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Inequality and the Environment: The Economics of a Two-Headed Hydra

Abstract

Preserving environmental quality and addressing economic inequality both feature prominently in public discourse. Neither of these two issues can be fully understood in isolation, and policies aiming at one issue will increasingly have to consider interactions with the other. We synthesize theoretical mechanisms that underpin inequality-environment interlinkages, and take stock of the empirical evidence. Our review is structured into four main blocks, describing, first, how the distribution of environmental amenities and dis-amenities is associated with income and wealth, second, how economic inequality affects environmental outcomes, third, how the cost of environmental policy is often borne unequally, and, fourth, how both the distribution of environmental quality and economic inequality shape welfare considerations underlying public policy appraisal. We argue that it is crucial to consider inequality-environment interlinkages even if one's primarily concern is one or other of these issues, and close by highlighting a number of areas for future research.

JEL-Codes: D310, D330, E250, Q520, Q560.

Keywords: environment, inequality.

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Introduction

Environmental degradation and economic inequality have emerged as two of the defining challenges of the twenty-first century. Policy makers from around the world increasingly prioritize both issues in their national and global agendas, as exemplified in the United Nations Sustainable Development Goals.[1] The two challenges are the subject of intensive research, driven by recent advances in understanding of the nature, causes and consequences of economic inequalities (e.g., Alvaredo et al. 2018; Anand and Segal 2008; Johnson and Papageorgiou 2020; Piketty and Saez, 2014) as well as concerns about the widespread and accelerating deterioration of environmental goods and services, due to climate change and the loss of biodiversity in particular (Dasgupta 2021; IPCC 2014, 2018; IPBES 2019; Nordhaus 2019; Stern 2007). But research on the two topics is largely separate. Like the Greek hero, Heracles, researchers and policymakers focus on cutting off one head of a two-headed hydra and thereby often miss crucial and growing interdependencies: Economic inequality can influence environmental outcomes, while changes in environmental quality[2] and environmental policies in turn affect economic inequality. The failure to address this interplay limits the ability of economists to formulate effective policy recommendations for reducing inequality or preserving the environment, thereby allowing the Hydra to grow back more heads.

The yellow vest movement in France is a case in point. The announcement of moderate fuel tax increases in 2018 was perceived as unfair by many in the French population and incited widespread protest, resulting in multiple deaths, and stalled progress on reducing carbon emissions. Similar examples are abundant around the world, such as the failed fossil fuel subsidy reforms in Nigeria and, more recently, Ecuador. Addressing adverse interdependencies of economic inequality and environmental quality seems imperative to ensure the welfare of societies over the coming decades. Both the United States (US) and the European Union (EU) recognize this importance in their current debates around “environmental justice” and around a “just transition”, and addressing both issues also features prominently in China’s latest Five-Year Plan. Economic research will thus be called on to provide insights into how inequality and the environment interact in order to inform sound decision-making in the decades ahead.

This review synthesizes the large and growing literature concerned with the various ways in which economic inequality and environmental quality intersect. While single facets of this intersection have been explored in previous reviews (e.g., Banzhaf et al. 2019; Bento 2013; Fullerton 2011; Hsiang et al. 2019), we bring together research on different key channels of interaction between inequality and the environment, thereby shining a light on previously unrecognized feedbacks, rebound effects and synergies. Our findings will help researchers who focus on either inequality or the environment to identify promising new research areas, inform decision making by policy makers, and provide students with an overview of the interlinkages between two topics that are increasingly being featured in academic curricula (e.g., Bayer et al. 2020). Naturally, our review remains limited. Our primary focus is on income inequality among individuals and households, as opposed to, for instance, intergenerational inequality or inequality among specific societal groups. Our review is structured into four building blocks.

The first block (Section A) deals with the *incidence of changes in environmental quality* in physical as well as monetary terms. It is well known that environmental goods and services, for example relating to air quality, ambient temperatures or access to greenspaces, are often distributed unequally, and in ways that correlate with income. But mere correlations are rarely informative, as the relationship is mediated by a number of mechanisms, including residential sorting or decisions on the siting of pollution sources. Depending on the mechanisms at play, environmental inequality may simply reflect underlying economic inequality, or it may add a second, reinforcing layer of inequities. And even when all members of society face the same environmental conditions, they may be affected by them in different ways. All of this

[1] The United Nations adopted 17 SDG’s in 2015, which make explicit reference to “reduced inequality”, “no poverty”, “climate action”, “life below water”, as well as “life on land”

[2] Alternative terms used to describe environmental impacts include environmental “footprint”, “intensity”, “burden”, “pressure”, and “pollution”, or, on the flip-side, environmental “goods”, “services” or “amenities”.

gives rise to various sources of heterogeneity across the population in terms of their willingness-to-pay (WTP) for enhancing environmental quality or avoiding degradation.

The second block (Section B) examines the *environmental consequences of inequality*. The distribution of economic means shapes consumers' aggregate demand for polluting goods, as well as affecting citizens' demand for measures to protect the environment, and their ability to make their voices heard or influence the policy process. Any policy aimed at economic redistribution, such as progressive tax reform, may therefore inadvertently influence access to environmental goods and services, and their distribution, among others by changing the distribution of consumption patterns.

The third block (Section C) focuses on the *incidence of environmental policy costs.* Most environmental policies generate costs that are unequally distributed across individuals. We discuss approaches to distributional incidence analysis, including the common partial equilibrium approaches focused mainly on demand-side effects as well as more recent general equilibrium approaches that also consider supply-side effects. We highlight how distributional predictions can differ with the method of analysis, the specific design of the policy at hand and the environmental problem that the policy seeks to mitigate.

The fourth block (Section D) builds on insights from the previous blocks to elucidate the role of *inequality in environmental policy appraisal.* The distribution of both economic means and environmental quality matters for evaluating the potential effects of competing policy proposals. Any approach to policy appraisal requires values judgements on how to aggregate welfare changes across individuals, which mediate the effect of inequality for the ranking of policy proposals. In the utilitarian approach, common to economics, this includes specifying how income and environmental quality influence the utility of individuals and how a social planner should aggregate these. Our discussion highlights that, in doing so, we have to consider the distributional effects identified in the first three building blocks.

For each of these blocks, we provide a conceptual framework and review the theoretical underpinnings. We then synthesize available empirical evidence and outline knowledge gaps. We strive for an integrated overview highlighting the various ways in which these thematic areas intersect. In doing so, we seek to put individual research agendas into perspective, show how they can inform one another, and sketch potential avenues for future research.

We close by drawing conclusions for research and policy analysis. We hope that our integrated review provides an impetus for future research that reaches across the boundaries between these—until now—largely distinct literatures on economics inequality and the environment. A researcher exploring ways to design environmental policy that has certain distributional characteristics—generating, say, net effects that disproportionately benefit low-income households—should for instance consider feedback effects that may affect achievement of the environmental outcome that motivated the policy in the first place. A government economist using cost-benefit analysis to evaluate different policy options—generating, say, monetary estimates of WTP for improved environmental quality—should consider how these valuations change when accounting properly for inequality. Likewise, economists primarily concerned with economic inequality will increasingly have to consider inequalities induced by changes in environmental quality and environmental policies—taking into account, say, how the economic transformation necessary to achieve decarbonization of economies in line with the Paris Agreement on climate change will reshape the distribution of capital, labor and associated incomes. These examples highlight the need to adopt an integrative approach towards tackling both economic inequality and environmental change.

Section A: The distributional effects of environmental quality

Knowing how environmental damages and benefits are distributed across socio-economic groups, and why, is fundamental for a better understanding of the inequality-environment nexus. Environmental justice concerns in the US have mainly focused on how pollution is distributed across race and class (e.g. Banzhaf et al., 2019), providing evidence that lower-income households are disproportionally exposed to and affected by pollution. This section focuses on such environmental justice effects, adopting the following procedure (see Figure 1).

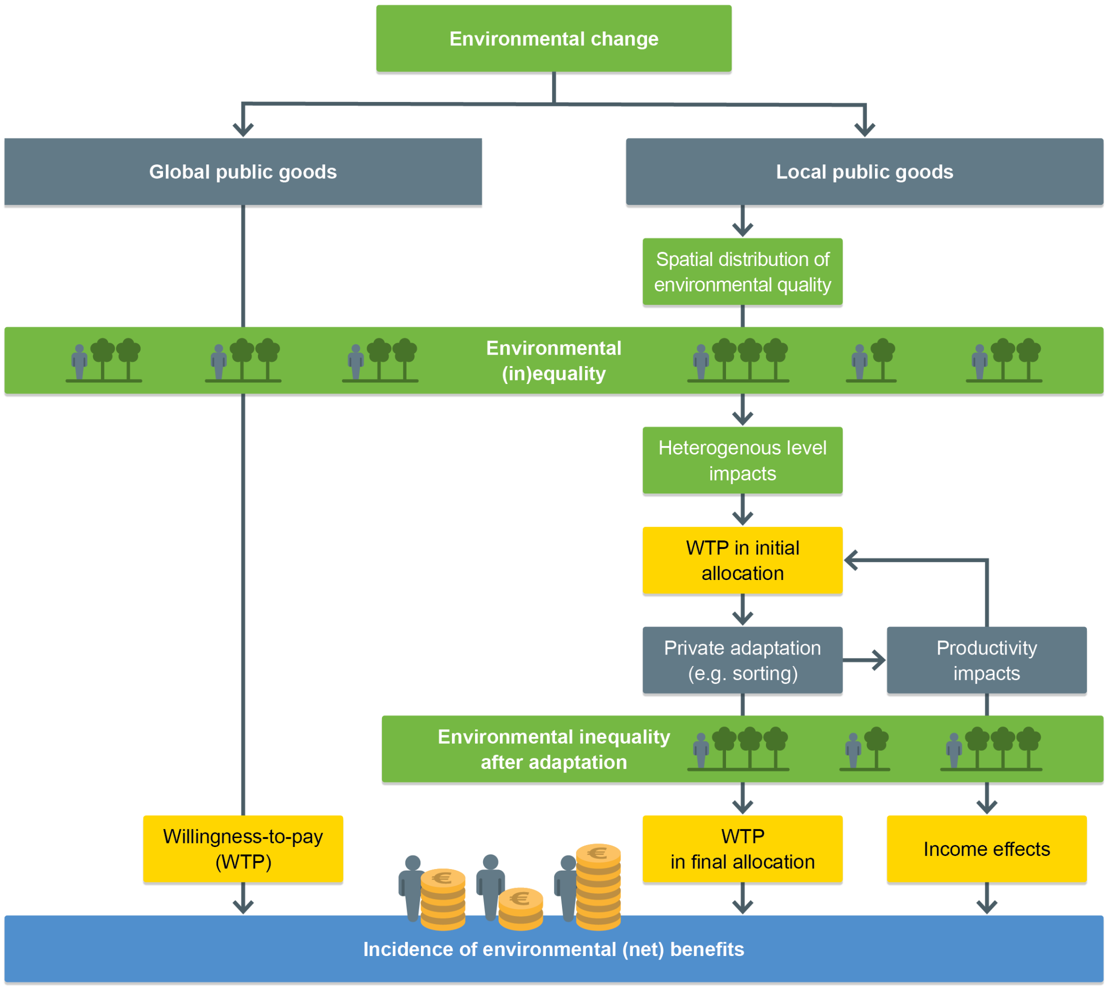

Figure 1: Conceptual framework for the incidence of environmental damages and benefits
Note: For global public goods (left panel), an environmental change maps directly into the incidence of environmental benefits, given by the distribution of willingness-to-pay (WTP). For local public goods (right panel), the spatial distribution of environmental goods coupled with heterogenous impacts and individual reactions to this distribution via private adaptation activities mediates a further change in the mapping of environmental goods and this is reflected in the final distribution of WTP and potential amenity-related income effects.

First, we consider a given *change in environmental quality*, such as a 0.1°C increase in global mean temperature, or a change in air quality due to the opening of a new coal-fired power plant. *Second*, we analyze the *spatial distribution pattern* of this change. For instance, there may be higher-than-average warming over parts of Europe compared to Africa, while wind-dispersed pollutants will be present in different concentrations across locations. *Third*, we identify disparate effects due to *non-linear marginal damages or benefits* linked to the pre-existing quality of the environment in different areas. For instance, an additional 0.1°C of warming may be less of a concern in Scandinavia than in Mexico. In addition to amplification processes, non-linear process may give rise to saturation effects. For example, if temperatures are already so hot that one cannot go outside without protective equipment, any additional warming may be of less concern than in other locations where the same temperature increase makes a noticeable different to the experience of going outside. *Fourth*, we consider the extent to which *adaptation by individuals* can uncouple the physical distribution of environmental change from the actual exposure to its impacts experienced by individuals. Such adaptive behavior includes defensive measures, substitution of private goods for environmental goods, and avoidance behavior, as well as residential sorting or migration. Adaptive capacity by households is usually strongly linked to available income, which will likely lead to a more unequal distribution of environmental goods along the income distribution. Fifth we consider repercussions of the distribution of environmental changes on the ability to generate income, as lower (higher) environmental quality may impact labor productivity, leading to vicious (or virtuous) cycles that reinforce the persistence of environmental inequalities over time.

Finally, we examine the likely reactions of firms and policy makers to the distribution of incomes and WTP. This relates in particular to decisions of firms on the siting of polluting facilities and to government interventions that make it easier or harder for households or firms to cope with or adjust to the spatial distribution of such environmental damages. Adaptation, siting and intervention then feed back into the distribution of environmental goods across space.

Organized around this multi-step procedure, this section develops a conceptual overview of how the distribution of environmental damages and benefits affects economic inequalities, and summarizes empirical evidence relating to the different steps.[3] We start by isolating the effect of the first step in our framework, that is how an *environmental change* maps onto an *incidence of environmental benefits* along the income distribution (cf. Drupp et al. 2018). To do so, we focus initially on the special case of a global pure public environmental good. Subsequently, we allow environmental goods to be spatially distributed and consider the different layers of complexity that this adds. In this process, we pay close attention to studies that focus on specific mechanisms that affect the incidence of environmental benefits and damages and highlight areas where further research is needed.

A.1 Global public goods

We first consider the case in which individuals derive utility from a market-traded consumption good, C_i, and an environmental good, E, that is a global pure public good, i.e., $E_i = E$ for all individuals i. Individual utility is given by $U(C_i, E)$. One example of this type of good are non-use services derived from biodiversity, such as existence values. As all individuals, irrespective of individual income or traits, enjoy the same amount of the public good, distributional effects are determined solely by differences in valuation—commonly assessed using the WTP for a marginal change in the quantity of that good—across the income distribution (Ebert 2003). For normal goods, WTP is a positive function of income. Consider a simple example with constant-elasticity-of-substitution (CES) utility derived from the environmental public good, E, and a numeraire consumption good C. In this case $C_i = Y_i/P$, where Y_i, is income and P is the price level normalized to unity. Individuals differ in income, Y_i, but not in their preferences:

$$U(C_i, E) = \left(\alpha E^{1-\eta^W} + (1-\alpha) C_i^{1-\eta^W}\right)^{\frac{1}{1-\eta^W}}, \quad (1)$$

where α is the utility share parameter for the environmental public good, and η^W is the (constant) income elasticity of WTP, which is inversely related to the elasticity of substitution between both goods (cf. Baumgärtner et al. 2017, Ebert 2003). In this setting, individual WTP, defined as the marginal rate of substitution between the environmental and the consumption good, is a function of income to the power of the income elasticity of WTP:

$$WTP = \kappa Y_i^{\eta^W}, \quad (2)$$

where $\kappa = \frac{1-\alpha}{\alpha} E^{1-\eta^W}$. The income elasticity of WTP is given as $\eta^W := \frac{\partial WTP}{\partial Y_i} \frac{Y_i}{WTP}$ and indicates the distributional effect of the benefits of a pure public good. Environmental benefits are distributed progressively (regressively) [proportionally] if the income elasticity of WTP is below (above) [equal to] unity (cf. Ebert 2003). Consider the case of an income elasticity below unity ($\eta^W < 1$). If income increases by one percent, WTP increases by less than one percent. Relative to their income, lower-income households have a higher WTP for the environmental public good and environmental benefits are distributed pro-poor. And if WTP increases more than proportionally with income ($\eta^W > 1$), environmental benefits are distributed pro-rich.

[3] We draw here on previous reviews by Hsiang et al. (2019), who study the distribution of environmental damages, focussing on the role of cross-sectional patterns and heterogeneous marginal damages, and Banzhaf et al. (2019), who examine environmental justice literature with a focus on siting, sorting, bargaining and policy interventions.

There are a number of empirical estimates of income elasticities of WTP for environmental goods, including a few meta-analyses (e.g., Drupp 2018; Drupp and Hänsel 2021; Kristrom and Riera 1996). Jacobsen and Hanley (2009) provide a meta-analysis of 46 WTP studies on biodiversity conservation and calculate an average income elasticity of WTP of 0.38. Subroy et al. (2019) conduct a meta-analysis of 47 WTP studies on protecting threatened species. They find an income elasticity of almost twice this magnitude when using the same modelling framework as Jacobsen and Hanley (2009), but they obtain an insignificant income effect when applying an alternative estimation model. Overall, most existing studies find that income elasticities of WTP for environmental goods are smaller than unity, implying that benefits from biodiversity conservation are distributed pro-poor.

The role of the income elasticity of WTP discussed above suggests that the incidence of environmental benefits likely varies with the type of environmental good and the degree to which it is perceived as a substitute to market consumption (Ebert 2003). However, even in the case of a pure public good, the distributional implications can be more intricate. While this equal-preference framework has been extended to a case with preference heterogeneity if the distributions of income and preferences are independent from each other (Drupp and Meya 2021), perceptions of substitutability may also be heterogeneously distributed across individuals in a way that depends on income. Within this framework, we have to consider how the correlation between income and perceptions of substitutability affects benefit incidence along the income distribution, and also how benefits are distributed for a given income level depending on underlying preferences. Targeted empirical studies are needed to disentangle how income, substitution and interaction effects impact benefit incidence of non-market goods.

A.2 Local environmental goods

A crucial source of heterogeneity driving the incidence of environmental benefits relates to the *spatial distribution* of environmental goods. Indeed, most environmental goods are not pure global public goods. Instead, their location generates heterogeneity in exposure, that is E_i differs across individuals. In many instances, E_i is a function of the distance of individual i to the source, for example an environmental amenity, such as an urban green park, or a source of pollution. In such cases it is important, first, to clearly capture the spatial distribution of environmental goods. In a second step, we can consider the correlation between the spatial distribution of E and of income Y (Meya 2020). Again, the regressivity or progressivity of environmental benefits derived from local public goods is determined by the appropriate income elasticity of WTP, but we have to be mindful of a host of mediating factors that correlate with income (e.g., Banzhaf et al. 2019; Hsiang et al. 2019). These mediating factors, which we discuss below, render the correlation between access to environmental goods and income endogenous. In addition, due to heterogeneity in other characteristics, such as preferences, abilities and health conditions, there is likely a substantial degree of environmental inequality at each income level. Furthermore, there can be vicious or virtuous cycles in the sense that exposure to environmental benefits (lower pollution or better nature recreation possibilities) in turn affects labor productivity and thus the ability to generate higher income. Combined with income-dependent sorting, this can lead to persistent spatial distributional effects. In the following, we discuss different channels of interaction between environmental exposure and income and review selected empirical evidence.

A.2.1 Spatial distribution

In many instances where there is a *change in environmental quality* due to a governmental policy, siting decision by a firm or some other driver, the change in the spatial distribution of environmental goods is straightforward to determine. Consider an improvement in water quality in a lake, an improvement in the habitat of a specific animal or the removal of a forest. The increasing availability of spatially disaggregated data—from remote sensing or ground-level monitor networks—continues to improve researchers' ability to link the spatial distribution of environmental goods to household characteristics (e.g., Colmer et al. 2020; Currie et al. 2020). Studies investigating the equity impacts of emission markets initially drew radii around polluting sources to study how the spatial distribution of pollution generation relates to socio-economic characteristics of people living within those radii (Fowlie et al. 2012). However, air pollutants can travel long distances, affecting populations in far-off places. Subsequent studies make use of chemical transport models to compute pollution trajectories or pollution dispersal originating from a given polluting source (Grainger and Ruangmas 2018; Hernandez-Cortes and Meng 2020), and link them to the spatial distribution of socio-economic inequalities. For climate change, numerous multi-model studies have investigated how an increase in global mean temperature translates into heterogenous (expected) changes in temperature and precipitation patterns across the globe. This allows researchers to better assess how climate forcing affects global income inequality (e.g., Diffenbaugh and Burke 2019; Mendelssohn et. al. 2006) and how projected climate change may reinforce existing inequalities within and across countries (e.g., Burke et al. 2015; Hsiang et al. 2017; Park et al. 2018).

A.2.2 Non-linear effects

We also need to consider the heterogeneity in base levels of environmental quality combined with *non-linear marginal effects* (Hsiang et al. 2019). In short, a 1°C temperature change will have very different impacts in a place with a long-term average temperature of 10°C, as in many EU countries, as compared to a place with an average temperature of say 25°C, as in India (Burke et al. 2015). *Non-linear marginal effects* include amplification and saturation effects. While damages from heat and air pollution are often amplified at higher exposure levels, as demonstrated for air pollution across Europe by Dechezleprêtre et al. (2019), saturation effects can be observed for many goods, particularly those with close substitutes. Having a park nearby is valuable, but any extra park in the vicinity will not add as much marginal benefit. Finally, *non-linear marginal effects* can shift from saturation to amplification along the baseline provision that is affected. Consider average rainfall per year: Some rainfall is very valuable, but saturation effects will kick in and very high levels of rainfall will cause damages. For crop yields in the US, Schlenker and Roberts (2009) show that yields increase with temperature up to a threshold of around 30°C, after which further increases become harmful. It is an empirical challenge to disentangle *non-linear marginal effects* from effects due to changes in adaptive capacity and adaptive behavior (Hsiang et al. 2019), to which we turn next.

A.2.3 Private adaptation

Households have a host of options at their disposal to adapt to the exposure to environmental quality. Adaptive capacity is typically a function of income, which makes the eventual distribution of exposure to environmental damages and benefits endogenous to the distribution of income. The following subsections review key private adaptation options.

A.2.3.1 Defensive expenditures

Examples of defensive expenditures include sound-proofed windows to reduce noise pollution, air conditioning to reduce heat exposure (Park et al. 2020), face masks and air purifiers to reduce exposure to air pollution (e.g., Ito and Zhang 2020; Sun et al. 2017; Zhang and Mu 2018), and sunscreen and sunglasses to protect against UV radiation. This category also includes pharmaceutical purchases for treatments of air pollution, studied by Deschenes et al. (2017), among others, for the case of NO_x pollution. Most studies on defensive expenditures do not investigate how such expenditures and implied WTPs differ along the income distribution. Ito and Zhang (2020) examine the WTP for clean air by studying air purifier markets in China. They find that marginal WTP is a positive function of income. While they do not estimate an income elasticity of WTP, they compare their implied value of statistical life with that of other studies and find that an income elasticity of unity could explain differences among studies. Sun et al. (2017) show that Chinese households invest more in face masks and air filters when pollution levels exceed certain thresholds and that higher income households are more likely to invest in expensive filters. While they only compare effects across three income groups, their results tentatively suggests that defensive expenditures increase inequality in exposure to air pollution along the income distribution. More research is needed to determine how benefits of avoided air pollution as a result of defensive expenditures vary with income.

A.2.3.2 Avoidance behavior

Avoidance behavior includes shorter-term behavioral changes in response to environmental threats, such as reducing exposure to severe air pollution events (e.g., Moretti and Neidell 2011) or the switching to bottled water in response to water quality violations (e.g., Graff Zivin et al. 2011). Graff Zivin et al. (2011) compare changes to bottled water purchase following water quality violations. Comparing the lowest and the top income quartiles, they find no significant differences for short-term violations related to microorganisms and nitrates; however, wealthier households respond by buying relatively more bottled water when faced with violations that lead to longer-term health risks, such as those related to levels of chemicals. Chen et al. (2020) examine the impact of air pollution on short-term aviation trips in China and show that the number of passengers on the flight increases significantly in line with the amount of air pollution in the origin city relative to the destination city. The number of first-class passengers increases about three times faster than the number of economy-class passengers, providing some indication of differential avoidance behavior along the income distribution No published study on avoidance behavior provides a detailed account of how the incidence of environmental benefits (or damage avoidance) is related to the distribution of incomes.

A.2.3.3 Sorting

While avoidance behavior typically focuses on short-term reactions to more temporary changes in environmental quality, sorting and migration occur in the medium to long term as a response to more persistent differences in environmental quality.[4] The literature on residential sorting builds on Tiebout's (1956) seminal model in which households 'vote with their feet' in sorting towards neighborhoods that provide a desired bundle of taxes and local public goods, including environmental amenities such as urban greenspaces or clean air (Banzhaf et al. 2019). Both the desire to sort, expressed in terms of WTP for a cleaner environment, and the ability to sort depend on income; as do a number of other potential mediating factors such as information, education, minority status etc. Households thus trade off higher housing costs against increased access to environmental amenities. The theoretical prediction is that, ceteris paribus, higher income households will sort themselves into neighborhoods with better environmental amenities, which results in higher housing prices in these areas (e.g., Brueckner et al. 1999; Lee and Lin 2018; Meya 2020). The opposite is true for poorer households. Banzhaf and Walsh (2008) provide evidence for Tiebout's hypothesis in the context of community-level sorting in relation to Toxics Release Inventory facility emissions in the US. They show that migration is correlated with emissions and that the presence of polluting facilities leads to communities becoming poorer. This is sometimes called the 'coming to the nuisance' effect (e.g., Depro et al. 2015). Relatedly, Lee and Lin (2018) show that the presence of persistent natural amenities is associated with a prevalence of high-income households, an effect which may be denoted 'coming to the amenity'. Thus, residential sorting can often lead to an increase in environmental inequality along the income distribution. Sorting responses may cause environmental policies to have unintended consequences. For example, measures to clean up polluted areas or increase the quality of urban greenspace in poorer neighborhoods will tend to increase demand for housing in these areas, with higher income households being able to outbid poorer ones in accordance with their higher WTP (cf. Banzhaf et al. 2019). This can lead housing prices and rents exceeding the WTP of poorer households for better environmental amenities, driving them out towards dirtier places, a process known as 'environmental gentrification'.

The empirical evidence on sorting in response to the siting of new environmental (dis)amenities appears mixed. While Greenstone and Gallagher (2008) find that Superfund-sponsored clean-ups of hazardous waste sites in the US cause insignificant changes in property and rental prices, more recent studies find that cleaning-up of polluted sites can lead to substantial increases in housing prices (e.g., Gamper-Rabindran and Timmins 2013; Haninger et al. 2017). Gamper-Rabindran and Timmins (2013) draw on high geographical resolution data

[4] Our discussion focusses on residential sorting while acknowledging that intra- and international migration is becoming a more active and increasingly important area of research (e.g. Chen et al. 2017).

and find that local housing values increase by around 15 percent on average following Superfund-sponsored clean-ups of hazardous waste sites, with housing values of cheaper houses exhibiting a disproportionate increase. Distributional effects depend on the distribution of home ownership in the vicinity of the clean-up sites. In a study of the effects of air quality improvements in compliance with the 1990 Clean Air Act Amendments (CAAA), Bento et al. (2015) find that the benefits are progressively distributed, based on changes in house prices and rents (see also Grainger 2012). They find that WTP for cleaner air relative to income declines considerably along median incomes of US census tracts. Yet, they do not find substantial evidence for sorting following air quality improvements due to the CAAA. Depro et al. (2015) draw on a structural model of neighborhood dynamics to shed light on observed correlations between income, race, and exposure to airborne toxins and find that residential mobility based on WTP for neighborhood amenities plays an important role in shaping these correlations.

Thus, while there is accumulating evidence of house and rental price increases, the evidence for 'environmental gentrification' is less clear. Indeed, as Banzhaf et al. (2019) explain, it is very challenging to pin down this phenomenon empirically, for a number of reasons. First of all, there are likely hysteresis effects that may cause sorting to materialize only after considerable time or not at all, for instance, due to costs of moving, non-monetary barriers to moving affecting certain population groups, such as discrimination (Christensen and Timmins 2018, Christensen et al. 2020), differential informational gaps across socio-economic strata (Hausman and Stolper 2020), or countervailing 'broken window' effects relating to a persistent under-provision of other public goods, such as safety, in a previously polluted area (Banzhaf et al. 2019). Heblich et al. (2021), for instance, trace existing spatial inequalities of income and air pollution in the UK back to neighborhood sorting during the industrial revolution and document substantial persistence in sorting. In addition to such hysteresis effects that may attenuate sorting, it is challenging to identify individual sorting behavior from aggregate population changes (Depro et al. 2015). More studies drawing on structural modelling, finer grained micro-data, and quasi-experimental and randomized controlled experimental studies, such as in Christensen and Timmins (2018), are needed to shed further light on the 'coming to the nuisance' hypothesis. It seems especially worthwhile to scrutinize how substitution possibilities differ across socio-economic strata and to determine the net distributional effects of local pollution (reductions) as mediated via individual sorting behavior. A better understanding of these drivers is crucial for determining overall welfare effects.

A.2.4 Impacts of environmental changes on income generation

An additional source of hysteresis leading to persistent (negative) correlation between income and exposure to pollution is the impact on labor productivity, via effects on physical and mental health. A growing body of literature documents the adverse effects of air pollution on labor productivity (e.g., Chang et al. 2016, 2019; Hanna and Oliva 2015; He et al. 2019), as well as on cognitive ability and learning (Ebenstein et al. 2016; Künn et al. 2019). Furthermore, UV-radiation can affect the ability to carry out skilled labor via its effects on eyesight (Andersen et al. 2016), while excessive heat adversely affects learning (e.g., Park et al. 2020) and labor productivity (e.g., Zhang et al. 2018). Exposure to pollution affects children and their later life outcomes (Currie et al. 2014), leading to inequalities in economic opportunities. These impacts of poor-quality environments on income generation are a cause of sticky wages, as well as affecting WTPs for improved environments, reinforcing sorting dynamics. Ketcham et al. (2019) document feedback-loops in the US between environmental goods, health and income that can trap senior citizens in a cycle of increasing illness, poverty and –exclusion from amenities. More work is required to examine such "vicious cycles" linking environmental inequalities and low incomes in more detail, and the extent to which these can explain the persistence of environmental and economic inequalities across generations.

A.3 Environmental inequality or injustice: the role of policy

The above synthesis of research findings on the relation between environmental inequality and the income distribution sheds light on the incidence of effects of environmental change. While these effects vary across environmental domains as well as spatial scales, there is accumulating evidence showing that access to environmental goods is unequally distributed among socio-economic strata, with lower-income households and minority groups—in terms of gender, race, and immigration status—tending to be exposed to higher levels of environmental degradation. On the other hand, non-market studies of WTPs relative to incomes show quite consistently that environmental benefits are distributed pro-poor.

Potential causes of the disparities revealed by these studies include heterogeneous spatial exposures, non-linear marginal effects, and a suite of private adaptation measures that can attenuate the damage or enhance benefits resulting from an environmental change. These include residential sorting or migration as well as avoidance behavior and defensive measures.

In general terms, adaptive capacity increases with incomes, which can lead to an increase in environmental inequalities along the income distribution. Yet, more quantitative studies of the distributional effects of specific private adaptation options are needed. Further research is also needed into how environmental inequalities in terms of exposures translate into distributions of benefits and damages; the conclusions of such studies will help determine how the welfare effects of such inequalities should be measured and evaluated (e.g., Boyce et al. 2016; Mansur and Sheriff 2021). For example, if environmental inequalities stem from sorting, this could be interpreted as an 'efficient' outcome given the prevailing allocation of budgets, and simply reflect that poorer households can enjoy less of all kinds of goods, including environmental goods (cf. Banzhaf et al. 2019). This may either shift the focus of discussion on environmental justice from environmental inequalities to income inequalities and lead to calls for an (additional) re-distribution of incomes, or lead to the conclusion that society should evaluate environmental inequalities differently from income inequalities. More research is thus needed to understand welfare implications of any observed correlation between environmental quality and income, as a basis for informed judgement on whether environmental inequalities are environmental injustices. This will require a more detailed understanding of the extent and causes of (i) inequalities in exposure to environmental quality and (ii) inequalities in the benefits heterogenous individuals derive from environmental goods, as well as (iii) informed debate on how society should evaluate such inequalities (which we discuss in Section D).

Ultimately, the challenge is to identify cases where unequal outcomes are a sign of failing markets or when policies exacerbate such failures. If exposure affects opportunities of children, for instance, direct policy intervention seems most likely warranted. In other situations, the mere fact of unequal exposure may not in itself warrant policy intervention. For instance, if the main driver of inequality in air pollution exposure across individuals is pure residential sorting, then the 'locus of control' for governments may shift from targeting environmental inequality directly to targeting sources of potentially unjust income inequality, or to addressing related factors that may impact the ability to sort, for instance discrimination or informational differences across socio-economic groups. Otherwise, attempts to alleviate environmental inequalities may aggravate inequality in terms of inclusive consumption, for example by leading to rental price increases to levels beyond those which lower income households are willing or able to pay. However, depending on the causes of environmental inequalities, in other cases more direct regulation or other policy approaches may be warranted, such as provision of environmental-social housing, support for relocation, information campaigns, or planning regulations with respect to siting decisions, etc. In addition to considering how such intentional policies can actively shape the distributional effects of environmental change, it is also crucial to study how governmental policies can unintentionally exacerbate environmental inequality and injustice. Such effects could include the unintentional re-distribution of air (co-)pollutants (e.g., Fowlie et al. 2012; Grainger and Ruangmas 2018; Hernandez-Cortes and Meng 2020), or environmental damages caused by social protection or health programs (e.g., Garg et al. 2020; Mullins and White 2020). Both the availability of more sophisticated empirical research methods and improved access to data can contribute to an improved understanding of environmental inequalities and how the benefits of environmental goods are distributed. Empirical data-driven studies in combination with conceptual and theoretical research is required to disentangle drivers of environmental inequalities, evaluate environmental justice concerns and inform policies to address these issues.

Section B: How does economic inequality shape environmental outcomes?

Could higher levels of economic inequality lead to more environmental degradation and less stringent environmental policy? This hypothesis is sometimes promoted in popular debates and by some academic scholars (e.g., Wilkinson & Pickett, 2010; Stiglitz, 2012). But it is far from clear—based on theory or from the empirical evidence—that there is indeed such a systematic relationship between economic inequality and environmental outcomes. In this section, we survey the relevant literature from the field of economics, identifying common themes and important knowledge gaps.

The degree of economic inequality in an economy may shape environmental outcomes in a number of ways, which can be grouped into three different channels: (1) consumer demand, (2) collective action and public good provision, and (3) political power (see Figure 2). In the following subsection we summarize the underlying theories and, if available, review the empirical support for each mechanism. The final subsection discusses the evidence for a relationship between inequality and the environment at the aggregate level.

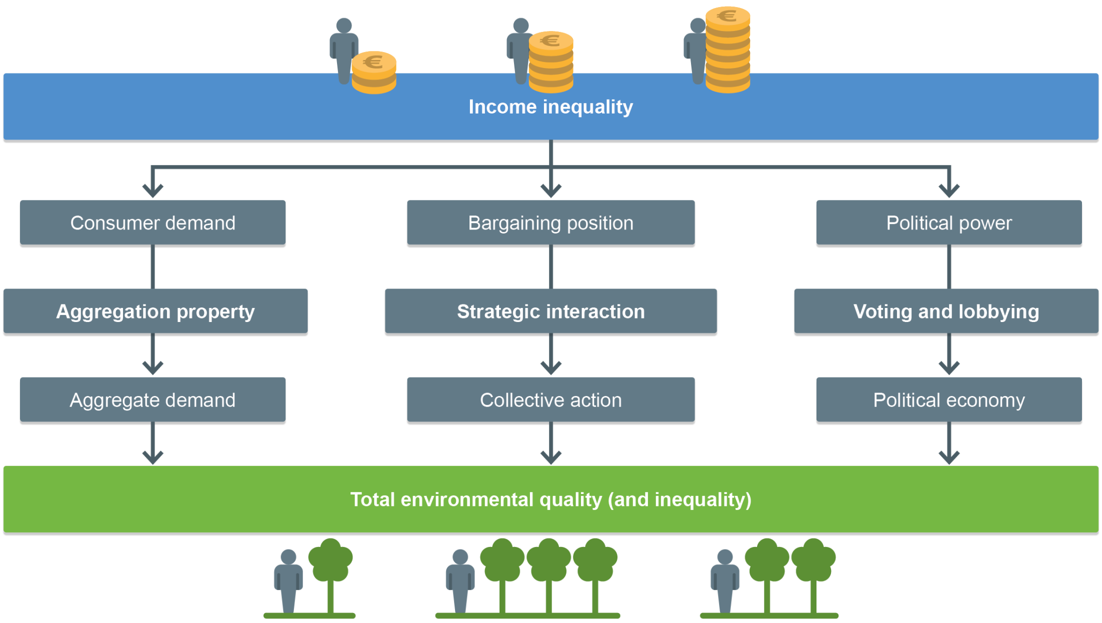

Figure 2: Conceptual framework for the environmental effects of inequality

Note: The diagram shows how income inequality might influence environmental outcomes. First, the distribution of incomes (and other resources) directly affects the bundles of goods and services consumed by individual households, which collectively determine the volume and composition of aggregate demand and the environmental pressures that come with it. Second, economic resource endowments also shape the strategic interests and bargaining power of participants in the collective bargaining processes that often shape environmental outcomes, in particular with regard to environmental public goods. Third, income can affect political preferences, and often also the level of political influence, of voters, which in turn shape the outcome of the political process, including environmental policy.

B.1 Consumer demand aggregation

The consumer demand channel is essentially a manifestation of consumption patterns across the income distribution. Various measures of environmental impact embedded in consumption are unequally distributed, across countries (Duro et al., 2013; Teixidó-Figueras et al., 2016) and along levels of income within (Levinson and O'Brien, 2019; Sager, 2019a). In short, consumers at different income levels demand bundles of goods with varying intensities of environmental impacts. As a result, the distribution of income affects aggregate environmental outcomes.

This effect is shaped by the income elasticity of demand for environmental impacts embedded in, or linked to, the consumption of goods and services, η^C. This channel was proposed by Scruggs (1998) and formalized by Heerink et al. (2001). It can be illustrated using the concept of environmental Engel curves (EEC), which describe the relationship between consumer income and the environmental impact (e.g., CO_2 emissions) of consumption by the average household at each income level (see Levinson and O'Brien, 2019; Sager, 2019a). For example, assume that environmental quality, E, is impacted by the environmental footprint of a human activity, Φ, for example a changing climate E due to greenhouse gas emissions Φ. That aggregate is a sum of individual footprints, ϕ_i, which in turn depend on individual i's income level (Y_i) and idiosyncratic differences in tastes (λ_i). Holding constant the number of households, N, the aggregate environmental impact, Φ, rises and falls with the average footprint, $\bar{\phi}$ (see Sager 2019a):

$$\bar{\phi} = \frac{1}{N}\sum_{i=1}^{N} \phi_i \text{ where } \phi_i = f(Y_i) + \lambda_i = \sum_{k=1}^{K}\left[C_{i,k}(Y_i) \cdot e_k\right] + \lambda_i \tag{3}$$

The function $f(.)$ describes the part of environmental impact that is systematically related to household income—the EEC. It is a function of demand for goods $k = 1, \ldots K$, $C_{i,k}(Y_i)$, weighted by their environmental intensities, e_k (e.g., emissions per unit). Whenever this relationship is non-linear, then the distribution of incomes across households will affect aggregate environmental outcomes linked to consumption (see Heerink et al., 2001).

The shape of the EEC is key for the environmental impact of income redistribution, as illustrated in Figure 3. When the EEC is concave (left panel), formally $f''(.) < 0$, the marginal change in environmental impacts linked to consumption (e.g., kg of CO_2 per dollar) decreases with income. In this case, more inequality in the form of a mean-preserving spread in the income distribution results in smaller aggregate environmental impacts. The average environmental footprint with a dispersed income distribution, $\bar{\phi}$, is smaller than the footprint when everyone has mean income, $\phi(\bar{Y})$. If EECs are convex (right panel), the opposite holds. While the example we give is of negative environmental impacts in the form of CO_2 emissions, the same logic applies to positive impacts of, for example, emission abatement efforts.

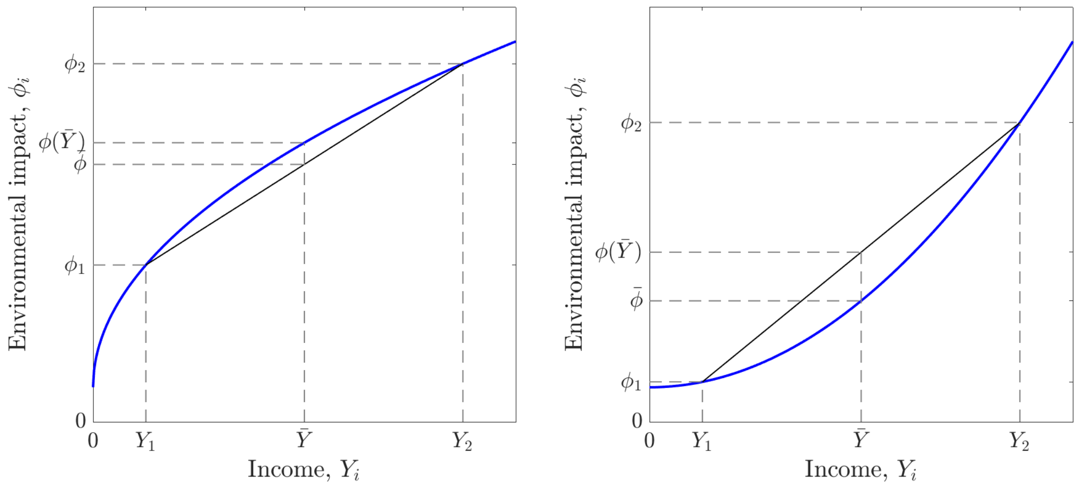

Figure 3: Illustration of the aggregate environmental impact for a two-household example

Note: The left subplot shows concave environmental Engel curves and how they matter for the aggregation of environmental impacts. The right subplot shows the convex case.

While empirical estimates of EECs are relatively recent (Levinson and O'Brien, 2019; Sager, 2019a), there is ample evidence of income elasticities of demand for different goods, and these are often related to the shape of EECs. Specifically, if an environmental burden is related to luxury goods (where $\eta^C > 1$), then the EEC is likely convex and more inequality will tend to increase the aggregate burden. For necessary goods ($0 < \eta^C < 1$), more inequality will likely decrease the embedded burden. However, sole knowledge about income elasticities may not always be sufficient to determine the shape of EECs, so that a quantitative analysis of the inequality-environment relationship will often require explicit estimation of EECs[5].

Evidence: Consumption patterns suggest an "equity-pollution dilemma"
Levinson and O'Brien (2019) estimate environmental Engel curves (EEC) for local air pollutants (PM_{10}, VOC, NO_X, SO_2 and CO) in the US. Sager (2019a) does the same for CO_2 emissions, again in the US. Both find that EECs are upward sloping ($\eta^C > 0$), since higher income households consume more and hence are responsible for higher levels of embedded emissions. But both also find that EECs are concave (and that $\eta^C < 1$), i.e., the relationship is less than proportional, so that emissions are increasing less than in proportion with income. In short, emissions embedded in household consumption appear to arise from the consumption of necessary goods (rather the luxury goods). This finding is in line with income elasticities of demand for energy services below unity (e.g., Kahn, 1998; Cox et al., 2011; Fouquet, 2014).

These results suggest a dilemma: *Progressive income redistribution may inadvertently raise aggregate emissions arising from consumption.* Sager (2019a) shows how environmental Engel curves can be used to quantify the "equity-pollution dilemma". His estimates of quadratic EECs for CO_2 emissions embedded in the consumption of households in the US indicate that progressive income transfers may raise CO_2 emissions by about 5% at the margin and 2% under full equality. In other words, evidence from consumer micro-data suggests that more income inequality is linked to lower emissions CO_2. Levinson and O'Brien (2019) estimate concave EECs local air pollutants in the US, implying that the above dilemma also may hold for those pollutants. Of course, there is no theoretical principle which predicts that the "equity-pollution dilemma" would necessarily hold in other countries, at other times, or for other environmental impacts. Moreover, the shape of EECs may not be fixed, but could change in line with changes in consumer preferences, aggregate income levels, production technologies, and value chains.

While the literature on the consumer demand channel is largely focused on inequality within countries, the aggregation property may also play a role at the global scale. At the global level, studies on the environmental Kuznets curve[6] tend to find a concave relationship between aggregate economic development and negative environmental impacts. If consumer demand for goods and services with embedded environmental impacts is non-homothetic[7], then changes in global inequality will affect the global aggregate environmental footprint of consumption.

B.2 Collective action in social dilemmas and public good provision
The second channel is based on the observation that many environmental goods and services, and the policies to preserve them, have public good or common pool resource characteristics. Lack of excludability creates a danger of overuse. Collective action is thus often necessary to achieve, or preserve, desirable levels of environmental quality. And the degree of inequality may well shape the capacity for effective collective action. This is so because the distribution of economic resources shapes the bargaining position of individual actors, including their strategic objectives, as well as their relative influence on collective decision-making.

Olson (1965) argues in an early seminal work that *more inequality may make the efficient provision of public goods more likely*. In a nutshell, Olson argues that in groups that are more equal, the benefits of public good provision are diffuse and evenly so. If the group is large, all members receive similar, relatively small benefits. Meanwhile, the costs of engaging in and organizing collective action are relatively high. By contrast, per-person benefits are higher in small groups and in groups with unequal access to the public good. Some members

[5] Convexity (concavity) of $f(.)$ is only strictly equivalent to $\eta^C > 1$ ($\eta^C < 1$) when $f(0) + \lambda_i = 0$, i.e. when consumers with no income generate no environmental impacts. This is not usually the case.
[6] See Caron and Fally (2018) for a recent discussion of the environmental Kuznets curve, and Stern (2004) for a critical review of that literature, which often relies on questionable statistical associations at the country level. Oswald et al. (2020) provide some evidence on between-country differences in energy intensities of consumption.
[7] If preferences are homothetic, scaling income by a constant positive factor increases the demanded consumption bundle by the same factor and Engle curves are straight lines. In this special case, any redistribution of income changes neither aggregate demand nor the associated environmental impact, i.e. $\lambda_i = 0$, $f(0) = 0$ and $f''(.) = 0$.

of such unequal groups, namely those who benefit disproportionately from the public good, have an incentive to contribute to its provision. Taking this argument to the extreme, imagine a public good with entirely unequal benefits, so that only one group member benefits and no one else. This is, of course, no longer a public good and the free rider problem ceases to exist.

Predictions are less clear for the management of common-pool resources such as forests, fisheries and other natural resources. Baland and Platteau (1999) present a systematic analysis of how the degree of inequality within a group may influence the group's ability to maintain a common-pool resource. They find that inequality has potentially important implications, but the sign of the relationship is ambiguous. If we consider *inequality in access rights*, the prediction is intuitive: Inequality in access rights results in stronger incentives for resource preservation among favored groups but lowers incentives for preservation among those with reduced access rights. When a society sets up an agency to regulate resource use, the work of the agency becomes more difficult under unequal access rights.

Clarifying these opposing effects of unequal access rights, Dayton-Johnson and Bardhan (2002) show that in a non-cooperative common-pool resource game, the relationship between inequality and preservation levels is *U-shaped*. Both very low and very high levels of inequality can in theory favor high levels of preservation. The finding is driven by two forces: strategic competition between fishermen and intertemporal management of the fish stock. Strategic competition leads to an equilibrium, whereby conservation is the mutual best response for rivals with claims of equal size. Preservation is a strategic complement. But as inequality in fish stock claims rises, the second force starts to dominate: Fishermen with smaller fish stock have less of an incentive to preserve it. The upward-sloping part of the U-shape is reached when the claim of one fisherman becomes sufficiently large that preservation becomes individually optimal. A more cooperative framework is proposed by Ostrom et al. (2009), who argue that common-pool resources are easier to sustain and manage if users share ethical views on contributions to a group and have trust in each other to adhere to agreements. While the relation of such shared norms and social capital to the distribution of resources is certainly not trivial, these might erode at certain levels of inequality.

Some key environmental policy issues do not only involve public goods at the local or national level, but global public goods. Whether it be ocean plastic pollution or ozone depletion, the global nature of environmental public goods (and 'bads') introduces additional obstacles to effective environmental policy. Climate change is a textbook example of this, since it not only concerns an externality—emissions of heat-trapping greenhouse gases—that is not only large-scale but also one that transcends the boundaries of nation states. The literature on *international climate negotiations* highlights a particular form of inequality: that between rich and poor countries (distinguished by mean income levels). Finding mixed levels of inequality aversion among policymakers, Dannenberg et al. (2010) suggest that we may not be able to rely on inequality aversion to override national interest in international climate negotiations.

Rich and poor countries often disagree on both emission reduction targets and on how the burden of mitigating emissions and adapting to climate change should be shared. The degree of between-country inequality may well affect the nature of strategic interaction. The literature exploring the consequences of global wealth inequality for international climate negotiations largely focuses on public goods games with the typical individual incentive to free ride augmented by wealth inequality between players.

In the absence of a global government, international environmental agreements rely on the voluntary commitments of national states. A rational, self-interested state will thus have incentives to not participate in an agreement if the anticipated free-rider pay-off exceeds the net benefit of being a member to the agreement. This feature makes the performance of environmental agreements sensitive to the distribution of expected damages and abatement costs. Studies of international environmental agreements find that the effect of a more unequal distribution of damages and abatement costs on environmental performance crucially depends on the availability of transfers (Meya et al. 2018; Lessmann et al. 2015, Finus and Pintassilgo 2013; Weikard 2009; Finus and McGinty 2019). Without transfers to compensate states with dominating incentives for free-riding that induce them to stay party to the agreement, an unequal distribution often complicates cooperation, as it creates losers and winners. By contrast, when transfers are available, a more unequal distribution increases the stability of environmental agreements. Finus and McGinty (2019) show that certain, highly skewed combinations of costs and benefits may increase the prospects for cooperation. Similarly, Buchholz and Rübbelke (2020) show that more inequality may lead to increased public good supply and that the assumed form of preferences is decisive for that relationship. In an evolutionary version of a threshold public good game, Vasconcelos et al. (2014) show that, wealth inequality may actually increase group achievement rates across the risk spectrum. However, this effect may be reversed by high levels of homophily, i.e., when feedback and learning that occurs only among individuals of the same wealth level. Intuitively, an important means of upholding cooperation is for rich countries to learn from poor ones. The value of feedbacks between unequal participants in public good games is also found in experiments. But Tavoni et al. (2011) show that cooperation under inequality can be sustained if there an institution exists to promote coordination, such as early commitments on the part of the rich. Similarly, Milinski et al. (2011) find that intermediate targets may help sustain cooperation among groups with unequal endowments.

Evidence: Laboratory experiments suggest that inequality hinders collective action
The experimental evidence from public good games tends to find that inequality does lower group cooperation (Anderson et al., 2008; Tavoni et al., 2011; Gächter et al., 2017). This suggests that inequality is linked to less ambitious environmental policy, assuming that the behavior observed by study participants in a laboratory setting approximates the real-world behavior of country representatives at international negotiations.

In addition to altering the nature of strategic interactions, inequality can also influence the outcome of policy negotiations if concerns for fairness and common equity criteria[8] promote cooperation in public goods games (Lange and Vogt, 2003; Kesternich et al., 2014). When surveying participants in climate negotiations, Lange et al. (2007) find that 75% consider equity to be of "high importance" or "very high importance" for international climate policy. But the same equity criteria may also be used self-servingly to promote private interests of individual countries and undermine cooperation (Lange et al., 2010; Brick and Visser, 2015). As a case in point, Lange et al. (2007) find that representatives of low-income countries are more likely to support the so-called "poor losers rule", in essence lowering the burden of countries like themselves. Both real and self-serving equity concerns would plausibly intensify under higher levels of between-country inequality.

B.3 Political power, social capital and culture

The previous channels discussed whereby inequality may shape environmental outcomes are manifestations of patterns of consumption and collective action. However, inequality may also affect social cohesion and the distribution of political power. These factors are less easily measured and more challenging to model but may nevertheless play an important role. Studies of the political economy channel posit that the degree of economic inequality directly shapes the distribution of political influence (Boyce, 1994; Torras and Boyce, 1998), which in turn translates into changes in environmental outcomes when more and less powerful groups differ in their preferences for the environment. The political power channel has not received much attention from economists but is the topic of research in environmental studies and related disciplines (summarized in Cushing et al., 2015).

The fundamental assumption is that individuals with higher incomes have more political influence, for reasons including access to formal education, procedural knowledge, language barriers, and the ability to engage in lobbying activities (Hamilton, 1995). For pure public goods, this is combined with an assumption that those of greater economic means have less incentive to engage in costly policy measures to preserve the environment. More economic inequality—so the story goes—shifts the power balance further in favor of those who benefit disproportionately from environmental degradation. Less stringent environmental policies are

[8] Another branch of the literature is concerned with formulating fairness and equity criteria in the context of an international climate policy (e.g. Helm and Simonis, 2001; Böhringer and Helm, 2008; Bretschger, 2013).

the result. The reverse holds, however, when moral concern for environmental issues, such as the climate, is a luxury reserved for the rich, as is also sometimes asserted.

For spatially distributed local public goods, power imbalances can mean that the rich are more effective at lobbying to preserve environmental quality in their communities, e.g., via zoning or permits. This can result in inefficient outcomes, whereby environmental benefits are negatively correlated with income. There may be no compensation, or at best imperfect compensation, for the local environmental degradation that disproportionately affects low-income communities. Even if communities have property rights over local environmental goods, Coasean bargaining may result in environmental outcomes that, while efficient, are unequal, which is particularly problematic for essential goods. For example, this may occur if poorer communities had a lower willingness-to-accept compensation for environmental degradation.

Besides influencing the political process, inequality may affect social capital and culture in different ways. For instance, inequality may erode the levels of trust within a society (Alesina and La Ferrara, 2002), which in turn could hinder the social cooperation needed to preserve the environment. Another line of reasoning suggests that inequality shapes consumer preferences. Proponents of this view argue that inequality leads to more intense competition among consumers for the status conferred by conspicuous and positional consumption (Wisman, 2011). But this relationship is far from clear and largely depends on ad hoc modelling assumptions. Some studies find that inequality can spur expenditure cascades when consumption is "upward-looking" (Bowles and Park, 2005; Bertrand and Morse, 2016). Others suggest that when relative consumption is "positional", motivated by the desire to overtake others, it may actually intensify when there is more equality (Hopkins and Kornienko, 2004; Samuelson, 2004). It is possible that no generalizable rule can be established about the effect of income inequality on the degree of relative consumption.

Evidence: There is little direct evidence of an effect of inequality mediated by political power
In a study of US states, Boyce et al. (1999) find an association between higher levels of power inequality and weaker environmental policy. To our knowledge, there is no empirical evidence for the claim that high-income citizens have less concern for the environment. However, there is ample evidence for the influence of political processes on the provision of local public goods. For example, low-income and otherwise disadvantaged communities are more likely to be exposed to toxic pollution (e.g., Hamilton, 1995; Brooks and Sethi, 1997), and often receive lower levels of compensation (Timmins and Vissing, 2019).

B.4 Evidence at the aggregate level
The above review of the three channels through which economic inequality may shape environmental outcomes finds that, at the micro-level, the evidence for these effects is mixed. Concave EECs suggest that aggregate demand for polluting goods and services decreases with inequality, while the effects via collective action and politics are ambiguous. In this subsection we consider evidence for effects of inequality on environmental outcomes, independent of the specific mechanism.

The most common approach reported in the literature (surveyed in Berthe and Elie, 2015) is to look for a correlation between income inequality and environmental degradation at the aggregate level, for countries, states or cities. Some studies find that inequality is positively correlated with levels of environmental degradation. For example, in a study of US states, Baek and Gweisah (2013) find that higher Gini index values are positively correlated with per capita CO_2 emissions. Kasuga and Takaya (2017) find a positive correlation between levels of income inequality in Japanese cities and concentrations of air pollutants such as SO_2, NO_X and PM. Torras and Boyce (1998) find a positive correlation between Gini index values and local air pollution levels across cities and countries. Besides air pollution, there is also some evidence for a positive correlation between within-country inequality and measures of national biodiversity loss (Mikkelson et al., 2007; Holland et al., 2009).

However, other comparable empirical studies report opposite findings. For example, Heerink et al. (2001) find a negative correlation between Gini index values and annual per capita CO_2 emissions in 180 countries between 1961 and 2001. Ravallion et al. (2000) find that inequality, both between countries and within countries, is negatively correlated with CO_2 emissions—a finding that is confirmed by Coondoo et al. (2008). These results appear consistent with the consumer-level evidence of the "equity-pollution dilemma" (Sager, 2019a).

Not only are these results mixed and inconclusive, but the literature as a whole (similar to the literature on the environmental Kuznets curve) suffers from serious limitations to inference. Any correlation between aggregate levels of inequality and environmental outcomes hardly constitutes evidence of a causal effect. There is a large range of factors which covary with both inequality and environmental outcomes. In particular, economic development is often hypothesized to drive both environmental degradation (shown by the environmental Kuznets curve) and inequality (shown by the original Kuznets curve). Other important drivers of both inequality and environmental outcomes are related to industrial composition, technology penetration, political systems, and culture.

B.5 Discussion and direction for future research

Much remains to be explored about the potential effect of economic inequality on environmental outcomes. Inequality can in theory influence environmental outcomes through (at least) three channels, i.e., via consumer demand, collective action, and political power. Recent evidence suggests that the different channels may well work in opposite directions. For example, at the level of consumer demand, efforts to reduce inequality face an "equity-pollution dilemma" whereby progressive redistribution raises emissions; while political cooperation to achieve environmental policy becomes more likely under higher levels of equality. Ultimately, the magnitude and direction of the association between inequality and environmental outcomes is an empirical question, and the existing evidence is mixed.

Important gaps in the literature remain. Existing studies of consumption patterns and embedded emissions suggest that income inequality is associated with lower aggregate demand for emissions-producing goods and services, though this effect may be small. But the evidence is still scarce, with studies largely focused on the United States and CO_2 emissions. Future research into the shape of environmental Engel curves, and the magnitude of the economic effect of the postulated "equity-pollution dilemma" in other countries and for other environmental impacts would certainly be useful to assess the environmental consequences of changes in income distributions.

The collective action channel may well work in the opposite direction, and at a different scale. In particular, the literature on behavior in public good games consistently finds that inequality reduces cooperation on environmental policy. This channel seems particularly important for between-country inequality and its effect on international environmental negotiations. Studies of the role of inequality in collective action and public good provision could benefit from more closely linking evidence from highly stylized laboratory experiments to real-life political deliberations both nationally and on the global stage.

The political power channel is the most speculative among the three, and studies of this effect rely on a number of strong assumptions. Both the relationship between income and power and the relationship between income and environmental preferences may well be context specific. A more systematic analysis of the political power channel—which one might call a *Political Economy of Inequality and the Environment*—would be helpful. Political power and how it is distributed certainly matter for environmental outcomes, but there is still a need to base analyses of this relationship on robust theoretical foundations and to provide convincing empirical support.

Section C: How are costs of environmental policies distributed?

Environmental policy shapes inequality because the means selected for achieving environmental benefits (or avoiding environmental damage) affect the nature and distribution of economic activity. The standard economic approach to analyzing how the burden of a policy is distributed across the population is policy incidence analysis (Parry et al. 2006). Households are divided into groups, such as deciles, based on a welfare measure that is usually annual income or consumption, possibly adjusted by household size. For each group, the relative welfare change resulting from the policy is calculated as the ultimate costs incurred by households. Of course, the effective incidence, after economic adjustments have been made, can be quite different from the statutory incidence of the policy. Welfare changes may be calculated as the equivalent variation in income, as the change in consumer surplus, or as the additional expenditure due to the environmental policy (West and Williams 2004). The first two of these indicators can include behavioral change at the intensive margin, e.g., in the form of consuming less of a good, as well as at the extensive margin, e.g., in the form of switching to a different technology. The relative welfare change defines the policy's cost incidence: a policy where the burden falls disproportionately on the less well-off groups is termed regressive and tends to increase inequality. The cost of a progressive policy instead falls disproportionately on the better-off, and consequently reduces inequality.

Figure 4 illustrates the key dynamics that shape the cost distribution of environmental policy. It considers the case where firms are regulated, for example through a tax on fossil fuels. If a policy regulates consumer behavior, for example with a driving ban in inner cities, this directly impacts on consumer demand. A common conjecture in the literature (e.g., Bento 2013, Klenert and Mattauch 2016) is that environmental policies are regressive due to demand-side effects. If an environmental policy is introduced, part of compliance costs of firms is passed on to consumers in the form of higher prices. These higher-priced goods tend to be necessity goods, which represent a higher share of total expenditure for low-income households, as already discussed in Section B. Typical examples are water and energy. However, the burden of an environmental tax may be progressive if the taxed good is a luxury good, which is often the case in developing countries (for example fuel taxes). Moreover, there are several equilibrium effects that may alter policy incidence. First, on the demand side, consumers react to price changes from the policy by adjusting their demand. If low-income households adjust their demand more than high-income households, the distributional impact becomes less regressive. Second, on the supply side, firms absorb part of the compliance costs themselves. Usually, less than the full cost is passed on to consumers, while we may also see changes in worker incomes and, with firms reducing profit margins, as well as lower shareholder dividends. If the polluting sector is capital intensive and high-income households receive a larger share of their income from capital than poor-income households, this also makes the environmental policy more progressive. Lastly, the environmental policy can be combined with redistribution between households and compensation to firms, or other policy measures, again changing the final incidence of costs and benefits. Each of the effects in Figure 4 can vary in sign and significance depending on policy design and coverage, as well as the economic environment.

This section reviews the literature on how the costs of environmental policies are distributed as a result of the effects shown in *Figure 4*. We focus on the use of taxes, standards and permits targeting climate change and air and water pollution. A literature review on the distributional consequences of environmental policy can be found in Bento (2013). Fullerton (2011) conceptualizes the effects highlighted in Figure 4, to which Fullerton and Muehlegger (2019) add distributional effects of market imperfections. We supplement these reviews by discussing the findings of recent empirical and theoretical studies.

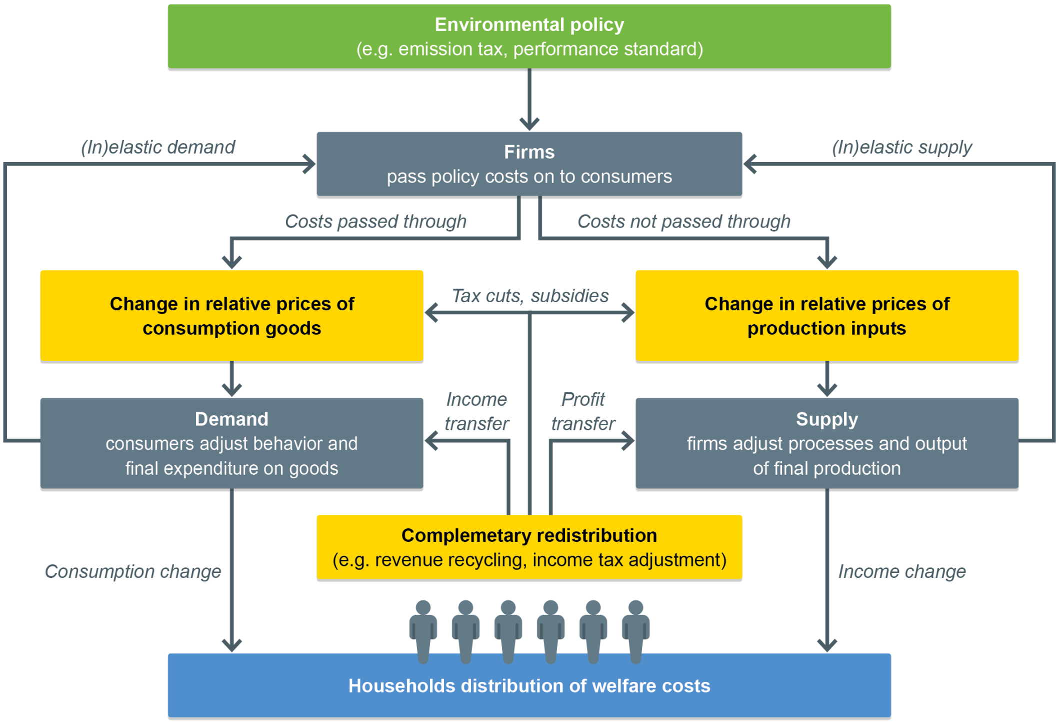

Figure 4: Conceptual framework for the incidence of environmental policy costs
Note: Environmental policy generates compliance costs for firms that are partly passed on to consumers. Passed-through costs change relative prices of goods making cleaner goods cheaper thus triggering demand adjustments (demand side effects on the left). Compliance costs that are not passed through change relative prices of factor inputs (labor and capital) for firms. Firms adjust production processes and output, which changes factor incomes (supply side effects on the right). Complementary policy measures, such as redistribution and compensation, additionally change demand, incentives for firms, and income of households. All channels determine the policy incidence, calculated as the change in welfare across households.

C.1 Distributional impact prior to other adjustments in the tax and welfare system

Many studies focus on the distributional effects of policies prior to recycling of any revenue raised or additional policy changes. Estimates of these effects are of political importance, since they provide an indication of the burden on the population arising from an environmental policy, and identify the need for other policies to avert increasing inequality. Economic analyses assess the distributional effects of a policy based on different assumptions about how the economy reacts (Kosonen 2012; Ohlendorf et al. 2020). Partial equilibrium models, such as microsimulation tools, assume that a policy changes relative market prices for goods, and that demand and supply react with assumed or estimated elasticities to these price changes (Dorband et al. 2019, Brannlünd and Nordstrom 2004). The price elasticity of demand relative to the price elasticity of supply determines the pass-through rate of price changes to consumers, which can be close to 100% (Doyle et al. 2008). At 100% pass-through, the economic burden falls entirely on consumers, while at 0% pass-through producers carry the full burden (prior to other policies). In general equilibrium analyses, policy changes affect factor incomes as well as commodity prices (Fullerton and Muehlegger 2019). Eventually, all policy costs fall on households, through changes in commodity prices (demand side) and, through effects on incomes from wages, capital returns and other sources (supply side). The sign and relative importance of the various effects differs across policies. We first consider policies to address climate change and then those targeting air and water pollution.

C.1.1 Climate policy

The distributional impact of climate policy can be split into two parts. *Direct* distributional effects come from higher prices for the polluting fossil fuels that households consume themselves, such as for heating or transportation. *Indirect* effects result from higher prices for other goods, which have emissions embodied in their upstream production. In that case, producers pay the tax but may pass on the costs to households. The sum of both effects is the total distributional impact of the policy on the demand side.

Many, but not all, partial equilibrium models of demand-side effects, find that direct taxation of gasoline, carbon taxation and carbon emission permit markets with full auctioning are regressive in countries with higher income and progressive in countries with lower income (Tiezzi 2005; Wier et al. 2005; Bento et al. 2009; Datta 2010; Feng et al. 2010; Grainger and Kolstad 2010; Sterner 2012a,b; Berri et al. 2014; Berry 2019; Dorband et al. 2019; Douenne 2020). In middle income countries, the distributional burden may be U-shaped, with middle income households carrying the largest burden. A main contributing factor to progressive or U-shaped burdens is that car ownership in poorer countries is limited to better-off households. Low-income households in these countries are therefore often only mildly affected by the taxation policy through the transportation channel. Another contributing factor is that water and electricity can be a luxury good in some developing countries so that low-income households are again less affected by any price increases. In high-income countries, energy or carbon taxation tends to be regressive.[9] In these countries, energy is a necessity good, i.e., its usage increases less than proportionally with income, so that the consumption of emission intensive goods makes up a larger budget share for low-income households compared to those with high incomes. As in Section B, the income elasticities of demand for different goods, combined with their emission intensities, determines the pattern of distribution. If the income elasticity of consuming dirty goods (η^C) is below one, low-income households consume dirty goods disproportionately, while consumption by high-income households predominates for an elasticity above 1. Consumption is proportional to income if the elasticity equals one.

Some studies allow households to adjust their consumption pattern in response to price changes based on income-dependent price elasticities. West (2004), West and Williams (2004) and Santos and Catchesides (2005) find that low-income households react more strongly to a change in energy prices than those with high incomes, which results in a less regressive distributional impact of taxation. Contrary to this, Kayser (2000) finds that households with higher incomes react more to price changes than low-income households. Such demand-side effects drive the realized incidence of policy changes if consumers' demand is inelastic compared to producers' supply. In that case, price increases from climate policy are mostly passed on to consumers. There is much evidence that pass-through rates of carbon, energy and fuel taxes are close to 100% in many sectors (Sijm et al. 2006; Doyle et al. 2008; Marion and Muehlegger 2011; Davis and Kilian 2011; Li et al. 2014; Fabra and Reguant 2014; Joltreau and Sommerfeld 2019; Andersson 2019). Yet, a number of sectors cannot fully pass on additional costs to consumers (Joltreau and Sommerfeld 2019); for example, pass-through rates are estimated at 60% for some sectors covered by the European emissions trading scheme (Sijm et al. 2006) and 70% in US manufacturing (Ganapati et al. 2020).

In general equilibrium analyses, supply-side effects are added on. Here, the policy changes not only relative prices of commodities and consumers' demand but also the prices of input factors. Labor and capital demand adjust, and with them the distribution of factor incomes. Consumers absorb these changes, modifying the incidence of the policy. The additional general equilibrium effects often render the incidence of a carbon tax more progressive (Rausch et al. 2010; Rausch et al. 2011; Dissou und Siddiqui 2014; Beck et al. 2015; Goulder et al. 2019). This is driven by reduced returns on capital due to taxation. Rich households face a higher share of policy costs through this general equilibrium channel. as firms that are greenhouse gas emissions intensive are also more capital intensive, and because

[9] Klenert and Mattauch (2016) relate the regressive consumption pattern of emission intensive goods often found empirically to a subsistence level that households in high-income countries need to consume. In a theoretical model they show that "the existence of a subsistence level of polluting consumption is a strong driver of the regressivity".

high-income households derive a larger income share from capital. Fullerton and Heutel (2007) show that an environmental tax places a higher burden on capital if the polluting sector is capital intensive, or if firms can more easily reduce pollution by increasing expenditure on labor rather than capital investment, although this does not hold in all economic environments. Focusing on unemployment, Yip (2018) shows that low-educated workers suffered disproportionately from job losses following the introduction of carbon tax in British Columbia.

Studies of different command-and-control policies implemented to regulate fossil fuel use show how sensitive the distributional impact is to the choice of policy instrument. Davis and Knittel (2019) find that fuel standards are more progressive than taxation prior to revenue recycling, while carbon taxation is found to be more progressive than clean energy tax credits by Borenstein and Davis (2016), and more progressive than energy efficiency standards by Levinson (2019). Clean vehicle subsidies are also found to be regressive (Tovar-Reanos and Sommerfeld 2017), as well as subsidies for renewable energy carriers (Neuhoff et al. 2013; Frondel et al. 2015). Bruegge et al. (2019) find that lower income households are adversely affected by building energy codes in California. Ohlendorf et al. (2020) perform a meta-analysis on the distributional impacts of climate mitigation policies. They find that generally lower national income, the use of transport policies, indirect effects, and behavioral adjustments in demand render climate policy less regressive. Sager (2019b) adds another dimension to climate policy incidence analysis by considering the global distribution of impacts of mitigation policies on households. Sager finds that a carbon tax has a globally regressive demand-side impact, before revenue recycling. Regressivity is driven by inter-country differences: low-income countries tend to have a higher emission intensity of output. Households from these low-income, high-polluting countries tend to populate the lower end of the global income distribution. While the tax might be progressive within low-income countries as discussed above, it remains globally regressive, at least before revenue recycling. Feindt et al. (2020) show the same for carbon pricing in the EU: while impacts in individual countries are mostly proportional across income levels, a carbon tax is regressive across European households.

C.1.2 Water and other air pollution policies

While the bulk of environmental incidence analysis deals with greenhouse gas emission regulation, there are also some studies of the incidence of other air pollution regulations. Gianessi et al. (1979) analyze the 1970 US Clean Air Act that regulates air pollution through command-and-control instruments. Including environmental benefits and policy costs, they find that the lowest income group gains most from air pollution reduction. Excluding benefits, Robison (1985) find a regressive effect of pollution abatement costs in the US, based on a study of "Pollution Abatement Costs and Expenditure" reports.

Studying NO_X and SO_2 emission permit markets with full grandfathering, Parry (2004) shows that these have regressive effects in the US, while Curtis (2018) finds that young workers and new-hires are particularly prone to unemployment and declines in earnings. Jha et al. (2019) investigate particulate matter and ozone pollution control under the US Clean Air Act that are regulated through air quality standards. They find that environmental regulation increased income inequality in the period 2005–2015 (with the benefits of emission regulation again included in the overall regressive impact). Also focusing on the distributional effects among workers, Walker (2013) shows that workers with high earnings were more adversely affected by the 1990 Clean Air Act Amendments than low-income workers.

There are also some older studies of the distributional consequences of water regulation in the US. Lake et al. (1979) investigate the Clean Water Act of 1972 and find a regressive impact of pollution control costs, which remains regressive under different policy instruments for financing municipal water facilities (see Parry et al. 2006). Collins (1977) shows that the subsidies of the Clean Water Act redistribute income from the middle to higher income classes in the Midwestern US. Ostro (1981) finds that in the Boston area, the program redistributed income from high- to low- and middle-income classes. More recently, Ruijs (2009) shows that switching from a block pricing to a flat pricing system for water in the Sao Paulo region redistributes welfare from the middle- to low- and, especially, high-income groups.

C.2 Incidence of environmental policies

Environmental policies may increase or decrease inequality, prior to any other adjustments in the tax and welfare system, depending on the instrument used and the economic environment. If the aim is to avoid increases in inequality, redistribution, such as recycling of revenues raised by environmental taxation or adjusting the income tax system, can be introduced along with the environmental policy (Rausch and Schwarz 2016). The sum of distributional impacts of all design elements of the environmental policy reform determines its final incidence.

In the context of carbon pricing, uniform lump-sum rebates of collected taxes typically render the final incidence progressive while income, value-added or capital tax cuts tend to have a more regressive impact (Rausch et al. 2011; Klenert and Mattauch 2016; Goulder et al. 2019). Optimal taxation theory suggests that pollution taxation in conjunction with uniform lump-sum transfers is a salient policy reform when the income tax system faces incentive constraints (Jacobs and de Mooij 2015; Klenert et al. 2018).

To protect the poor, targeted transfers may also be used. Murray and Rivers (2015) show that such transfers rendered carbon tax incidence progressive in British Columbia. With reference to Latin America and the Caribbean, Vogt-Schilb et al. (2019) demonstrate that only 30% of carbon tax revenue needs to be returned to the poor to offset the adverse effects of carbon taxation. Rausch et al. (2010) highlight that, in addition to revenue recycling, adjustments to the tax and welfare system have an important role to play. For the US they show that inflation index-linked transfers to low-income households protect the poor from price increases and even render the incidence of carbon pricing modestly progressive prior to revenue recycling. On the global scale, Sager (2019b) shows that revenue recycling via national carbon dividends could render the net incidence of carbon pricing progressive not only within countries, but also globally. Feindt et al. (2020) find a similar progressive effect of national per-capita revenue recycling within the EU. However, Fullerton and Monti (2013) find, based on analysis of a theoretical general equilibrium model, that targeted transfers to the poor are often not enough to protect them from all adverse effects of pollution taxes.

Revenue recycling is not the only redistribution mechanism applied in the context of environmental policy. Within emissions trading schemes, some or all permits can be allocated at no charge. Where a distinction is made between output-based versus grandfathered permit allocations, this indirectly leads to a redistribution of effects on consumers through changes in capital income, as some firms receive additional rents, or windfall profits. If these windfall profits predominantly increase income from capital for high-income consumers, the tax is likely regressive. Parry (2004) showed that this was indeed the case in the US for carbon, NO_X and SO_2 emission regulation. Grainger and Costello (2016) and Keppler and Cruciani (2010) highlight that, in addition to rents from grandfathering, permit markets also create inframarginal rents for some firms, that benefit from prices rises above their marginal costs, an effect that can further exacerbate the distributional consequences of windfall profits in US fishery and European emission permit markets.

Other policies, in addition to the redistribution of taxation revenue, can be used to address inequality concerns. Ruijs et al. (2008) and Ruijs (2009) demonstrate that block pricing in the water sector can be used to avoid large burdens on the poor in the Sao Paulo region, albeit with efficiency costs. In the context of the German renewable feed-in-tariff system, Neuhoff et al. (2013) suggest that investing in energy efficiency and reducing other electricity taxes through a nonlinear pricing system are viable options to mitigate increased inequality arising from the policy. Of course, there is a multitude of other policy options through which unequal effects of environmental policy may be reduced, and national circumstances will shape the effectiveness of specific policies.

C.3 Gaps in the literature

More research is required to gain a comprehensive understanding of what drives the incidence of environmental policies. First, the majority of analyses are carried out in high-income countries, specifically in the US and European countries. More studies in other countries would broaden the understanding of drivers, and enhance the ability to devise comprehensive policy packages. In addition, comparison of existing studies is difficult, as the policies investigated differ in their scope. A second and related limitation of existing research is that few studies compare policy incidence across countries (see exceptions in Harding et al. 2014; Flues and Thomas 2015; Sterner 2012a; Ohlendorf et al. 2018; Dorband et al. 2019). Ohlendorf et al. (2018) were the first to conduct a meta-analysis of the drivers of climate policy incidence; such studies should be undertaken regularly as new evidence becomes available. Lastly, the bulk of the literature considers energy and climate policies and there are few studies of the distributional impact of other environmental policies. For instance, it would be useful to know more about the economic incidence of biodiversity conservation policies, to inform the substantial reforms needed for the targets of these policies to be achieved.

While microsimulation and general equilibrium modeling have been combined to widen the scope of studies of policy impacts in recent years, such models usually rely on future macroeconomic trends as inputs for baseline scenarios (Dellink et al. 2020). Few if any studies employ coupled models that consider long-term macroeconomic changes due to environmental policy (see Bertram et al. 2018) in combination with general equilibrium distributional analysis.

Incidence analyses are usually performed at the national level. Transboundary pollution problems, such as climate change, have distributional consequences that transcend nation states. In the first published analysis of international carbon pricing effects, Sager (2019b) shows that demand-side effects of a carbon tax are globally regressive, mostly due to differences in average incidences across countries. Feindt et al. (2020) report results of a distributional analysis of effects across Europe. In general, there is a need for more studies of this type, which raise important questions about international equity. Since fiscal policy falls under national jurisdiction, it remains an open question how environmental policies and arrangements for redistribution among countries can and should be designed to alleviate concerns relating to between-country distributional effects. Initiatives to address these concerns should take account of the extensive literature on collaboration between countries to address transboundary environmental problems (Chichilnisky and Heal 1994, Knopf et al. 2015, Dorsch et al. 2019).

More research is also needed to identify additional policies, in particular social or economic policies, required to mitigate increases in inequality arising from environmental policy. Studies often focus on very specific policy packages that are being implemented or considered for implementation, or analyze generic policy responses such as lump-sum transfers or income tax cuts. A systematic understanding of which environmental policies should be combined with which additional measures, and under which economic circumstances, would be a valuable addition to current knowledge from both an academic and a policy perspective.

Finally, recent research has started looking at horizontal equity, i.e., the distribution of costs within income groups (Cronin et al. 2019). Such studies recognize that not all equity concerns revolve around income. Important examples of horizontal inequity relate to the rural vs urban divide and to temporary or permanent job losses in specific industries, both of which feature prominently in policy discourse. Future research should identify appropriate disaggregation procedures and indicators for incidence analysis that consider other factors beyond incomes and consumption.

Section D: Inequality in environmental policy appraisal

How can we account for economic inequality when designing and evaluating environmental policy? Any environmental policy appraisal is an inherently normative process involving prior value judgements on *what* has a value, which in economics is often represented by the utility function, and on *how to aggregate* individual values, often formalized by the social welfare function (SWF). The latter represents an ethical judgment on inequality. Economists need to account for pre-existing inequalities and the distributional consequences of an environmental policy at the policy evaluation stage, such as during cost-benefit analysis. And they should be able to do so in a way that reflects different legitimate moral ethical stances. In the preceding sections, we implicitly assume a SWF when studying the incidence of environmental benefits (Part A) and policy cost (Part C) by considering monetary (equivalent) changes relative to income. We now discuss such normative choices explicitly, and how policy makers can take account of inequalities in a systematic way when evaluating alternative projects and policies.

The guiding question for this section is therefore *How can environmental policy appraisal account for inequality?* Figure 5 provides a conceptual overview. We focus on the social welfare approach to social choice, which is largely confined to consequentialist ethics, i.e., justice of outcomes, rather than procedural justice. Our focus is on intratemporal inequality at a given moment in time, but we consider the effects on both intratemporal ('static') and intertemporal ('dynamic') valuation.[10]

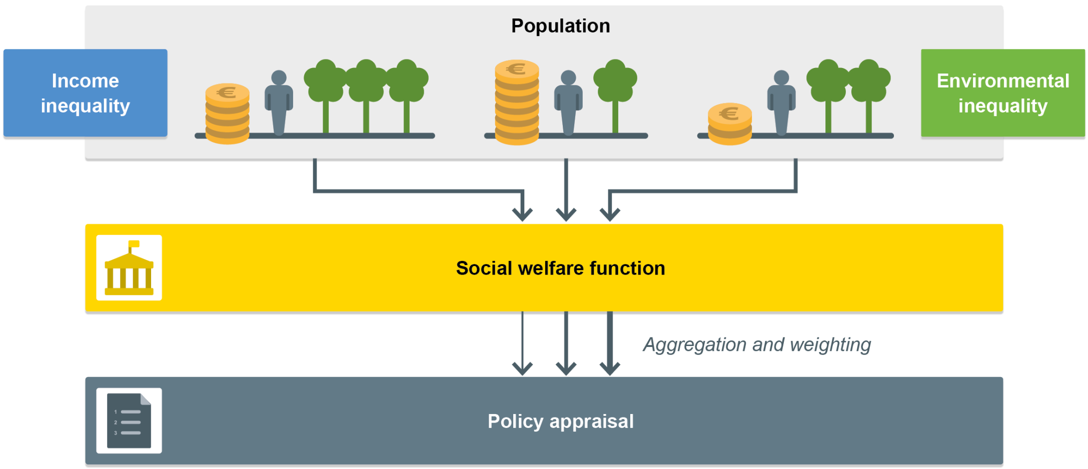

Figure 5: Conceptual framework for the role of inequality in environmental policy appraisal
Note: The ranking of different options in policy appraisal is determined by the prevailing distribution and the concept of social welfare. First, the effects of policy being evaluated depend on the distribution of income and environmental quality in the population. Second, how these changes in individual well-being are aggregated and weighted depends on the normative choice of a social welfare function that aggregates and weights individuals' well-being.

D.1 How to account for the prevailing inequality in static valuation?

D.1.1 Social welfare and equity weighting

How can we aggregate measures of individual utility change (e.g., WTP) resulting from an environmental change to inform societal decision making? Applied welfare economics bases individual utility on individual preferences, and the ranking of options (policies, projects etc.) at the societal level on aggregate individual utilities.[11] This thinking can be organized in a SWF, which formalizes ethical preferences and generates a societal ranking of outcomes. A SWF involves value judgements on at least two levels (Boadway 2006): regarding (i) an individual's utility function and (ii) the aggregation of individuals' utility.

To illustrate, let U_i denote the utility of household i and let us distinguish between the consumption of a manufactured good, C_i, and that of an environmental good, E_i. Contingent on individuals' preferences, and assuming inter- and intrapersonal comparability of utility (e.g., d'Aspremont and Gevers 2002), the social welfare function (SWF) then maps any allocation of goods into a measure of social welfare, W:

$$W(C_1, \dots, C_n; E_1, \dots, E_n) = SWF\big(U_1(C_1, E_1), U_2(C_2, E_2), \dots, U_n(C_n, E_n)\big). \qquad (4)$$

[10] We do not discuss here how the distribution across generations should affect the intertemporal valuation or how intergenerational equity should affect the appropriate welfare framework, as this has been discussed in depth in the literature (see, e.g., Asheim 2010; Zuber and Asheim 2012; Heal 2016; Cairns et al. 2021).
[11] The question "Equality of what?" or, technically, which aspects of the individuum should be compared and aggregated can also be based on individual's capabilities instead of preference-based utility (Sen 1985).

Valuation studies have shown how monetary measures of individual utility changes, such as WTP, for a change in the environmental public good depend on the individual's endowments of income and environmental goods. Consequently, aggregate WTP depends on the pre-existing distribution of attributes (income, environmental good, health, etc.) and on how these will be changed by the policy under evaluation. How a particular change in the distribution of attributes is valued depends on the SWF, which specifies how to aggregate individual utility changes.[12]

A popular specification is an isoelastic, additive separable SWF with a parameter for society's inequality aversion with respect to the distribution of individuals' utility (see e.g., Adler 2016, Boadway 2006, Johansson-Stenman 2005, Nurmi and Ahtiainen 2018):

$$W(C_1, .., C_n; E_1, \dots, E_n) = \sum_{i=1}^{n} \frac{U_i(\mathrm{C_i}, E_i)^{1-\rho}}{1-\rho}, \tag{5}$$

where $U_i(.) > 0$ is household i's utility depending on the allocation of attributes (C, E) and $\rho \geq 0$ measures society's aversion to inequality. For $\rho = 0$ the SWF is utilitarian, for $\rho = +\infty$ maximin (or Rawlsian) and for $\rho = 1$ not defined. d'Aspremont and Grevers (2002) provide an overview of the ethical underpinnings of different SWFs, including those already mentioned and leximin, which compares utilities of the worst-off individuals (see Adler et al. 2016). Under the utilitarian social welfare function ($\rho = 0$), which sums up individual utilities $W = \sum_{i=1}^{n} U_i(C_i, E_i)$, societal welfare is increasing in total utility but independent of the distribution of utility. However, the distribution of attributes (C, E) still matters as long as these utilities are non-linear. When aggregating individual WTPs, they need to be weighted to account for pre-existing endowments of attributes that determine WTP. This can be done with distributional weights, which can be chosen to correspond to a certain SWF and hence require ethical choices (Adler 2016, Fleurbaey 2019). Recent reviews on distributional weights in cost-benefit analysis are provided by Fleurbaey and Abi-Refeh (2016) and Adler (2016).

Adler (2016) presents a common approach to formalizing distributional weights: Let $\left(C_i^k,\ E_i^k\right)$ denote the individual's bundle at outcome k and let $(C_i^0,\ E_i^0)$ be the individual's consumption bundle at the status quo. ΔC_i is the equivalent variation so that $U_i\left(C_i^0 + \Delta C_i, E_i^0\right) = U_i\left(C_i^k, E_i^k\right)$. Individual i's marginal utility of consumption at the status quo is $\frac{\partial U_i(C_i^0, E_i^0)}{\partial C}$. For the general case of a positive inequality aversion ($\rho > 0$), the change in welfare of outcome k is given as follows (see also Appendix A.1):

$$\Delta \mathrm{W}^k \approx \sum_{i=1}^{n} U_i\left(C_i^0, E_i^0\right)^{-\rho} \cdot \frac{\partial U_i}{\partial C}\left(C_i^0, E_i^0\right) \cdot \Delta C_i^k. \tag{6}$$

A change in the consumption equivalent of individual i from outcome k is weighted not only by its marginal utility of consumption under the status quo, $\frac{\partial U_i}{\partial C}\left(C_i^0, E_i^0\right)$, but also by the "marginal moral value of utility" (Adler 2016, p. 272) of this individual, i.e., $U_i\left(C_i^0, E_i^0\right)^{-\rho}$. Since the latter equity weight is a convex and decreasing function of utility, it further increases the weight given to those with lower utility levels. The larger society's inequality aversion ρ, the more weight is given to changes in equivalent consumption ΔC_i^k of the worse-off. For a small change around the status quo, the utilitarian distributional weights (that is with $\rho = 0$) are equal to the marginal utility of consumption in the status quo (C_i^0, E_i^0), which depends on both the level of consumption and environmental goods.[13]

[12] This includes the choice of whose preferences count in a certain policy appraisal, i.e. to determine 'Who has a standing in CBA?'. For estimates of the social cost of carbon some countries only consider damages to their own population, while others consider global damages.

[13] For instance, if utility is logarithmic in consumption, $U(C_i^0, E_i^0) = ln(C_i^0) + g(E_i^0)$, then ΔC_i is weighted by the inverse status quo consumption, i.e. the utilitarian distributional weight for household i becomes $\frac{\partial U_i}{\partial C} = \frac{1}{C_i^0}$. This is a special case of isoelastic utility, $\left(C_i^0, E_i^0\right) = h\left(E_i^0\right) \cdot \frac{{C_i^0}^{1-\beta}}{1-\beta} + g(E_i^0)$, where β is the elasticity of marginal utility

This highlights two points: First, simply adding-up monetary benefit estimates—which is a standard approach in applied welfare analysis—implicitly assumes that the pre-existing distribution of resources is completely egalitarian or that society has no inequality aversion. The SWF is utilitarian and individuals' utility is quasi-linear, so that the marginal utility of consumption is constant (Boadway 2006).[14] Welfare economists therefore generally reject unweighted cost-benefit analysis, as "it is connected to no good welfare economics" (Fleurbaey and Abi-Refeh 2016, p. 302) and argue that using no weights "is actually the worst of the possible choices" (Fleurbaey 2019, p. 671) as it ignores pre-existing inequalities. However, distributional weights are seldom used in public sector cost-benefit analysis with some notable exceptions.[15] The reasons for this are probably related less to the lack of conceptually convincing case studies and more to the lack of ready-to-use procedures for the use of distributional weights in specific contexts (Fleurbaey and Abi-Refeh 2016), including empirical estimates of the corresponding preference parameters.

Second, even when distributional weights are considered, these mostly relate to pre-existing income levels (Fleurbaey 2006). But, as we show above, endowments of environmental goods are equally important (Adler 2016, Meya 2020). Such *environmental distributional weights* are likely more important for environmental goods that are essential to human well-being, where supplies do not rise above subsistence levels and/or levels at which people are reluctant to substitute them by market-traded consumption goods. The magnitude of the distributional weights depends on two elasticities. The elasticity of marginal utility with respect to the level of consumption indicates by how much the utilitarian weight differs over the distribution of consumption. That elasticity is $\mu_{CC} := -\frac{d(\partial U(C_i,E_i)/\partial C_i))}{d\, C_i}\frac{C_i}{\partial U(C_i,E_i)/\partial C_i}$. In the context of a utilitarian SWF, μ_{CC} is often referred to as the intratemporal consumption inequality aversion (e.g., Groom and Maddison 2019), since differences in the marginal utility of consumption are the only channel by which intratemporal inequality enters the utilitarian SWF. Since the marginal utility of consumption at the status quo depends also on the endowment of environmental goods, the analogous elasticity of the marginal utility of consumption with respect to the environmental good is $\mu_{CE} := -\frac{d(\partial U(C_i,E_i)/\partial C_i))}{d\, E_i}\frac{E_i}{\frac{\partial U(C_i,E_i)}{\partial C_i}}$.

D.1.2 Empirical estimates of inequality aversion and applications of distributional weights

We divide the empirical literature on distributional weights into three groups: (i) approaches that use stated or revealed preference methods to test the extent of agreement between public preferences and common SWFs, (ii) approaches that estimate a parameter within a social welfare framework, such as inequality aversion, (iii) applications of distributional weights.

First, philosophers argue that ethical frameworks or principles of distributive justice need to be amenable to rational debate (e.g., Rawls 1990, Habermas 1971). This necessarily includes a reflective process of interaction between those who propose a certain SWF and the wider public. Empirical studies that elicit the ethical views held by citizens can contribute to this process. In the words of Venmans and Groom (2021): "by testing the normative framework, [empirical research] can be thought of as providing an important iteration towards a Rawlsian *reflective equilibrium*, through which normative ideas are iteratively tested against their implications, and their assumptions revised accordingly." To engage in this process of reflection, environmental economics can draw on a range of revealed or stated preference methods, but must take care not to confuse ethical preferences regarding social decisions with those relating to individual behavior (cf. Sen 1970). In other words, a person may express different preferences as a consumer than as a voter.

of consumption and $h(E_i^0) > 0$, $g(E_i^0)$ are constants and environmental quality is fixed at E_i^0 (Adler 2016). In this case, the utilitarian distributional weight is $\frac{\partial U_i}{\partial C} = \left(\frac{1}{C_i^0}\right)^{-\beta} \cdot h(E_i^0)$.

[14] An alternative is to use a weighted utilitarian SWF and implement Negishi-weights (Nordhaus and Yang 1996).

[15] Exceptions include the UK's government guidelines on cost-benefit analysis (HMT 2011) and the valuation of climate change damages in Germany, which are estimated using distributional weights (UBA 2018).

Dietz and Atkinson (2010) find in a discrete choice experiment that the WTP for reductions in local air pollution or greenhouse gas emissions increases significantly if the costs are distributed in line with the polluter-pays or the ability-to-pay principles, and that respondents trade off these equity considerations against efficiency. Cai et al. (2010) find that individual WTPs for different climate policy options depend on how their costs are distributed in combination with the respondent's distributional preferences. Svenningsen and Thorsen (2020) find that the majority of Danish households express some aversion to inequality in the distribution of future climate change damages across countries. Such studies highlight that the two-step approach to social welfare that interprets individual utility as purely self-regarding and only considers inequality concerns when aggregating them to social welfare might conflict with the ethical views held by the wider public.

Second, within a certain ethical framework, reflected by a SWF, any application to policy analysis requires specifying the parameters of the SFW. In the context of distributional weights, the key parameter of the SWF is inequality aversion, ρ . Most empirical approaches to inequality aversion have been conducted for a utilitarian SWF, by estimating the elasticity of marginal utility, and for a single consumption good. For instance, in a meta-study of the UK, Groom and Maddison (2019) find that the elasticity of marginal utility of consumption does not differ significantly across empirical approaches and amounts to around $\mu_{CC} = 1.5$. Little is known about such elasticities for non-market goods, and particularly the elasticity of the marginal utility of consumption with respect to an environmental good, μ_{CE}. But these are necessary in order to be able to calculate environmental distributional weights and to compare them to distributional weights for consumption. Groom and Venmans (2021) estimate the related environmental inequality aversion using an experimental task with a student sample and find an intratemporal inequality aversion of $\mu_{EE} = 3$. Studies like this allow investigation of whether inequality aversion regarding the distribution of environmental quality differs substantially from income inequality aversion. Based on studies on income inequality aversion (e.g., Almås et al. 2020, Cappelen et al. 2007), one may expect that environmental inequality aversion may depend on the source of inequality, i.e., whether disparities are driven by differences in income, preferences, access to education and information, luck in terms of geographical location, or discrimination.

Third, empirical applications of distributional weights for environmental policies are sparse and mostly conducted in a dynamic context (see Section D.2). One exception is Numri and Athianen (2018), who specify inter- and intraregional distributional weights for their study of WTP for water improvements in the Baltic Sea based on contingent valuation surveys in all neighboring countries. For standard choices of the inequality aversion parameter, they find that that the sum aggregate WTP for all countries is three times higher than in the unweighted case, and that the ordering of countries by aggregate WTP is reversed: after distributional weighting, aggregate WTP in poor countries is several times higher than in richer countries.

D.1.3 Pareto-efficiency and distribution

One way to avoid the interpersonal comparison of utility implied by a SWF is to adhere to the Pareto-principle, which, however, only allows for a ranking of options in the very special case that one is Pareto-superior to the others (Fleurbaey and Abi-Refeh 2016). There is unlikely to be a unique Pareto-optimum for evaluations of a policy that affects many members of society, as environmental policy tends to do. Rather than ranking options, the aim of a CBA is then (only) to check whether an option is Pareto-efficient. According to the Lindahl-Samuelson condition, the Pareto-efficient supply of public goods requires that the sum of individual WTP equals the marginal cost of supplying the public good. Yet, there may be many allocations that are Pareto-efficient and, in this case, a societal value judgement, for example in the form of a SWF, would be needed to choose among them.

Unweighted cost-benefit analysis is often justified by the Kaldor-Hicks criterion, that merely requires that winners could hypothetically compensate losers (Kaldor 1939, Hicks 1940). This transfers the additive structure of utility in utilitarianism to money-metric changes in utility, such as WTP, in CBA. By thus ignoring inequality in pre-existing endowments of attributes (income, environment, health, etc.) and it "fails to make relevant interpersonal comparisons" (Fleurbaey 2019, 670) by assuming marginal utility of income is identical for all individuals[16]. This procedure leads to cyclical, non-transitive policy conclusions due to changes in relative prices (Boadway 1974). Since the willingness-to-pay may differ from the willingness-to-accept a compensation, the Kaldor-Hicks-criterion also depends on the allocation of property rights (Dietz and Atkinson 2010). In sum, using hypothetical compensation as a welfare criterion does not provide a justification for unweighted CBA (Boadway 1974). Furthermore, claims that equity and efficiency can be separated if distributional effects are compensated for through redistribution via the tax system are politically unrealistic in most circumstances.[17]

Pareto-efficient levels of (environmental) public goods also depend on the distribution of attributes (again except for the special case where utility is quasi-linear). When aggregate WTP is simply the sum of individual WTPs, more equal societies have a higher societal WTP for homogenously distributed public environmental goods if the constant income elasticity of WTP, η^W, is below one (Baumgärtner et al. 2017; Drupp et al. 2018). For mean preserving spreads, this follows directly from Jensen's inequality (Baumgärtner et al. 2017): If the income elasticity is below one, then individual WTP increases with income, but at a decreasing rate. Therefore, any Pigou-Dalton transfer, transferring income from a rich to a poor individual in society (leaving mean income constant), increases aggregate WTP. The increase in WTP by the poor more than compensates the loss of WTP by the rich. The effect is reversed if $\eta^W > 1$, whereby a higher income inequality increases aggregate WTP. If the environmental good is distributed heterogeneously, there is a similar effect for environmental inequality (Meya 2020), to the extent that the effect of income inequality might be reversed if the rich have a relatively high endowment of environmental goods. The resulting inequality adjustment factors for Pareto-efficiency are equivalent to a utilitarian distributional weight, as Pareto-efficiency and the utilitarian SWF functions share the same unweighted, additive structure.

D.2 How to account for prevailing inequality in dynamic valuation?

Aggregate benefit or cost estimates of future environmental change, such as the social cost of carbon (SCC), require aggregating monetized impacts over people with different endowments of income and non-market goods. Implicitly or explicitly such estimates are based on an intertemporal SWF, incorporating specific value judgements on equity and distributive justice at each point in time (Anthoff and Tol 2010, Fankhauser et al. 1997).

When estimating optimal targets for environmental policy by the means of integrated assessment models, economists often rely on representative agent frameworks (e.g., Nordhaus 2008, 2017). This implies that (i) there are either no intratemporal inequalities in the distribution of a policy's environmental consequences or in the pre-existing distribution of both market and non-market goods or that (ii) welfare is utilitarian and the marginal utility of market and non-market goods is constant (see section C1). Hence, the same objections of welfare economists to unweighted cost-benefit analysis (e.g., Arrow 1951, Boadway 1974, Fleurbaey 2019) apply to representative agent integrated assessment models (IAM). Nevertheless, many IAMs studies are based on a discounted utilitarian SWF (e.g., Nordhaus 2017, Hänsel et al. 2020).

The moral stance taken on intratemporal inequality shapes the results of these IAMs and, when intratemporal inequality is accounted for, this tends to increase the SCC in high-income countries, because equity weights emphasize the greater climate damage suffered by poorer countries. So far inequality aversion in IAMs has been mainly implemented on the level of regions. For instance, Fankhauser et al. (1997) and Tol (2002) use several SWFs in the FUND model, including an isoelastic constant inequality aversion SWF (similar to that in Eq. 2), that assigns more weight to the welfare of poorer regions relative to richer ones. As the poor suffer higher climate damages, optimal mitigation effort increases with the degree of inequality

[16] When summing individual WTP, the utility change of those with a higher marginal utility of income (i.e. the poor) is given a lower weight in calculating non-market benefits as aggregate WTP (see Nyborg 2012).

[17] Harberger (1978), and studies building on drawing on his approach, argue that CBA should only be concerned with efficiency and that equity considerations should be treated separately through taxes and transfers. Johansson-Stenman (2005) shows that as soon as society has some degree of inequality aversion, it is optimal to use distributional weights in cost-benefit analysis, even when the income tax could be adjusted.

aversion. Depending on the reference region, Anthoff et al. (2009) find that equity weights substantially raise the SCC. Alder et al. (2017) assign more weight to worse-off regions using a "non-discounted prioritarian" SWF for a two-region model implemented in RICE, finding a substantially higher SCC compared to when using discounted utilitarianism. Further studies that incorporate interregional inequality preferences in IAMs when estimating the SCC include Anthoff and Tol (2010), Tol (2010) or Hope (2008). Some regionalized IAMs calculate region-specific SCCs (Ricke et al. 2018) that allow evaluation of how monetized climate damages are distributed among regions (given a set of value judgments), a question related to discussions in Section A. Anthoff and Emmerling (2019) present a SWF that separates aversion against inequality over time (discounting) from aversion against inequality between individuals at a given point in time (equity weighting). Using the US as a reference region, they find that the SCC calculated using an IAM increases by factors of 2 to 3 when applying the disentangled equity weighting approach, with weights specified for between-country differences in income.

While these studies include equity weights for income differences *between* regions in the SCC estimates, they do not do so for differences between individuals (i.e., *within* region) and thus capture only a part of the heterogeneity. Denning et al. (2015) model within-region income distribution using the RICE model and find that inequality substantially affects the SCC and that the effect is comparable to the choice of the discount rate within commonly assumed parameter ranges. Kornek et al. (2021) develop a model that accounts for inequality within and between nations and show that SCC depends on whether a country's low-income households are compensated for climate damages. None of the studies on the SCC we are aware of uses weights to account for differences in the pre-existing distribution of natural capital.

Related studies investigate how social preferences relating to intertemporal distribution, as captured by a social welfare approach to social discounting, can account for intratemporal inequality aversion (Emmerling 2018, Emmerling et al. 2017, Fleurbaey and Zuber 2015, Gollier 2015, Yamaguchi 2017). For increasingly scarce environmental goods, their shadow price relative to that of consumption goods increases with environmental inequality aversion under discounted utilitarianism (Venmans and Groom 2021).

Apart from climate change studies, very few intertemporal valuations of natural capital consider intragenerational equity. Fenichel et al. (2016) examine how climate change reallocates wealth in form of natural capital in an inclusive wealth framework. Meya et al. (2020) show that intratemporal income inequality affects accounting prices for public natural capital and that the direction of the effect depends on the degree of substitutability of natural capital by manufactured goods. Cairns et al. (2021) show for a two-agent model how the intratemporal inequality aversion of a social planner affects the optimal sustainable development path. In general, little is known about how distributional effects affect natural capital values themselves, e.g., how heterogenous growth rates of income or environmental quality, and their correlation with initial endowments, affect aggregate intertemporal WTP for different ethical frameworks and societal inequality preferences.

D.3 Directions for future research

The results of conceptual and empirical research in environmental economics send a clear message: The economic appraisal of environmental policies depends on and must account for pre-existing inequalities and the distributional effects of the policies concerned. It should be acknowledged and justified that the way inequality and distributional effects are considered is an inherently normative decision. Nevertheless, there is a gap in the literature regarding environmental policy appraisal that is grounded in welfare economics, which may partly be explained by the sparseness of empirical research on preferences related to inequality and the environment. The widespread use of unweighted cost-benefit analysis ignores pre-existing inequalities and can only be justified if one accepts extreme normative assumptions regarding (i) individuals' utility and (ii) societal inequality aversion. Since these moral premises are controversial, economic appraisal that incorporates different moral preferences will likely elicit a more positive response from the public and policy makers (Nyborg 2012). The limited empirical evidence suggests that accounting for income inequality in static and dynamic economic valuations results in advocating more ambitious environmental policies.

While these are well-known challenges common to any welfare economic analysis, environmental economics still has much to do to devise methods that account more appropriately for inequality in environmental cost-benefit analysis. Most recent advances are in the field of climate economics. But even there, the SWFs applied in IAMs need to be broadened to capture ethical frameworks beyond discounted representative agent utilitarianism and to reflect a diversity of legitimate ethical approaches and societal distributive preferences. Existing simulations highlight that considering inequality substantially alters the estimates for the SCC and the recommendations for climate policies.

While there is an extensive literature on how to account for income inequality in cost-benefit analysis by using distributional weights, there is hardly any work on alternatives to (discounted) utilitarianism to do so. While this reflects the dominance of utilitarian ethics in modern economics, alternative ethical frameworks may be highly relevant to matters concerning inequality and especially those relating to the distribution of basic environmental goods. Broadening the analysis to incorporate alternative ethical frameworks and account for non-income-related pre-existing inequalities (such as endowments of environmental goods) would help increase the relevance of economic analysis for those who do not subscribe to a utilitarian valuation of environment goods. One prominent alternative, which puts more weight on the least well off is *maximin* (or Rawlsian) social welfare, which focuses on the utility of the least well-off individual in society; another is egalitarianism, which ranks options based on measures of equality with respect to selected variables (see e.g., Gosepath 2021).

Future valuation studies should be designed to improve the conceptual and quantitative understanding of how preferences for environmental goods change with both income and environmental endowments. These would improve the evidence base to specify distributional weights in cost-benefit analysis. In climate economics, estimates for the SCC using distributional weights exist for income inequality *between* regions, but not for income inequality *within* regions. Even less is known about ethical views and preferences regarding the distribution of environmental goods across households and generations. Groom and Venmans (2021) present a recent experimental study to elicit environmental inequality aversion in a student sample. More research in this direction would provide inputs for economic analysis based on SWFs that more closely mirror the ethical preferences of stakeholders, in accordance with the Rawlsian concept of reflective equilibrium. One possibility would be a survey of individuals' preferences with respect to rules for aggregating individual WTPs to calculate societal values for different environmental goods.

At a foundational level, existing welfare analysis is almost exclusively anthropocentric. The well-being of non-human species is only considered in SWFs, if at all, to the extent that they have an instrumental value which contributes to human wellbeing. However, for many people and cultures, nature has a value in itself ("intrinsic value"), irrespective of human preferences. For instance, Carlier and Treich (2020) argue that purely anthropocentric welfare analysis is inconsistent with the utilitarian tradition of economics, which should, at least to some degree, include the well-being of animals. Fleurbaey and Van der Linden (2021) incorporate animal ethics in social welfare analysis. They explore ways to incorporate human preferences for animal welfare in the SWF and consider implications of incorporating pro-animal preferences in economic analysis for Pareto efficiency. How to move the boundary of welfare analysis to encompass non-instrumental values of nature and extend the set of individuals to include non-human species, and how this would affect judgements regarding the distribution of economic resources, are all open research questions. This also points to the limitations of consequentialist ethics, which currently underpins most economic valuation. As long as other species are excluded from SWFs, evaluating actions solely by their consequences will fail to capture the intrinsic value of nature.

Public discourse on Environmental Justice often focuses as much on process as on the consequences. However, analysis of procedural justice is largely absent from economic analysis and there is hardly any research exploring how economic valuation relates to virtue and deontological ethics. Future work should seek to take these ethics into account, to complement the standard consequentialist approach.

Conclusion

Environmental change and economic inequality both feature prominently on national and global policy agendas. We argue that neither issue can be fully understood or addressed in isolation. Their interdependence reminds us of a two-headed hydra: While economic inequality can influence environmental outcomes, environmental policies also affect economic inequality. Of course, not all environmental policy also needs to reduce inequality, or vice versa. Following the classical proposition by Jan Tinbergen, achieving two objectives usually requires at least two policy instruments. But in the case of environmental quality and economic equality, instruments targeting one objective often have important repercussions for the other, as this review shows. These interlinkages between inequality and the environment will become increasingly important, as environmental damages due to climate change and biodiversity loss, if unabated, will likely have substantial welfare repercussions, and policies to address these issues will likely have considerable distributional implications in turn. As a guide for further research and teaching, as well as to enable economists to offer more robust policy advice, we propose an integrative perspective on the inequality-environment nexus. Our review is structured into four interlinked blocks: Section A describes how environmental change affects the distribution of well-being. Section B describes how the income distribution affects the state of the environment. Section C describes how the cost incidence of environmental policies affects the distribution of well-being. Section D discusses how inequalities should be considered when evaluating policies with environmental consequences.

Several common themes emerge from our review. Conceptually, each block connecting environmental quality to economic inequality is shaped by income elasticities, as summarized in Table 1. The distributional incidence of environmental change, for instance, is determined largely by the income elasticity of willingness-to-pay (WTP) for an environmental improvement, η^W (see Section A). If this elasticity is larger than unity, environmental benefits are progressively distributed. If the elasticity is smaller than unity, benefits are regressive. Similarly, the consumption-side cost incidence of environmental policy is driven by the income elasticity of demand for carbon-emitting goods and services, η^C (see Section C). The same elasticities shape the aggregation of individual environmental benefits (see Section D), and the aggregation of individual environmental footprints (see Section B). Our review makes clear that income elasticities are a shorthand representation of how economic inequality and the environment interact. We therefore recommend that individual empirical studies of these interactions should consider incorporating estimates of income elasticities, for two main reasons. First, this will facilitate comparison of effects across studies. Second, elasticities corresponding to different channels can be combined to provide a holistic understanding of inequality-environment interactions and feedback loops. While, as shorthand descriptions, income elasticities do not capture all important dynamics at play, they are often key inputs for more complete general equilibrium modeling. Systematic reporting of elasticities could therefore advance our understanding of the two-headed inequality-environment hydra.

Table 1: Incidence and aggregation effects related to environmental quality and pollution

	Income elasticity of WTP for environmental quality		**Income elasticity of demand for environ. polluting goods**	
		Sec. A		Sec. C
Incidence	$\eta^W > 1$: Progressive benefits	$\eta^W < 1$: Regressive benefits	$\eta^C > 1$: Progressive cost	$\eta^C < 1$: Regressive cost
		Sec. D		Sec. B
Aggregation	$\eta^W > 1$: Equality decreases aggregate WTP for env. quality	$\eta^W < 1$: Equality increases aggregate WTP for env. quality	$\eta^C > 1$: Equality decreases aggregate env. impacts	$\eta^C < 1$: Equality increases aggregate env. impacts

In some areas, empirical evidence on these elasticities is already sufficiently strong to draw first conclusions. Consider the example of climate policy. Evidence suggests that the income elasticity of demand for embedded emissions is smaller than unity in developed countries. This drives the regressive incidence of pollution pricing, at least before revenue recycling is considered, that has received widespread attention in the wake of the French yellow vest movement. It also points to the existence of an "equity-pollution dilemma", whereby progressive income redistribution may inadvertently raise aggregate emissions. At the same time, evidence suggests that the income elasticity of WTP for avoided climate damages is smaller than unity, implying that efforts to mitigate climate change have progressive benefits.

These examples highlight the central role of measuring income elasticities for policy evaluation. But income elasticities and fundamental parameters are likely context dependent. Elasticities may change over time as consumer tastes change and production technologies evolve, and vary across space. For example, the income elasticity of demand for pollution-intensive goods has been found to be larger, and sometimes even greater than one, in some developing countries. This relates to another research gap identified throughout our review: Most empirical studies focus on the US and, to a lesser degree, Europe—although there has been a recent surge in applied studies focusing on China. The extent to which the results of these studies are applicable to other countries, in particular developing countries, is unclear. Similarly, most studies of the environment-inequality nexus focus on climate change, and results may not be applicable to other environmental goods. More research is needed on benefit and cost incidence relating to non-climate environmental goods, such as biodiversity.

In terms of measurement, there is far more research on the distribution of economic resources, in terms of consumption, income, wealth, than on the distribution of environmental goods such as clean water, access to urban green spaces, or opportunities for recreation in biodiverse landscapes. Economic resources are often easier to observe and measure. Yet, recent advances in measuring environmental quality with improved precision and granularity, combined with more systematic surveys on preferences for the environment, should help close this gap. Many research opportunities remain as the dynamics discussed in this review may vary across spatial scales and environmental domains.

Another finding of our review is that while reviews or meta-analyses exist on the topics discussed in each of our four blocks, these rarely consider cross-cutting dynamics, making it difficult to formulate robust policy advice. For example, studies of the distribution of the costs of climate policy among households often solely focus on the demand-side effects, informed by the income elasticity of demand for embedded emissions. Few of these studies also consider supply-side effects, i.e., effects of policies on wage and capital incomes, which may mediate or even reverse conclusions drawn on distributional effects based on demand-side effects. Similarly, existing studies of the distribution of the costs of climate policy do not routinely take account of the distribution of benefits from climate change mitigation. In all these cases the net distributional effect that is key for the appraisal and communication of polices remains unclear.

At a more fundamental level, our review highlights interdependencies and feedback effects. While there is a lot of research on each of the four blocks, few studies engage with two or three of these blocks or multiple channels within a block and, to our knowledge, none consider all four. Such omissions can generate flawed policy analysis. Consider the case of carbon pricing. An analysis of the distributional effects of a carbon tax (see Section C), raises the issue of a regressive cost driven by the income elasticity of demand for embedded carbon. It also points to revenue recycling and income effects as additional elements through which greater progressivity can be achieved. But shifting income towards low-income households, who have a higher propensity to spend it on carbon-intensive goods, may weaken the emissions reduction effect of carbon pricing (Section B). Tinbergen's proposition holds: We need at least two instruments, a carbon price and income redistribution, to achieve two objectives, efficiency and equity. But this does not mean that we can ignore the distributional effects of carbon pricing or the efficiency cost of income redistribution. On the contrary, accounting for the interlinkages outlined above will likely alter the optimal design of both instruments.

Another case in point is the issue of poor air quality in low-income neighborhoods (Section A). We may interpret this as a mere manifestation of income inequality, the result of lower income households investing less in local air quality. Policy makers could then focus on income redistribution alone. But such an interpretation becomes untenable if feedback effects are considered. For example, unbeknownst to consumers, lower air quality may lead to higher healthcare expenditures or lower levels of human capital accumulation (e.g., in terms of the ability to learn and thus education) amongst low-income households. Such externalities would exacerbate the effects of the unequal distribution of air quality. Moreover, low-income households may find it more difficult to influence the political process, which would reinforce the vicious cycle (Section B). Explicit consideration of the co-variation of income and pollution, and their drivers, would change the welfare calculation underlying a cost-benefit analysis of measures to improve and/or spatially re-allocate air quality.

Finally, what matters is not the distribution of bio-physical measures or economic resources per se, but the distribution of welfare. This suggests an important role for non-market valuation techniques when environmental goods are (partly) public. And it highlights the value of integrated—and explicit—welfare analysis. Our review finds that incidence analysis focuses mainly on the distribution of policy costs among different income groups within a nation state. While this is indeed important, other important topics, such as the distribution of environmental benefits in general, and their distribution beyond the nation state, have received much less attention. This bias is understandable given the focus of many policy makers. But it implies a very restricted conception of social welfare, in which solely those who live in a certain location and at a certain point in time matter, and in which pro-poor benefits of environmental policies tend to be overlooked. There are trade-offs here that need to be considered between inequalities of different populations and at different spatial scales: The failure to implement an environmental policy because of the within-state distributional effects of the policy cost tends to (i) increase overall (global) environmental inequality, since the poor have fewer means to adapt to global environmental change; and it tends to (ii) shift the burden of environmental degradation to future generations. Explicit welfare analysis can help avoid such implicit biases and suggest alternative ways to appraise policies. Of course, much of economic welfare analysis is embedded in the utilitarian approach, focusing on consequences for humans while ignoring considerations of procedural justice, virtues, freedom, rights or the well-being of other species. To facilitate a better understanding and management of environmental justice problems, a more holistic approach to welfare analysis that reflects alternative ethical approaches should be considered. In absence of careful welfare analysis, policies to reduce environmental inequalities in bio-physical terms could even increase inequalities in welfare. For instance, a well-meaning project to improve environmental quality via pollution clean-ups may leave poorer individuals less-well off due to changes in house prices and other feedback effects.

In summary, economic inequality and environmental outcomes are interdependent, and it is essential to consider their myriad interconnections when assessing current policy agendas promoting either equality or sustainability. Measures that aim only to improve environmental quality or reduce inequality—thereby cutting off one head of a two-headed inequality-environment Hydra—may undermine efforts in the other domain. Following our metaphor, the Greek legend recounts how Heracles eventually succeeded when he targeted all heads of the Hydra simultaneously. Our review suggests that the twin threats of environmental degradation and economic inequality may pose a similar challenge. Future economic research should thus (i) integrate analysis of different inequality-environment nexuses, (ii) be more explicit and intentional in the application of welfare analysis, and (iii) study environmental inequalities across different contexts, and temporal and spatial scales. This will require drawing on different fields within economics, including welfare theory as well as labor, health, and development economics, and also to increasingly build on interdisciplinary collaboration. Such a more comprehensive understanding of inequality-environment interlinkages will be indispensable to assist governments in designing policies targeted towards both distributive justice and preserving the environment.

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Appendix A.1

Let a cost-benefit analysis measure the change in welfare ΔW^k for outcome k compare to the status quo 0. For a small change in outcome, that does not affect the prices for the consumption good, and an isoelastic social welfare function (Eq. 5) the welfare change ΔW^k is

$$\Delta W^k := W^k - W^0$$
$$\overset{(5)}{=} \sum_{i=1}^{n} \frac{U_i\left(C_i^k, E_i^k\right)^{1-\rho}}{1-\rho} - \sum_{i=1}^{n} \frac{U_i\left(C_i^0, E_i^0\right)^{1-\rho}}{1-\rho}$$
$$\approx \frac{1}{1-\rho} \sum_{i=1}^{n} \left[U_i\left(C_i^0 + \Delta C_i^k, E_i^0\right)^{1-\rho} - U_i\left(C_i^0, E_i^0\right)^{1-\rho} \right]$$

Taylor series expansion of degree one around $\Delta C_i^k = 0$ gives

$$U_i\left(C_i^0 + \Delta C_i^k, E_i^0\right)^{1-\rho} \approx U_i\left(C_i^0, E_i^0\right)^{1-\rho} + (1-\rho)\, U_i\left(C_i^0, E_i^0\right)^{-\rho} \cdot \frac{\partial U_i}{\partial C}\left(C_i^0, E_i^0\right) \cdot \Delta C_i^k$$

Using this in the equation above and collecting terms yields

$$\Delta \mathrm{W}^k \approx \sum_{i=1}^{n} U_i\left(C_i^0, E_i^0\right)^{-\rho} \cdot \frac{\partial U_i}{\partial C}\left(C_i^0, E_i^0\right) \cdot \Delta C_i^k,$$

which contains as a special case the welfare change for a utilitarian welfare function ($\rho = 0$):

$$\Delta \mathrm{W}^k \approx \sum_{i=1}^{n} \frac{\partial U_i}{\partial C}\left(C_i^0, E_i^0\right) \cdot \Delta C_i^k.$$