Retiring Old Capital to Foster Decarbonization

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Abstract

A majority of anthropogenic greenhouse gas emissions come from fossil fuel combustion. Combustion nearly always involves some form of durable capital, which includes vehicles, appliances and power generators. Many policies aim to improve environmental outcomes by regulating the efficiency or emissions of this capital. Most such policies focus on *new* capital. This paper discusses the importance of policies that target *used* capital as a complement to such regulations. In particular, the paper argues that used capital policies that are designed to accelerate retirement of used capital, either by taxing its use or subsidizing its scrappage, can have efficiency benefits by addressing unintended consequences of policies that target new capital. The paper also argues that retirement subsidies are likely to be a relatively progressive policy instrument, as compared to alternatives. Policy makers should understand the role that such policies might play in fostering equitable decarbonization of the economy.

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1 Introduction

The broad goal of this paper is to highlight the importance of policies that target *used* durable markets as part of a portfolio of policies that aim to spur decarbonization and to foster an equitable energy transition.

Climate mitigation policy is, to a large degree, policy that pertains to capital (durable goods) that uses energy. As a result, a major emphasis of environmental policy is the regulation of this capital, which ranges from vehicles to power plants to residential appliances. Policies aim to make new capital more efficient through innovation and to induce switching from dirtier to cleaner fuel sources.

Regulation of new capital, however, cannot address all of the sources of inefficiency in free market outcomes, and such regulations tend to lead to unintended consequences. This creates a potential role for policies focused on used capital to increase economic efficiency. These policies can act as complements to the regulation of new capital.

Decarbonization policy is also, to a large degree, innovation policy. When thinking about innovation, it is natural to focus attention on new products, where innovation is directly embedded. For durable goods, however, there are deep connections between used and new product markets. These follow from the fact that new and used durable goods are substitutes, which means that demand for new, innovative products is inherently connected to capital turnover and retirement. Conversely, policies targeting the new product market can impact the utilization and retention of used durables. For energy-consuming durable goods that produce pollution, the used stock will generally be the dominant factor governing emissions in a period, which makes attention to them critical.

The paper proceeds in three steps. First, it begins by discussing the nature of regulations that govern emissions from new durable goods, explaining how the structure of existing policies creates an opening for complementary policies focused on retirement and scrappage to increase efficiency. The main consideration here is that policies focused on new durable markets fail to realize efficiency benefits that can come from accelerating retirement. Instead, they often exacerbate existing market inefficiencies by elongating the life of older, dirtier capital by increasing replacement costs. A faster pace of innovation implies that the gains from complementary policies are larger. Directed technical change implies a feedback loop in which retirement policies can accelerate innovation through a market-size effect. In addition, because the majority of emissions come from used capital, policies targeting the stock of capital will tend to have larger impacts.

Second, the paper outlines alternative policies that can play a complementary role to new durable regulation by fostering retirement. Capital retirement policies can come in the form of subsidies for retiring older, dirtier capital. Alternatively, they can take the form of pollution-based taxes or fees that shift relative prices in favor of newer, cleaner capital. The paper distinguishes five classes of pro-retirement policy: emissions taxes, taxing used capital, subsidizing scrappage, mandating retirement, and subsidizing new capital.

Third, the paper assesses the relative merits of these alternatives touching on efficiency, equity and political economy. They are not all equivalent on efficiency grounds, but all of these policies can be used to counteract unintended consequences caused by the regulation of new durables and to spur innovation through market-size effects to some degree. They will tend to differ in their incidence and administrative costs, but the incidence differences largely turn on how subsidies are funded or how tax revenue is recycled in the economy. In terms of political economy,

In the end, the paper argues that scrappage subsidies—which pay existing capital owners to retire older, dirtier durables—stand out as a policy of interest because they can provide efficiency benefits and achieve progressive outcomes, while benefiting from favorable political economy. Capital taxation can also be efficient and equitable, but capital taxes are only progress if revenue is carefully recycled or eligibility is dependent on income. Moreover, revenue-raising policies will generally enjoy less favorable political economy. Similarly, the efficiency benefits of subsidizing scrappage can be replicated by subsidizing new capital, which will also enjoy a favorable political economy. But new capital subsidies are likely to be more regressive than scrappage policies when ownership of newer capital is concentrated among higher-income households and lower-income households own older capital, as seems to be the case for many products. Scrappage subsidies are likely to be less efficient than tax based alternatives because of information challenges in their design, so some efficiency loss is the trade off for equity and political economy benefits.

Taken together, these findings suggest that pro-retirement policies, and in particular scrappage subsidies, could deliver both efficiency and equity benefits if deployed as part of a portfolio of policies that targets rapid innovation and decarbonization. Policy analysts should thus continue to study this important class of policies so as to provide additional guidance. This is not to suggest, however, that these types of policies are part of a first-best solution. The potential benefits of using retirement incentives owe to assumed (and realistic) limitations of the design of pollution charges. In a world with fully-priced emissions and an optimized subsidy for innovation, the interactions described here would still exist, but the need for retirement subsidies would be mostly or fully eliminated.

2 How do we typically regulate new capital?

When it comes to energy-consuming durable goods, economic theory suggests two main policy prescriptions. First, pricing externalities associated with the production and the use of fuels to reflect marginal damages in the spirit of Pigou (1932) will enhance efficiency. Pricing externalities corrects market distortions associated with the utilization of the goods, as well as giving buyers incentives to choose more energy-efficient versions of a good and to switch between fuel sources when one source runs on a cleaner fuel. In turn, this increased demand for emissions reduction will spur product innovation and research in the direction of improved efficiency and other ways to reduce emissions.

Policies that price pollution will thus spur innovation, but they will not be sufficient to deliver the optimal amount of innovative activity to the extent that innovation comes in the form of basic knowledge that generates spillovers, is otherwise difficult to appropriate, or involves directed technical change or increasing returns. In such a context, economic theory also calls for subsidies to research and development or other policy instruments that foster innovation.

While pollution is sometimes priced in some jurisdictions, a frequent alternative is to directly *regulate new capital* as a way to address environmental externalities. For example, the main policy addressing greenhouse gas emissions from automobiles in the US is the Corporate Average Fuel Economy (CAFE) standard, which is a flexible performance standard that requires automakers to sell vehicles that achieve a target fuel-economy level on average. Similarly, minimum energy efficiency standards for appliances and equipment impose efficiency requirements on new products. New building codes mandate performance characteristics for new construction. A variety of air and water pollution regulations impose limits on emissions from new power plants or industrial facilities.

In all of these examples, the regulations imposed on new capital leave used capital outside the regulation. When CAFE regulations are tightened, there is no requirement translated to the used fleet. Minimum efficiency standards for products and equipment only apply to new units. Building code updates do not mandate retrofits, though they often require updates to current code during renovations. Many environmental regulations of power plants and industrial facilities grandfather existing facilities (Stavins 2006).

When policies target new capital, they forego critical efficiency gains related to the usage and retirement of the used capital fleet, and they can even backfire by elongating the lifespan of older, dirtier capital. This can blunt incentives for innovation as well by shrinking the new product market and slowing the rate of turnover. Together, these possibilities point to the critical role of policies that focus on used capital, in particular policies that are designed to accelerate retirement. In a setting with first-best pollution pricing and incentives for research and development, there might be no need for additional policy instruments targeted at capital turnover. But, given the ubiquity of energy policies aimed at new durable goods, it is important to understand the potential for pro-retirement policies or other incentives that address used capital directly.

3 The efficiency benefits of used capital policies

3.1 Most emissions are among used durables

Why should we be concerned with used capital when thinking about energy-consuming goods? Put simply, the used capital stock is inevitably where most of the emissions are.

Among long-lived capital like automobiles, buildings, energy infrastructure and power plants, at any given moment the vast majority of energy consumption, and hence emissions, are associated with capital that is years, or even decades, old. As such, policies that create incentives to directly change the utilization of the full capital stock can be much more efficient than policies that regulate only the new product market. For example, a gasoline tax is typically understood to be far more efficient at reducing gasoline use and greenhouse gas emissions than a fuel-economy standard that only binds on the new product market in part because the gasoline tax induces owners of used cars to adjust their miles driven (Anderson and Sallee 2016; Austin and Dinan 2005).

Table 1 shows the average age and a measure of typical life expectancy for a selection of key capital investments associated with energy consumption in the US. The first group are vehicles. Light-duty vehicles are typically on the road for two decades or more, though they are driven systematically less as they age. Over time, the average age of automobiles has risen, in part because reliability and performance has improved. S&P Global reports that the average age of light-duty cars and trucks have both reached an all time high and continue to rise. Lu (2006) estimates that cars last 20 years on average and trucks (including vans, SUVs and pickups) last 25 years, though this is based on earlier data and so is probably an underestimate for today's new cars. In the current fleet, cars are older than light trucks, but this is due to the fact that there has been a pronounced surge in the sales share of light trucks in recent years, contributing to a younger fleet.

Many countries have a national goal of achieving 100% electric (or other non-petroleum) new vehicles sales by some future year. The US does not have such a national policy, but California has a 2035 target for 100% clean new vehicle sales. Between now and then, millions of additional new petroleum vehicles will be sold, and the fleet will continue to create emissions in the state well beyond 2050 given historical patterns of usage even if it can meet its ambitious targets.

Commercial trucks tend to be used more intensively and subsequently turnover somewhat faster. The table includes calculations of the average age among medium duty (Class 2-7) and heavy duty (Class 8) trucks in California, based on registration data provided by the California Department of Motor Vehicles. The heaviest vehicles tend to be driven very intensively. The mean annual mileage for a long-haul class 8 truck is over 60,000 miles, according to the Department of Energy. As a result, the fleet of commercial vehicles tends to be somewhat younger, as shown in the table.

The second panel in table 1 shows ages and lifespans for key energy-consuming household appliances. The biggest two targets for decarbonization are gas-powered furnaces and water heaters, which can be converted to electricity. The table shows average ages of the current fleet for a nationally representative sample of households from the Residential Energy Consumption Survey (RECS) and a California sample from the Residential Appliance Saturation Survey (RASS). The average furnace is more than a decade old in the US, and the average age is noticeably higher in California. Water heaters are 8 to 9 years in the current fleet, and refrigerators are around 7 to 8 years old.

The National Energy Renewable Laboratory (NREL) compiles information about typical lifespans for appliances. These estimates show that all of these appliances have substantial lifespans. This means that waiting for a natural rate of turnover of these appliances in order to decarbonize creates substantial inertia that bakes in emissions for one to two decades after production. In terms of fuel-switching for appliances, we are only beginning to establish goals for rapid electrification.

Industrial equipment can last even longer in many cases. To emphasize that point, table 1 shows estimates of the average age and expected lifespans of three main types of thermal power generators in the US, as reported by S&P Global. Coal plants in the US

Table 1: Age and life expectancy of capital by category in US

	Average age of fleet in years (source)	Typical life expectancy in years (source)
Vehicles		
National		
Light-duty cars	13.1 (S&P)	20 (NHTSA)
Light-duty trucks	11.6 (S&P)	25 (NHTSA)
California		
Medium-duty trucks	9.66 (ARB)	11.85 (ARB)
Heavy-duty trucks	7.49 (ARB)	9.82 (ARB)
Residential appliances		
National		
Furnaces	10.55 (RECS)	20 (NREL)
Water heaters	8.11 (RECS)	13 (NREL)
Refrigerators	7.43 (RECS)	17.4 (NREL)
California		
Furnaces	15.09 (RASS)	20 (NREL)
Water heaters	9.33 (RASS)	13 (NREL)
Refrigerators	7.81 (RASS)	17.4 (NREL)
Power plants		
National		
Coal	40 (S&P)	50 (S&P)
Natural gas steam	50 (S&P)	47 (S&P)
Natural gas combined cycle	14 (S&P)	27 (S&P)

Light-duty vehicle ages are for 2022 and come from S&P Global. Average life of light-duty vehicles are from Lu (2006) in 2006. Medium and heavy duty truck information are author's calculations for 2019 from California data provided by the Air Resources Board. Residential appliance average age are author's calculations from the 2015 Residential Electricity Consumption Survey (RECS) or 2019 Residential Appliance Saturation Survey (RASS). Appliance expected lifetimes are taken from the National Residential Efficiency Measures Database provided by the National Renewable Energy Laboratory (NREL). All power plant statistics are load-weighted values taken from S&P Global.

have had a typical retirement age around 50 years in recent years. The average plant in the fleet is not far from that age, indicating that many coal plants are near their end of life. Little new coal capacity has been added in the US in recent decades, but that is not true elsewhere in the world, where new facilities continue to come on line.

The older generation of natural gas plants relied on steam. These plants have a long lifetime, and like coal plants, the remaining fleet is at its end of life. Newer gas plants tend to be combined cycle plants, which are expected to have a shorter typical lifespan and are, on average, much newer.

Taken together, the point of table 1 is that energy-consuming capital in transportation, in homes, and in power generation turns over on the decadal time scale. This means that, even where new policy achieves rapid diffusion of cleaner alternatives, if incentives are insufficient to accelerate retirement of the existing capital stock, emissions will continue for years or decades. This highlights the potential benefit of policies that directly seek to accelerate retirement of older, dirtier capital.

3.2 Regulation of new durables suffer from the Gruenspecht effect

Economists have long been concerned that new durable regulations can inadvertently elongate the life of older, dirtier capital by raising replacement costs. This phenomenon is often called the Gruenspecht effect, after Gruenspecht (1982). The idea is that new environmental regulations that increase the cost of new capital by requiring the adoption of pollution control technologies may inadvertently lengthen the lifetime of used capital by making it more expensive to turnover. This effect has been considered in analysis of automobiles (Gruenspecht 1982; Jacobsen and van Benthem 2015; Jacobsen, Sallee, Shapiro, and van Benthem Forthcoming) and power plants (Gruenspecht and Stavins 2002; Stavins 2006; Bushnell and Wolfram 2012).

An idealized Pigouvian tax on emissions would raise the operating cost of older capital, shifting the market towards faster turnover. In contrast, a new durable regulation implicitly raises the asset value of pre-existing, older capital by making replacement more expensive. Policies that directly encourage retirement can create an efficiency benefit by countering this phenomenon. The turnover model in Jacobsen et al. (Forthcoming) formalizes this result in an analytical model and demonstrates the intuitive finding that a tax on used capital can counteract the Gruenspecht effect. In that model, a subsidy to new capital would be isomorphic to a tax on used capital.

3.3 How does innovation impact the need for capital retirement policy?

The speed of innovation, and the stringency of innovation policy, determines the potential efficiency gains from capital retirement policies. This interaction occurs through three distinct channels.

First, even in the absence of a policy that triggers a Gruenspecht effect, if new capital is cleaner than older capital, then the free market will turn over capital more slowly than the social optimum (if the pollution is not priced). Where innovation is more rapid, the wedge between the free market and the socially optimal rates of turnover will be larger. Thus, the gains from capital retirement policy will be larger when the speed of innovation is greater.

Newer capital might be cleaner than older capital either because there is a secular trend in efficiency or emissions control, because policy is tightening over time, or because emissions control equipment degrades with age. If emissions are fully priced, then the owners of capital will take those differences into account when thinking about the optimal rate of turnover. If, however, emissions are not priced (or are priced below their true social value), then the private market will turnover capital slower than the social optimum. The turnover model of Jacobsen et al. (Forthcoming) shows this result formally. This is another reason that retirement policies can have an efficiency benefit.

Second, where innovation policy increases the cost of new capital, tighter innovation policy implies a larger Gruenspecht effect, and thus a larger welfare gain from capital retirement policies that counteract it.

Third, where market innovation is able to move quickly, the regulation of new durables is more likely to lag behind the technological frontier. In these situations, a capital retirement policy that helps move the market more quickly can create efficiency gains because of the imperfections in the regulation of new durables.

Many regulations affecting new capital operate on a substantial lag. For example, the Department of Energy operates the product and equipment standards programs, which mandate minimum energy efficiency for dozens of types of devices, ranging from light bulbs to commercial refrigerators. Rules are made given an existing state of the market, but the analysis and review process for a new standard typically takes a couple of years, at which point industry is given a several year lead time to comply, and, by statute, rules cannot be changed again for six years.

Similarly, building codes are typically adopted even more slowly, with a standards review and updating process that takes years and is deliberately backward looking. In addition, building codes are fragmented and regional, which limits their potential to spur innovation through market size effects and coordination.

When secular innovation is able to move faster, these lags create a bigger gap between what is economically feasible in a year and what is mandated by policy for new durables. As such, used capital retirement policy that accelerates change can be useful.

3.4 How does capital retirement policy affect innovation?

The main channel through which capital retirement policies might affect innovation seems to be through directed innovation.

The theory of endogenous growth and directed innovation has long identified a market-size effect on innovation. Put simply, more innovation occurs in areas when the payoff to innovation is larger, which is tied directly to the demand for the relevant product. The size of the new durable market is directly tied to demand for used durables, so taxing used durables (or subsidizing their retirement) accelerates turnover and expands the new vehicle market. Thus, when progress itself is determined endogenously because of directed technical change or learning by doing, policies that accelerate turnover and expand the new product market can accelerate innovation through the market-size effect. Put another way, endogeneous technological progress amplifies the inefficiencies of new durable regulation associated with inefficient turnover.

A second way in which capital retirement policy might affect innovation is through a feedback loop that accelerates regulation of new durables. To the extent that capital retirement policies boost new innovation through market size effects, this can feed back into stronger policy to the extent that policy is itself dependent on the state of innovation and the set of products in the market.

4 Policy options for accelerating retirement

The previous section argued for potential benefits of policies that seek to spur innovation and decarbonization by directly targeting used capital. Supposing that policymakers do wish to pursue such policies, what options do they have?

Tax fuel usage (or emissions): It is worth pointing out, again, that a simple solution to many of the problems for most markets does exist. If emissions, or fuel inputs, can be taxed directly according to their marginal external damages, then many of the problems induced by new product regulations can be attenuated or eliminated. Taxing diesel fuel, for example, would accelerate the retirement of older commercial trucks, which accelerates turnover towards new zero-emission technologies.

This solution is harder to implement in some other cases. For example, it is straightforward to price carbon emissions into wholesale natural gas and electricity markets, which then passes into residential rates. But, utilities recover system fixed costs through volumetric prices for gas and electricity, which means that consumer prices are generally distorted away from social marginal cost (Davis and Muehlegger 2010; Borenstein and Bushnell 2022ab). As such, even with an idealized carbon price in place, there may still be systematic mispricing.

The focus on policy alternatives below starts from a premise that there are political obstacles, administrative or enforcement challenges, or other factors like utility pricing models that prevent reliance on corrective taxes as the primary solution.

Taxing old capital: Another option is to directly tax existing capital stocks. This can be designed to mimic the incentives of the ideal emissions tax, at least as it pertains to some margins of behavior, by pegging the taxes to the expected damages associated with usage. As one example, Jacobsen et al. (Forthcoming) estimate large social gains from taxing used automobiles according to their local air pollution emissions.

Administratively, such taxes are easy to imagine for some products, but not for others. Personal and commercial vehicles already have an annual registration process and in nearly all jurisdictions pay some sort of annual fee. It is straightforward, as an administrative matter, to make those fees a function of emissions. Indeed, this is common practice in many countries outside North America. The state of California is exploring such a system for commercial vehicles.

Similarly, power plants and industrial facilities are already tightly monitored by the Environmental Protection Agency, and it would not be difficult to collect operating fees. Many already pay some sort of annual license fee.

In contrast, there would be substantial challenges in implementing a new tax on existing residential appliances and equipment. The government does not already have systematic information on the fleet of refrigerators, air conditioners, furnaces and water heaters. It is certainly possible to imagine a system for collecting such information and assessing fees, but it would require large new administrative capacities in order to implement a system that was accurate and verifiable.

Subsidizing retirement: Instead of taxing used capital, it is possible to subsidize its retirement. A number of policies have taken the form of some sort of scrappage subsidy that paid users a subsidy for switching to a newer, cleaner version of a product.

Examples include the so-called Cash for Clunkers program in the US, which paid a subsidy for buyers who retired an older car and purchased a newer one that met fuel economy criteria. Some states include related programs on an ongoing basis, like California's Clean Vehicle Rebate Project, which gives a subsidy for income-eligible households who switch to a zero-emission car. Utilities have often run appliance rebate programs that have a similar design. These have been done in other countries as well as the US. On a grander scale, Germany has attempted to move towards a cleaner energy system by buying out the coal industry.

Mandating retirement: As discussed above, many regulations grandfather the existing fleet and eschew requiring them to make changes, at least until a facility undergoes a renovation or retrofit. But, this need not be the case. It is conceptually possible to mandate retrofits or retirement directly.

One example of such a policy are commercial trucking regulations in California. There, a policy called the Truck and Bus Rule required all trucks operating in the state to either undergo a retrofit to a newer engine that complied with new standards or to be retired (from the state). This law phased in over a decade. Operators primarily complied by switching to newer vehicles.

Interestingly, this same approach in California is now constrained by law. A new provision of state law prohibits the Air Resources Board from forcing the retirement of commercial trucks that exist prior to new regulations before the end of their "useful life," which is defined as 18 years of operation, unless the vehicle reaches 800,000 miles driven, in which case its useful life can be as low as 13 years.

Subsidizing new capital: Some of the inefficiencies and problems discussed above follow when new durable regulation increases prices of new durables, and thus shrinks the new product market and depresses innovation and reduces turnover.

This can be directly counteracted by subsidizing new durables directly. We have many examples of tax subsidies for environmentally-friendly capital, ranging from rooftop solar incentives to tax credits for electric vehicles to a range of utility-run programs that subsidize electrification or energy-efficient appliances. The Inflation Reduction Act has an aggressive set of subsidies that take this form.

5 Comparison of retirement policies

The key question for turnover is the relative price of new versus used capital. In a simple framework, the relative price of used capital can be manipulated by subsidizing or taxing new or used capital. More precisely, if the goal is to accelerate retirement of used capital, one can achieve the same effects in a simple framework by taxing used capital, by subsidizing the scrappage of used capital, or by subsidizing new capital in order to achieve the desired relative price.[1] What factors might distinguish among these options?

Any of these policies, or some combination of them, can thus be used to counteract the Gruenspecht effect, to foster innovation through a market size effect, and to otherwise overcome inertia and facilitate change. The policies will, however, differ in their incidence, which is described in the next subsection, as well as in whether they raise or require revenue, which has indirect efficiency consequences. They may also differ in their ease of implementation and administrative costs.

5.1 Efficiency considerations among retirement policies

A first source of efficiency difference relates to *flexibility of compliance*. Market-based mechanisms in general are appealing on efficiency grounds because they offer market participants, who typically have more information about costs and benefits than the regulator, an option to change behavior or pay a price to continue polluting. Retirement mandates will often constrain this type of choice, so the price-based mechanisms (subsidies or taxes) will tend to be more efficient.

A second potential efficiency difference relates to the ability of each policy to create *consistent incentives for abatement*. The efficiency gains from market-based mechanisms

[1] This is precisely true in the model of Jacobsen et al. (Forthcoming) for the case that considers no substitution to an outside good. In that case, a subsidy to new products, a tax on used products, or a scrap subsidy for used products would all have an identical effect on the new vehicle market share, which is isomorphic to the retirement rate.

that put a price on pollution come from the fact that, when all agents face the same price for pollution, the market allocation will be cost effective. That is, the agents with the lowest cost of abatement (reduction of pollution) will tend to abate their pollution, and those with the highest cost will pay the policy price.

In theory, harmonized incentives can be created by either taxes or fees, but in practice, it is harder to create differentiated subsidies because the design of a subsidy hinges on an unobservable counterfactual. Consider a case where a car buyer is choosing between a variety of vehicles, some of them electric and some of them gas-powered. To accurately price pollution, the regulator needs to assign a tax to each vehicle based on its pollution. To accurately subsidize clean vehicles, however, the regulator needs to assess the counterfactual—i.e., what gasoline-powered vehicle would a buyer have chosen instead of an electric vehicle. As such, a tax requires measurement of pollution from an actual choice (which may in itself be challenging), but a subsidy requires information also about an unobservable counterfactual choice.

In general, paying for the *reduction* of pollution (a clean subsidy) will involve more inaccuracy than charging a fee for pollution, which gives tax mechanisms an edge in terms of efficiency.

Third are *market size effects.* Taxing dirty capital versus subsidizing its retirement (or subsidizing new capital) will also differ in the way it affects total market size. Prior research has made an important distinction between externality-correcting policies that impose taxes versus those that operate in a zero net revenue fashion, such as through a performance standard. Take Corporate Average Fuel Economy standards as an example. They require a fleet-wide average fuel economy. This acts as an implicit subsidy to vehicles that are more efficient than the minimum and an implicit tax to vehicles that are less efficient than the minimum. If all of the vehicles create negative externalities, then the first-best solution is to tax all vehicles (with a bigger tax for the less efficient ones). Compared to that first-best solution, the performance standard keeps the average price of vehicles lower, which leaves the overall market too large.

Holland, Hughes, and Knittel (2009) formally shows that a performance standard is equivalent to an emissions tax, plus an output subsidy. This is an inefficiency of performance standards, as it leads to an overly large market. For this reason, the intuition from traditional models is that a tax on used capital is more efficient than subsidies. In a context with directed technical change and/or learning by doing, however, a bigger new capital market accelerates innovation. In that context, a policy that either subsidizes new capital or subsidizes the scrappage of used capital could be more efficient than a tax on used capital.[2]

5.2 Equity considerations among retirement policies

There is no general law governing whether taxing dirtier capital should be progressive or regressive. The equity implications of retirement policies will vary from case to case.

That said, there are some common findings that create a baseline expectation about likely equity implications of pricing pollution or subsidizing capital retirement.

A large literature in environmental economics consider the equity implications of pricing pollution. It is common to find that taxing pollution is regressive (when burdens are measured in proportion to income, as is most common), but that regressivity can easily be offset through targeted revenue recycling (examples include Cronin, Fullerton, and Sexton (2019) and Rausch, Metcalf, and Reilly (2011)). Most of that literature is focused on pricing pollution in broad terms rather than taxing capital per se.

Examples of taxes on old capital also tend to find regressive impacts (Jacobsen et al. Forthcoming) because, in most cases, wealthier households hold newer capital on average. I explore this further below.

A related literature finds that subsidies for new, green products is often highly regressive (Borenstein and Davis 2016). The basic intuition for this is that subsidies tend to be for new, more expensive products or investments and early adopters tend to be wealthy. Some such subsidies are capped by income, including vehicle tax credits under the Inflation Reduction Act, in an attempt to improve distribution.

To the extent that household income is negatively correlated with capital age, one will expect the initial incidence of taxes on old capital to be regressive. In contrast, this means that subsidies for retiring old capital would be expected to be progressive. This difference is an important potential benefit of retirement subsidies.

Do lower-income households own older capital? We might initially expect that pricing capital to foster decarbonization will be regressive in its initial incidence. By initial incidence I mean to indicate both that we are abstracting from how revenue is raised for a subsidy and that we are not taking account fully of general equilibrium effects. Regarding the latter, a subsidy to a new product initially purchased by higher-income

[2] The implicit output subsidy can also turn out to be desirable in a setting with pre-existing factor price distortions (Goulder, Hafstead, and Williams 2016).

households can still benefit lower-income households if it drives down the price that lower-income households face in the future for the used product.

Regarding the former point, if a green product subsidy goes to rich households, but it is entirely funded by taxing the rich, then it need not be regressive. If a tax on old cars is paid entirely by low-income households, but the revenue is redistributed to the same households, it need not be regressive. The strategic use of the revenue will tend to dominate the equity implications of most environmental taxes (Sallee 2019).

Nevertheless, our question here is simply on the initial incidence. That initial incidence will have an important impact on optics and political economy, and it of course needs to actually be counteracted by revenue policies, which does not always happen in practice.

Lower-income households drive older vehicles—To look at the likely initial incidence of a tax on older cars that scales with vehicle age, I consider data from the 2017 National Household Transportation Survey, which is a nationally representative survey of households that includes information on their transportation.

Figure 1 shows that, as expected, lower income households have vehicles that are older than their higher-income counterparts. The difference is economically significant and tightly related to income. Taxes on older capital would thus be expected to be regressive.

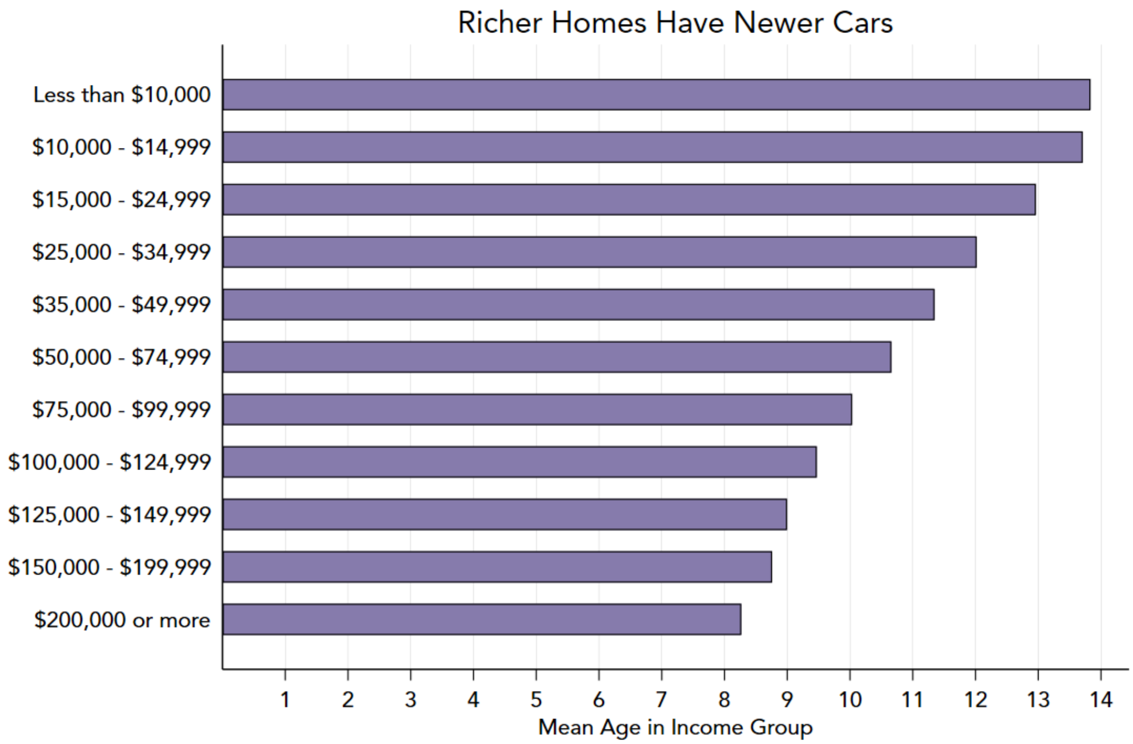
Smaller businesses operate older trucks—Most of the existing literature on incidence focuses on households and consumer products. But, similar issues may arise for commercial products.

A key question around fairness that has political economy consequences is the degree to which different policies would be thought to impact small businesses disproportionately.

As one example, I plot the distribution of commercial trucks in California based on data provided by the state's Department of Motor Vehicles by operator size. The sample include all commercial trucks licensed from 2017-2019. These vehicles are connected via an address match to their operators in Dun and Bradstreet, which provides information about firm characteristics.

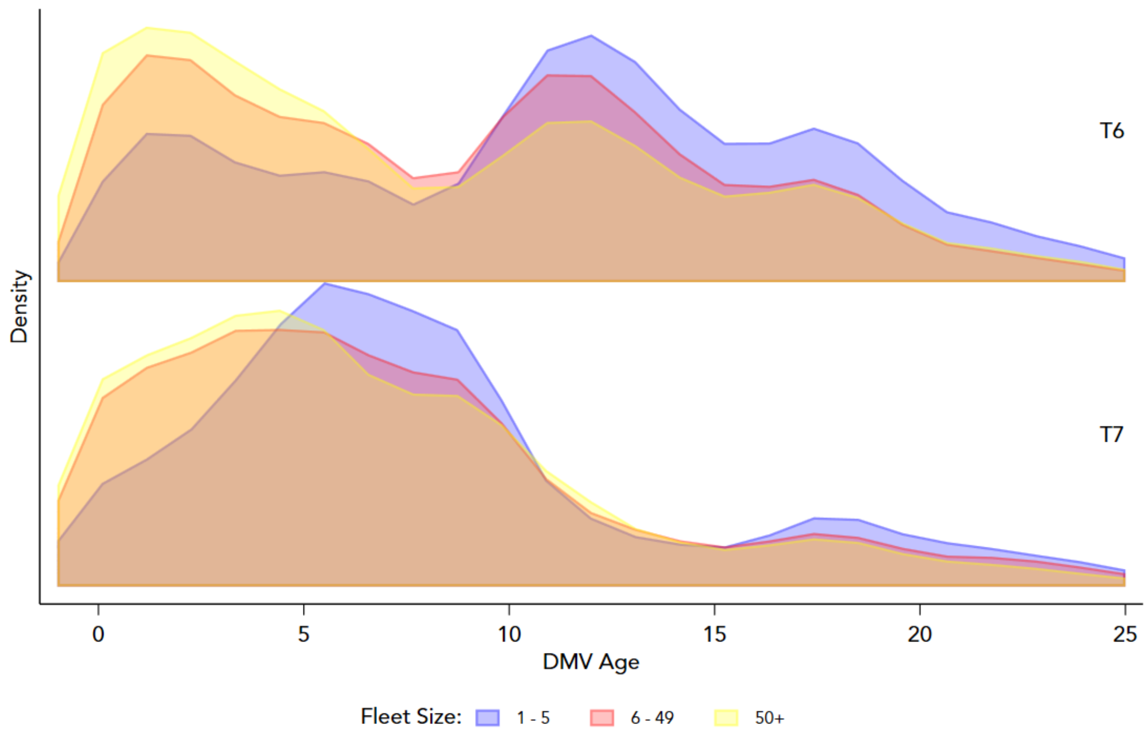
Figure 2 shows that firms that operate smaller fleets have older trucks. The graph shows the histogram of the age of currently registered trucks by whether the operator has 1 to 5 trucks in their fleet, 6 to 49 trucks, or 50 or more. The graph breaks down

Figure 1: Average vehicle age by household income category



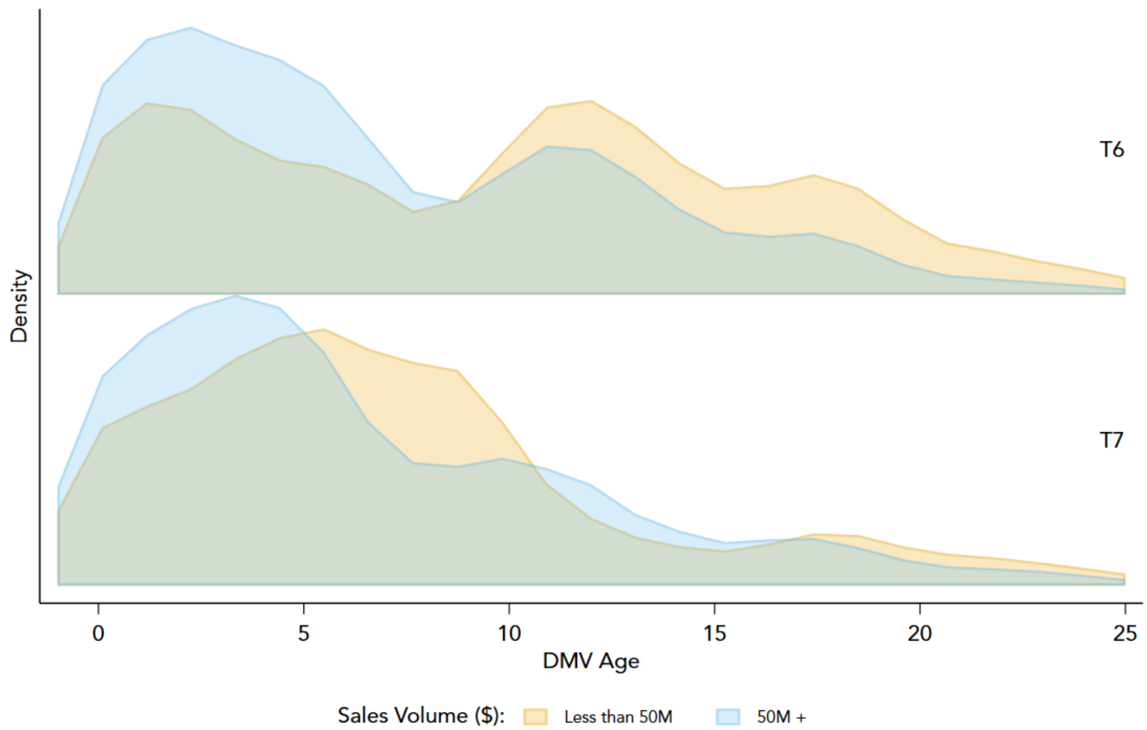
Note: Data come from the 2017 National Household Transportation Survey. Income is measured in 2017 USD.

Figure 2: Age distribution of commercial trucks by fleet size



Note: Data from the California Department of Motor Vehicles, 2017-2019. T6 vehicles are Class 4 through 7, Gross Vehicle Weight Rating 14,001 - 33,000 pounds, and T7 vehicles (Class 8, GVWR 33,001+ pounds).

Figure 3: Age distribution of commercial trucks by firm revenue



Note: Data from the California Department of Motor Vehicles, 2017-2019. T6 vehicles are Class 4 through 7, Gross Vehicle Weight Rating 14,001 - 33,000 pounds, and T7 vehicles (Class 8, GVWR 33,001+ pounds).

medium trucks (T6, Class 4 to 7) and the largest trucks (T7, Class 8) separately. The first of these categories encompasses a mixture of vehicles including box trucks, walk-in vans, and bucket trucks. The large category includes a more limited set, including cement mixers, dump trucks, and large tractors.

Some large companies may operate small fleets because it is not central to their business operation. The same relationship is shown in figure 3 by revenue, separating firms by revenue (above or below $50 million) instead of fleet size. The same difference emerges—smaller businesses own older vehicles on average.

Income is not strongly associated with residential appliance age—Survey data also asks customers about the age of the appliances in their home. These are self-reported data, and they may be subject to some measurement error, but nevertheless are likely to provide a proximate guide. Given a focus on electrification, the appliances of most interest are space and water heaters.

Figure 5 shows the average age of water heaters by household income in the US, based on data from the most recent Residential Energy Consumption Survey (RECS), which is a nationally representative household survey. There is little correlation between water heater age and household income. This is consistent with a model of change in which households mostly hold onto a water heater until it fails.

Figure 5 shows the same correlation with the same data for space heaters. Similarly, there is little correlation. This means that, unlike vehicles, there is less reason to believe that taxing older home appliances is likely disproportionately affect lower income households.

Together, these results suggest that there are likely some equity benefits associated with subsidizing the retirement of older vehicles, rather than taxing them, though this relationship is weak or non-existent for key residential appliances.

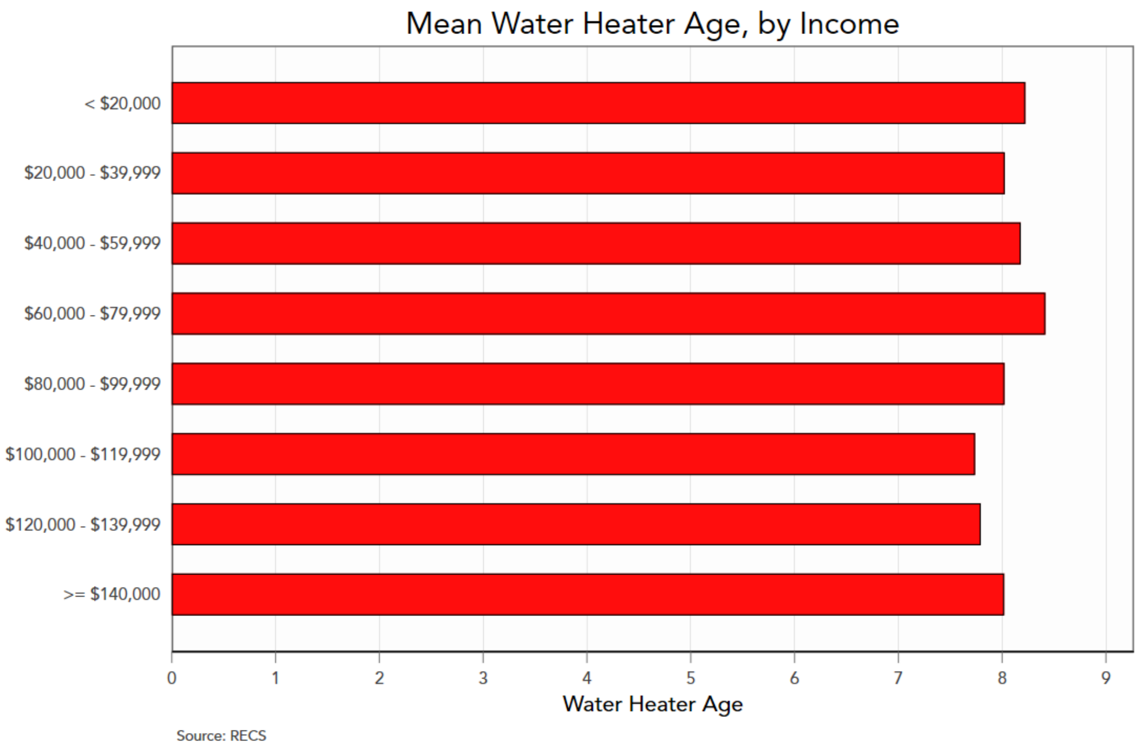
5.3 Political economy considerations among retirement policies

Are capital retirement policies likely to gain favor in the policy process? I suggest three distinct political economy questions.

First, *is there support for decarbonization policy of any sort?* Those who stand to gain (or lose) from policies fostering decarbonization will generally support (or be against) pro-retirement policies that are designed to aid decarbonization.

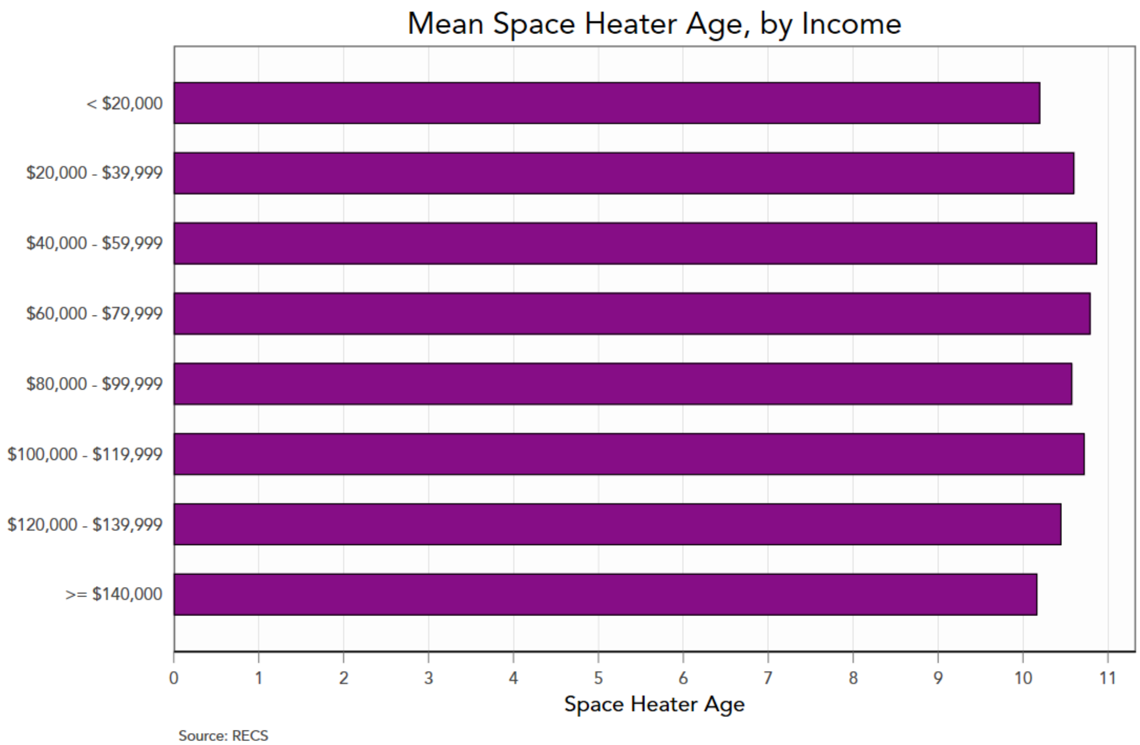
The obvious opponents to decarbonization policy in general are fossil fuel incumbents.

Figure 4: Average age of water heaters by household income



Note: Data from the 2015 Residential Energy Consumption Survey.

Figure 5: Average age of space heaters by household income



Note: Data from the 2015 Residential Energy Consumption Survey.

Policies that accelerate a sectoral trend away from petroleum based motor fuels or from the use of natural gas in buildings will naturally meet objection from the oil and gas industry. Fuel producers are thus the most obvious opponents to pro-retirement policies. But this is not particular to pro-retirement policies, it would be true of any policy supporting rapid decarbonization.

Second, *presuming that policy makers are going to push for decarbonization, would stakeholders want a pro-retirement policy to be part of a suite of policies?* Capital retirement policies should gain some favor with the manufacturers of durable goods to the extent that they accelerate turnover and boost demand for new products. Broadly, the same should be true of retailers and installers. Any policy that accelerates turnover is good for business to the extent it expands their core market. As a first-order consideration, this suggests a positive political prospect for some form of pro-retirement policy.

Policies that focus on fuel switching, or other major technological changes that require fixed costs, may gain less favor with these same groups. Manufacturers of durable goods may face large investment costs that, in equilibrium, will be difficult to pass on to customers through higher prices. Such investment costs become sunk costs when firms are setting strategic pricing. For retailers, there is often a learning curve required to sell new products. Automobile dealers also stand to lose from the shift to electric vehicles to the extent that they require less maintenance, which is a major revenue stream for dealerships. Similarly, fuel switching for home appliances can complicate the installation process substantially. As such, fuel switching may face some resistance from key stakeholders, but this again speaks to a broader issue of decarbonization policy, rather than something particular about pro-retirement policies in particular.

The third question then is, *among stakeholders that do want a pro-retirement policy, are taxes or subsidies more popular?*

As compared to taxes, subsidies have several obvious political economy advantages. First, subsidies tend to expand a given market by lowering average costs, whereas taxes will tend to shrink a market by raising costs. For stakeholders in a given industry, this makes subsidies more appealing. Second, subsidies that are funded from a general budget will usually burden a diffuse set of taxpayers in order to deliver benefits to a concentrated set of stakeholders in a particular industry. Conversely, taxes place the burden on a concentrated set of stakeholders in order to deliver benefits to a diffuse set of taxpayers. The logic of collective action suggests that more concentrated stakeholders tend to better organize and lobby for their interests (Olson 1965), which suggests a political economy advantage for subsidies.

Third, the tax or subsidy in a particular industry will often be more salient than the same amount of revenue added or subtracted from a larger, pooled budget. That is, a pollution tax that raises $1 billion may more visible than a change in the income tax that also raises the same. Under a subsidy, the more salient component of the policy is the benefit, and the cost side of the equation is more opaque.

It is important to note that a tax on used capital would raise revenue that could be used to achieve the same distributional benefits. As such, the same political economy benefits could be obtained. In practice, it is often more difficult to actually collect revenue and then redistribute it to stakeholders than it is to simply design a policy that treats them favorably up front.

Fourth, and finally, *among subsidies, which policy is more favorable, one that subsidies retirement, or one that subsidizes new products?* Among subsidies, one can foster greater turnover by simply making new durables cheaper, or by subsidizing the scrappage of used durables. The political economy difference boils down to the difference in incidence discussed above.

Subsidizing new products raises the payoff to manufacturers and lowers the consumer price of the new durable. This will lower the asset value of used durables, because their main substitute is less expensive. In contrast, subsidizing the scrappage of used durables will raise the asset value of the used durables (which can be be scrapped for a payoff). This still creates a benefit to manufacturers by shifting demand up, but it raises the cost to the buyers of new durables. So, the choice between subsidizing new versus used durables resolves to whether one wishes to deliver more benefits to the buyers of new or used durables.

5.4 Summary of alternatives

Table 2 summarizes the differences across policies based on these categories. Notable in this summary is that subsidies for scrappage are unique in providing a progressive instrument. The table lists the most likely outcome based on the arguments in the text, but incidence will be context specific and is, as noted above, highly dependent on how revenue is used.

Table 2: Impact and equity features of policy alternatives

Policy	Targets New Durables	Targets Used Durables	Revenue Impact	Initial Incidence
Tax emissions (fuel inputs)	X	X	+	Regressive
Tax used capital stock		X	+	Regressive
Subsidize new capital	X		-	Regressive
Subsidize scrappage		X	-	Progressive
Mandate scrappage		X	0	Regressive

The table describes whether the policy has a direct, initial affect on new or used durables, but, in equilibrium, all policies have an effect on both. A plus indicates that the policy raises revenue; a minus that it uses revenue; and a zero implies neutrality. The initial incidence listed in the column is context specific and highly dependent on how revenue is raised or recycled, but the column lists the most likely outcome based on the arguments provided in text.

6 Conclusion

This paper highlights the importance of policies that attend to used capital, and in particular policies that seek to accelerate the retirement of used capital. The focus is on decarbonization and environmental externalities.

In many domains, the predominant policy instruments regulate new capital. These sorts of policies open the door for important complementary benefits from policies that accelerate used capital retirement.

Retirement policies are unlikely to be part of a first-best policy design, but they can play an important role by attenuating or eliminating inefficiencies created by new durable regulations, and they can generally be designed to have progressive distributional impacts, in particular when they take the form of retirement subsidies for older capital. This makes them appealing on political economy grounds as well as efficiency. Greater economic attention to the scope and design of this class of policies could help guide policymakers interested in fostering an equitable and efficient transition towards a cleaner future.

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