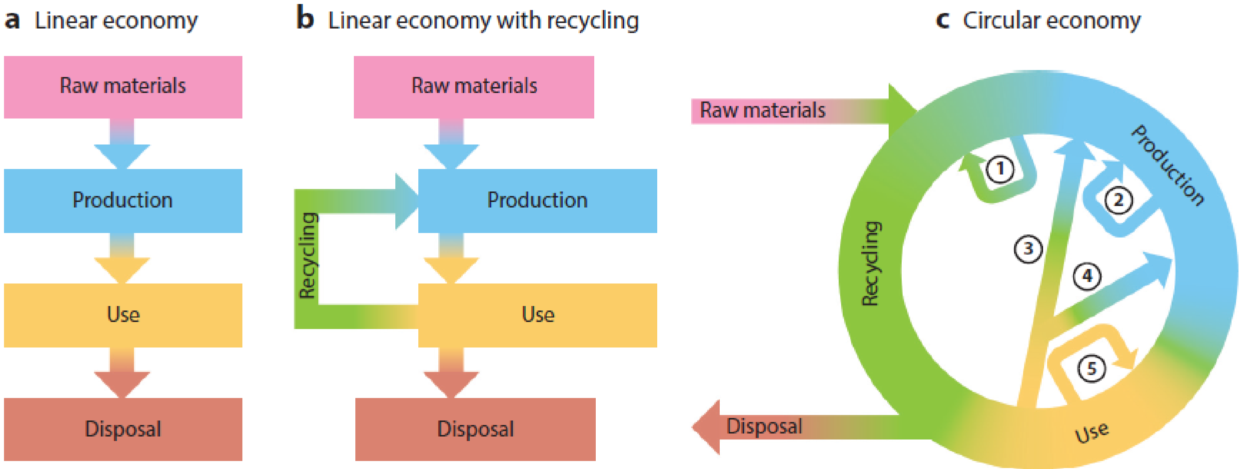
Most businesses and consumers in most countries dispose of waste cheaply because of abundant landfill space, incineration, and disregard for negative externalities from disposal. As a result, production of commodities has followed a linear progression: cheap extraction of virgin materials, product designs that ignore post-consumption disposal costs, and disposal choices that minimize private costs by putting materials back underground. Only recent decades have seen the suggestion of a "circular economy" (CE) that could reduce materials extraction and instead use recycled materials in new production, thus reducing waste. A more circular economy could design products for easier recycling and for durability, cutting the need for disposal. The recent intellectual development of these ideas is reviewed in *Nature* by architect Walter Stahel (2016). This new literature is very interdisciplinary, involving civil engineers, industrial ecologists, and social sciences other than economics. To be sure, economists have studied separate elements of CE, including resource extraction, green design, product repair, renovation, reuse, and recycling. But little if any economics research has studied how all those elements interact.

To start with the big picture, Figure 1 illustrates the logical progression from a "linear economy" (on the left-hand side) to a "linear economy with recycling" (in the center), and then to a fully circular economy (on the right-hand side). The economics literature historically follows a similar progression: study of natural resource extraction, which is part of the linear economy, and then the study of recycling in the center of the figure. Below, I review the transition from a linear economy to a recycling economy by looking at empirical trends. Then later sections discuss various market failures around the entire circle of the circular economy, from raw materials extraction to product design, production, and consumer use, as well as (1) waste as a resource, (2) remanufacture, (3) repair, (4) resale, and (5) reuse.

Figure 1. A Linear Economy, Recycling, and a Circular Economy



Circular activities include: (1) waste as a resource, (2) remanufacture, (3) repair, (4) resale, and (5) reuse.

Discussion of CE within economics is recent. A 2021 search of economics journals (Fullerton *et al,* 2022) found only 71 mentions of circular economy. All but five appear later than 2016, and 68 of 71 have no authors from North America. No general economics journal nor top field journal in environmental economics had mentioned circular economy. Thus, that review article concludes that "the huge majority of North American economists have never heard of 'circular economy'" (p. 495). The interdisciplinary CE literature does not cite economics literature either.

That search of economics journals did not include two other sources. “Circular economy” was first mentioned by an economist (Boulding, 1972, p.351), and it was the title of Chapter 2 in the resource economics textbook by Pearce and Turner (1990). That chapter describes how the environment interacts with the economy in three key ways: (1) provision of resources as inputs to production, (2) capacity to assimilate or absorb wastes, and (3) direct benefits of aesthetic enjoyment. They note that the First Law of Thermodynamics implies those input resources are not destroyed but must go somewhere – either converted into another material, good or bad, or they are dissipated and absorbed back into the environment. A portion of materials are already being recycled, but the rest must result in resource depletion. For this textbook, the circular economy was a pedagogical device, to teach environmental economics and the importance of pricing resource inputs and waste outputs. But it was primarily a positive description of interactions between the economy and environment, not a normative prescription.

While ignoring economics research (and the origins of CE in that 1990 economics textbook), the next 30 years of interdisciplinary literature on the circular economy included ecological sciences, construction practices, and engineering. For example, Stahel in the 2016 *Nature* article says that a CE “would change economic logic because it replaces production with sufficiency: reuse what you can, recycle what cannot be reused, repair what is broken, remanufacture what cannot be repaired.” (p.435). Non-economists latched onto that terminology with a much more normative purpose. “Governments and regulators should adapt policy levers, including taxation, to promote a circular economy in industry” (Stahel, 2016, p.436).

Clearly, the goal of this interdisciplinary literature is to adopt a circular economy. In contrast, the goal in economic research usually is how to maximize some definition of economic or social welfare. In this essay, I will take the latter approach, discussing what policies might increase welfare by making better tradeoffs between economic efficiency, equity, and environmental protection. But several points from the CE literature are important for economists.

First, economists can learn from this interdisciplinary literature about how producers can save costs by use of recycled instead of virgin materials and about alternative CE policies, some of which might efficiently reduce negative externalities of production and disposal. Policy can encourage technologies to reuse waste by-products, and to design products that facilitate remanufacturing and recycling, all while reducing disposal, incineration, and illicit dumping.

Second, economists can follow the lead of the interdisciplinary CE literature by adopting more complete models that capture the interdependence of all decisions by all actors around the circle. Economists have studied how tax or regulatory policies toward mining can internalize negative externalities from mining, but not yet considered how those same policies can also raise firms’ demands for recycled materials, encourage a shift in disposal toward recycling, and thus shift away from landfills and dumping – to reduce an additional set of negative externalities. Analogously, economists have studied optimal polices toward green product design, or toward landfill disposal and illegal dumping, but not yet considered how those policies may also reduce externalities from extraction. Given interactions across the CE, no individual policy can be set optimally without first considering whether each of the other policies is also set optimally.

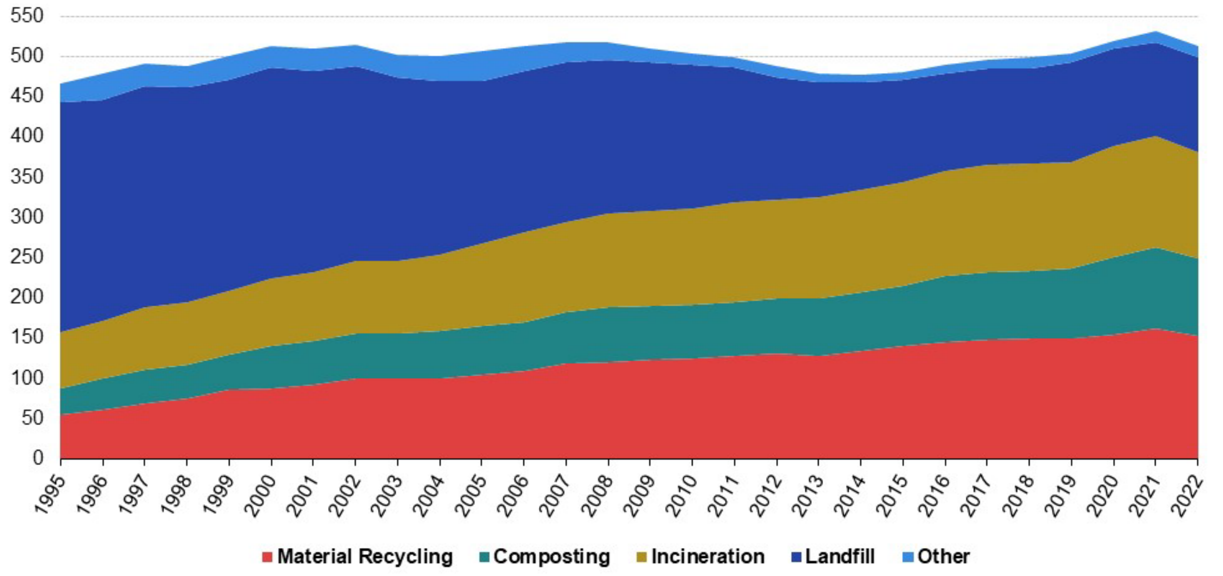
Third, the interdisciplinary CE literature also points to other problems that a CE might help solve. Economists can translate that literature into economic models to identify market failures other than negative externalities from extraction and disposal. That is, economists can clarify “what is the problem” that a circular economy might help solve. In addition, the CE literature is highly concerned with social equity in the economy, and how the transition to a circular economy might help or exacerbate injustices. Economists are well-tooled to discuss not only overall impacts on social welfare, but also the distribution of impacts of a transition to a CE, especially impacts on marginalized populations. Moreover, economists can evaluate the progress made toward solving the problems identified, and policies that might help encourage that progress.

The next section reviews data showing trends in recycling and the lack of data on other CE activities such as repair, reuse, renovation, or remanufacturing. Then the following section will list and discuss multiple possible market failures. A later section then reviews federal, state, and local policies that might help reduce those market failures and improve economic performance. Some of these policies can correct certain market failures perfectly in a simple theoretical model, but other policies may work better in practice, depending on the context, for reasons related to administration, monitoring and enforcement, distributional effects, political feasibility, or coordination with other policies in a second-best framework. Throughout the analysis, I discuss how some ideas from the interdisciplinary circular economy literature are likely to be useful for models built around both overall economic welfare and measuring distributional impacts.

Empirical Trends over Time

Starting with the European Union (EU), Figure 2 shows trends in the treatment of municipal waste. The largest dark area near the top of the figure shows that the fraction of municipal waste going into landfills fell from over half of the total in 1995 to less than a quarter of the total by 2022. This large reduction was more than replaced by increases in materials recycling (the bottom shade in the figure), by increases in composting (second from the bottom), and even larger increases of incineration (third from bottom). As an aside, the CE literature debates whether incineration is circular. In any case, the sum of recycled and composted waste in the EU in 2022 was 48 % of total municipal waste.

Figure 2: Municipal waste treatment, EU, 1995-2022 (kg per capita)



Note: estimated by Eurostat.
Source: Eurostat (online data code: env_wasmun)

Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics

Compared to the EU, the US recycling rate is somewhat lower (and US incineration is small). Published recycling data from the U.S. EPA (2024) extends from 1960 only to 2018, but these data show that the percentage of US municipal solid waste (MSW) that gets recycled and composted grew slowly from 6% to 10% during 1960-1980, but it grew rapidly from 16% in 1990 to about 35% in 2010. It then leveled off from 2010 to 2018.

Where does recycling go? In the EU and US, some materials are sold domestically, and some are exported. Mixed paper is two-thirds of U.S. post-consumer recycling, half of which is shipped abroad, but 70% of those shipments went to China in 2015. For years, China complained about the high fraction of these shipments contaminated by non-recyclables. Finally, China's "National Sword" policy announced a 2018 ban on imports of various types of paper and plastic (and tighter controls over other imported materials).

Thus, starting in 2018, many countries had no place to send their formerly exported materials. Along with all major newspapers, the NY Times (2018) reported that "thousands of tons of material left curbside for recycling in dozens of American cities and towns … have gone to landfills". Many Americans received this striking news and stopped recycling entirely. The Solid Waste Association of North America (SWANA, 2021) explains that the shortfall in recycling capacity caused by China's ban was resolved in the short run partly by increased landfill but mostly by increased US exports to other countries.

Sigman and Strow (2024) study China's ban. They show that US prices for PET plastic and paper mostly tracked each other until 2018, and then both fell dramatically. They also show a sharp recovery of these prices between 2020 and 2021, indicating recovery of processing capacity to make use of those materials. They conclude that "estimated effects on landfilling and recycling dissipate quickly over time, which is consistent with reports that the US developed greater domestic recycling capacity for wastepaper a few years after the ban" (p.27). Unfortunately, news about increased capacity was not as dramatic as news about China's ban. Some towns shut down curbside recycling collection, and many housholds still believe it all goes to the landfill, so they never returned to recycling.

Further indicating recovery, SWANA (2021) reports that the price per "blended" ton of recyclables more than doubled from $51.65 in 2019 to $134.26 in 2021. They also report the price information shown in Table 1, employed here to make four points.

First, recycled materials are far from homogeneous, as the price by material varies from under $100/ton to over $2000/ton. Second, prices increased from 2020 to 2021 for all the individual categories shown in the table, some dramatically. Third, markets for aluminum (over $1000 per ton) and HDPE (over $2,000 per ton) are quite vibrant, but all these prices are highly volatile. This price volatility may discourage entry or continued operation by a materials recycling facility (MRF) that cannot be sure their sales prices will cover their costs, and it may drive producers away from recycled feedstock toward virgin materials.

Fourth, of course, private sector prices reported in this table do not reflect the true social value of these recycling activities. Important external benefits of recycling include avoided damages from extraction of raw materials made unnecessary by recycling and avoided negative externalities from waste in landfills. In addition, the market price of recycling ignores the benefit of saving the tipping fee charged for disposal at the landfills. For example, the market price of used glass bottles is virtually zero (not shown in the table), but a municipal authority might be advised to recycle glass and pay someone to take it, if that cost is less than the tipping fee per ton.

Table 1: Prices per ton (if cleaned, crushed, and baled)

Commodity	Dollars per Ton	
	September 2020	September 2021
Corrugated cardboard	$60	$171
Mixed paper	$18	$96
HDPE	$1,100	$2,169
PET	$130	$511
Polypropylene	$105	$663
Aluminum cans	$915	$1,550
Steel cans	$78	$250

Source: SWANA (2021). HDPE is high-density polyethylene. PET is polyethylene terephthalate.

Finally, the CE literature in economics journals is not well developed, but it is least well-developed regarding repair, reuse, renovation, and remanufacturing. MRFs collect data on their recycling, for use by governments and organizations like SWANA in Table 1, but data are hard to obtain on repair, reuse, or renovation. These activities are often known only to the individual business or household undertaking them. Large surveys of diverse populations may help, but they require time and money. Some researchers have found creative ways to measure reuse. For example, Taylor (2019) uses retail data to find that California's ban on disposable plastic carryout bags led to a 120% increase in purchasing garbage bags, revealing a 12–22% *reuse* of plastic carryout bags as garbage bags before the ban went into effect.

What Problem is a Circular Economy Intended to Fix?

The interdisciplinary CE literature points out that principles of a circular economy could be used by households to reduce their own costs of waste disposal and by private firms to reduce their own costs of materials inputs. Thus, to some extent, CE ideas are intended to help businesses minimize their own costs and maximize their own profits. If those cost savings were available, then recycling markets can arise to get those waste materials from households to firms. New business models and practices are being devised all the time, including ways that entrepreneurs can start their own business to offer new reuse or repair services that do not currently have well developed private markets. On the other hand, transactions costs may prevent entrepreneurial entry, *i.e.*, real and persistent costs may cause those markets to fail.

The OECD (2019) describes five types of circular business models, including: Circular Supply, to emphasize inputs based on recovered and renewable materials; Resource Recovery, to produce secondary material inputs from waste products; Product Life Extension, to avoid both virgin resource extraction and landfill disposal; Sharing, for one consumer durable to serve multiple households; and Product Service Systems, for consumers to pay for use of durables when needed (and not be responsible for disposal).

Even without government intervention, these new business models and circular business practices can be facilitated by new technology. For example, blockchain can be used to record transference of materials across sectors or transport across regions. A new product might be possible with use of high-quality used materials, if firms know exactly how much material of what quality is available at each location. Blockchain can allow creation of a market that might not otherwise exist because of high transactions costs. It can also facilitate enforcement of policies to encourage green design by firms and recycling by households.

While many economists are interested in those business models and practices, others are interested in where private markets fail to maximize overall welfare, why they fail, and how to fix them. In some cases, policy can be designed to fix those market failures and maximize overall economic welfare. In general, private firms can efficiently collect curbside garbage cans and recycling carts, and the firm can charge households enough to cover their own private costs (truck costs, labor costs, and tipping fees at landfills). What, then, are the possible market failures that a circular economy could help fix?

Negative Externalities from Garbage.

Collection and disposal of garbage can impose external costs on others, including truck noise at 6am, odor, litter that falls off the truck, and landfill emissions of leachate and methane. Repetto *et al* (1992, p. 25) cite consulting studies of those costs that find marginal external damage (MED) is about $0.71 per 32-gallon bag of garbage. More recently, Kinnaman (2014) argues that estimate is too high, based on studies of landfill emissions, hedonic house price estimates of neighborhood dis-amenities, and life-cycle assessment (LCA) studies of materials. Recently built landfills for most U.S. waste comply with requirements for sanitary lining, collection of leachate, venting of methane, and burning of methane for electricity generation. From his review of estimates through the year 2000, Kinnaman finds that the MED is $10 per ton, or about 15 cents per 32-gallon bag (one-fifth of the size in Repetto *et al*). Inflation since 2000 would increase that 15 cents to about 25 cents per bag today. As discussed below, the first-best tax on garbage that maximizes overall economic welfare might be that MED, just 25 cents per bag. If so, then commercial or household waste disposal might shift slightly from garbage toward recycling.

Externalities from Other Forms of Disposal.

Negative externalities from recycling are not well estimated either. Tanaka *et al* (2022) indicate substantial harm in developing countries that recycle lead-acid batteries from the US. Even within the US, external damages from curbside recycling are likely to include the same kinds of costs as for garbage (truck noise at 6am, odor, litter that falls off the truck, various emissions from the recycling processing plant). Hedonic house price studies would find similar dis-amenities from location near recycling plants. Thus, the likely MED from recycling is not lower than from garbage. If so, then the just-mentioned “optimal” ($0.25/bag) tax on garbage that shifts households toward recycling would not raise welfare at all. In any case, these markets failures do not yet motivate major shifts toward a circular economy.

As pointed out by Fullerton and Kinnaman (1995), however, a tax on garbage might shift disposal not just toward recycling but also toward litter and illegal dumping. Negative externalities from litter or dumping are also not well estimated but are likely to be substantially higher than the MED from garbage or recycling. If so, then, the “optimal” tax on garbage ($0.25/bag) might *reduce* overall economic welfare – by increasing litter and dumping.

Regarding damages from litter or dumping, Jambeck *et al* (2015) estimate that 1.7% to 4.6% of plastic waste generated in 192 coastal countries is mismanaged and enters the ocean each year. UNEP (2014) estimates that plastic waste in marine ecosystems causes $13 billion in damages annually. By viewing all wastes as possible feedstocks, a circular economy approach might encourage more wastes to remain in the economy, thus internalizing some externalities.

Externalities from Virgin Materials Extraction.

Kinnaman (2014) also points to a limited number of LCA studies that find extraction of selected raw materials can have very high marginal external damages, more than $200 per ton (twenty times his estimated MED of landfill disposal). If a ton of aluminum or heavy metals recycling reduces extraction of virgin materials by a corresponding amount, then the marginal external *benefit* of recycling those materials could be $200 or more per ton. While not mentioning "circular economy," Kinnaman effectively argues that recycling cannot be studied on its own without considering how it indirectly affects other behavior all around the circle. The first-best optimal correction for externalities from virgin materials extraction is proper regulation or taxation of externalities from virgin materials extraction, but those industries are underregulated, even in developed countries. They are especially underregulated in developing countries. If the US or EU cannot reduce external spillovers of damages from developing countries by direct regulation of those mining activities, then a second-best solution might reduce those worldwide damages indirectly by starting to subsidize recycling of those same materials.

***Information as a Public Good*.**

Some commodities are non-excludable, which means that a private firm cannot exclude use by those who don't pay. Some goods are non-rival, which means that the marginal social cost (SMC) per additional use is zero (so the optimal price is zero). A lighthouse is the quintessential example, helping all ships within range at no marginal cost (whether they pay or not). The private market fails to provide a pure public good, but a public project can provide total social benefits that exceed the cost. Information is another example. The individual household or firm that collects and compiles the relevant information about recycling bears substantial costs that can easily exceed their own private benefits. Yet that information could be disseminated widely and cheaply, providing total benefits to society that exceed the cost. In other words, government can facilitate recycling markets by providing valuable information about each different material, how to recycle it, how to process it, and how it can be used back in production.

***Transaction Costs*.**

Municipal solid waste (MSW) authorities could require households to buy a sticker to place on each bag or can of garbage at the curb, but those stickers have to be printed, stores need to be paid a percentage of each sticker they sell, and households have to remember to buy more stickers before collection day. Because of these transaction costs (and voter objections), cities usually charge households for garbage collection through local property taxes, or through a monthly bill for collection. The result is that households do not face a price per bag of garbage. Because the marginal price for extra garbage is zero, households have no financial incentive to sort carefully the items that properly belong in recycling.

Other transaction costs cause other market failures further down the line. Even if households do recycle all items properly, a recycling plant can collect only a small price for some items like used glass or certain kinds of plastic, but it incurs transactions costs such as advertising the material's availability, storing the material until sale, finding a buyer, and negotiating a contract. If these transaction costs exceed the likely sale price, then the market for this recycled material can fail to exist. The recycling plant refuses to accept such material, and the city tells households not to recycle those materials. These market failures compound each other: households face no marginal cost for putting those recyclable materials into garbage, but the city must pay marginal cost of trucks, labor, and tipping fees. Thus, it could be worthwhile to recycle and sell those items even at a small negative market price, in order to avoid more costly landfill disposal.

Seven Types of Policy Responses to Fix these Market Failures

Individual market failures might each be fixed by a specific policy, such as those discussed in this section, but some market failures are small enough that overall economic welfare is not necessarily improved by a specific policy that requires its own government authority, monitoring, and other government interference. For these reasons, later discussion will consider whether broad policies to encourage a circular economy might help improve many minor market failures around the circle of the circular economy. Next, however, is a list of seven specific policy types.

Pay As You Throw (PAYT)

As discussed above, most households pay for garbage collection through annual property taxes or monthly fee, but they do not bear any extra cost for adding garbage to their weekly collection. In other words, households do not pay the private marginal cost (PMC) of collection (additional manpower, fuel, truck space, and tipping fees). For a numerical example, suppose this PMC is $4 per 32-gallon bag or can of garbage (though this cost varies widely by location, either higher or lower than $4). Households also ignore the MED, described above, approximately an additional 25 cents. Thus, social marginal cost in this example is $4.25 (where SMC=PMC+MED). Households that ignore those costs would likely generate too much waste. This problem has been addressed in many towns by a system that collects a price such as $4.25 for each bag or can. At local grocery stores, households can purchase specially-labelled bags (or stickers to put on their own bags). Empirical effects of PAYT are studied in Bucciol *et al* (2015).

The PAYT system follows the standard economic principle that consumers pay the true SMC of what they buy. Indeed, if garbage and recycling were the *only* two disposal alternatives, then this price would probably reduce garbage, increase recycling, and provide net increases to overall economic welfare. But households might turn to litter, illicit burning, or dumping – with environmental costs that exceed those of disposal into a sanitary landfill (which collects leachate and vents methane for energy generation). If so, then charging a price of $4.25 per bag of garbage can increase dumping and convert that net welfare gain into a loss.

Externality Tax (ETAX)

Perhaps towns or haulers cannot charge a price per bag because of high transaction costs. Even then, however, they still collect garbage for the landfill and impose negative externalities on others. Pigou (1932) points out that this pollution problem can be managed optimally by a tax on each polluting activity. Under simple assumptions, Baumol and Oates (1988) provide a formal proof that overall economic welfare is maximized by an externality tax (ETAX) that imposes a tax t_i per unit of each pollutant i at a rate equal to μ_i, defined as marginal external damage. Then those who impose externalities bear the full social marginal cost of their polluting activity (both PMC and MED), and they have incentive to choose the optimal amount.

In fact, a full ETAX system could fix a lot of problems around the circular economy. Suppose any firm that buys a new buzzsaw or forklift – or household that buys a new dishwasher – has to pay all Pigovian taxes that cover full external costs from producing that machine, from using it, and from disposing of it. If so, then anybody contemplating a new machine as a replacement has incentive to use the old one longer to avoid disposal tax on the old one and additional Pigovian tax on a new one. Buyers have incentive to purchase a more durable replacement that lasts longer, to repair it when broken, to have it remanufactured, or to buy a used machine – instead of paying tax on a new one. As Bernard (2019, p.1184) says: "Design choices influence material choices, production technologies, energy performance during use, recyclability, durability, and so on," For further discussion, see *e.g.,* Fullerton and He (2024).

Furthermore, any hauler that pays a Pigovian tax on landfill disposal has an incentive to get materials sorted for recycling and to negotiate with other firms able to re-employ that waste back into production. This tax can induce changes in behavior to reduce waste by any method cheaper than paying the tax. However, a tax on any one pollutant might induce shifts in firm or household activities that reduce the taxed pollutant and increase other pollutants instead. A fully correct (first-best) ETAX system would need to tax *every* pollutant. In this case, economically optimal disposal behavior would require a tax on garbage equal to its external damage, a tax on recycling to reflect emissions from recycling, a high tax on illicit dumping to match its high damages, and further Pigovian taxes on each type of mining activity reflecting high damages from extraction. But not all such taxes are possible. Any tax or regulation on litter or dumping faces severe problems of monitoring, enforcement, and administration. Thus, a Pigovian tax just on landfill garbage might increase dumping and cause larger damages.

Subsidy To Recycling (STR)

If dumping cannot be monitored or controlled, and so a full ETAX system is not possible, then a subsidy to recycling might be able to raise overall economic welfare by shifting consumers from garbage toward recycling – but with less dumping. If this STR is paid for each recycled beer can or glass bottle, then it is similar to the familiar a 25-cent refund in some U.S. states. If a payment per can or bottle has high transactions costs, however, then a STR could just pay recycling plants an amount like $100 per ton of cleaned, crushed, and baled aluminum or other material.

Consumer-voters certainly prefer to receive a subsidy than to pay a tax. But government must somehow raise funds for a subsidy, using other taxes that have their own excess welfare costs. Thus, a recycling subsidy by itself is sub-optimal. If control of dumping is not feasible, an economic model could be used to derive the second-best optimal (SBO) combination of policies (*e.g*. tax per unit garbage and a positive or negative tax on recycling).

The heterogeneity of recycled materials is important for CE, because different materials have different external damages from improper disposal. And some uses of recycled materials could cause more damage than in a landfill. For example, recycled PET plastic bottles can be used in making synthetic garments, but "washing of synthetic textiles could contribute 35% of the release of primary microplastics to the oceans" (De Falco *et al*, 2020, p.3288). Also, a broad subsidy to *all* recycling could induce people to put non-recyclable contamination in the recycling cart, and it might divert some materials toward recycling that would optimally be used longer. A broad recycling subsidy could inhibit repair, remanufacturing, or renovation for reuse.

An Advance Disposal Fee (ADF)

Disposal is often not a market transaction with an invoice from the seller to the buyer that can be used by tax authorities to help administer and enforce a Pigovian tax on disposal. Palmer *et al* (1997) introduce the idea of an advance disposal fee (ADF), a product tax at the time of purchase that reflects its later costs of disposal. This policy does not generally lead to the first-best choice of disposal method, because it is not applied at a rate that depends on the later disposal choice.

But it might work well in a case where the disposal method is predetermined (and it avoids the over-recycling that might accompany a recycling subsidy).

A simple example to compare how these policy alternatives work is a "fish aggregating device" (FAD) used in the open ocean to attract wild fish for harvesting (see Imzilen *et al*, 2022). After the FAD is visited multiple times for harvesting, it might be left in the ocean where variable currents can take it in unknown directions to cause damage on some pristine coral reef or island. In the case with no policy, the fishing firm can ignore those damages. And its cost to retrieve the FAD can easily exceed the private benefit of reuse, so it does not get retrieved. In this case, the user of this device does not *choose* the final disposal location. In special cases like this one, as shown here, the ADF can be equivalent to an ETAX. Given a location where a FAD is employed for the last time and then abandoned, ocean currents might carry it to any of a finite set of N final destinations indexed by i (for $i = 1, \dots, N$). Each destination i might have a different MED from disposal, μ_i. Suppose also that policymakers and all firms share the same reliable estimates of the probability p_i that this FAD will drift to destination i.

The ETAX for this case would tax the responsible firm at a rate equal to μ_i, the MED at the single eventual disposal location. The firm does not know what fee must later be paid, but its expected disposal cost is the probability-weighted average MED, equal to $\sum p_i \mu_i$. Even with a perfect ETAX system, a risk-neutral firm only reacts to that expected cost, not the risk that the actual cost will be higher or lower. Thus, any such firm would behave the exact same way if policy required the firm to pay an initial ADF calculated as $\sum p_i \mu_i$, before anybody knows the final disposal destination. This ADF has the same effects as the variable Pigovian tax under the conditions stated here, because the fishing firm is not choosing the disposal method at the end of the useful life of the FAD. This firm only gets to choose where to leave it in the ocean.

Directions of currents likely differ according to the initial location of the FAD, however, so the probabilities of each destination depend on where the FAD is abandoned. For perfect efficiency, then, policy would need to calculate a different ADF rate $\sum p_i \mu_i$ for each different initial location (or have a program to make data-intensive calculations for each initial location). Moreover, each initial location might be associated with a different number of possible destinations. Thus, the use of this policy option might impose high information costs on policymakers.

If retrieval and reuse would maximize total economic well-being, then the ADF is not efficient. The ADF would not induce the firm to retrieve the FAD. The ETAX could be efficient, if it is not collected on a retrieved FAD. This example highlights some of the complexity of the circular economy that would be interesting to study further.

Deposit Refund System (DRS)

Using a simple static general equilibrium model, Fullerton and Kinnaman (1995) consider the case of waste with multiple methods of disposal – for example recycling R, garbage G, and dumping D. Assume dumping has the highest MED ($\mu_R < \mu_G < \mu_D$). Consistent with earlier research, they show that welfare is maximized by an ETAX imposed on every type of disposal. But the cost of monitoring and enforcement is lower for a tax on a market activity like garbage or recycling and possibly prohibitive for a tax on a non-market activity like litter or dumping. They then show that the same first-best outcome is achieved by a deposit-refund system (DRS) that first collects a tax on sale or purchase of virtually any product, t_P, at a rate equal to the MED from improperly dumping it ($t_P = \mu_D$). This DRS then provides a subsidy upon that product's proper disposal (a negative tax of $t_G = \mu_G - \mu_D < 0$). That combination leaves a net tax of μ_G

on proper disposal in a landfill. The optimal DRS also provides a subsidy to recycling the item (a negative tax $t_R = \mu_R - \mu_D < 0$). The net tax on a recycled product is μ_R. Policy has no need to monitor and enforce a tax on dumping, in this model, because the external cost μ_D is already paid at the store by anybody who buys the initial product and then dumps it.
For the FAD problem, at least conceptually, this DRS would have to collect a tax on every new FAD at a rate equal to the MED of landing on the destination with the maximum damages. Then if the FAD lands at a place with MED less than that maximum, the maker or user of the FAD would be able to collect a refund equal to the excess tax that was collected (above the MED of the actual destination). Thus, makers or users would have some incentive to put tracking devices on each FAD, to find where it ultimately lands, so that they could get a refund if eligible.

Extended Producer Responsibility (EPR)

More generally, optimal outcomes could also depend on product design, that is, choices made by the firm before production – such as choosing a design that reduces the cost of disassembly at the end of the product's useful life. Disassembly could include mechanical separation of metal components from plastic or glass components, or molecular separation of polymers within a plastic item to be recycled. Fullerton and Wu (1998) consider a model where the firm can incur some cost to design and build a product with easier recycling, and it can incur some cost to sell and ship the product with less packaging. They show that the same first-best welfare-maximizing designs and disposal *can* be attained by an ETAX system with a tax on each type of disposal, or by a DRS, or by a different policy called extended producer responsibility (EPR).

An optimal EPR policy could simply require the producing firm to be responsible for disposal of any associated waste before sale of it, during shipping of it, and after consumers are finished with it. An intuitive example is where the EPR successfully requires any producer to "take back" packaging and the product itself at the end of its useful life. For this plan to work perfectly, the firm must then pay the full MED for all waste disposal. In their simple general equilibrium model, the consumer pays nothing for disposal, but the producer who is held responsible pays all damages from any disposal. The producer may charge more for the product, to break even in equilibrium, but the producer has optimal incentives to design the product for easier recycling and to use less packaging. For further discussion, see *e.g*., Eichner and Pethig (2001).

For the FAD problem, this policy would have to require each FAD maker or user to label their FAD so that anybody who finds it can identify the responsible party. Then, any nation affected by the landing of a FAD would simply call that party to come take it away. More generally, an EPR does not strictly need for the original user to come get it; instead, the responsible firm can pay a disposal firm to go pick it up for proper disposal.

A major point, however, is that the design of the product can be important for minimizing damages from any method or location of that product's disposal. If final *users* must pay the MED at the end, they will optimally demand products that use a design that allows disassembly or other technology to reduce the private costs of recycling – so that users can recycle and thus avoid the high MED on other forms of disposal. If users send market signals to firms to make products that are easier to recycle, then – depending on circumstances – the right incentives can be provided by any of the four policies discussed above (ETAX, ADF, DRS, or EPR).

Municipal Provision of Services (MPS)

Discussion above lists failures in private markets and how policy can fix them. But to maximize economic welfare in the face of many market failures for MSW collection and disposal services, cities often abandon private markets and use municipal provision of services (MPS). Some towns own and manage the collection trucks, and others use public funds to pay private firms. Towns can fix externalities by charging SMC for each service (prices that differ from private market prices). They can certainly provide relevant information about how and where to recycle. They can create markets for recycling materials and thus overcome transaction costs. Perfect execution of this approach can indeed maximize economic welfare, but perfect execution is rare. Public provision is often faulty, and garbage collection does not fit the standard definition of a "public good" (because additional use does not have a zero social cost, and it *can* be charged a price). Moreover, the circular economy involves not just MSW, but extraction, design, and reuse.

Other Pros and Cons of Alternative Policies

For many of these seven types of policies, perfect implementation can drive polluters to the same first-best optimal (FBO) level of waste and disposal method. But economic efficiency is only one consideration. This section discusses other goals of good policy, to explain the tradeoffs faced by policymakers when trying to choose among these policies.

The EPR is a regulatory mandate, with no revenue, but positive net tax revenue is raised by the ETAX, ADF, or DRS. All four can be perfectly efficient, but that efficiency does not depend on the use of the revenue or compensation to those who bear external costs. Efficiency means maximizing the net gain, summed over all individuals, whereas compensation is an issue of fairness or equity. As discussed further below, fairness can be another goal of environmental policy, but concepts of fairness differ with personal value judgements.

Suppose members of society do agree to compensate victims of pollution, and that government budgets are perennially short. A subsidy to recycling (STR) has a revenue cost, which must be covered eventually by other non-environmental taxes (with their own excess efficiency costs). Then the goal of fairness might suggest the use of a policy that does raise revenue, rather than a using subsidy (STR) or mandate (EPR). But revenue can instead be used for other vital functions of government, such as covering the administrative costs and monitoring costs of enforcing any tax system (PAYT, ETAX, ADF, or DRS). This discussion has already introduced half of the eight competing considerations for good environmental policy listed in Table 2.

Table 2: Competing Considerations

1. Economic Efficiency
2. Administrative Efficiency
3. Monitoring and Enforcement
4. Information and Uncertainty
5. Political and Ethical Considerations
6. Equity and Distributional Effects
7. Other Distortions
8. Flexibility and Dynamic Adjustment

The main point here is that economists historically have emphasized economic efficiency, as in the previous section of this paper, but economic efficiency is only one of the eight listed considerations and might well have to be sacrificed in light of other needs.

Space here allows only brief examples of these tradeoffs. A tax or ban on litter and dumping could improve efficiency but is difficult to monitor and therefore difficult to enforce. Also, to be efficient, each Pigovian tax must be applied at a rate equal to marginal external damages (or a mandate must reduce pollution to the right quantity). But information necessary to measure the optimal tax or quantity is not readily available. Policymakers could guess the appropriate tax, and then adjust it as necessary, but then the policies are uncertain to firms and households who cannot know how best to comply. Some voters or politicians might think that a tax on polluters is ethical, but others might think the right to buy a pollution permit is unethical. And political feasibility in the US means that any Pigovian tax gets little serious consideration.

Good policy also needs to consider "other distortions" such as other taxes or market failures. A monopoly may already have reduced production, to raise price and maximize profits, but then the associated reduction in pollution can change the optimal pollution tax to a lower rate. Papers in economics implicitly consider the circular economy when discussing optimal durability and "right to repair" for products sold in markets that are not competitive (*e.g.* Bernard 2019).

Finally, in this brief discussion of Table 2, policymakers may need flexibility to change policy when circumstances change, but those changes increase uncertainty for those who need to comply. In any case, policy needs to consider future changes in the economy, and policy needs to adjust to those changes. For more discussion of these competing objectives, see Fullerton (2001).

Circular Sustainability May Require Environmental Justice

Though good policies can facilitate the transition to a circular economy, political enactment and continuation may depend not on efficiency gains but instead on how these policies affect different kinds of people. Economic models are often well positioned to estimate and predict broad distributional effects of a proposed policy on market prices and thus on people distinguished by age, income, wealth, geographic location, or by urban vs. rural areas. Many policies to restrict various pollutants are found to raise the cost of commodities that constitute a high fraction of low-income household budgets (*e.g*., food and energy). Such policies are therefore said to be regressive (where burdens as a percent of income are larger for low-income households than for high-income households). Policies might also affect relative wage rates, returns to investment, and government transfer programs. Mackie and Haščič (2019) review recent studies of the distributional aspects of environmental quality and policy. Less is known about social and distributional consequences of circularity *per se*, perhaps because circularity is not a single policy nor even a concept that can easily be inserted into those economic models.

Aside from broad distributional effects through market prices, an environmental effect or policy may impose specific distributional consequences. Consider the tradeoff between equity and efficiency in our example of a FAD that may land randomly on any Pacific Island. Residents of that island suffer damages and could justifiably deserve compensation, which suggests a major difference between the ADF and the DRS or EPR policies discussed above. The fishing firm has efficient incentives to reduce damages under all three of those policies, but the ADF does not make the firm compensate the islanders or take back the FAD – either by requirement (*e.g*., EPR) or by incentive (*e.g*., DRS). Yet the entire issue of this floating debris is raised and emphasized by those who suffer the damages, not by anybody interested in maximizing total economic welfare! In other words, for an efficient policy to get sufficient support for enactment and continuation, it helps to be socially acceptable and politically sustainable.

Analogously, a decision to add recycling capacity broadly can certainly make the economy more circular, but that plan cannot remain effective or sustainable if new recycling plants are located in disadvantaged communities. For this reason, interdisciplinary CE literature has correctly viewed social sustainability as a necessary ingredient of the transition toward a more circular economy.

In balancing the tradeoffs between equity and efficiency, a key consideration is "who came first". Consider the location decision for a new landfill, recycling plant, or any other noxious facility. Efficiency requires this new location decision to account for all costs imposed on existing neighborhood residents. A strong equity case can also be made for compensating those neighbors, since they might suffer a considerable surprise loss in house value. On the other hand, suppose the facility was built years ago. Then that decision has already reduced property values. New folks who move into the area undoubtedly suffer dis-amenities, but they may already have been compensated by the reduction in price paid to buy the house in that neighborhood. They moved voluntarily, so fairness might not require compensation.

In fact, the entire issue of compensation is muddled by capitalization effects, *i.e.,* changes in house prices and stock prices. To explain, suppose a newspaper reports that an old landfill is now seeping toxic material into groundwater. To avoid this danger, nearby owners sell their house – at a loss. Newcomers buy it for cheap, and suffer damages, so they sue. But any damage awards are neither from those responsible nor to those who lose. The firm's stockholders were the "responsible owners", but stockholders at the time the landfill accepted toxic material sold their stock earlier. New stockholder/owners must pay damages, but they aren't the ones responsible for the damage. Prior landfill users are the ones who benefited, as they did not pay true social costs of disposal. But courts cannot take back the benefits from former landfill users to compensate former residents. This example illustrates the extreme difficulty of charging those responsible for damages after the fact, or compensating those who suffered the damages.

Looking forward, many potential noxious facilities have a difficult process finding a suitable site, because of local community objection. That difficulty might be due to a siting process that is political rather than designed to pay all the social costs of each site choice. If the firm were actually to pay local residents enough to accept the facility, including the social costs of the facility at that site, then the outcome might be both more equitable and more efficient. In any case, an equitable transition toward a circular economy would likely require discussions with all relevant stakeholders, including especially low-income and minority communities.

Social issues also affect circularity. Engineers might think technology determines extraction, waste, product designs, recyclability, and the ability to remanufacture, repair and reuse products. Economists tend to emphasize incentives, behavior, and policy interventions. But nobody yet models the extent that both technology and behaviors are determined by culture and existing social structure. Household choices about reuse or recycling face barriers such as family habits, social norms, cultural standards, structural constraints, and perceptions of social justice. Also, these barriers are heterogeneous because of locations with different physical environments, jurisdictions with different regulations, and people with different types if capital assets, labor skills, learning costs, and discount rates (Khanna and Zilberman, 1997). For these reasons, any transition to a CE will also be heterogenous across populations and locations. Thus, achieving a more circular society may require CE policy to recognize structural and cultural barriers, to be able to dismantle them – ideas not well captured in economic models.

Second-Best Policies for All Market Failures and Social Justice

One section above describes five kinds of market failures, and another describes seven types of policies to deal with them. Historically, economists have thought about which policy would best address each market failure (*e.g.*, specific regulations for virgin materials extraction or for waste disposal). In that thinking, however, a policy to regulate one type of extraction or disposal does not account for effects on other activities around the circular economy. Maximizing social welfare likely would not match each market failure with one policy. A tax or regulation on raw material extraction may not only reduce that extraction but also affect demand for recycled materials and therefore household waste disposal. Similarly, if an STR increases recycled materials, it can affect the need for new materials extraction. And either of those policies may also affect green design that can make products from recycled materials or that can make products more easily recycled. Hence, policy analysis itself may benefit from a more holistic CE approach – considering all policies and their interdependent effects on all outcomes.

In economics, that logic implies the need for analytical or computational general equilibrium (CGE) models that can solve simultaneously or dynamically for effects of a change in any one policy on all quantities and prices in all relevant market choices by households (what to buy and how to dispose of it) and choices by firms (extraction, their own recycling, use of other recycled materials, and product design for recyclability). Ideally, such models could also account not just for effects of prices on behavior, but also effects of social norms and culture.

Finally, policy analysis of market failures and distributional effects in a circular economy will also need to forego first-best optimal policy and think hard about second-best solutions to real-world problems. The reason, essentially, is that the SBO level of any tax or regulation targeted at one activity depends on stringency of every tax or regulation on each other activity around the circle (mining, product design, production waste, consumer use, and household disposal).

Conclusion

Research about the circular economy is dominated by engineers, architects, and social scientists in fields other than economics. The concepts they study can be useful in economic models of policies – to reduce virgin materials extraction, to encourage green design, and to make better use of products in ways that reduce waste. This essay attempts to discuss circular economy in economists' language about market failures, distributional equity, and policies that can raise economic welfare by making the appropriate tradeoffs between fixing those market failures and achieving other social goals.

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