2 WHY REPAIR MATTERS

Repair is inevitable. Things break. They degrade, wear down, and fall apart. This is not an indictment of the artifacts we create, although some are more durable than others. It's an inescapable fact of the universe. Entropy – that gradual but ineluctable descent into disorder – comes for us all. Repair is a response to this fundamental truth, an effort to resist it, and maybe even reverse it. No repair is permanent, but it can stave off the return to dust and rubble that awaits everything we build, acquire, and use.

Repair is also ubiquitous. It forms part of the social and technological backdrop of everything we do. Too often though, we think of breakdowns as aberrations, rare and unexpected disruptions to our plans and routines. But it's the daily practice of repair – of our roads and subways, our office buildings, our electrical grids and sewage systems – that make those plans and routines possible in the first place.[1] Nonetheless, repair remains invisible for most of us until something goes wrong, until our car won't start or our laptop keyboard fails. As a result, we undervalue the role repair plays in our lives.

All sorts of things require repair. We sometimes talk about repairing our bodies, relationships, and even societies.[2] But for our purposes, *repair* refers to the mending or reconditioning of human-made goods to restore their form or function. Even within that narrower definition, repair captures a range of approaches and motivations. Often repair is strictly a question of regaining functionality. If your car won't start, you're unlikely to interrogate the mechanic about the color of the spark plugs they install, so long as they get you back on the road. But

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in other instances, we are more sensitive to the aesthetics of repair. If you take a favorite jacket to a tailor to mend a torn seam, you probably hope the repair will be undetectable.

Either way, a successful repair can work a kind of magic. Say you take your dented car to the body shop after a parking-lot collision. If executed well, replacing a damaged fender can, in a way, rewind the clock. It can return you to the moment just before you distractedly backed into that light post. Repair rarely perfectly restores an object to its original condition.[3] But it can undo damage and extend the useful lives of the things that surround us. In that sense, repair looks like a conservative undertaking. The effort to return a thing to an earlier form – if not its original condition – is a backward-looking enterprise, even if it is only aspirational.

Restoration, a close cousin of repair, shares this fixation with the past. When a new owner restores a Victorian home to something approaching its original condition, they are attempting to rematerialize the past. But in the process, they are arguably erasing intervening decades of history.[4] Perhaps that is for the best. But it is a choice that has implications for our relationship with change and the objects embodying it. Cumulatively, the minor, daily accretions and erosions artifacts experience can change their meaning over time. *Notre Dame de Pilar*, better known as the Black Madonna, is a wooden icon dating back to 1508. As part of the recent restoration of the Chartres Cathedral, hundreds of years of soot and smoke were removed from both the twelfth-century structure and the icon it houses. As a result, the Madonna is no longer black, disconnecting this European figure from a multiracial global tradition that venerates the dark mother archetype.[5] As one critic put it, the restoration "transformed the Mother of God into a simpering kewpie doll."[6] When restoration and repair are undertaken in ways that ignore or deny the past, they risk stripping objects of meaning and context.

Maintenance is another practice closely associated with repair. But rather than intervening after some acute breakdown in functionality, maintenance is preventative. It staves off failures or

prevents them altogether. Compared to repair, maintenance tends to be routine, predictable, and less invasive. Regularly brushing and flossing your teeth is maintenance. A root canal is a repair. In practice though, repair and maintenance often intertwine and overlap. Say your car drifts slightly from right to left on the freeway. Is a wheel alignment from your local auto shop a repair or mere maintenance? Functionality isn't binary. Your car still works with misaligned wheels, although not as well as you might prefer. The line between maintenance and repair is malleable, but the distinction is still helpful. Maintenance is about prolonging the present state of affairs, while repair is a matter of returning to some prior condition.

These impulses to preserve the present or return to the past are at odds with a dominant cultural narrative that celebrates innovation and emphasizes newness.[7] From technology, to pop culture, to politics, the drive to break with the past in order to make room for a more promising future is pervasive, if often unfulfilled. Why fix a decade-old internal-combustion car when you can replace it with an electric one? Why repair a three-year old laptop when a new one is lighter, faster, and comes in your choice of color? That's not to say that true innovation shouldn't be valued. Both groundbreaking inventions and incremental improvements can better our lives in measurable ways. But we have to be careful to separate those contributions from mere product differentiation masquerading as innovation. The innovation narrative, for all its promises of a brighter tomorrow, tells an incomplete and biased story about the future. That story is designed to instill a set of values and preferences that encourage us to prioritize the experience and very idea of newness. But newness is, by definition, temporary. Our thirst for it is never slaked, at least not for long. Even putting aside the tantalizing promise of newness, this narrative ignores the many costs of extracting raw materials, manufacturing products, and eventually disposing of them – the sooner, the better to drive the engine of newness. And it turns a blind eye to the opportunity costs of our collective fascination with the new. How might we

spend our time, energy, and money if we weren't busily differentiating this year's phone from last year's model?

Once the costs of newness are taken into account, repair reveals itself as surprisingly forward-looking. It grows out of a recognition that resources are finite, that the planet is small, and that a culture that overlooks those facts imperils its future. Repair allows us to extract maximum value from the artifacts we create. A laptop, for instance, represents significant human investment. Beyond the materials harvested across the globe, it embodies generations of technological advances, painstaking design, the labor of factory workers, and the costs of packaging, shipping, and advertising. Resigning a laptop to the scrapheap because it needs a routine repair, or simply because a new model is available, discards those investments. It is inefficient. It is wasteful. And collectively, that waste imposes costs on us all. From this perspective, repair is not an effort to return to the past, but a project informed by a sober vision of the future.

In this light, repair exhibits a complicated relationship with time and change. It is not some naive effort to reverse the clock and deny the unavoidable passage of time. Nor is it an effort to rush headlong into some imagined, consequence-free future of infinite plentitude. Instead, repair is an attempt to reconcile past and future. It is a clear-eyed compromise between the promise of human ingenuity and the harsh material reality of the world. Everything breaks eventually. But that process of breakdown can be negotiated. It can be managed. The mindset of repair is simultaneously hopeful, yet unflinchingly realistic. Through repair, we can keep that car running for another year or that coat warm enough for another season, even if we know that entropy always wins in the end.

Despite its tendency to go unnoticed, repair contributes to society in important ways. This chapter considers three sets of concrete benefits that flow from repair. First, repair helps consumers save money by extending the lifespan of products and fostering secondary markets. Second, repair lessens the massive environmental burden of modern consumerism, from the extraction of natural resources to the eventual disposal of the

devices we buy. Finally, repair helps us grow and flourish as people. Through repair, we become better informed about the world around us, develop analytical and problem-solving skills, exercise greater autonomy, and build stronger communities.

The Economic Benefits of Repair

To the average consumer, the economic case is intuitive. Repair extends the useful lives of the products we buy. That saves us money in two ways. First, by replacing our purchases less often, we spend less. Second, repair helps ensure that when we finally do replace an aging device, it still has some residual value on the used market.

Imagine your refrigerator breaks. If you can correctly diagnose the problem – a failed compressor, let's say – then find the necessary part and successfully install it, you've likely spent considerably less than you would have on a brand-new fridge. The logic is simple: the longer the things we buy work, the less often we need to replace them. If we can slow the replacement cycle, we will spend less over the course of our lives on clothes, cars, and electronics. And those expenses add up. Collectively, we spend unthinkable sums on new devices – $500 billion a year on smartphones, and roughly the same on household appliances.[8] Both of those figures, however, are dwarfed by the nearly $3 trillion we spend every year buying cars.[9]

Extending Product Lifespans

The lifespans of the products we buy are central to their value. Whether it's worth it to spend $2,000 on a new refrigerator depends in large part on how long you expect it to last. When we talk about the lifespan of a device, it's important to distinguish between two different meanings of that term. By "lifespan," we might mean the length of time the device will continue to perform its intended function – how long it will work. Repair, in a very direct way, extends this functional lifespan. In another sense though, a device's lifespan isn't determined solely by how

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long it functions. Other factors play into our decision-making. New features, aesthetic trends, or the yawning void at the core of modern life could all convince you to replace a perfectly operational refrigerator. This replacement lifespan – how long you keep a purchase before substituting a new one – is often a better measure of our behavior.[10] Repair can certainly influence replacement rates, but it contends against other considerations.

Measuring changes in average product lifespans is challenging, given the absence of reliable longitudinal data.[11] But across categories, consumers express frustration that products don't last as long as they used to, or as long as they should.[12] Empirical studies support this shared anecdotal sense that products' lifespans are dwindling.[13] That's true for household appliances like washing machines and refrigerators. By some estimates, the lifespan of the average washing machine dropped by three years over the course of a single decade.[14] According to a survey conducted by Consumer Reports, 30 percent of new washers break within just five years.[15] And an estimated 40 percent of refrigerators last only five years before problems emerge.[16]

For electronics, the trend is even more apparent. A 2015 study found that older CRT televisions lasted for an average of fifteen years, but newer flatscreen models had average lifespans of just six years.[17] The introduction of higher-definition displays, smart features, internet connectivity, and steadily declining prices, are likely driving even shorter replacement cycles for TVs today. Likewise, a computer purchased in 1985 might last a decade.[18] But by 2005, purchasers were replacing them after just two years.[19] Smartphones have only been around for twenty years, but their lifespans have always been short. On average, consumers in the United States and Europe use a smartphone for about two years before upgrading.[20] This figure has risen modestly – by two or three months – in recent years. Mobile carriers have shifted away from heavily subsidized phone upgrades designed to keep subscribers under long-term contracts. Faced with sticker prices of $1,000 or more, consumers have been understandably persuaded to hang onto their devices for a bit longer. Aside from improved cameras and

ornamental design tweaks, this year's phone typically offers few new features over last year's model.

Cars are a notable exception to the trend of shrinking product lifespans. In 2019, the average age of a vehicle on the road in the United States was just under twelve years. That's the highest figure recorded over the nearly two decades the statistic has been tracked.[21] But unlike smartphones, where increased price transparency and stagnating innovation explain consumer behavior, cars seem to be lasting longer because they are better made. Advances in engineering, material science, and manufacturing have given rise to vehicles that are, overall, more durable and reliable. But incremental scientific improvements don't tell the whole story. Increased global competition and higher regulatory standards likely played roles in raising the bar for quality. Drivers may also be holding onto cars longer in response to a sluggish economy. Whether this trend will survive the impending transition to an electric fleet is an open question – one that depends on improvements in battery technology, the design decisions of carmakers, and the responsiveness of regulators.

Cars aside, the lifespans of the products we buy continue to wane. Too often, the devices we toss out are still in working order.[22] Just as troublingly though, firms take steps to help keep our broken stuff broken. They have strong incentives to encourage us to discard our purchases early and often since replacement sales are a crucial, renewable resource for device makers. As we will see, manufacturers have developed a host of strategies, techniques, and tools to encourage us to replace the products we own. But when repair is available, affordable, and effective, consumers are more likely to keep their existing devices rather than spend more money on something new.

Supplying Secondary Markets

Repair offers another important economic benefit for consumers. It helps sustain secondary markets. Refurbished laptops from eBay, used bikes found on Craigslist, power tools uncovered

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at garage sales, and blenders donated to Goodwill are all examples of products acquired through secondary markets. These transactions are valuable to both buyers and sellers. For sellers, they provide an opportunity to recoup some of the investment in their initial purchase. For buyers, they add to the stock of used inventory available for budget-minded shoppers. Importantly, secondary markets also put downward pressure on the price of new goods. Manufacturers and retailers know that if prices climb too high, some consumers will buy used instead.

Repair is central to the used market. A product that doesn't work is, unsurprisingly, worth less than one that does. So, if your current car has to be towed to the dealer, you shouldn't be too optimistic about its trade-in value. That said, buyers might still be willing to purchase a used car if they are confident they can repair it at a reasonable cost. And even if a vehicle appears to be in working order, the ability to fix it should something go wrong is priced into its value on the secondary market. A used car that could never be repaired would be a bad investment no matter how well the test drive went.

While often overshadowed by new sales, secondary markets are a sizable segment of the economy. The growing resale market for smartphones is estimated at about $25 billion annually.[23] Measured by units sold, demand for used phones outstrips new ones. The used appliance and secondhand clothing market each account for tens of billions of dollars in sales.[24] And in the United States, twice as many used cars are sold each year than new ones.[25] All told, secondary markets for consumer goods represent hundreds of billions of dollars in annual sales. And much of that value depends on repair.

Secondary markets run the gamut from Sotheby's auctions to Goodwill thrift stores. But secondhand goods are especially important in economically marginalized communities. Those who lack the resources to buy new clothes, housewares, electronics, and vehicles have traditionally relied on used goods.[26] And research suggests that as incomes increase, families show a greater propensity to replace rather than repair.[27] So secondary markets facilitate the transfer of resources from the affluent

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to the relatively poor. That's true both within countries and between them. Beyond used sales within the local economy, a robust global market exports the castoffs of developed economies to poorer nations around the world.[28] When we engage in repair, we are enabling these markets to flourish. And when repair is restricted or unaffordable, it is often the poor who suffer the most.

The Cost Savings of Repair

Calculating the cost savings from repair with precision is a challenge. To figure that out, we'd need reliable data on not only the price of every repair, but also how much more a replacement would have cost. That's true for every refrigerator with a failed compressor, every smartphone with a depleted battery, every television with a faulty power supply, and every car with a loose timing belt. We'd also need to know how successful those repairs were. Did they stave off replacement for six months? Five years? But even without precise calculations, there is good reason to believe repair leads to significant cost savings in the aggregate. A recent study found that the average US household spends just under $1,500 per year on electronics. Extending product lifespans through repair would save those households an estimated $330 annually, which amounts to $40 billion across the US consumer economy.[29]

Let's examine just one tiny corner of the repair market more closely. Broken smartphone screens are the flat tires of the digital era – inconvenient, surprisingly expensive, and nearly inevitable. In 2017, Americans broke roughly 50 million phone screens. Many replaced their phones, while others just lived with a busted screen. But those who did repair their screens spent on average $170, totaling an estimated $3.4 billion for some 20 million repaired screens.[30] If instead, each of those consumers had purchased new iPhones, they'd have spent about $20 billion – or a mere $14 billion for the relatively budget-friendly Samsung Galaxy 9. In either case, repair saved consumers several billion dollars. Of course, that total reflects

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savings for one type of repair to one category of product, in a single country, and over the course of just one year. Once we consider the full impact of repair in communities around the world, the savings are staggering.

Precisely how much economic benefit we derive from repair depends on how much it costs to fix things. In some corners of the repair market, there are troubling signs that consumers are overpaying. From 2000 to 2017, the price of vehicle repair increased by more than 60 percent according to the United States Bureau of Labor Statistics.[31] In part, that increase reflects the rising cost of replacement parts, which are commonly patented. As a result, General Motors boasts profit margins of more than 30 percent on aftermarket parts.[32] Because of those expenses, more collisions are resulting in cars being "totaled" – in other words, the cost of repair exceeds the value of the car. The high price of repair helps explain why car parts and service account for nearly half of car dealer profits in the United States, more than either new or used vehicle sales.[33] And in the market for farm equipment, where companies like John Deere have taken aggressive steps to limit competition, repair is five times as profitable as equipment sales.[34]

Apple claims to be bucking the trend of highly profitable repairs. The company told a US congressional committee in 2019 that its "costs of providing repair services ... exceeded the revenue generated by repairs."[35] According to Apple, it lost money on repairs. Anyone who has received a repair bill from Apple might be surprised by this claim. Putting aside routine charges of hundreds of dollars to swap out batteries and broken screens, Apple charges $599 just to replace the cosmetic glass covering the back of some iPhone models.[36] In perhaps the most extreme example, a customer took his MacBook Pro to Apple because the display was completely dark. After months of attempted repairs totaling more than $10,000 – including two replaced logic boards and eventually an entirely new laptop – an Apple technician uncovered the issue. The screen brightness was turned to zero, a problem solved with a single keystroke.[37]

So how could Apple's repair program lose money? In the movie industry, "Hollywood accounting" is the colloquial term for bookkeeping practices designed to avoid royalties and profit-sharing by making a highly profitable film look like a box office bomb. By generously estimating overhead costs, hits can look like losers on paper. According to the studios, blockbuster films from the *Star Wars*, *Lord of the Rings*, and *Harry Potter* franchises lost hundreds of millions of dollars.[38] In its response to Congress, Apple almost certainly engaged in some creative accounting of its own, even if its answer was technically true. Perhaps the company included some portion of its retail store overhead in that calculation. Maybe it included warranty repairs, like the $10,000 laptop fix, which cost the company $4.1 billion in 2018 alone. It also may have factored in the cost of its steeply discounted $29 battery replacement program, offered after the company admitted to slowing down the processors of older iPhones. The same may have gone for Apple's free replacement of defective butterfly keyboards on millions of laptops. If so, Apple's claim to Congress tells us nothing about the profitability of charging $329 to replace an iPhone screen.

None of this is to say repair shouldn't be profitable. Quite the opposite. If we hope to see widespread availability of replacement parts and repair services, profit is essential. The trick is calibrating those incentives in a way that best serves the needs of consumers. For many products, the current market discourages repair and steers consumers towards replacement. The prices of televisions, kitchen appliances, and other devices have dropped considerably in recent decades, but during that same period, repair has grown more expensive.[39] A more competitive market for parts and service would keep those expenses in check, allowing consumers to make more efficient choices between repairing and replacing.

The Potential Costs of Repair

So far, we've focused on the economic upsides of repair. But what about its potential downsides? If repair reduces consumer

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spending on new purchases and shifts money into secondary markets, surely someone is losing out. The obvious candidates are device makers and retailers. One risk is that they will raise prices in response to anemic sales. As any Intro to Economics student will tell you, a price hike in the face of weak demand is a counterintuitive strategy. And it's one that's likely to backfire. If prices go up, we should expect even more consumers to hang onto their workhorse devices, repair them whenever possible, or turn to secondary markets.

But even assuming device makers increased retail prices, would that really be such a bad outcome? Hear me out. No one likes paying more, but higher prices might be just what consumers need – not as a penance for frivolous spending, but as a means of forcing disclosure of information. Sellers know things most consumers don't. They know how long the device they are selling you is likely to last, how long you're likely to keep it, and how much you are likely to spend on maintenance and repair over the product's lifetime. That information asymmetry gives sellers an advantage. It allows them to hide costs that aren't apparent to most of us. As consumers, we tend to focus on the sticker price, ignoring or underestimating the long-term costs of ownership, like broken phone screens and regular vehicle maintenance. But for sellers, these expenses are known and accounted for. So, if products last longer and repairs are less expensive, higher retail prices for new devices would expose the amount sellers anticipated extracting from us all along. They were always planning on charging us more – either by selling us a replacement or charging high prices for repairs. Price increases simply let us in on the secret.

It's fair to assume that embracing repair might result in declining sales and lower profits for some device makers. That's bad news for shareholders, but not necessarily for the rest of society. Along with a handful of major banks, device makers like Apple and Samsung are among the worlds' most profitable companies. In 2018, Samsung earned nearly $40 billion in profits. Apple's haul was just shy of $60 billion.

The company regularly boasts net profit margins above 20 percent and has cash reserves of nearly $200 billion. Not only would the company survive if it made less money, the world would be a better place for it. Rather than adding to Apple's treasure hoard, that money could be put to better use by consumers. To Apple, an extra hundred, thousand, or even million dollars would go unnoticed. To the average family or locally owned repair shop, however, those sums have real value.

Admittedly, not all firms enjoy Apple's surfeit of cash, so reduced profits can't be shrugged off so easily. But profitability should not be seen as an end unto itself. There are two primary reasons we should be concerned about the effect repair has on companies' bottom lines. First, we might be concerned that firms will invest less in research and development. With fewer resources dedicated to creating new technology, the worry goes, innovation will slow, and the public will suffer. It's true that smaller budgets at established firms might impede or delay new product features. But we shouldn't confuse every new refrigerator model or minivan redesign with innovation. In fact, a plausible case can be made that disrupting the steady flow of profits from selling tweaks to existing products could result in more innovation, not less. Denied easy profits from annual updates, firms would be pushed to develop truly novel features or even entirely new product lines if they want to remain profitable.

Job losses are a second worry. Factory workers, industrial designers, truck drivers, and retail employees all depend on the relentless churn of new products replacing the old. But repair offers its own career opportunities.[40] Repair is skilled, labor-intensive work. Unlike manufacturing, it is difficult to automate and tends to benefit local, small businesses rather than global giants. Our collective embrace of throwaway products has come at the expense of repair workers. In 1966, there were 200,000 people employed as home appliance repairers in the United States. Today there are about 40,000. Over that period, the number of professionals repairing television and stereo equipment dwindled from 110,000 to just 30,000 – all while the US population increased by more than 130 million residents.[41]

From a purely economic perspective, the case for repair is hard to deny. It saves consumers money, helps ensure the availability of goods on secondary markets, and makes the most efficient use of existing resources. These calculations, however, only consider the direct costs of our devices. Beyond their sticker price, our cars, appliances, and electronics embed a shocking environmental toll that, collectively, we must confront.

The Environmental Benefits of Repair

When it comes to consumer devices, our current levels of consumption are untenable. The global production, distribution, and disposal of electronics and other durable goods is responsible for staggering levels of environmental damage. As public awareness of the effects of climate change and other environmental harms grows, device makers are starting to take note. They are releasing ambitious sustainability plans, committing to aggressive carbon-neutrality goals, and touting their investments in recycling programs. But most firms remain unwilling to acknowledge the core tension between environmental responsibility and business models built around the ever-escalating production, sale, and replacement of billions of consumer devices every year. Repair is crucial to disrupting this global network of consumption. When we fix the things we already own, they last longer, reducing demand for new products and slowing the global flow of electronic waste. Through repair, we can ease the environmental strain caused by modern consumerism without denying ourselves the benefits of technology. We don't have to give up our phones and dishwashers, but we do need to make them last.

Curbing Electronic Waste

The most obvious environmental harms occur at the end of the product lifecycle. Far too often, when we replace phones, TVs, and appliances with new models, our old devices make their

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way to landfills. In the United States alone, we dispose of more than 400,000 mobile phones every day – roughly 150 million each year.[42] As the prices of new goods continue to drop, the urge to replace rather than repair only intensifies. According to a U.N. report, discarded consumer electronics accounted for nearly 54 million metric tons of e-waste in 2019 alone.[43] That's enough to fill "a million 18-wheel trucks stretching from New York to Bangkok and back."[44] And the problem is growing. E-waste increased more than 20 percent over the last five years and continues to climb by 2.5 million metric tons per year. By 2030, annual totals are projected to reach nearly 75 million metric tons.[45] These mountains of electronic junk are the byproduct of global urbanization and industrialization, but as the United Nations recognized, the shortage of repair options is a key contributor.[46]

E-waste is particularly problematic because it contains high levels of heavy metals, like arsenic, lead, and mercury, as well as toxins like brominated flame retardants.[47] In the United States, e-waste makes up just 2 percent of the trash dumped in landfills, but it accounts for as much as 70 percent of toxic waste.[48] Over time, those toxins make their way into surrounding soil, where they can contaminate groundwater and effect the food supply. And many landfills around the world burn solid waste, which releases acrid fumes and pollutants into the air. As a result, toxicity levels are far higher near landfills and e-waste sites, often considerably exceeding health-and-safety standards. One study found heavy metal concentrations near e-waste sites in India were 30 times higher than normal for topsoil and nearly 120 times higher for subsoil samples.[49]

The adverse health effects of these chemicals are not fully understood, particularly when people face exposure to multiple toxins. But studies point to a host of documented harms.[50] Exposure is associated with reduced lung and thyroid function. It has been tied to cognitive impairments, neurodevelopmental anomalies, and attention disorders. And it has been linked to abnormal reproductive development, increases in premature and still births, and reduced childhood growth rates.

Notably, the harms e-waste inflicts are not evenly distributed. For decades, discarded electronics have flowed from wealthy countries to relatively poor ones.[51] The United States, for example, is the second largest e-waste producer, after China. Despite signing the Basel Convention – an international agreement banning the export of hazardous waste – in 1990, the United States has failed to ratify the treaty or comply with its terms.[52] Decades later, it continues to ship hazardous electronic waste around the world, primarily to Africa and Asia.[53] The volume of those exports is hard to pin down, in part because shipments of e-waste are sometimes falsely labeled as "used electronics" intended for resale in an effort to circumvent legal restrictions.[54] Even within any particular nation, the harms of e-waste are not shared equally. The poor live near landfills; the rich do not. And in countries like the United States, where systemic racism compounds those disparities, black and brown communities are far more likely than white ones to contend with those harms.[55]

Repair can stanch the flow of electronic waste that is clogging landfills, tainting soil, and poisoning water around the globe. If repair were more affordable and widely available, we could significantly extend the average lifespan of the devices we buy. In a world in which cell phones lasted for five years rather than two, or televisions still worked for a decade or more, we would expect to see a precipitous drop in annual e-waste pollution. Repair keeps devices in the hands of owners and out of landfills. Admittedly, cheap, accessible, and reliable repair won't put an end to the desire to buy new devices. Consumers today discard functioning and broken devices alike, often driven by a compulsion for the latest hardware update. But repair alters the replacement calculus for owners, tilting it in favor of longer lifespans. Equally importantly, readily available repair makes used devices more valuable, whether they are working at the moment or not. Even if wealthy or environmentally insensitive consumers toss their year-old smart speaker for a new model, secondary markets can absorb used devices, diverting them from the landfill. That's especially true if would-be purchasers are confident that used devices can be repaired should the need arise.

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Reducing Extraction and Production

The environmental consequences of our collective obsession with new devices are not limited to their disposal. Their production gives rise to its own harms, on both the local and global level. From the destructive extraction of raw materials to energy-intensive assembly lines, each step that leads to the giddy-yet-fleeting experience of unboxing a new PlayStation is laden with environmental damage. And those costs are amplified by the sheer scale of the device economy. Each year, manufacturers produce about 1.5 billion new phones. Add to that the hundreds of millions of TVs, tablets, and laptops, the nearly 100 million motor vehicles, and the tens of millions of washing machines and other home appliances, and the immense proportions of modern device manufacturing begin to take shape.[56]

Despite their sleek designs and innovative features, our devices don't come from the future. They come from the earth. They are made of metals, embedded in rock for billions of years. Even their plastics are derived from crude oil pumped from below our feet. At least seventy-five of the eighty-three known stable elements are found in smartphones.[57] They include aluminum, cobalt, copper, gold, indium, iron, lithium, nickel, silicon, silver, tantalum, tin, tungsten, and sixteen of the seventeen rare-earth metals. These raw materials are extracted, processed, and transformed to manufacture the feats of precision engineering we carry in our pockets.

As Brian Merchant explains in his history of the iPhone, *The One Device*, building a single 4.5 ounce iPhone requires 75 pounds – or 34 kilograms – of ore extracted from the earth.[58] As of 2018, when Apple stopped sharing sales figures, it had already sold 2.2 billion iPhones.[59] That translates to roughly 75 million metric tons of ore mined just for iPhone production.[60] Once we factor in smartphones from other manufacturers, laptops, desktops, and the ever-growing menagerie of wearables, smart appliances, and assorted digital ephemera, the device economy is literally reshaping the planet.

Wresting metals, like the gold and copper used in smartphone circuitry, from the ground requires environmentally violent mining practices. Open-pit mines entail the excavation of massive amounts of ore and waste rock. The largest, Utah's Bingham Canyon copper mine, is three-quarters of a mile deep and two-and-a-half miles wide. Hard-rock mining, in contrast, involves drilling and blasting vertical shafts and horizontal adits to access subsurface ore. All of that digging and exploding pollutes the air. Gold mines, in particular, are a leading cause of mercury pollution.[61] And respiratory problems, from tuberculosis to lung cancer, are all too common among mine workers.[62]

Once the ore is removed, valuable metals have to be isolated from the waste rock surrounding them. That process is water intensive, which helps explain why a single smartphone requires 100 liters of water to produce.[63] Even more worryingly, the waste product – a slurry of water, rock, and metal particles – is typically stored in ponds where it can wreak environmental damage. Residents of the island of Bougainville in Papua New Guinea, to take just one example, recently filed a lawsuit alleging that the Australian mining firm Rio Tinto failed to clean up millions of tons of waste at its copper and gold mine, contaminating the island's drinking water and causing upper respiratory and gastrointestinal illness among its children.[64] What's worse, gold mines, which remove as much as 91 tons of ore to produce a single ounce of the precious metal,[65] often deploy cyanide leaching. That process uses toxic chemicals to dissolve gold and separate it from the ore, leaving behind particularly hazardous wastewater that threatens wildlife, farmland, and water supplies.[66]

In addition to these familiar elements, our devices incorporate a variety of rare-earth metals.[67] Dysprosium, neodymium, and terbium are crucial ingredients in the magnets smartphones use for vibration and sound. Cerium is commonly used to polish glass screens, while europium and yttrium are among the elements necessary for them to render color. And circuit boards contain gadolinium, praseodymium, and other rare-earth metals. Unlike other metals, the rare earths are almost uniformly found

intermingled with thorium and uranium. The refining process breaks down the ore using sulfuric acid – along with ample water and electricity – leaving behind a slurry that is not only toxic, but radioactive. When it leaches into the groundwater or dust particles escape, the health of surrounding communities is put at serious risk. For instance, a rare-earth mine in California flooded the Mojave Desert with 300,000 gallons of radioactive material.[68] And a sprawling rare-earth facility in Malaysia is facing closure after failing to safely contain growing piles of radioactive waste and concerns over tainted groundwater.[69]

Distressingly, the bulk of rare-earth mining occurs in jurisdictions with weak or nonexistent environmental standards. Twenty minutes outside of Baotou, a city of more than 2 million people in China's semi-autonomous Inner Mongolia, sits a toxic lake described by the BBC as a "nightmarish ... hell on earth."[70] It is filled with "black, barely-liquid, toxic sludge" – the byproduct of the nearby Baogang Steel and Rare Earth mine. This noxious muck has leached into local waterways and irrigation systems with devastating consequences.[71] Decades before it became the center of the rare-earth trade, Baotou was surrounded by fields of watermelons, eggplants, and tomatoes.[72] These days, the soil can no longer support crops, the livestock has died off, and residents are battling leukemia and pancreatic cancer.[73] Others report their hair and teeth falling out.[74]

The disregard for human suffering revealed by these mining practices often manifests itself in other ways. Several metals, among them cobalt, tantalum, tungsten, and tin, are often extracted under conditions that seem designed to maximize human misery. Cobalt is a crucial component in the lithium-ion batteries found in phones, laptops, and electric vehicles. Global demand exceeds 100,000 metric tons per year and is expected to increase more than fourfold by 2030.[75] Prices peaked at nearly $100,000 per metric ton in 2018 but have settled around $35,000 today. The most significant costs of cobalt, however, are borne by those who mine it. Most of the world's cobalt supply is found in the Democratic Republic of Congo (DRC). While much of that cobalt is extracted by

industrial operations, about 20 percent is mined by hand by a quarter of a million local *creuseurs*. They dig narrow tunnels, prone to fatal collapses. They inhale toxic cobalt dust, which contributes to an array of health conditions. They are often paid less than a dollar a day for their labor. And an estimated 35,000 of them are children as young as six years old.[76] Even with diligent efforts, device makers struggle to ensure that all the cobalt they purchase is mined ethically. And recycling efforts provide them with only a tiny fraction of the cobalt they need.

Just as troublingly, profits from mines in and around the DRC have funded armed conflict in the region. Children as young as seven mine coltan, the mineral from which tantalum is derived. Tantalum is used to produce circuits, capacitors, and resistors. It's prized by device makers because it allows them to build smaller and thinner devices. As a result, they buy up half the world's supply every year.[77] The lucrative tantalum trade, however, has helped fuel one of the bloodiest conflicts since World War II, one in which millions have died, rape is employed as a form of terrorism, and children are routinely conscripted as soldiers.[78] The central role of electronics firms in driving demand for coltan and indirectly funding the conflict led some to dub it the PlayStation War.[79]

In response to these atrocities, the United States, the European Union, and China have enacted regulations meant to limit the flow of money from these conflict minerals.[80] And firms have felt significant pressure to clean up their supply chains. But the exploitation of children isn't limited to the DRC. Roughly a third of the world's tin supply comes from informal Indonesian mines that frequently suffer fatal collapses and employ children.[81] At Cerro Rico, a mine in Potosí, Bolivia, children as young as six years old toil in the deepest, narrowest recesses to retrieve tin, silver, and zinc. Dozens have died in a single year.[82] As recently as 2013, Samsung admitted to acquiring tin from Indonesian mines that exploited child labor, and Apple relied on tin from Cerro Rico until 2017.[83]

Once this array of raw materials is procured, manufacturers can begin fashioning the parts that make up our devices – from

microprocessors and batteries to haptic engines and LED displays. Building these tiny, intricate components requires huge sums of energy, water, and other resources. When it comes to microchips, the manufacturing process demands meticulously constructed clean rooms, free from stray particles, that have more in common with the vacuum of space than the surface of earth. The constant filtering, scrubbing, and purifying of air and water in these massive facilities consumes unseemly amounts of energy.[84] The process also relies on fluorinated gases to etch microscopic patterns in semiconductors and to clean chemical reactants from the chambers where chips are fabricated. These gases include perfluorocarbons and nitrogen trifluoride, "a greenhouse gas that is 16,100 times more powerful than carbon dioxide at trapping atmospheric heat."[85] This notoriously dangerous oxidizer is capable of burning concrete, sand, and even asbestos on contact.[86] According to the US Environmental Protection Agency (EPA), as much as 80 percent of these gases escape manufacturing facilities, making their way back into the air.[87] Manufacturers have deployed disposal and containment solutions to address these dangerous byproducts, but they are hardly foolproof. When fluorines escaped into the parking lot at one facility, the gases reportedly melted car windshields.[88]

These energy-intensive manufacturing processes, combined with the extraction techniques described above, contribute significantly to the carbon footprints of consumer devices. Not including the energy used in its operation, a single laptop generates as much as 468 kg, or roughly 1,000 pounds, of carbon dioxide equivalent.[89] Sony's PlayStation 4 console is responsible for a comparatively modest 89 kg of CO_2.[90] By the time Sony released its successor, the PlayStation 5, in 2020, it had sold 100 million PS4 units, totaling nearly 9 million metric tons of CO_2 released into the atmosphere. The per-unit carbon footprint for manufacturing an iPhone is a bit less – roughly 70 kg.[91] But given the staggering volume of iPhone sales, their total CO_2-equivalent emissions are on the order of 150 million metric tons. That's double the tonnage of ore mined to produce

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them. Like other major manufacturers, Apple and Sony have promised carbon-neutral production, but those goals are decades off.[92]

Finally, there's the impact of shipping and distribution. About 90 percent of trade relies on oceangoing ships.[93] Most run on highly polluting heavy fuel oil. In addition to carbon dioxide, these vessels release considerable volumes of sulfur dioxide and nitrogen oxides. Collectively, they emit more greenhouse gases than all but five countries.[94] New regulations, alternative fuels, and renewable energy sources have the potential to reduce shipping pollutants, but their effectiveness remains to be seen. Shipping billions of cars, phones, and appliances – not to mention the raw materials used to produce them – across oceans creates pollution, but so does their delivery to our homes. As online shopping and two-day delivery become the norm in many countries, we must consider the environmental costs of instant gratification. Medium-duty freight vehicles, like those commonly used by Amazon and its shipping partners, are among the most polluting vehicles on our roads. And since rush shipping often requires drivers to cover more miles to deliver fewer items, it is far from efficient.[95] According to one estimate, Amazon deliveries were responsible for 19 million metric tons of carbon in a single year.[96] Amazon has made big promises to reduce its environmental impact, pledging to make half of its deliveries carbon neutral by 2030 and to purchase 100,000 electric delivery vehicles. But that new fleet embeds its own upfront environmental costs.[97]

The havoc wreaked by device production on both the environment and human welfare is fueled by our insatiable desire for new devices. In response to that demand, device makers ramp up production, pressuring their suppliers to deliver more components, year after year. Those suppliers, in turn, insist on greater volumes of raw material from smelters and refineries. To keep pace, miners are forced to dig deeper to access dwindling supplies of natural resources. As demand for new devices increases, the greater the damage they cause.

So how can we interrupt this cycle of consumption? One approach is to make the prices of new devices fully and accurately reflect their costs. Just as device makers hide the total cost of ownership from consumers, they also conceal the full cost of production. When you buy a new laptop, the sticker price doesn't fully account for the rivers poisoned by rare-earth mining, the health hazards of air pollution from gold and nickel mining, and the exploitation of workers. Those costs are what economists call externalities. Neither the seller nor the buyer has to account for them because these costs are foisted onto third parties. By contracting with mining operations in countries with lax labor and environmental rules, device makers can avoid having to price them in. And since they don't have to cover them, neither do consumers. In other words, our purchases are being subsidized by marginalized communities in Bolivia, the DRC, Mongolia, Papua New Guinea, and elsewhere. If device makers had to make these communities whole for the damage they suffer, prices for new devices would skyrocket.

Short of fully internalizing those harms, we can hope that rising costs and public pressure encourage firms to redesign products to reduce their environmental impact. Some have made modest strides in recent years, eliminating mercury and arsenic from displays and glass, for example.[98] But there is simply no escaping the fact that these firms are in the business of converting billion-year-old rocks into complex electronic devices on a massive scale. For instance, Tesla has announced plans to make cobalt-free batteries.[99] That decision will likely lower the cost of electric vehicles and avoid the environmental and human rights issues – not to mention public-relations headaches – associated with mining in the DRC. But it will also drive demand for nickel, a metal that raises its own environmental concerns. Nickel mining in Norilsk, the most polluted city in Russia, was responsible for plumes of smoke that belched 350,000 metric tons of sulfur dioxide into the air each year.[100] In the course of just four years, the nearby Daldykan river ran blood-red on three separate occasions, the result of overflowing metallurgical waste and spilled diesel fuel.[101] In response,

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indigenous communities in the arctic Taimyr region have pleaded with Tesla to reconsider the impact of nickel mining.[102]

From an environmental perspective, repair is central to any serious effort to reduce the damage caused by the device economy. Effective and affordable repair extends the life of our devices, slowing the replacement cycle and deescalating extraction and production. Once we've mined and refined ore, manufactured components, assembled devices, and had them shipped express from halfway across the planet, they represent a sizable expenditure – not just on our credit-card statements, but also in terms of their impact on the planet. The only way to responsibly recognize that investment is to keep them working as long as we reasonably can.

The Promise and Reality of Recycling

In recent years, device makers have begun stressing the importance of recycling. Rather than mining deep in the earth, materials can be harvested from the mountains of cast-off devices we throw out each year. This shift, no doubt, is motivated in part by genuine concerns over sustainability and environmental impact. But emphasizing recycling also makes sense as a matter of economics. In 2019 alone, our electronic waste contained $57 billion in iron, copper, gold, and other metals.[103] And those resources are highly concentrated in discarded devices. The US EPA estimates that "one metric ton of circuit boards can contain 40 to 800 times the amount of gold and 30 to 40 times the amount of copper mined from one metric ton of ore."[104] So, recovering raw materials from e-waste is often more efficient than extracting virgin metals. For other materials, like some rare-earth elements, dwindling supplies may leave firms with little choice but to recycle.[105]

Shifting the conversation to recycling is also a smart public-relations move. As the device economy faces greater environmental scrutiny, firms are eager to burnish the green image of the high-tech sector. Apple touts its shift to recycled aluminum for MacBook enclosures, tin in logic-board solder, and rare-earth

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metals in iPhone Taptic engines.[106] Microsoft boasts of the millions of pounds of waste diverted by its recycling efforts.[107] And Tesla points to its investments in battery recycling.[108]

Firms are also quick to publicize innovative recycling technologies, complete with friendly, focus-grouped names. Apple's Daisy robot is designed to recycle iPhones. For every 100,000 devices it processes, Daisy recovers 1.1 kg of gold, 83 kg of tungsten, 790 kg of cobalt.[109] Daisy can recycle up to 200 phones per hour – an impressive figure, until you realize Apple produces more than 20,000 iPhones an hour, twenty-four hours a day, three hundred sixty-five days a year. Compared to its production lines, the scale of Apple's recycling program remains modest, to put it charitably. By 2019, the company had received 1 million iPhones for recycling, or less than 0.5 percent of the new units it sold that year.[110] That year, Apple and its recycling partners processed 48,000 metric tons of e-waste, less than 0.1 percent of the annual global total.[111]

Elsewhere, researchers have developed new techniques, isolating rare-earth metals with carbon nanotubes and separating valuable metals using powerful underwater sound waves.[112] New processes and technologies will undoubtedly be crucial to scaling up e-waste recycling. But these efforts – like futuristic recycling robots – tend to reinforce the comforting narrative that new technologies can save us from ourselves. To paraphrase the twentieth-century American philosopher Homer Simpson, "To technology! The cause of, and solution to, all of life's problems."[113]

Make no mistake, more recycling is good for the environment. Policy makers should encourage it, and we should applaud companies that invest in it. Nonetheless, there are risks to overstating the benefits of recycling. Unlike repair, recycling doesn't reduce demand for or slow production of new devices. And in fact, it has the potential to increase consumption. By reducing the costs of inputs, recycling could lower prices and shorten the lifecycles of new products. At the same time, it offers consumers an easy way to absolve themselves of responsibility without fully confronting the consequences of

their choices. Recycling an old laptop is certainly better than tossing it into a landfill. But recycling isn't without its own costs. It requires a collection infrastructure, shipping networks, and energy-consuming facilities outfitted with specialized equipment.

Those costs aside, electronics recycling rates today are far too low to sustain demand. In 2019, only 17.4 percent of global e-waste was recycled through formal channels – about 9.3 million metric tons. And the growth rate of recycling is easily outpaced by e-waste production.[114] When we compare recycling rates across the globe, there's plenty of room for improvement. Europe leads the way, safely recycling 42.5 percent of its e-waste, the result of strict regulation and significant investment. But even there, more than half of e-waste isn't recycled. The rest of the world fares far worse. Asia recycles just 11.7% of its e-waste; the Americas, 9.4%; Oceania, 8.8%; and Africa, less than 1%.[115] To realize significant benefits from recycling, governments and firms need to take aggressive steps to capture a far greater portion of the e-waste stream. But even if e-waste recycling rates reached 100 percent, demand for raw materials would still outstrip supply. According to the United Nations, device makers would need an additional 14 million metric tons of iron, aluminum, and copper each year to keep pace with growing demand.[116]

So far, we've focused on formal, documented recycling. That process requires compliance with health, safety, and environmental regulations that protect workers and the surrounding community.[117] Partly because of those justifiably high standards, more than 82 percent of e-waste escapes the sanctioned recycling chain. Much of it ends up in landfills. Some is exported to developing economies for repair or repurposed for used parts. But every year, millions of tons of electronic waste are broken down by unregulated, informal recyclers. These operations challenge the popular conception of recycling as an environmentally friendly solution.

Informal recycling sites are scattered across Asia and Africa, from China and Vietnam to Ghana and Nigeria. Although they

are generally small, independent operations, they tend to be found in clusters of dozens, hundreds, or even thousands. At one time, Guiyu, a city of 150,000 on the coast of the South China Sea, was known as the "electronic graveyard of the world."[118] Thousands of small-scale, backyard recycling operations dotted the city. Tens of thousands of workers – men, women, and children – disassembled e-waste with hand tools, like hammers and chisels. They leached gold and other valuable metals from circuit boards in open-pit baths of nitric and hydrochloric acid. And they burned electrical wiring and cables to uncover the copper inside.[119] After Chinese authorities cracked down on the importation of e-waste, much of that waste was redirected to countries like Vietnam and the Philippines, where the same practices continued.

Without the high-tech equipment, protective gear, and strict regulations that characterize formal recycling, communities forced to rely on backyard recycling face serious health and environmental risks. Melting plastic releases toxic fumes, and heavy metals find their way into the water and soil.[120] These pollutants are associated with a litany of health problems for workers and local communities. Cancer, miscarriage, birth defects, decreased lung function, neurodevelopmental issues, and increased mortality rates have all been linked to informal recycling.[121]

One seemingly straightforward response to the harms of informal recycling is to redirect more e-waste to licensed, regulated recyclers. But a 2016 study that tracked displays and printers sent to formal recyclers in the United States found that 40 percent of those devices were exported. Nearly all of them ended up in developing economies that rely on the dangerous, unregulated recycling practices described above.[122] So the boundary separating safe, responsible recycling from the toxic, exploitative export of e-waste is more porous than we might hope.

Given the costs of both formal and informal recycling, repair offers obvious comparative advantages. Rather than shredding a phone with a dead battery, melting its components, and using

them as manufacturing inputs, we could simply replace the battery. Repair – although it requires a steady stream of replacement parts – uses less energy and fewer resources than formal recycling. And it avoids the risk that our devices will contribute to the harms informal recycling inflicts on vulnerable communities. Perhaps most importantly, repair teaches us better habits. Resources are limited, but too often our appetites are not.

The Social Benefits of Repair

The most obvious upsides of repair are economic and environmental. On their own, those virtues ought to prompt us to rethink existing policies and behaviors. But repair offers another set of benefits that are more easily overlooked. When we diagnose and fix the things we own, we are reconfiguring our interactions with the world around us. At the same time, we are refining our understanding, developing new skills, and strengthening social ties within our communities.

Repair can change the way we relate to the world around us. It empowers us to exert control over technology. When our devices break, our plans and expectations are disrupted. Imagine you've been planning a bike ride at the end of a long workday. You mentally map out your route, looking forward to some head-clearing physical exertion. You change into more suitable clothes, fill your water bottle, and strap on your helmet, only to discover a flat tire. If you have the parts, tools, and know-how to swap out a punctured inner tube, the flat is an annoyance, a mere a stumbling block. But without the ability to repair, your plans are undone. You are defeated by circumstance.

Repair cultivates a sense of self-sufficiency and autonomy that is increasingly rare in a world shaped by networked technologies. A bicycle, at least, is within your physical control. What happens to family movie night when the popcorn is popped, the group is assembled on the sofa, but the internet goes down for no apparent reason? When we can't understand or control our devices, we cede authority to external forces. Our

relationship with technology grows more passive and dependent. That trend is particularly problematic given the extent to which our lives, even our identities, are intertwined with electronics. We outsource mental processes to our smartphones. They remember our friends' phone numbers, our relatives' birthdays, and our appointments so we don't have to. They navigate us through city streets we used to know by heart. For better or worse, we rely on these devices as extensions of our brains. It's no wonder that when they break, we rush to replace them. For some, this problem is even more pronounced.

Many people rely on medical devices like cochlear implants and insulin pumps. These devices can be the difference between life and death. But existing regulatory processes don't always ensure that they work properly. Nearly half a million Abbott pacemakers, for example, were susceptible to remote attacks that could rapidly and fatally drain their batteries.[123] And the company's purported fix came with its own risk of malfunction.[124] Or consider how the inability to repair motorized wheelchairs can leave their users immobile and isolated. When the battery in the motorized wheelchair Kenny Maestas used couldn't hold a charge, the device maker told him it would be a month before a technician could look at it.[125] Even if the company had the necessary parts in stock, its policy insisted on separate inspection and repair appointments. In the end, it took more than two months before Kenny's wheelchair was running again.

If these devices – from smartphones to medical devices – are extensions of ourselves, the right to repair them is vital to our personal freedom and agency. Without repair, we are dependent on the companies that sell those products to ensure that we can commute to work, communicate with our loved ones, heat our homes, cook our food, and stay alive. These firms, though, often have goals that diverge from our best interests. Rather than simply hoping they do right by us, repair gives us some measure of independence and self-reliance. It helps us transcend the role of passive consumer to become more active and responsible participants in our lives.

In moments of crisis, that freedom to operate is even more essential. Under normal circumstances, if something goes wrong with a piece of vital equipment there are channels for having it repaired – original manufacturers to call, warranties to enforce, and experts to enlist. But those channels can be interrupted, and supply chains can be broken. As COVID-19 unsettled life across the globe in 2020, hospitals found themselves unable to access parts and service needed to keep life-saving equipment operational. Increased demand for ventilators and other equipment revealed the degree to which hospitals are dependent on authorized repair providers and underscored the need for in-house repair technicians. Beyond medical equipment, consumers confronted other, less-dire interference with established repair channels. As retailers across the world closed during the pandemic, thousands of customers found their devices stranded behind shuttered storefronts, awaiting repair. And unknown thousands more were stuck holding onto broken devices as those stores remained shuttered for months.[126] Repair cannot fully insulate us from the effects of a pandemic, of course, but it can make our technological infrastructure more resilient in the face of local and global disruption.

Beyond a sense of personal control, repair helps us better understand the world around us. Despite the centrality of modern technology to our daily lives, most of us have, at best, a cursory understanding of how our devices work. When they operate as designed, these tools recede into the background. It's not until they break that the question of *how* they do what they do occurs to us. That question presents an opportunity. It is a chance to engage with these tools in a new way, one that reveals not only how they work, but how they fail, and if you are lucky, how to set things right again. Successful or not, attempts at repair can teach us something. They reveal the sometimes-hidden and often-ignored mechanisms that operate just below the surface of our lives.

Aside from a more secure understanding of the operation of technologies, repair helps develop valuable problem-solving skills. Repairs vary in their difficulty. Some failures are easy to

diagnose and simple to fix. But often, repair is far from straightforward. There is no simple algorithm or checklist to follow. It requires a creative, even improvisatory approach. These more challenging repairs require you to start with an immediate problem – your car won't start – and identify potential causes within a complex system. Maybe the battery is dead, or maybe it's one of a dozen other possible problems: a failed timing belt, a clogged fuel filter, carbon-fouled spark plugs, a cracked distributor cap, a bad fuel pump, or an oversensitive security system, among others. Determining the right diagnosis requires some combination of experience, intuition, educated guessing, and trial and error.[127]

The same is true for remedying a problem. In some cases, you simply substitute a broken component for a new one. But when tools or replacement parts are unavailable, too expensive, or unreliable, a more creative solution is often necessary. Lara Houston, in her study of Ugandan mobile-phone repairers, describes one such technique. Replacing a handset's microphone used to be a simple, straightforward repair. But once microphones were integrated into the devices' motherboards, repair required access to infra-red soldering stations, which were not widely available. Instead, enterprising repairers relied on "looping," a technique that used thin copper wires to connect the motherboard to the microphone.[128]

Not every attempt at repair is successful. But the effort is worthwhile even when a repair fails. Like many abilities, if we don't use our repair skills, they can atrophy. Studies, for example, have found that drivers who rely on turn-by-turn GPS instructions exhibit lower brain activity than those who navigate by their sense of direction and memory.[129] A culture that prioritizes replacement over repair not only devalues competencies like diagnosis and systematic problem-solving, but is less likely to develop and maintain them.

That's not to say repair and innovation are at odds – quite the opposite. Innovation isn't reserved for the design of new products. Repair requires its own measure of inventiveness, and it builds skills and knowledge crucial to the process of creating

something new. Once you understand how a technology works, why it fails, and how it can be repaired, the leap to developing an improvement is a small one. In Douglas Harper's ethnography of a small-town repair shop, *Working Knowledge*, he introduces Willie, a skilled and experienced mechanic. After repairing countless Saab door handles, Willie designed his own, replacing weak, white metal components with a stronger alloy and eliminating a problematic plastic ball bearing altogether.[130] Willie's innovation improved the lives of his customers but had little impact beyond his local community. In contrast, one of the most impactful inventions of the twentieth century was conceived in a repair shop. Before their groundbreaking aeronautical work, Orville and Wilbur Wright ran a bicycle repair shop in Dayton, Ohio. There, they developed wood and metalworking skills and became familiar with hardware, like the sprocket drive train they later incorporated into the first airplane.[131] While not a direct outgrowth of their bike shop, the Wrights' invention undoubtedly benefitted from the knowledge and skills they honed through repair. Similarly, the early decades of the automobile – when self-repair was expected and encouraged – proved fertile ground for user innovation. Farmers repurposed their Model Ts to power agricultural tools. And as Kathleen Franz writes, "affordable, mass-produced automobiles opened new and exciting possibilities for the American consumer to practice technological competency and demonstrate his, and occasionally her, own ingenuity."[132]

Repair also allows us to recognize and honor sentimental attachment to objects and the history they represent. Maybe it isn't economically rational to repair your grandmother's old record player. But sentimental attachment to an object is often just as important as its market value in determining its subjective worth. The decision to repair reflects a mix of economic considerations, social conventions, and emotional commitments. This mindset helps explain why some objects seem to celebrate their repair. Maybe you own an old, beloved pair of jeans that have been patched and mended, again and again. Or

perhaps your neighbor owns a beat-up truck with mismatched paint, evidencing decades of repair. These objects advertise their longevity, their resilience, and their owners' determination to wring from them every last bit of utility.

But maybe I've just described an eyesore. Consider instead the Japanese tradition of *kintsugi*, a technique for repairing broken ceramics that dates to the sixteenth century.[133] A shattered cup or bowl is reassembled with a tree-based lacquer resin called *urushi*. Those joints, rather than being concealed, are then dusted with gold or silver, giving the technique its name, literally "golden joinery."[134] By deliberately directing attention to the cracks and their repair, *kintsugi* draws on the Japanese notions of *mottainai* – a feeling of regret over waste – and *wabi-sabi* – an aesthetic tradition that embraces imperfection and impermanence.[135] Not only does *kintsugi* extend the useful life of objects, but it respects the effort and artistry of the original creator and the repairer in equal measure. In doing so, it offers a commentary on the relative value of repairing or discarding the things we create. Importantly, *kintsugi* also results in a new and potentially more valuable object, highlighting repair's capacity for transformation.

Finally, repair helps us build communities. It is a participatory, collaborative exercise that involves the sharing of knowledge and skills. That's true for professionals like the Xerox repair providers profiled in Julian Orr's *Talking about Machines*, who traded "war stories" as a means of supplementing official procedures and documentation.[136] And it's an accurate description of amateurs, like Belgian steam-locomotive enthusiasts, who volunteer to repair trains, exchanging strategies and experiences.[137] In some cases, repair networks are formalized. Mobile-phone repairers in Dhaka, Bangladesh train new generations through apprenticeships.[138] Others, like the repair cafés and clinics that have sprung up around the world in recent years, offer a less-formal model.[139] Novices drop in, their broken stuff in tow, and learn from volunteers with varying degrees of expertise.

Regardless of the form it takes, independent repair promotes the distribution of knowledge and skills. People learn from each other, share their successes, and learn from their failures. But

hostility to independent repair tends to concentrate expertise – and with it, power – within manufacturers' own tightly controlled networks, effectively exporting repair knowledge out of local communities. Rather than a group of farmers taking turns peering quizzically under the hood of a temperamental tractor until they collectively puzzle out a solution, an authorized technician interprets proprietary diagnostic codes. That centralization of repair knowledge corrodes existing communities and prevents new ones from emerging. And it leaves us beholden to device makers. Despite their market incentives, manufacturers aren't always accountable to consumers or responsive to their needs. Nor do device makers necessarily invest in developing the sort of specific, context-sensitive knowledge that communities of common interest might cultivate.

Repair helps us construct a more complete picture of the world, its design, and its flaws. It sharpens the skills we need to identify, analyze, and remedy those shortcomings. It prepares us to not only mend what is broken, but craft new solutions to long-standing problems. It emboldens us to take control of the forces that shape our lives and encourages coordination to achieve shared goals. In that sense, repair teaches technologically literate civics. Contemporary policy debates, from internet platform regulation and digital surveillance to automation and artificial intelligence, demand some engagement with and understanding of technology. The practice of repair, while no substitute for hard-earned subject-matter expertise, better equips us to evaluate arguments and make informed choices between competing policy visions. It makes us better citizens.

That said, recognizing the value of repair and the inevitability of breakdown doesn't mean we must – or even should – insist on repair in every instance. Our decisions about repair turn on the needs and material circumstances of individuals and communities. While repair is generally more cost-effective than replacement, there are times when the frequency or expense of fixing an old car, for example, will justify replacing it. Assessing the environmental impact of repair requires a similar calculus. Because of their batteries, electric vehicles

are considerably more carbon-intensive than internal combustion engines at the production stage. But over the lifetime of the vehicle, electric cars reduce carbon emissions significantly.[140] So replacing an aging internal combustion vehicle with an electric one may be the better choice. But to realize those environmental benefits, we need to drive electric vehicles for a long time. That will require functioning markets for parts and repair services.

These calculations – weighing environmental, economic, and social implications – are complex, but humans have plenty of experience making them. Stone Age hunter-gatherers in the Karoo, South Africa, to take one example, adopted differing approaches to repairing tools depending on their lifestyles.[141] Groups that moved camp frequently repeatedly repaired tools used to hunt and collect food, but replaced tools used for hide-making and maintenance. For groups that remained in long-term camps while sending hunting parties out on expeditions, the opposite was true. They replaced hunting implements, but repaired maintenance tools. Just like our ancient ancestors, we live in a world of inevitable breakdown, and repair strategies remain crucial to managing our limited resources. As the next chapter details, repair has been a key component of our relationship with technology throughout human history. Efforts to impede repair, on the other hand, are a creation of the modern consumer economy.