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Managing the Distributional Effects of Environmental and Climate Policies: The Narrow Path for a Triple Dividend

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Abstract

This paper reviews the literature on the distributional effects of environmental and climate policies, focusing on ex-post empirical evidence. It decomposes the distributional effects into the main dimensions to understand which policy packages are more likely to achieve a triple dividend of environmental effectiveness, economic efficiency and equity. This paper also takes stock of the related literature on the political acceptability of environmental policies to assess proposals of compensation policy packages, including green recovery plans, environmental tax reforms and progressive subsidies to green technologies.

The paper first finds that distributional effects are generally regressive on income and progressive on nonpecuniary benefits, such as health. Estimates depend on the specification of the estimated model, but regressive income effects are often significant and below 5%. Importantly, all effects become more regressive in the long term. Second, command-and-control policies appear worse than market-based policies, both in terms of equity and efficiency. Third, managing the trade-offs between objectives can be particularly difficult due to the spatial dimension of the economic effects. Fourth, carefully designed compensation policies are required to mitigate equity-efficiency trade-offs. Fifth, the feasibility of any policy depends on trust in government and contextual factors such as the existing level of inequality. Finally, a longsighted and broad political discourse should motivate a country's plan to jointly tackle urgent environmental problems, restoring a sense of fairness in the mission of public policy is essential to mobilise all actors in the critical transition to a low-carbon and sustainable economy.

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Resumé

Ce rapport passe en revue la littérature sur les effets distributifs des politiques environnementales et climatiques, en se concentrant sur des preuves empiriques ex post. Il décompose les effets distributifs en dimensions principales pour comprendre quels ensembles de politiques sont les plus susceptibles d'atteindre un triple dividende d'efficacité environnementale, d'efficience économique et d'équité. Le document fait également le point sur la littérature connexe sur l'acceptabilité des politiques environnementales pour évaluer les propositions de mesures de compensation, y compris les plans de relance verte, les réformes fiscales environnementales et les subventions progressives aux technologies vertes.

Le rapport souligne d'abord que les effets distributifs sont généralement régressifs sur le revenu et progressifs sur les avantages non pécuniaires, tels que la santé. Les estimations dépendent de la spécification du modèle estimé, mais les effets régressifs sur le revenu sont souvent significatifs et inférieurs à 5%. Il est important de noter que tous les effets deviennent plus régressifs à long terme. Deuxièmement, les politiques de commandement et de contrôle semblent pires que les politiques fondées sur le marché, à la fois en termes d'équité et d'efficacité. Troisièmement, la gestion des compromis entre les objectifs peut être particulièrement difficile en raison de la dimension spatiale des effets économiques. Quatrièmement, des politiques de rémunération soigneusement conçues sont nécessaires pour atténuer les compromis entre l'équité et l'efficacité. Cinquièmement, la faisabilité de toute politique dépend de la confiance dans le gouvernement et de facteurs contextuels tels que le niveau d'inégalité existant. Enfin, un discours politique large et clairvoyant doit motiver le plan d'un pays pour s'attaquer conjointement aux problèmes environnementaux urgents, restaurer un sens de l'équité dans la mission des politiques publiques est essentiel pour mobiliser tous les acteurs dans la transition critique vers une économie sobre en carbone et durable.

Mots clés: analyse distributionnelle, politique environnementale, inégalités

Classification JEL : D30, H22, H23, Q52

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Introduction

All public policies have distributional effects and environmental and climate policies are no exception.[1] Increasing social welfare through pricing or capping pollution implies that somebody has to pay the bill. The fact that environmental policies may have substantial distributional effects was already highlighted in the landmark paper of Ronald Coase (Coase, 1960[1]). In the classical case of a company polluting a natural resource that gives nonmonetary benefits to the local population, there is an obvious conflict between the polluter and the local population over the actions that should be undertaken to reduce pollution and who bear the costs of it. In this and several other cases, the distributional outcomes in terms of monetary and non-monetary well-being will depend on whether the polluter has the right to pollute or the population has a right to a clean environment. In most practical cases, well-known policy distortions, such as fossil fuel subsidies, excess grandfathering of emission permits or tax exemptions for energy-intensive companies, illustrate how lobbying efforts have transferred the costs of pollution abatement from the polluters to the entire population (e.g., Ekins and Speck, 1999).

Given these distortions, the distributional *status quo* of environmental policies is quite far from the "ideal" benchmark of the polluter pays principle, which is the widely accepted ethical foundation of environmental policies in several countries, and implies that polluters pay the social costs of their action (EC, 2004[2]; OECD, 1972[3]). In such a *status quo*, polluting companies and polluting individuals do not pay in full for the social costs inflicted to the whole population (Tessum et al., 2019[4]) in terms of, among other things, increased mortality rates, permanent cognitive deficits on exposed children and the existential threat posed by climate change (e.g., Currie, 2011[5]; Graff Zivin and Neidell, 2013[6]; OECD, 2014[7]; Hsiang, Oliva and Walker, 2019[8]).The unfairness of the *status quo* is exacerbated by the fact that the health damages caused by pollution are usually concentrated among the poorest (the so-called environmental justice gap), who work and live near the most polluted areas (Banzhaf, Ma and Timmins, 2019[5]; Zwickl, Ash and Boyce, 2014[6]; Mackie and Haščič, 2019[7]).[2] Moreover, the widespread use of subsidies to clean energy investments (i.e., electric cars, home weatherization) disproportionately benefit richer households, further amplifying the inequity of existing environmental policies (Borenstein and Davis, 2016[8]). Importantly, the dramatic increase of inequality in last four decades looms as the backdrop of this unfair *status quo* (Atkinson, 2003[9]; OECD, 2011[10]; Piketty and Saez, 2003[11]).

In such context, environmental policies (or, better, a mix of policies) should aim to minimise unfair distributional effects and, at the same time, reduce pollution at the lowest cost. This is clearly challenging as there are always trade-offs between equity, efficiency and cost-effectiveness in emission reductions. Moreover, several factors may undermine the political acceptability of a policy package that copes with these trade-offs in the most effective way. The recent case of the Yellow Vest movement in France shows that political acceptability is far more complex than what would have been predicted by the mere projection

[1] The review focuses on the distributional effects within a country because these are largely driven by national policies, for which the existing evidence and the available data is most comprehensive. Cross-country distributional effects are highly relevant to understand the politics of global commons, such as climate change and are covered in a related literature (Piketty and Chancel, 2015[139]; Ricke et al., 2018[141]).

[2] Inequality in pollution exposure was reduced together with the large emission reductions in developed countries, but it remains high (see Section 3.1).

of distributional effects (Douenne and Fabre, 2020[12]). In this case, a small increase in gasoline prices triggered a substantial political opposition from a significant fraction of the French population. Another prominent example is that of the "job killing argument": while there is no evidence that environmental policies lead to net destructions of jobs at the aggregate level, the argument is recurrently used (and widely accepted) to undermine unilateral environmental policies, also by the very workers who experienced the damage of pollution exposure (Vona, 2019[13]).

Understanding the link between acceptability and distributional effects requires to shed more light on the several dimensions through which distributional effects of environmental policies take place. On the one hand, economic costs of such policies affect those working in polluting industries or consuming a larger share of polluting goods (Metcalf, 1999[14]). On the other hand, the benefits, especially health and non-market benefits, can accrue disproportionately to those who were mostly affected by local pollution in the *status quo* (Drupp et al., 2018[15]) and to those, usually the poor, that were more exposed to extreme whether events induced by climate change (Hsiang et al. (2017[16]). Note that, in most cases, reducing greenhouse gas emissions, a global pollutants, leads to concomitant reductions of local pollutants, so there are substantial health co-benefits of climate policies, especially for disadvantaged populations.

As already pointed out by Fullerton (2011[17]), distributional effects can offset or amplify each other, thus changing the amount of compensation required to increase the level of political acceptability. To complicate matters and policy design, distributional effects can be very large for households with similar income deciles because the demand of polluting inputs – concerning both local and global environmental problems – depends on other factors, e.g., the urban-rural gap in the availability of public transport.

The goal of this background paper is to decompose the distributional effects into its main dimensions to understand which policy packages (including compensating mechanisms) are most likely to generate a triple dividend, where the trade-offs between key Sustainable Development Goals, namely environmental effectiveness, economic efficiency and equity, are minimized. In doing so, it is important to acknowledge that the perception of each distributional effect can be very different depending on the individuals' assessment of the fairness of the policy effects, their preferences, perceptions of environmental damage and other factors. Even if non-market benefits, e.g. health improvements, tend to be large and progressive (see definition box), the poor have a low willingness to pay for environmental quality and thus weight them less than small and regressive (see definition box) income losses. Such low willingness to pay is mainly the resultant of two factors. First, environmental quality is (or is perceived as) a non-essential need. Second, there is imperfect information regarding environmental damages, which is most prevalent among the poor. Besides being affected by preferences and equity considerations, the political acceptability of a policy package needs to be considered as an additional dimension of policy evaluation. Widespread aversion against specific environmental policies – often emissions or fuel taxation – may be highly inertial and go beyond rational calculations of equity and efficiency effects of those policies. This paper takes stock from the findings of the literature on the political acceptability of environmental policies to assess several proposal of compensation policy packages, including green recovery plans, environmental tax reforms and progressive subsidies to green technologies.

The paper focuses mostly on ex-post empirical literature that aims to find evidence of distributional effects using quasi-experimental and panel data econometrics, and leaves aside some of the modelling literature that deals with ex-ante assessments of the distributional aspects of environmental policies (for an entry point into that literature, see van Ruijven, O'Neill and Chateau, 2015[20]). However, because indirect distributional effects are usually missed in these empirical analyses, the paper will interpret these findings in light of theoretical models and ex-ante modelling evaluations, which allow to broaden the scope of the analysis and put empirical findings in context.

1.1. Outline of the paper

In Section 2, the paper reviews the main distributional effects by source- and use-side of income (see the box for a definition). Usually these effects are directly perceived and evaluated by individuals when asked to express their support for an environmental policy. This survey complements existing literature reviews and background papers,[3] by focusing on two types of source-side effects: i. between capital owners and wage earners; ii. among wage earners with different skills. The survey shows that it is particularly important to look at the skill-biased effects of environmental policies to understand source-side distributional effects.

[3] See, e.g., OECD (1994[207]; 2004[135]), Metcalf (1999[14]), Fullerton (2011[17]), Sterner and Köhlin (2012[62]), Bento (2013[136]), Heindl and Löschel (2015[46]), McInnes (2017[137]), Banzhaf et al. (2019[5]; 2019[128]), Hsiang et al. (2019[18]), Fullerton and Muehlegger (2019[159]) and Pizer and Sexton (2019[61]).

Box 0.1 . Definitions

Source-side income effects: There are different sources of earnings, e.g. wages, profits, rents, etc. The main distinction made here is between capital earnings (e.g., profits, dividends) and wage earnings. Note that the ratio between capital and labour earnings increases with income. An environmental policy is said to have a source-side distributional effect when policy costs and benefits unevenly affect the remuneration of capital and labour. Likewise, an environmental policy can change the ratio between the wage earned by high- and low-skilled workers, or the returns to different types of skills, i.e. social vs. mathematical skills. For instance, the introduction of new energy-saving capital may reduce (resp. increase) the demand of unskilled (resp. skilled) workers and their wages.

Use-side income effects: Individual well-being depends on real earnings, thus earnings divided by a consumers' price index. Environmental policy increases the prices of certain goods more than of other, proportionally to their pollution content. If households consume baskets of goods with different pollution content, an environmental policy will generate use-side distributional effects.

Health and non-pecuniary effects: Individual well-being depends on health and environmental quality (e.g., amenity services). Environmental policies reduce exposure to pollutants, thus they have distributional effects if initial exposure correlates with income. For instance, the rich are less likely to live near a landfill sites or a coal power plant than the poor, thus they will benefit proportionally less than the poor from a cleanup of these sites.

Direct and indirect effects of environmental policies: For the scopes of this review, it is useful to distinguish between direct and indirect effects of the policy. The former (usually denoted as partial equilibrium effects) has to do with the primary mechanism at work. For instance, environmental policy reduces pollution or increases the price of polluting goods relative to non-polluting ones. The latter (usually denoted general equilibrium effects) has to do with second-order price and quantity effects, that usually spread in several markets. For instance, an improvement in environmental quality increases the attractiveness of a certain neighborhoods as well as housing prices.

Progressive or regressive effects: A distributional effect is said to be regressive (resp. progressive) when the net benefits increase (resp. decrease) more than proportionally with income. For instance, subsidizing organic food benefit proportionally more the rich because the poor may not consume organic food even with the subsidy. A regressive effect does not imply that the cost of the policy is higher for the poor, but that the cost is higher as a share of total income.

Market-based and command-and-control policies: Market-based environmental policies refer to policies that use markets and prices to incentivise behavioural changes that reduce emissions. These policies include pollution taxes (which set a price per unit of pollution) and emissions trading schemes (which limit the number of emission permits and allows firms to trade the emission permits). Command-and-control policies are regulations and standards, which mandate the use of specific technologies or emission limits.

Next, Section 3 looks at the distribution of nonpecuniary benefits that are spatially correlated (Hsiang, Oliva and Walker, 2019[18]). Most nonpecuniary benefits are health benefits associated with a reduced exposure to pollution, toxic releases or hazardous materials. On this respect, benefits appear generally progressive or at least large and widely diffused. However, indirect effects, such as capitalization of environmental improvements into housing prices, tend to mitigate progressivity – meaning they tend to benefit richer households. Importantly, because the willingness to pay for a clean environment is increasing with income (e.g. Greenstone and Jack, 2015[21]), low-income households may be unwilling and/or unable to exchange large health benefits for small income costs, reducing the political acceptability of environmental policies.

The final part of this Section discusses the regional dimension of source side effects for communities where the trade-off between job losses and health benefits is particularly stark and difficult to solve.

Section 4 takes stock from a common theme emerging in this literature review, namely the need to design compensation policies to overcoming the constraints preventing a successful transition from a brown to a green lifestyle or job. The poorest are at a disadvantage in undertaking this transition that requires upfront investments in retraining and investments in green technologies. After reviewing the possible offsetting policies and the main constraints, the paper emphasizes the role of those policies that directly tackle such constraints and explicitly consider the dynamic aspects of the transition process. Some of these compensation policies are theoretically well-grounded and thus should be reinforced, especially retraining programs, clean-up of polluting sites and infrastructural investments in the green economy (e.g, Bartik, 2020[22]; Popp et al., 2020[90]). However, other options targeting low-income households, i.e. subsidies to home weatherization and clean vehicles in the US, have shown to be quite costly relative to the program targets (Fowlie, Greenstone and Wolfram, 2018[19]; Muehlegger and Rapson, 2018[20]). One possible explanation is that these "carrots" were not combined with a "stick", such as a carbon tax reducing the incentives to consume energy, but further research to understand how behavioural responses vary depending on income is required.

Overall, the path to a triple dividend, namely to mitigate the trade-offs between different policy objectives, is narrow as long-term adjustments make the effects of environmental policies more regressive. Although several policy packages are promising, there is a clear need for long-sighted and coordinated policy strategies to address the several trade-offs between distributional goals, effective emission reduction and economic efficiency.

The last part of Section 4 discusses results of survey and behavioural studies that try to assess the political acceptability of different policy instruments. A growing literature examines political acceptability using surveys and experiments reaching quite clear conclusions on the ranking of different policy packages. This review adds to this important strand of literature using insights that emerge for the review of distributional effects along several dimensions. Notably, increasing the willingness to pay for environmental quality of the poor is also essential to create a broader support to environmental policies, but this may require a redistribution of income far larger than that achieved by green deal plans, lump sum redistribution and progressive green subsidies.

Section 5 suggests some promising avenues for future research as well as a summary of main policy advices.

1.2. Policy Insights

The paper provides six policy insights that are summarized here.

First, source- and use-side income effects are generally regressive, while nonpecuniary benefits are generally progressive. Importantly, all effects become more regressive in the long term. Long-run regressivity is exacerbated by capitalization effects (e.g., on housing prices), induced technological change (e.g., which seems labour-saving), and by financial constraints for low-income households (e.g., to purchase green technologies).

Second, although empirical evidence comparing the effectiveness of different environmental policies is still limited, most command-and-control policies (standards and subsidies) appear worse than market-based policies (taxes and emission trading), both in terms of equity and efficiency. This does not imply that certain command-and-control policies are not effective at addressing particular environmental policies[4]. For

[4] For instance, clean-up of polluting sites or emission standards for diffused pollutants such as PM2.5 are highly progressive and effective.

instance, subsidies to clean technology targeted to poor and middle income households can play a role in boosting the mass consumption of certain green goods, but may not pass standard cost-benefit tests.

Third, managing the trade-offs between objectives can be particularly difficult when the economic effects are spatially concentrated. On use-side effects, lump-sum redistribution of carbon revenues may not be enough for commuters living in urban areas not served by public transport. On source-side effects, the spatial concentration of economic costs in communities hosting polluting activities make it difficult to design green reindustrialization plans with short-term benefits.

Fourth, carefully designed compensation policies are required to mitigate equity-efficiency trade-offs. There is not a clear ranking among different compensation policies. However, well-designed green recovery plans (e.g. investments in renewable energy infrastructure, public- and low-carbon transport options, cleanup of polluting sites, etc.) can be more acceptable

in the aftermath of the COVID-19 crisis than environmental tax reform. Green deal plans (the "carrots") can be particularly effective in reducing emissions when combined with carbon pricing mechanisms (the "stick") and in reducing labour market inequalities when they include retraining investments.

Fifth, the feasibility of any policy depends on trust in government and contextual factors such as the existing level of inequality. The other causality nexus is indeed important: Indeed, an excessive level of inequality can be a key constraint for the approval of ambitious environmental policies, conditional on the level of development and other intervening factors.

Finally, environmental policies should be seen in the broader context of other public policies: a longsighted and broad political discourse should motivate a country's plan to jointly tackle urgent environmental problems, especially climate change, income inequality and the COVID-19 crisis. In doing so, eliminating well-known policy distortions of both climate (i.e. fossil-fuel subsidies) and non-climate policies (i.e. tax havens) can be part of such ambitious plan. Restoring a sense of fairness in the mission of public policy is essential to mobilise all actors in the critical transition to a low-carbon economy.

Five caveats should be mentioned before moving to the core material of this background paper. First, the papers reviewed in this study are mostly on energy and climate policies, thus creating a bias towards certain pollution problems rather than others. While most patterns are likely to hold also for other environmental problems, i.e. both subsidies to organic food and to clean energy tend to be regressive, this claim has to be validated by additional research evaluating the distributional effects of policies tackling other environmental problems, such as waste management and the circular economy. Second, the review will not systematically compare different types of environmental policies, notably market-based and command-and-control policies, along all relevant dimensions. These dimensions include equity, but also efficiency and acceptability. This has been done in previous research with the clear finding that market-based policies outperform command-and-control ones in terms of efficiency (e.g., Goulder and Parry, 2008[26]). Conversely, this study will compare the effects of different compensation policies used to offset the undesirable distributional effect of carbon taxes or technology standards. Third, distributional effects are usually evaluated on current spending, incomes and pollution exposure rather than on permanent ones, such as wealth, due to data limitations. Having lifetime measures of these variables would enhance our understanding of distributional effects, but the correlation between, e.g., current and permanent income ensures the credibility of the existing findings. Finally and related to the previous point, the policy insights that emerge from this critical reading of the literature apply to developed countries for which empirical evidence is available. The stage of development of a country can be a crucial element to mediate environmental policy effect and on which more research is certainly needed.

2 Source- and use-side distributional effects

This section reviews the literature on the socio-economic distributional effects of environmental policies looking at both "sources of income" and on "use of income" effects (see the definition box). For the sources of income dimensions, Section 2.1 covers distributional effects that are determined by the split of policy induced costs between firms' profits and workers' wages (functional distributional effects). Section 2.2 extends the analysis to the distributional effects on workers with different types and levels of skills. Section 2.3 reviews the voluminous literature on use-side effects on households' spending, including a discussion of ex-ante evaluation approaches and a succinct comparison of the effects of existing policies on use-side effects. Recall that this section considers *gross* distributional impacts, that is: impacts before compensatory policies rebalance distributional effects, while Section 4 assesses the role of these compensatory policies.

2.1. Source-side: capital vs. labour

The costs imposed by environmental regulation can be passed back to the owners of production factors that are used intensively in polluting industries. For functional distribution effects, we refer to an uneven split (or pass-back) of the costs imposed by the policy between profits (*r*) and wages (*w*). Although the distinction between capital owners and wage earners is blurred in advanced economies where firm ownership is diffused, the high concentration of capital ownership makes any effect on *r/w* distributionally relevant.

Obviously, understanding the functional distributional effects of environmental policies is challenging because several factors concur in the determination of wages and profits, including labour market institutions, market power, policy design and other structural trends such as automation and globalisation. Therefore, theory is essential to formulate testable predictions and isolate the role played by environmental policies.

Fullerton and Heutel (2007[21]) consider the simplest possible model: a frictionless economy with three inputs (capital, labour and pollution), two sectors (a clean and dirty one using pollution) and returns to each factor of production that equates marginal productivity. In this setting, distributional effects depend on the interaction of two effects: i. a between-sector compositional effect associated with the increase in the share of the clean sector; ii. a within-sector substitution effect that depends on the elasticities of substitution between inputs. To illustrate, if the polluting sector is capital-intensive compared to the clean sector (Antweiler, Copeland and Taylor, 2001[22]) and if it is relatively easier to substitute pollution with capital than with labour, the functional distributional effect of a pollution tax would favour capital owners over workers. The authors assess the magnitude of these effects for reasonable configurations of the key parameters, showing that within-sector substitution effects tend to be quantitatively more important than between-sector compositional effects. However, regardless of the parameters' choices, functional distributional effects remain small (below 1% for a 10% increase in a pollution tax). This result is not surprising in a model where factor prices are equalized across sectors. Simply put, the aggregated distributional effect of a tax is small because polluting industries and the share of polluting inputs represent a small fraction of the total economy.

For analytical tractability, the approach of Fullerton and Heutel (2007[21]) is static and does not allow substitution possibilities to evolve in the long-run as a result of technological change. Substitution effects may take longer to emerge because factors of production are typically complements (resp. substitutes) in the short (resp. long) run. [5] Conversely, compositional shifts start emerging in the short term to satisfy the increased demand for the green product, but these induced compositional shifts in the product mix were relatively muted in the countries with the most stringent environmental policies (e.g., Levinson, 2009[31] for the US; Brunel, 2017[32] for Europe).

Understanding the magnitude and the time profile of substitution effects is very important. Ultimately, substitution effects inform us on whether green and energy-efficient technological change induced by an environmental policy is labour- or capital-saving. Empirically, it is possible to assess such substitution effects by comparing cross-price elasticities[6] of labour (or capital) to energy prices (or other environmental policies). For capital, the meta-analysis of Koetse et al. (2008[23]) indicates that capital and energy are substitutes: the best guess of the cross-elasticity is +0.3 in the short-run and +0.5 in the long-run.[7] For labour, the short-term cross-elasticities to energy prices are small, but negative and significant, ranging between -0.08 (Marin and Vona, 2021[24]), -0.1 (Barreca et al., 2013[25]) and -0.2 (Dussaux, 2020[26]; Kahn and Mansur, 2013[27]). Importantly, effects are twice larger in the long-run in the establishment-level analysis of Marin and Vona (2021[24]). Both Marin and Vona (2021[24]) and, indirectly, Dussaux (2020[26]) estimate a cross-elasticity of the capital-to-labour ratio to energy prices between +0.17 and +0.48, depending on the specification. The claim that capital is a better substitute to polluting production inputs (and especially energy) than labour is further reinforced by recent research on electrification (Fiszbein et al., 2020[28]).[8] Finally, the threat of relocating production in a pollution haven is also a factor that is likely to favour capital owners over wage earners in the long-run.[9] Hence, this branch of the literature indicates that environmental regulation – without compensation measures – disproportionally burdens workers over capital owners.

The extent to which these shifts in relative demand for capital and labour would translate into changes in profits and wages depend on several factors. The scant empirical evidence available point to a muted

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[5] Transitional dynamics are also complicated by creative destruction effects within each sector. Because a pollution tax accelerates the scraping of machines that embody dirty technologies, investments in clean capital should go temporarily up to accelerate the replacement of the dirty capital stock, thus returns to green investments should go up as well.

[6] Cross-elasticities measure the responsiveness in the quantity demanded of one good (e.g. labour or capital) when the price for another good changes (e.g. energy).

[7] This means that for a 10% increase in energy prices the demand for capital increases by 3% in the short run and 5% in the long run. The authors find that the two oil crises reinforced the substitutability between capital and energy, also in line with evidence of substantial acceleration in energy-saving technological change (Hassler, Krusell and Olovsson, 2012[212]). Using establishment-level data and a shift-share instrument for the French manufacturing sector, Marin and Vona (2021[24]) estimate a long-run price elasticity of +0.34 that is an order of magnitude larger than the short-term one.

[8] Electrification is a clean technology as long as electricity is produced with renewable energy.

[9] Indeed, capital is relatively more mobile than labour, thus, in presence of asymmetric environmental policies, the relocation threat increases the bargaining power of capital owners increase with respect to the bargaining power of wage earners. While evidence on pollution haven effects is limited, a negative effect of globalization on the workers' bargaining power has been documented in the labour literature.

effect of environmental policies on firm's profits in polluting industries, which mostly depend on the generous exemptions granted to polluting firms under most environmental policies. In turn, wage losses are more frequently reported. For profits, Marin et al. (2018[29]) find a small increase in mark-ups for European firms treated under the EU-ETS compared to a suitable counterfactual and other papers document a positive relationship between allowance prices and profits for the EU-ETS (e.g., Bushnell, Chong and Mansur, 2013[40]; Hintermann, Peterson and Rickels, 2016[41]).[10] For average wages, Walker (2013[30]) finds negative and modestly large effects for the US Clean Air Act using matched employer-employee data. Yip (2020[31]) shows that the revenue-neutral British Columbia carbon tax (of around CAD$30) decreases wages by 2.7%, with wage cuts concentrated among new hires. Marin and Vona (2021[24]) find that large energy price increases (+50%) have a negative effect on establishment wages, but effects are very small and often statistically insignificant, except in energy intensive industries. Differences in labour market institutions affecting the degree of downward wage rigidity and the workers' bargaining power may explain the difference in the effects on wages. Cross-country studies are much needed to shed light on the role played by the interaction of different policies in shaping wage and functional distributional effects.[11]

Moreover, as a natural counterpart of the depreciation of sector-specific assets in polluting sectors, e.g. coal mines, there will be also winners within both the entrepreneurs and the workers. The winners are owners of assets that will gain value such as green skills and other intangible or tangible capital assets that can be profitably reused in green sectors. An example is that of several patents in aerodynamics, mechanics and material science that help developing wind turbines. Also, the value of land is likely to increase because, e.g., renewable energy is typically more land-intensive than fossil fuel energy, while an improved environmental quality typically increases the value of houses.[12] In the next section, we will examine these asset depreciation and appreciation effects for workers' skills as they have a first-order influence on the entire income distribution, while distributional effects within the group of entrepreneurs have only an effect at the top of the distribution.

Overall, we can conclude that the functional distributional effects of environmental policies are modestly regressive, especially in the long-run. Regressivity is particularly unfair and difficult to accept in this case because it adds to a situation characterized by policy distortions that disproportionately benefit capital owners, who have higher incomes. Widespread examples of these distortions are excess of free allowances (Martin et al., 2014[32]; Goulder, Hafstead and Dworsky, 2010[33]), fossil fuel subsidies (Coady et al., 2017[34]), lower trade tariffs for dirty goods compared to green ones (Shapiro, 2020[35]) and generous exemptions of energy taxes for energy-intensive industries in several countries (e.g., Ekins and Speck, 1999[48]). Especially for climate policies, such distortions are justified by, often unfounded (Dechezleprêtre and Sato, 2017[36]; Martin et al., 2014[32]), claims that unilateral climate policies harm industrial competitiveness. This opens a broader discussion on the role of international cooperation in resolving or amplifying apparent trade-offs (and the associated policy distortions) between competitiveness and equity in the design of domestic climate policies, which is beyond the scope of this survey.

[10] This result is consistent with the usual wisdom that excess grandfathering under the EU-ETS results in higher firms' profits at the expenses of the government budget limiting government revenues and thus the ambition of welfare policies (Joltreau and Sommerfeld, 2019[146]). Note that excess grandfathering creating rents for incumbent companies has been documented also in the US (e.g., Goulder, Hafstead and Dworsky, 2010[45]). A other few papers also discuss other mechanisms through which environmental policies can increase barriers to entry and thus profits for the incumbents (e.g., Puller, 2006[176]; Ryan, 2012[177]).

[11] The work of Oueslati et al. (2017[147]) represents a promising endeavor in this direction. The authors find a positive association between energy taxes and the Gini coefficient, which is however more likely to be driven by changes in the returns to skills rather than by changes in the *r/w* ratio.

[12] The effect on housing prices is extensively discussed in Section 3.2.

2.2. Source-side: skills

As it has been anticipated in previous section, the dichotomy between capital and labor does not suffice to precisely identify the winners and losers of environmental policies by sources of income. This paper focuses on heterogeneous effects across workers with different skills as wage earners are the vast majority of the population. First, skills are, at least in part, sector- and task-specific, effects are thus heterogeneous between workers specialized in brown tasks compared to workers specialized in green tasks. Second, environmental policies reduce wages and employability of workers specialized in brown tasks, but improve the labour market outcomes of workers specialized in green tasks.

The mechanics of the skill-biased effect is similar to that of capital-labour effects described by Fullerton and Heutel (2007[21]), hinging on which skills are a better substitute for polluting production inputs. To illustrate, environmental policies induce technological and organizational changes that are biased in favour of a set of "green" skills and against a set of "brown" skills, thereby changing the relative demand for workers who possess those sets of skills. The specific way through which skill-biased effects emerge depends on labour market institutions. In perfectly flexible labour markets, the unemployment rate is zero and relative wages respond in full to change in relative demand. Conversely, in regulated labour markets, downward wage rigidities may prevent the adjustment to full employment, thereby increasing the duration and the incidence of unemployment (e.g., Krugman, 1994[53]). Labour research shows that skill depreciation effect is directly proportional to the duration of the unemployment spell and the distance in the skill sets required in the old and new job (e.g., Edin and Gustavsson, 2008[50]; Kambourov and Manovskii, 2009[51]; Gathmann and Schönberg, 2010[52]).

The magnitude of distributional effects depend on the extent to which workers with brown skills can be retrained to acquire "green skills", thus on reallocation costs. Using a general equilibrium model with search frictions, Castellanos and Heutel (2019[37]) show that the unemployment effect of a carbon tax in fossil fuel sectors depends on the assumptions on how costly it is to reallocate workers to other sectors, including renewable electricity generation and the rest of the economy that is only indirectly affected by the carbon tax. In their model, when labour mobility across sectors is absent because skills are fully sector-specific, unemployment spells are much longer for workers in brown sectors (and the aggregated unemployment effect of the tax much worse) than in the scenario without mobility frictions.[13] Note that considering unemployment as a distributional outcome is important given the strong association between unemployment status and well-being, which is partly driven by the non-pecuniary effects of unemployment on happiness (e.g., Winkelmann, 2014[55]).

Reallocation costs are thus important not only to assess distributional effects, but also for the effects of environmental policies on economic efficiency. Empirically, the main challenge is to understand how large reallocation costs are and to what extent they depend on the need of retraining workers displaced by environmental policies in polluting sectors. Walker (2013[30]) follows a direct approach to retrieve reallocation costs. He estimates the foregone lifelong earnings for workers displaced by the US Clean Air Act (CAA), a command-and-control policy imposing emission standards for several pollutants, in polluting sectors relative to a credible counterfactual group[14]. His main finding is that earning losses are substantial for workers that have to change sector, which are more likely to experience a depreciation of their sector-specific skills.[15] Unfortunately, the high data requirement of this approach makes it difficult to replicate for other countries.

[13] Induced skill depreciation during unemployment will increase reallocation costs.

[14] Walker (2013[30]) follows over time a cohort of workers that in 1990 was employed in the same industrial sector but in counties with different level of policy stringency. The counterfactual is the industry in the county that is not affected by the command-and-control policy.

[15] Note that the aggregated costs of the Clean Air Act in terms of earning losses are small compared to the total

Vona et al. (2018[38]) use an indirect approach by identifying and ranking the skills that are most important in green jobs. Establishing a "green skill benchmark" is important to construct proxies of reallocation costs based on skill proximity measures at the occupation level and the associated retraining costs. The authors find that the most important "green skills" are engineering and technical skills followed by operation management, and monitoring and science. Their green attribute is obtained by comparing the skill sets of two similar occupations (i.e. chemical and environmental engineers): when a skill is more intensively used (at conventional level of statistical significance) for a green occupation than for the comparable occupation, the skill is labelled as green. Two important remarks are in order here. First, "green skills" are general because they are also used to perform non-green activities and tasks, so they compute skill proximity measures to assess reallocation costs. Second, green skills are not necessarily skills requiring more education to be performed.

The authors find that green skills are to a certain extent different from the skills required to use and develop digital technologies. For digital technologies, general skills, such as problem solving, mathematical and social skills, are particularly important (Autor, Levy and Murnane, 2003[39]; Deming, 2017[40]), while for green jobs more specific engineering and technical competences are prevalent.[16] Moreover, the most important green skill, i.e. engineering and technical skill, is not correlated with the level of education required in the occupation, being used intensively in both occupations requiring university education (engineers) and in occupations requiring lower levels of education (technicians and skilled manual workers). Finally, green jobs appear to be more similar to brown jobs than to other jobs, but also have significantly higher on-the-job training requirements (Consoli et al., 2016[41]). However, in the crucial job-to-job change for the low-carbon transition, that from extraction and mining workers to construction jobs related to energy-efficient building and low-carbon infrastructure, the skill proximity is relatively low and the training gap relatively high (Vona et al. (2018[38])). As discussed extensively in Section 5, this highlights the importance of training investments to mitigate the distributional effects of climate policies.

Some papers look directly at the effect of environmental policies on the demand for workers with different types of skills using "employability" rather than wages as a proxy of well-being (. Vona at al. (2018[38]) estimate the effect of a recent amendment of the US Clean Air Act on the demand for skills, using the green skill measures described above. While the CAA has no effect on total employment and on the demand for routine and non-routine tasks, it increases the demand for "green skills" in the workforce, especially so for technical and engineering skills. In another study on the British Columbia carbon tax, Yip (2020[31]) finds that the induced increase in the unemployment rate is concentrated among those with low-education (+2.4%) and medium-education (+1.4%). Marin and Vona (2019[42]) examine the effect of long-term changes in energy prices on the relative demand of coarse occupational groups (managers, professionals, technicians and manual workers) for a long panel (1995-2011) of EU countries and industrial sectors, controlling for other intervening factors such as import penetration and ICT investments. The preferred specification indicates that the large historical increase in energy prices explains around 13.5% of the concomitant increase in the share of technicians, while such increase explains only 5% of the decline in the share of manual workers.

In sum, these findings suggest that the skill-biased effects of environmental policies are aligned to those of automation and globalization in harming low-skilled manual workers. However, technical skills appear far more important for green technologies than for digital ones. Put it differently, distributional effects are

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estimated benefits of the regulation in terms of air quality improvements. However, it remains unclear whether foregone lifelong earnings due to displacements in polluting sectors are small or large compared to displacements induced by other structural transformations.

[16] Historical investigations of the process of electrification in the first half of the 20thtwentieth century provide also indirect insights on the skill-biasedness of a potentially green technology. Gray (2013[156]) and Fiszbein et al. (2020[28]) find a pattern similar to that of ICT technologies with a decline in the demand of routine tasks and an expansion of non-routine tasks, but they do not test the effect for other, more specific sets of skills as in Vona et al. (2018[38]).

regressive also along the skilled-unskilled dimension, only the winners within the skilled group are different. Compared to ICT technologies, the new policy implication is that investing in technical education, which is also acquired through on-the-job and vocational training, will be particularly important for the green transition (see also Section 4.2).

Several mechanisms remain largely unexplored in these reduced-form regressions.[17] First, induced technological and organizational changes are not directly observed, thus it is difficult to draw more specific implications for educational and training policies. Second, skill-related reallocation costs can be extremely low for the case of the transition from a coal mining job to a low-skilled service job, but the loss of well-being can be very large in terms of wages. Indeed, not only the prevalent wage rate in the latter job is much lower than the prevalent wage rate in the former one,[18] but also psychological costs should be accounted for (i.e., loss of work identity). Third, a comprehensive picture of the labour market distributional effects requires examining the joint effect of policies that impose a cost on polluting inputs and that subsidize the green economy. This, more macro, perspective will be adopted in Section 4.2.

2.3. Use-side effects

Households care about real income that can be altered by the effect of environmental policies on prices. Defining as *w/p* the real income of a household, where *w* is the wage and *p* is the price of the basket of goods consumed by the household, use side income effects concern *p* rather than *w*. Such effects can be heterogeneous across households because of differences in their consumption baskets. Since environmental policies change relative prices of polluting and clean goods,[19] households with dirtier consumption baskets are at disadvantage relative to households with cleaner consumption baskets (See Box 1 for a detailed definition of direct and indirect effects). The main measurement challenge here is that consumer expenditure surveys do not contain fine-grained information regarding the characteristics of products bought by a household. Most surveys only contain information on the consumption of broad classes of goods such as food, energy for transport and heating or clothes. Because it is relatively straightforward to infer emission from energy consumption, the literature focuses on energy policies, especially energy and carbon taxation, cap-and-trade systems, renewable portfolio standards, etc.

Conceptually, the regressivity of energy policies depends on the fact that the share of energy consumption (a necessity as food) decreases with income (the so-called Engel curve, e.g., Levinson and O'Brien, 2019). The key parameter is the elasticity (or responsiveness) of energy (or pollution) consumption to income. If energy consumption is a necessity, the elasticity of energy consumption to income is smaller than one and the average share of income (or total expenditure) allocated to energy expenditures decreases with income.[20] As a result, use-side effects are regressive. In turn, the effects are progressive if the elasticity is

[17] In this context, reduced-form regressions describe a a situation where an explanatory variable (e.g. environmental policy) can affect an outcome variable (i.e. wages) in several ways, whose relative importance cannot be examined by the regression itself. . A reduced form model allows estimating the effects of the exogeneous explanatory variables on the endogeneous outcome variable.

[18] Coal mining jobs or in general jobs in the industrial sector are still more unionized than low-skilled service sector jobs. Thus, wage rates for the unskilled tend to be higher.

[19] The price of polluted goods increase proportionally to the abatement costs or the tax liability induced by the policy.

[20] Not only essential goods are a larger portion of income low-income than for high-income households, but the essential goods' basket is likely to be dirtier for former than for the latter. For example, households driving less fuel-efficient cars will likely pay more for petrol compared to households with more fuel-efficient or electric vehicles. Similarly, households using oil heating will likely pay more relative to comparable households using solar thermal or gas as their main indoor heating source.

above one. The estimated elasticity of energy consumption to income varies by fuel but it is usually between 0.7 and 0.9 (Espey and Espey, 2004[43]; Flues and Thomas, 2015[44]). In other words, for a 10% increase in income, energy consumption typically increases by 7-9%.

The literature on use-side effects of energy policies is older and far more established than the literature of source-side effects, dating back to the seminal paper of Poterba (Poterba, 1991[45]). Given the lack of historical data on carbon taxation, most studies adopt ex-ante evaluation methods such as micro-simulation and computational general equilibrium models (CGE henceforth), combined with input-output-based measurement of carbon and energy intensity of products that allows to track both direct and indirect energy (or carbon) consumption (Heindl and Löschel, 2015[46]). Ex-ante evaluation methods allow to model behavioural responses, endogenous substitution effects and the source-side effects discussed above, thus they are particularly suitable to study the effect of compensation policies and revenue recycling schemes that will be discussed in Section 4.2.

Table 2.1 summarizes a selection of papers that retrieve the direct effect of carbon and energy taxation; that is: the effect net of indirect price effects, behavioural adjustments and offsetting policies.[21] The direct effect is the first to emerge, thus it is immediately perceived by households and more likely to have consequences in terms of political acceptability. Although results clearly depend on the method used, the following four findings emerge.

[21] In other words, these effects do not include indirect price effects (as specified in Box 1) occuring, for instance, through increases in housing prices. Furthermore, they do not account for some behavioural adjustments, which imply changes in behaviour as a response to the environmental policy (e.g. fuel switching towards less pollution-intensive fuels, limit of driving etc.). For expositional purposes, while the papers reviewed in Table 1 often discussed policies aimed at offsetting negative distributional effects, the Table only reports the direct (or partial equilibrium) effect. Such offsetting policies will be extensively discussed in Section 5 .

Table 2.1. Use-side distributional effects, selected countries and papers

Country	Study	Welfare measure	Policy	Methodology	Direction and Size (compared to income)
Cross-country, OECD	Flues and Thomas (2015[44])	Annual income and expenditure	Taxes on various energy inputs	Micro-simulation model, direct impacts	Regressive for electricity and slightly regressive for heating fuel, but small (0.1-0.5%), heterogeneous and larger (1-3%) for fuel taxes especially in rural areas.
Cross-country, EU	Sterner (2012[47])	Annual income and expenditure	Existing gasoline taxes	Direct impact, inferred indirect impact	Slightly regressive and around 2%, but not for the poorest and when life-time income used
Cross-country, large EU	Symons, Speck and Proops (2002[48])	Annual expenditures (incomes for Germany)	Simulated carbon tax	Input-output (IO) model to retrieve direct and indirect impacts	Regressive for France, Germany and Spain, less for Italy and not for the UK. Large effects
Cross-country, developing	Dorband et al. (2019[49]) for 87 developing countries	Income at current consumption level	Simulated global carbon tax ($30/ton)	Microsimulation model combined with IO tables	Progressive, but heterogeneous, modestly small effects (2%-4% in largest countries) and negative on the poorest
US	Bull, Hassett and Metcalf (1994[50]); Fullerton (1996[51]); Metcalf (1999[14]); Grainger & Kolstad (2010[52]); Hassett, Mathur and Metcalf (2009[53])	Annual income, expenditure, life-time income (panel data)	Simulated carbon and env. taxes	IO models, combined with other methods	Regressive, small effect for tax of $15/ton (1-4%)
Spain	Labandeira & Labeaga (1999[54])	Expenditures, equivalent loss	Simulated carbon tax, various	IO combined with almost ideal demand system and micro-simulations	Proportional and modestly small (3-4%), but large (10%) for the upper bound of the tax ($40-45/ton)
Sweden	Brannlund & Nordstrom (2004[55])	Expenditures, compensated income variation	Simulated carbon tax, 100% increase	Almost linear demand system, econometrics	Slightly regressive, but small (below 0.5%) and concentrated in rural areas
UK	Symons, Proops and Gay (1994[56])	Expenditures	Simulated carbon tax, 240£/ton	IO combined with micro-simulations and almost ideal demand system	Regressive effects, very large (5%-15%)
Denmark	Wier et al. (2005[57])	Annual income and expenditure	Carbon tax, 81€/ton	Input-output models	Regressive, but small (<1%) and concentrated in rural areas
France	Douenne (2020[58])	Annual income and expenditure	Carbon tax, 44.6€/ton	Microsimulation model combined with an almost ideal demand system	Slightly regressive or proportional, but very small (<1%) and heterogeneous within income deciles
Italy	Tiezzi (2005[59])	Expenditures, compensated income variation	Energy tax, mostly on transport	Almost Ideal demand system	Slightly progressive; Small (<1%)
Ireland	Callan et al. (2009[60])	Annual income, deciles	Simulated carbon tax, $20/ton	Direct impact, microsimulation	Regressive, stronger for home heating and in rural areas

Source: Authors

First and foremost, effects of carbon and energy taxation on households' spending are found to be small and slightly regressive in developed countries, but progressive in developing ones (Dorband et al., 2019[49]). Indeed, the share of energy in total consumption is very small at low-income levels (i.e. energy deprivation line), then increases for the low-to-middle income levels (i.e., energy becomes affordable) and decreases for high-income households (i.e., energy is a necessity). In developing countries, the distribution of households is concentrated mostly in low- or middle-income groups, so the tax is progressive on average across the income distribution.[22] In turn, in the developed countries, households are mostly in middle and high-income groups, so the tax is regressive.

Second, energy for home heating is a necessity more than energy for private transport, which depends on, e.g., car ownership. Thus, the regressivity of the effects depends on the type of fuel targeted by the policy (Flues and Thomas, 2015). In developed countries, electricity taxation harms especially households in the bottom deciles because residential energy is a necessity (Hassett, Mathur and Metcalf, 2009[53]; Pizer and Sexton, 2019[61]).[23] In turn, gasoline taxes, which have been the trigger of the recent Yellow Vest protest in France, have a nonlinear effect harming especially households in the middle deciles (Sterner and Köhlin, 2012[62]; West, 2004[63]; West and Williams, 2004[64]). This is consistent with the inverted U-shaped Engel curve discussed above (Dorband et al., 2019[49]): poorer households use public transports rather than cars, so the effect is progressive at the bottom, while richer households drive new, energy efficient cars, so the effect is regressive at the top.

A third general finding is that the regressivity of the use-side effect in high-income countries is mitigated by using proxies of permanent lifelong incomes (Bull, Hassett and Metcalf, 1994[50]; Poterba, 1991[45]; Sterner, 2012[47]) and considering indirect effects of the tax on non-energy goods (Bull, Hassett and Metcalf, 1994[50]; Pizer and Sexton, 2019[61]). In particular, a good proxy of permanent income is total expenditures because individuals can borrow against future incomes, thus smoothening their consumption along the life-cycle. However, the mechanisms and the size of this consumption smoothing effect are not fully in this literature. As extensively suggested in Section 4.1, there are other mechanisms that exacerbate the regressivity of use-side effects in the long-run.

Finally, vertical distributional effects, i.e. effects across income groups, are often smaller than horizontal distributional effects, i.e. effects within each income group (Cronin, Fullerton and Sexton, 2019[65]; Douenne, 2020[58]; Rausch, Metcalf and Reilly, 2011[66]). This implies that, because other factors beyond income (i.e., availability of public transport) are important in explaining the energy and carbon content of a household's consumption, compensations based on income alone may be ineffective to neutralize the distributional effects of carbon taxation. Among other variables explaining residual differences in energy consumption, most studies found that the incidence of the tax is much larger in rural areas, which is consistent with the negative association between population density and household emissions from transport and home heating (e.g., Glaeser and Kahn (2010[67])). While these findings imply that the design of compensation policies cannot rely only on progressive rebates or means-tested subsidies[24], the

[22] Further, poor people in low-income countries usually work in the informal sector, thus they do not have tax liabilities. Both these factors contribute in making energy and carbon taxation progressive in developing countries.

[23] Note that, except very poor households that benefit from generous exemptions, low- and middle-income households pay already higher electricity prices per kWh due to quantity discounts and higher incidence of fixed costs such as network costs, thus the structure of energy prices exacerbate the regressive effect of carbon taxation. However, since residential energy is a necessity, most countries adopt policies to fight energy poverty and deprivation. This is clearly a critical aspect of residential energy taxation.

[24] Means-testing is a criterion to give subsidies based on the households' income, usually lower income households receive relatively more than to higher income households .

availability of rich datasets to enhance our understanding of vertical distributional effects would allow to reveal the relevant additional dimensions (i.e., urban vs. rural) to consider in compensating the losers.

2.3.1. Joint assessments of use- and source-side effects

Compared to micro-simulation models or to ex-post empirical evaluations of environmental policy effects, Computational General Equilibrium (CGE) models allow a more holistic approach by incorporating a wider spectrum of behavioural and price adjustments as well as the effects of several types of compensation policies (see van Ruijven, O'Neill and Chateau, 2015[20]). Another key advantage of CGE models is that they can be used to study the multidimensionality in the effect of carbon taxation. Indeed, the focus of several influential papers has been to treat in a unified framework both source-side and use-side effects (Araar, Dissou and Duclos, 2011[68]; Fullerton, 2011[17]; Goulder et al., 2019[69]; Rausch, Metcalf and Reilly, 2011[66]). Finally, CGE models assess the distributional effects of the policy, but also effects on economic and environmental efficiency, which are also in the objective function of policymakers. The downside is that they are very dependent on the assumptions made on a few key parameters, which are usually estimated at a different level of spatial and sectoral aggregation than that required by the models. Likewise, the breakdown of consumers' groups into income deciles does not allow to generate finely resulted distributional effects also within groups, especially differentiating source side effects by occupation or skill groups.

A first key result of these models is that a wide range of policies can be used to compensate the losers, with different pros and cons that will be part of the discussion of Section 4.3. A second result is that regressivity is mitigated when one combines source-side and use-side effects. Use-side effects are indeed regressive, but source-side effects are progressive because they favour workers over capital owners. However, as we discussed in Section 2.1, this assumption does not find strong empirical support. The reason lies in the mechanism stressed by these models where the source-side effects depend on the induced effect of the policy on the sectoral composition of the economy and follows directly by the assumption that clean sectors are relatively labour-intensive compared to polluting sectors (e.g., Araar, Dissou and Duclos, 2011[86]; Goulder et al., 2019[87]). Not only these differences in labour intensity appears small (e.g., Fullerton and Heutel, 2007[29]), but also sectoral composition effects induced by the policy may be too small to justify this conclusion (e.g., Brunel, 2017[32]; Levinson, 2009[31]). More importantly, environmental policies induce energy-saving technological change that is labour saving and capital augmenting. Thus, even if reallocation towards clean sectors may increase the relative demand for labour in the short-term, induced technological change reduces the relative demand for labour in the long-run. This dynamic aspect of factor substitution is muted in these models, leading to a less problematic assessment of the distributional effects. Finally, these models can be amended to enrich the characterization of labour market dynamics including sector-specific skills, wages and unemployment.[25] For instance, a manual worker displaced by manufacturing jobs in polluting sectors will end up earning less in low-skilled service jobs, thus the source side effect on welfare can be negative even if the service sector is relatively labour-intensive and there is no endogenous technological change.

These are crucial areas where ex-ante evaluations can make substantial progress by taking advantage from existing findings of the empirical literature. Notably, incorporating endogenous technological change in CGE model would greatly benefit our understanding of long-term distributional effects. Differentiating the effects for workers with different skills or including reliable proxies of reallocation costs (e.g., Castellanos and Heutel, 2019[54]) appears also very important to make advancements in identifying the real losers of the transition to a greener economy.

[25] Search and matching models have been recently used to study the unemployment effects of climate policies (Hafstead and Williams, 2018; Castellanos and Heutel, 2019; Aubert and Assouline, 2020).

2.3.2. Comparison of tax and non-tax policies

A digression on policy comparison is important at this point. It is well-known in the literature that market-based policies (i.e., taxes and emission trading schemes) allow to achieve emission reductions at the lowest possible cost, at least in an economy without existing distortions (e.g., Goulder and Parry, 2008[67]). Thus, market-based policies theoretically outperform command-and-control policies (i.e., emission performance standards or technology mandates) in terms of environmental effectiveness.[26]

An open question is whether they are also better in terms of equity.[27] On source side effects, the model of Castellanos and Heutel (2019[37]) shows that command-and-control policies lead to larger unemployment effects than a tax if reallocation costs, including retraining costs, are relevant. This implies that coal miners and other workers in brown sectors displaced by the policy will experience a longer unemployment spells with a command-and-control regulation.[28] Extending their seminal paper to technology and performance mandates, Fullerton and Heutel (2010[70]) note that the polluting sector receive an implicit output subsidy that is appropriated by the factor that is used intensively in this sector. If the polluting sector is (slightly) capital intensive relative to the rest of the economy, the distributional effect of command-and-control policies is more regressive than that of a pollution tax. Overall, command-and-control policies are expected to be more regressive than market-based policies, which is consistent with the well-known fact that firms appropriate the scarcity rents created by quantity restrictions (e.g., Fullerton, 2011[19]).

On use side effects, the literature is more advanced, but still scant. Levinson (2018) develops a simple conceptual framework to empirically show that a standard is more regressive than a tax in general and applies it to the case of gasoline regulation.[29] He begins by noting that an emission standard is equivalent to a tax imposed to inefficient appliances or vehicles, thus the standard is regressive because poorer individuals have less-efficient equipment (e.g., Kahn, 1998[90]). The rich consume more energy (a scale effect making the tax progressive, i.e. drive more), but with more efficient devices (a technology effect making the tax regressive, i.e. buy electric cars). Since standards switch off the scale effect of the policy, they are more regressive than a tax.

In light of the above argument, it should be clear that subsidies to green products are regressive and probably not particularly effective because the high-income households will purchase the green good or undertake energy efficient investments also without a subsidy. Note that the choice to buy green equipment is a discrete choice one. Higher income households have the resources to co-finance investments in green technology, thereby self-select themselves as investors in green durable goods. Indeed, even a subsidized electric vehicle can remain too expensive for low-income households (Tovar Reaños and Sommerfeld, 2018[71]; West, 2004[63]).[30] As another example, only home-owners can apply for the generous tax credits

[26] Rigorous empirical evaluations of this theoretical result are however scarce because two policy instruments rarely overlap. An exception is represented by the US Clean Air Act amendment of 1990 that encouraged the use of market-based policy and allow comparison of the performance of plants regulated under the old standard and of similar plants regulated under the new emission trading system. Using this strategy, Fowlie et al. (2012[209]) show that emission trading in California was much more cost-effective in reducing NOx emissions than emission standards.

[27] See Fullerton and Muehlegger (2019[159]) for a comprehensive discussion of distributional effects of nontax regulation.

[28] This is a consequence of the fact that each sector is obliged to abate regardless of its marginal abatement costs. See also the CGE model of Rausch and Mowers (2011[66]) for similar results on the worst performance of renewable energy standards compared to carbon taxes in terms of both equity and efficiency.

[29] Similarly, Davis and Knittel (2016[73]) show that widely used corporate average fuel standards (CAFE) impose an implicit subsidy to fuel-efficient cars and an implicit tax to fuel inefficient ones. The difference in regressivity between taxes and standards depend in this case on whether the tax revenues are recycled, but become very similar to those of Levinson once the effect on the price of used cars is incorporated (e.g., Jacobsen, 2013[180]).

[30] To correct this distortion that is particularly large for electric vehicles (Borenstein and Davis, 2016[8]), a recent policy experiment in California proposes a means-tested subsidy for the purchase of electric vehicles (Muehlegger and Rapson, 2018[20]).

for solar panels or home weatherization in force in the US since 2006 (Borenstein and Davis, 2016[8]). In Germany, feed-in-tariffs for solar energy, a fixed payment for green electricity that exceeds the spot market price, are regressive because adoption of solar panels is correlated with home ownership and the size of the dwelling (Grösche and Schröder, 2014[72]).[31] The same argument applies to almost all investments in green technologies. Borenstein and Davis (2016[8]) show that tax credits for residential energy-efficient investments and alternative vehicle purchases in the US are strongly skewed toward high-income households. As much as 60% of the tax credit goes to the top quintile (and even more so the top percentile), while only 10% to the bottom quintile. Using results from other papers, the authors also show that subsidies to clean investments are much more regressive than a carbon tax.

Importantly, market-based policies, if well-designed, allow to raise revenues that can be used to compensate the losers, while command-and-control policies often translate into higher rents for the incumbents. Thus, even in case when command-and-control policies are less regressive than market-based ones, the latter can offer more room to make the overall policy effect progressive or less regressive once revenue recycling schemes are considered. This is exactly the conclusion of Davis and Knittel (2016[73]) in their comparison of gasoline standards and taxes. However, the room for redistribution is quite limited if policy distortions such as excess grandfathering remained in place lowering the amount of revenues collected. Moreover, the effectiveness of means-tested redistribution can be limited by the fact that the bulk of the inequality generated by environmental taxation is across households with similar incomes rather than between households with different incomes. For residential energy consumption, Fischer and Pizer (2019[74]) show that market-based instruments may have larger effects on horizontal equity than command-and-control ones. As a result, equity-efficiency trade-offs may be far more difficult to manage in the real world, a point that we will discuss again in Section 4. The superiority of market-based policies over command-and-control ones should be also corroborated by more research for different sectors and pollutants, and jointly considering both the environmental and the economic effects.

[31] In several EU countries, subsidies to renewable energy are even more regressive as they financed by a levy paid by all consumers and proportional to electricity consumption (e.g., Grösche and Schröder, 2014[92]; Marin and Vona, 2017[181]). Moreover, large companies are usual exempted by such taxes for competitiveness reasons (Marin and Vona, 2017[161]).

3 Spatial effects and health benefits

This section reviews the literature on spatial distributional effects, with a particular focus on nonpecuniary benefits. Recall that the main goal of environmental policies is to reduce pollution and, indirectly, the harmful consequences of climate change on human well-being. Exposure to pollution and some extreme climate-related events, such as high temperature episodes, is typically heterogeneous across locations, so that it is the same for all households living in a specific community. More specifically, pollution effects cluster around hazardous waste sites, coal power plants or chemical factories, while urban areas are characterized by higher concentration of PM2.5 and NOx emitted by cars. Extreme climate events induced by global warming are concentrated in vulnerable locations (e.g. coastal areas), sectors (e.g. agriculture), and occupations (e.g. performed outdoor). Economic effects are also concentrated in space as the shutdown of a coal power plant would cost jobs only in the area where the plant is located, while green stimulus packages are likely to be directed to areas with specific characteristics such as a trained workforce or a high wind potential.

The next section presents evidence on the so-called environmental justice gap. Then, it discusses the effects of an improved environmental quality on housing prices and mobility. The final section examines the spatial concentration of economic effects.

3.1. The environmental justice gap

A preamble to understand distributional effects of reduced pollution is important at this point. A voluminous research shows that excessive exposure to pollutants[32] or extreme whether events induced by climate change do affects human wellbeing along several dimensions:[33] i. health and mortality (e.g., Chay and Greenstone, 2003[95]; Deschênes and Greenstone, 2011[96]); ii. human capital, especially at young ages (e.g., Currie and Neidell, 2005[97]; Currie, 2011[5]); iii. labor supply and productivity (e.g., Graff Zivin and Neidell, 2013[6]; Hanna and Oliva, 2011[98]). Importantly, effects on the accumulation of human capital creates large and permanent opportunity gaps between children from different family backgrounds, extending the consequences of pollution exposure across generation and making such type of inequality particularly unfair. For instance, health inequalities at birth, or even in-utero, that are associated with a differential exposure to pollution are particularly difficult to accept due to its long-lasting, intergenerational, consequences on individual well-being (Currie, 2011[75]).

A vast literature in economics and sociology find strong empirical support on the existence of an environmental justice gap, namely the fact that low-income households and ethnic minorities are significantly more exposed to several types of pollution risks including air pollutants, hazardous waste and various toxic chemicals (e.g., Hamilton, 1995[99]; Mohai and Saha, 2006[100]; Zwickl, Ash and Boyce, 2014[10]). Hsiang et al. (2017[16]) show that climate change is no exception, creating more damage to

[32] This survey refers here to "exposure" without distinguishing between "potential exposure", due to the contamination of the environment, and "realized exposure", which depends also on avoidance behavior. The distinction is extremely relevant for the voluminous literature on the health effects of pollution (Graff Zivin and Neidell, 2013[132]), but less so for the scope of this survey.

[33] See also the surveys of Graff Zivin and Neidell (2013[132]) and Hsiang et al. (2019[18]).

disadvantaged communities along several dimensions (i.e., excess mortality, agriculture productivity, labor supply, violent crime).[34] Recall that reducing greenhouse gas emissions has also well-known positive effects in terms of health co-benefits: Mitigation actions often also reduce local air pollutants, which in turn improve local air quality and health outcomes.

Looking at correlations between pollution exposure and various socioeconomic characteristics, such as income and race, is not enough to understand the distributional effects as well as mechanisms behind the observed environmental justice gap. Indeed, pollution exposure and environmental hazard co-vary with location choices and siting decisions of companies, which are in turn correlated with income, race and other neighbourhood's characteristics. Identifying the causal mechanisms behind these correlations is the goal of quasi-experimental approaches that try to isolate the effects of exogenous policy variation on pollution exposure and, when possible, health outcomes.

The empirical literature on the distribution of non-monetary benefits induced by environmental policies is primarily US- based with a few exceptions in developing countries, which are, however, difficult to compare with the US ones context as they address different environmental problems (see the survey of Hsiang, Oliva and Walker, 2019[8]). Obviously, the literature is concentrated on local pollutants for which the direct benefits are more visible. Because reduction in greenhouse gases goes hand-in-hand with reduction of local pollutants, the results of this literature should remain valid for climate policies.

A few early papers study the clean-up of hazardous waste sites under the Superfund program, which combines elements of a subsidy for the clean-up and a command-and-control policy to determine the eligibility rule.[35] To illustrate the health benefits of the program, Currie et al. (2011[75]) compare birth outcomes before and after the clean-up of mothers living within 2 kilometres of the site (treated) and between 2 and 5 km away (control). The authors find that the cleanup reduces the incidence of congenital anomalies by approximately 1/4. Considering the initial environmental justice gap, these findings suggest that public spending targeting clean-ups of hazardous sites are progressive, benefitting specifically lower income groups who are more likely to live close to polluted sites. Since proximity to hazardous waste or TRI sites (i.e. sites included in the US toxic release inventory) provoke substantial damage in terms of long-term cognitive development of exposed children (e.g., Persico, Figlio and Roth, 2020[103]), the clean-up of these sites is a top priority not only to achieve a decent level of environmental justice, but also to reduce a type of intergenerational inequality that is particularly unfair. The comprehensive study of Currie et al. (2020[76]) examines the effect of the CAA on the black-white exposure gap in PM2.5 over the last 20 years. Combining individual data, up-to-date measures of local air pollution and quantile decomposition techniques, their analysis reveals that the CAA accounted for over 60 percent of the reduction of the pollution exposure gap between black and white populations. Notably, the use of quantile decomposition techniques allows to retrieve the granular effect of the CAA at different percentiles of the PM2.5 distributions, including the most polluted ones. Again, these findings indicate that command-and-control policies implicitly targeting more exposed neighbourhoods have been effective in reducing the environmental justice gap.

Cap-and-trade programs are diffused around the globe as the main policy option to reduce both local and global emissions, but faced strong opposition from environmental activists for the inequities that they may

[34] The authors find that economic losses from climate are larger in regions that are already poorer, with an impact ranging between 2% and 19% of local gross county product depending on the modelling scenarios. Using a similar approach, Carlton et al. (2020[210]) estimate mortality-temperature dose response function for 40 countries and project them to understand the distribution of future climate impacts. Their analysis indicates that mortality will increase especially in poorer locations.

[35] The Superfund program of the United States Environmental Protection Agency (EPA) is responsible for cleaning up contaminated land and responding to environmental emergencies such as oil spills and natural disasters. The program allows the EPA to force the parties responsible for the contamination to either perform cleanups or reimburse the government. In the absence of a viable responsible party, the Superfund provides the necessary funds to EPA to clean up contaminated sites.

exacerbate. Under cap-and-trade programs, managers are free to choose which plant (and thus neighbourhood) is in charge of reducing emissions, hence the targeting to highly exposed neighbourhoods is not ensured. If affluent neighbourhoods are more efficient at exerting political pressure to obtain larger emission reductions (Hamilton, 1995[77]), cap-and-trade policy can be regressive, which from a distributional perspective can be a particular concerning for local pollutants such as NO_x, SO_x, PM etc.. Several recent papers examine the distributional impacts of cap-and-trade programs in US states for several air pollutants, focussing specifically on the distributional effects of pollution concentration and exposure To retrieve a causal effect, these papers compare changes in emissions between plants targeted by the policy and plants not targeted (or targeted by a command-and-control policy as for the case of RECLAIM), depending on neighbourhoods' characteristics. Overall, all but one study find that, even if benefits are not uniformly distributed, pollution reductions are widespread in all neighbourhoods.[36]

From a superficial reading of these findings, one may be tempted to draw the policy conclusion that command-and-control policies look more equitable than cap-and-trade programs. However, such conclusion would be rushed because it does not take into consideration the total size of the benefits (i.e. environmental improvements) of different policies, nor the possibilities for flanking policies that can be funded by the revenues of the policies (see next Section). Moreover, command-and-control policies such as emission standards tend to target different types of environmental damages than cap-and-trade programs (respectively concentrated emissions of PM2.5 vs. diffused emissions of CO2), so not always it is possible to choose between a market-based and a command-and-control approach. Finally, a popular non-market based policy, namely a subsidy to green technologies, is not only regressive from a use-side perspective, but can also be regressive in terms of health benefits. For instance, subsidies to electric vehicles remove emissions in rich communities where diffusion is high and reallocated them to poorer neighbourhoods where fossil-based power plants are located (Holland et al., 2016[78]). We will discuss the policy lessons from these results in greater details in Section 4, before we need to complete the general picture by discussing the extent to which general equilibrium effects interact with the direct distributional effects of the policy.

3.2. Gentrification and housing prices

Quasi-experimental research provides important insights on the distributional effects on individual income or pollution exposure, but does not capture policy effects on households' sorting choices and local prices, i.e., so-called general equilibrium effects. Moreover, it is ill-suited to answer normative questions such as the extent to which emission reductions are valued by households with different characteristics. Because low-income households may assign low value to large environmental improvements compared to small

[36] Some studies find regressive effects (Grainger and Ruangmas, 2018[169]) and, in relative terms, (Andaloussi, 2017[206]), others neutrality (Fowlie, Holland and Mansur, 2012[209]); (Mansur and Sheriff, 2021[130])) or even progressivity (Hernandez-Cortes and Meng, 2020[170]). The RECLAIM literature illustrates some of the controversial issues in the literature. Fowlie et al. (2012[209]) observe that changes in emissions do not vary significantly with the neighborhoods composition. Grainger and Ruangmas (2018[169]) show that such results are sensitive to the assumption made on pollution dispersion. Using a pollution dispersion model rather than simple circles around the polluting plant to map emissions onto location-specific pollution exposure, the authors find a regressive effect of the program with respect to income, but not to race. Hernandez-Cortes and Meng (2020[170]) also show that their conclusions are sensitive to the way of modeling pollution dispersion. Mansur and Sheriff (2021[130]) reconsider these findings by ranking pollution distributions, under minimal assumptions on preferences and abstracting from general equilibrium adjustments in housing prices and wages. Their main finding is that all groups benefited from the RECLAIM program compared to the command-and-control counterfactual, but the White group improves relatively more than the Hispanic and Black groups. Importantly, Andaloussi and Isaksen (2017[206]) reach similar conclusions for the Clean Air Inter-State Rule.

losses in terms of wages or employability, differences in preferences (and in the willingness to pay for environmental quality) have to be part of a fully-fledged welfare assessment of distributional effects.[37]

A simple way to understand the direction and the magnitude of general equilibrium effects is to directly estimate hedonic price models, where pollution reductions are capitalized into housing prices and thus may translate into higher rents (Rosen, 1974[79]). Since homeowners are disproportionately concentrated among the rich and renters among the poor in many countries (see indicator HM1.3 in the OECD Affordable Housing Database), a contemporaneous increase of housing prices and rents is expected to have a regressive distributional impact. The literature, primarily looking at the United States, inds that pollution reductions induced by exogenous shocks or environmental policies lead to a substantial appreciation in housing prices.[38] Effects on rents are found to be smaller in some studies (e.g., Bento, Freedman and Lang, 2015[107]; Grainger, 2012[108]), but as large as housing price increases by others (Sullivan, 2017[80]). More research using individual-level data on homeownership is needed to reach clear conclusions on the regressivity or progressivity of capitalization effects. However, as long as the poorest are less likely to own a house and more likely to pay a rent in many OECD countries, health benefits canmay be offset by higher renting costs at the bottom of the distribution. The hedonic approach can be also applied to study the capitalization of other environmental policies, notably feed-in tariffs schemes for renewable energy, which is typically land-intensive.

A second type of evidence is on environmental gentrification, that is: a demographic change towards rich and more educated households in neighbourhoods where environmental quality improves.[39] The process of environmental gentrification tends to recreate the disparities in exposure to pollutants in the long-run. Banzhaf and Walsh (2008[81]) find an increase in both income and population density in areas experiencing an improvement in air quality, inferred from the presence of toxic release inventory sites. Similarly, Gamper-Rabindra and Timmins (2011[82]) document that the Superfund cleanup changes the neighbourhood composition towards rich and more educated households. Similar mobility patterns are found by a recent paper evaluating the distributional effects of the Clean Air Act (Currie, Voorheis and Walker, 2020[104]) These effects on induced mobility could be simply driven by reverse causality, namely the polluting companies choose neighbourhoods with a larger proportion of ethnic minorities and poor households for non-economic reasons, i.e. higher political pressure of the affluent neighbourhoods to avoid emissions (Hamilton, 1995[77]). While it is difficult to give an ultimate answer to these questions, the careful analysis of Wolverton (2009[83]) provides convincing evidence that companies mostly decide where to locate polluting plants in response to standard economic drivers rather than to neighbourhood with a larger share of disadvantaged households. Finally, the survey of Cattaneo et al. (2019[84]) suggests that poor households are more vulnerable to climate change, but lack resources to adapt through migration. Overall, induced migration (or the need of migratingdue to of climate change) reduces the progressivity in the

[37] Recall that the gap in the WTP for environmental quality among the rich and the poor can be explained by non-homothetic preferences. That is: environmental quality is a good lower in the hierarchical scale than food or shelter.

[38] Greenstone and Gallagher (2008[173]) exploit a discontinuity in a risk index that determines the eligibility to remedial cleanup under the Superfund. Comparing changes in housing prices for sites just above and below the eligibility threshold does not lend support to an increase in residential property values. Gamper-Rabindra and Timmins (2011[82]) highlight an "ecological fallacy" in the analysis of Greenstone and Gallagher (2008[173]). Applying the same methodology, but using more disaggregated spatial data, they find a sizeable appreciation in median housing prices around cleaned sites, which is consistent with similar appreciation effects for brownfield redevelopment (Haninger, Ma and Timmins, 2017[174]), hazardous waste sites (Taylor, Phaneuf and Liu, 2016[175]) and opening of polluting plants (Currie et al., 2015[211]). Interestingly, these price effects are not obviously regressive. Exploiting a particular feature of the US CAA, Bento et al. (2015[95]) use monitor-level attainment status in 1990 as an instrument for PM10 air quality improvement. The authors find that benefits from pollution reductions are capitalized into higher housing prices and accrue to homeowners in the lowest quintile of the income distribution.

[39] This definition distinguishes the term "environmental gentrification", from the broader concept of gentrification, which may be caused by other, non-environmental improvements including for example improvements in service quality and availability.

distribution of environmental policy benefits and seems to occur mostly along an income, as opposed to a race, gradient.

An alternative approach is to impose a theoretical structure to the empirical analysis by jointly modelling households' mobility choices in response to policy changes and the resulting effects on housing prices, welfare and mobility (Banzhaf and Walsh, 2008[81]). Such an approach is particularly useful to derive credible estimates of the willingness to pay (WTP) for environmental quality improvements when changes in environmental quality are large and hence have significant general equilibrium effects. If, as it is also shown in the burgeoning literature at the intersection between development and environmental economics (Greenstone and Jack, 2015[85]), the WTP for environmental quality and reduced health risk is increasing with income, poorer households sort themselves into polluted neighbourhoods. Indeed, even if they face higher pollution risks on health, poor households prioritize basic needs and are thus stuck into a "pollution trap".

Few influential articles adding more theoretical structure to the analysis provide convincing evidence on the importance of modelling mobility and location choices (e.g., Bayer, Keohane and Timmins, 2009[115]; Depro, Timmins and O'Neil, 2015[112]; Noonan, Krupka and Baden, 2007[116]; Sieg et al., 2004[117]; Wolverton, 2009[113], Cruz Álvarez and Rossi-Hansberg (2021[86])). The main insight from this strand of research is that partial equilibrium and quasi-experimental analyses underestimate the welfare gains from large environmental quality improvements driven by environmental policy. As Sieg et al. (2004[87]) put it, locational equilibrium approaches assume that moving costs are negligible and thus provide an upper bound to the welfare effects, while partial equilibrium approaches assume moving costs are prohibitively high and thus provide a lower bound to the welfare effects. Finally, since most of these additional gains are capitalized into higher housing prices and rents, general equilibrium effects tends to benefit those with higher incomes.[40]

To summarize, given the current distribution of pollution exposure, environmental policies will have a progressive effect by improving the quality of life and the health of low-income households. Importantly, progressive effects are amplified by the indirect intergenerational, long-term effect on the accumulation of human capital of children that avoid extreme doses of pollution exposure. On the other hand, nonpecuniary progressive effects are at least in part diminished by environmental gentrification and indirect pecuniary effects on housing prices. These indirect effects become evident by modelling households' locational choices in the long-run. Finally, direct health benefits are perceived as less important than indirect economic costs (i.e. higher rents) by poorer households that attach less value (i.e. low WTP) to improvements in environmental quality than rich ones. This issue is discussed in the next section and then in relation to compensation policies in Section 4.

As a final remark, it is important to recall that most of these conclusions are valid for the US and very often for a single US state, California. Clearly, they may be no longer be valid in countries where housing markets and policies, i.e. social housing, are very different. For example, the levels of spatial segregation along income and ethnic lines are particularly high in the United States relative to other OECD countries, potentially making it difficult to transfer results to other countries (OECD, 2018[88]).

[40] In Sieg et al. (2004[87]), general equilibrium adjustments to the 1990 CAA in the Los Angeles metropolitan area can be up to +/-50% of the direct partial equilibrium effects.

3.3. The regional dimension of source-side effects

The job destruction side of environmental policies are expected to be spatially concentrated because emissions are highly concentrated in a few sectors. Moreover, polluting industries often produce tradable goods (e.g., steel, chemicals, fossil fuels), thus a local multiplier effect can amplify the direct job destruction in such industries resulting in reduced expenditures in goods and services that are produced locally. Therefore, the high concentration of potential job losses should be discussed with the help of the literature at the intersection between labour and economic geography (e.g., Moretti, 2010[118]).

Let us start with an example, above the obvious one of communities whose economies depend on natural resources (e.g., shale gas or coal mines). About one third of the industrial employment in the Taranto's province (Italy) would be destroyed if the mega steel factory will be forced to shut down to comply with existing environmental standards. Not only spatially concentrated employment effects are the most difficult to solve, but they also nourish the "job killing" argument in the political debate (Marin and Vona, 2019[42]). Indeed, the shutdown of large plants in communities dependent on polluting industries triggers a cascade of other negative externalities in these communities. Well-known examples are crime, the diffusion of opioids, poor mental health and life dissatisfaction in general (Bartik, 2020[22] for a review). The health-job trade-off is at its maximum tension in these very polluted communities: on the one hand, environmental policy saves lives; on the other hand, it can destroy the local economy in the short-term.

These expected effects of environmental policies compound with historical trends that were not rosy for communities whose economies depend on energy- and pollution-intensive industries (also referred to as "brown communities"). Recent research shows that regions with a higher proportion of energy-intensive industries and mining have been the main losers from European deindustrialization during the 20th century (Rosés and Wolf, 2018). A recent assessment of localized shocks documents the persistence of the labour market impacts of the decline of coal in the 1980s in the US (Autor, 2021[89]). Weber (2020[90]) shows that coal-intensive counties in the US are poorer than average, so more vulnerable to negative economic shocks induced by a stringent climate regulation.

The decline of the well-being of these mostly non-urban communities is in stark contrast with the flourishing of urban communities where high-tech industries and knowledge intensive business services are located. The latter are also the home of emerging green high-tech industries (Bontadini and Vona, 2020[91]). Such divergent urban-rural gap has been translated into a progressive polarization in political beliefs, with the distressed communities with structurally weak economies embracing populistic political platforms (Rodríguez-Pose, 2018[92]) and the associated climate change denial (Lockwood, 2018[93]). Importantly, the literature on large deindustrialization shocks in local labour markets, has shown that the combination of market forces, standard unemployment benefits and trade adjustment assistance is not enough to ensure a smooth return to the economic conditions (real wages, employability) that were prevalent before the shock (e.g., Autor, Dorn and Hanson, 2012[122]; 2013[123]).

Source-side effects can also create new opportunities in the green economy, but evidence on this is scant. Moreover, it is not clear if subsidies to the green economy will be effective in distressed brown communities, as seen for example by some cases of persistent underdevelopment in spite of significant policy support (e.g., North-west England, Southern Italy). Examining the 'green' component of the US American Recovery and Reinvestment Act (ARRA) across US commuting zones over the period 2005-2017, the recent study of Popp et al. (2021[94]) shows that green subsidies are significantly less effective in communities without a workforce with the appropriate set of green skills. Although this finding does not imply that brown communities cannot benefit from a green fiscal push, the positive correlation between income level and the green skill index suggests that distressed communities, including brown ones, will benefit less from green industrial policies. On the positive side, this study also shows that the "countervailing" job creation effects in sectors such as renewable energy, building retrofits and clean-up of polluting sites was concentrated among manual workers (e.g., green construction, waste management). Taken together with evidence presented in Section 2.2, this implies that some of the workers displaced by energy taxes and climate policies can be re-employed in the green economy with a limited cost in terms of retraining.[41] However, to the extent to which job destroyed and created are not located in the same region, reallocation costs related to the need to move workers can be large and should be properly considered in an fully-fledged analysis of costs and benefits.

Table 3.1offers a self-contained summary of the survey for the different strands of literature in Sections 2 and 3. Note that, in this Table, the convention is to attach a positive value to progressive outcomes, which can be justified in several ways (inequality aversion, role of luck, etc.). The desired level of progressivity can, however, vary substantially from country to country depending on individuals' preferences and cultural values.

Table 3.1. Summary of distributional effects, Section 2 and 3

	Taxes, emission trading schemes		Subsidies to green goods		Emission standards and limits	
	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Section 3						
Source side: capital vs. labour	=	-/=	?	?	-	--
Source side: skills	-	--	=	+/=	-	--
Use side: consumption	-	-/=	--	--	-	-
Section 4						
Non-pecuniary benefits (health)	+	=/+/++	?/-	?/-	+	=/+/++
Induced changes in housing prices	=	-	?	?	=	-
Induced migration	=	-	?	?	=	-

Note: ++ very progressive, + progressive, = neutral, - regressive, -- very regressive, ? unknown effect. A range of estimates is indicated using multiple symbols, separated by a "/". For example, -/=, means that effects can range from being regressive to being neutral.
Source: Authors.

[41] However, the wage of manual workers stagnates also in areas receiving more green ARRA spending, but this result requires further scrutiny using panel data to control for self-selection into manual occupations.

4 Offsetting distributional effects

As it was for the case of retraining and mobility induced by changes in local pollution, the distributional outcomes of environmental policies depend on the capacity of individuals with different income levels to adjust to the policy by capturing the bulk of the market and non-market benefits. These adjustments take time to emerge as they presume upfront investments, e.g., new skills or new capital equipment, before the full gains are reaped. For instance, households can reduce the carbon content of their consumption basket by buying energy efficient appliances. Constraints to perform these adjustments may differ depending on income or heterogeneous preferences. Next section discusses this problem in details.

Second, other policies, which typically complement environmental ones, can facilitate the adjustment processes. We refer to these policies as *compensation schemes* that enter the typical green policy package designed to ensure a triple dividend in terms of environmental effectiveness, economic efficiency and equity. Those compensation policies are discussed in Section 4.2.

4.1. Heterogeneous long-term adjustments and constraints

The main point of this section is that the long-term benefits of environmental policies may be more difficult to reap for low-income households. This insight already emerged in Section 2.1, because capital is a better substitute to polluting production inputs in the long-run, and in Section 3.2, because spatial mobility tends to increase the benefits appropriated by the rich. Understanding why poorer households face additional difficulties to successfully adjust to environmental policies is a key step to design compensation policies.

Concerning source-side effects, direct evidence on heterogeneous long-term adjustments is scant with the exception of Walker (2013[30]), but labour economics research offers insights that can be extrapolated to this context. First, higher levels of education allow to acquire general skills that are portable to alternative jobs. For example, a high-skilled engineer losing her job in the mining sector has either portable skills for a fast growing green job in the renewable energy sector, or the financial resources to pay for a retraining program, and usually a richer professional network. Second, retraining investments are typically less affordable for those with lower levels of education. Without generous unemployment benefits combined with targeted retraining policies (the so-called Flexsecurity schemes diffused in Northern Europe, e.g. Viebrock and Clasen, 2009[124]), manual workers in polluting sectors – displaced by an environmental policy – can hardly afford paying the costs of retraining and need to accept a job outside manufacturing, usually at a lower wage rate. Besides changing job, migration is another channel through which long-term adjustment in the labour market takes place. Evidence of migration induced by environmental policies is still scant because the effect of most policies was relatively small (either because the policy was not stringent or because it targets small sectors) relative to the size of the local economy. With more stringent environmental policies, out-migration effects can be larger as it happened during the coal bust of the 1980s in the US (Black et al. (2005)). Since coal industries are low-skilled intensive, migration costs will act as a tax on the less wealthy and hence exacerbate the source-side regressivity of environmental policy. Overall, without appropriate policy interventions for retraining or to subside workers' spatial reallocation, the burdens of the adjustment costs to both environmental policies and climate-related shocks are larger for low-skilled workers.

In the literature on use-side effects, consumers can respond to an increase in the price of polluting inputs by switching to cleaner inputs. Bento et al. (2015[95]) suggest that ignoring the effect of environmental policies on the rate of scrappage and adoption of new equipment lead to erroneous calculations of the distributional effects. West and Williams (2004[64]) estimate behavioural responses in a consumer demand system, showing that such responses reduce the regressivity of gasoline taxation. However, while the elasticity of demand to gasoline prices is larger for poorer households (i.e. they start driving less or using public transport), the estimates are imprecise especially at the bottom of the distribution possibly reflecting heterogeneity in transport choices among the poorest. Moreover, the authors only estimate short-term elasticities, but the real adjustment occurs in the long-term where investments in energy-efficient cars are carried out.[42] Recent studies also find higher elasticity of residential energy demand for low-income households using progressive gas subsidies as a source of exogenous policy variation (Auffhammer and Rubin, 2018[96]; Hahn and Metcalfe, 2021[97]). However, as for the case of gasoline prices in West and Williams III (2004[64]), it remains unclear the extent to which these elasticities reflect a successful adjustment or an energy deprivation induced by higher energy prices (or a jump in consumption near a deprivation threshold for the case of subsidies), with a concomitant reduction in well-being for the poor.

The OECD review on household behaviour and the environment (OECD, 2008[98]) and several other studies highlight a different general pattern. Because most environmentally friendly behaviours require upfront investments in new equipment, the adjustment is more difficult for low-income households that are likely to be financially constrained in presence of credit market imperfections.[43] In particular, low-income households are less likely to obtain the credit needed to switch to more energy-efficient vintages of cars, air conditioning and appliances, which allow avoiding part of the burdens of the environmental policies.[44] The discussion of Section 2.4 makes it clear that even a subsidized electric vehicle (or organic food) can be too expensive for low-income households. The subsidy may not be enough to pass the threshold of income (and implicitly wealth, which is often unobservable but correlated with current income) above which the purchase is feasible. Using very detailed data on metered electricity consumption in San Diego, Reiss and White (2008[99]) show that adoption of new energy-efficient appliances played a key role in explaining the observed decline in electricity consumption in response to an unexpected doubling in electricity price. Moreover, large electricity reductions were quick but concentrated among high electricity consumers, which are arguably in the bottom half of the income distribution. More in general, the available evidence is consistent with the general fact that credit market imperfections and uncertainty make wealthier households being more likely to adopt new technologies (Foster and Rosenzweig, 2010[100]).

Dynamic adjustments for the case of climate policies are however complicated by the fact that, in absence of the policy, adaptation to the new climatic conditions is more difficult for financially constrained households.[45] As for the case for technology, private investments in adaptation, such as in air conditioning systems and weatherization, require substantial upfront costs that poorer households (or poorer neighbourhoods, since part of adaptation investments have a public good nature) may not be able to afford in presence of credit market imperfections. Hence, an appropriate long-term evaluation should compare

[42] Typically, long-term elasticities are larger than short-term ones (e.g., Espey and Espey, 2004[61]).

[43] Also investments to adapt to climate related events, e.g. increase in temperatures, require investments at the household level in, e.g. in air conditioning. Barreca et al. (2016[187]) show that investments in air conditioning explain the bulk of the reduction in the mortality effect of high temperature in the US. However, for the same reasons discussed in Section 2.3.2, subsidizing air conditioning may benefit home owners and high-income households disproportionately.

[44] For instance, Attanasio et al. (2008[188]) provide indirect evidence on the existence of binding credit constraints in cars' market.

[45] For instance, migration induced by climate-related events is more difficult for financially constrained households (Cattaneo et al. (2019[84])).

the expected distributional effects with a carbon tax and the distributional effects without a carbon tax, which may entail a further exacerbation of current inequalities in the exposure to high temperatures and other climate-related shocks.

Besides financial constraints, behavioural inertia and habits are the other main constraints preventing low-income households to switch to greener consumption and lifestyles. As we discussed in Section 3.2, environmental quality is a need that is lower in the hierarchical scale relative to food, shelter or transport, thus low-income households value goods such as organic food, air purifiers and green electricity relatively less than high-income ones (e.g., Alberini et al., 2018[130]; Roe et al., 2001[131]). In line with the fact that preferences for environmental quality are non-homothetic, valuation studies show that more equal societies give a higher value to environmental public goods such as biodiversity conservation, clean air and natural parks (e.g., Drupp et al., 2018[18]). There are several mechanisms through which a positive relation between income and the preference for environmental quality emerge. An important one is that discount rates are typically higher for poorer households. As a result, long-term health and economic benefits are weighted much less than upfront economic costs by those households. A related mechanism is that low-income households are less forward looking than richer ones; thus, their habits tend to be more persistent (e.g., Hortaçsu, Madanizadeh and Puller, 2017[132]; Saussay, 2019[133]).

Habits' persistency and preferences can be linked to identity, values and socio-demographic characteristics too. A classic example is the strong attachment of middle-age men to meat consumption and intensive car use. Peer effects can also play a role in technology diffusion by removing information barriers, or because they reinforce beliefs and social norms within a group in a given community. As long as households are sorted into neighbourhoods depending on income, information on the economic value of green durable goods is less likely to receive positive feedback from friends and relatives in disadvantaged communities, thus exacerbating the adoption gap between rich and poor.[46]

Overall, the interaction of financial and behavioural constraints increases the regressivity of environmental policies in the long-run largely because low-income households have higher discount rates, more persistent habits and because of peer effects. Research considering long-term adjustments is still in its infancy and more evidence is needed to understand the interplay of financial and behavioural constraints along the income distribution. Improving our understanding of these constraints in different contexts will increase the salience of green policy packages. For instance, nudges, framing and well-crafted information campaigns may be a good way to tackle the behavioural constraint, while means-tested green subsidies would be needed if the financial constraint is binding. The next section will elaborate on some of the preliminary results discussed here to compare different policies to offset the distributional effects of environmental policies.

4.2. A comparison of different compensation policies

Previous discussions bring us directly to the key question of how to design compensation schemes to mitigate the trade-offs that emerge for the adoption of ambitious environmental policies. A successful green policy package should also keep an eye on economic effects of the policy in terms of employment and competitiveness. In the next section, we will compare the effect of five strategies to design offsetting compensation policies for an environmental tax or an auctioned emission trading scheme:[47] i. lump sum

[46] A few very recent papers examine the effect of social interaction on the adoption of green technologies peer effects, particularly residential PV systems (e.g., Gillingham and Bollinger, 2020[155]; Rode and Müller, 2020[190]). However, these works do not focus on the relation between spatial sorting, peer effects and inequality in adoption.

[47] Recall that market-based instruments outperform command-and-control ones in terms of environmental effectiveness. Moreover, market-based policies may generate revenues that can be used to offset the losers or accelerate the transition towards a cleaner economy. In turn, command-and-control policies just create rents for incumbent firms, thus amplifying regressive distributional effects.

redistribution; ii. broader tax reforms; iii. green fiscal push; iv. special stimulus packages for distressed communities whose economies depend on pollution-intensive sectors; v. progressive subsidies to green durable goods. These strategies are not mutually exclusive and can be combined, for instance targeting credit constraints at the individual-level be part of the green fiscal push.

Table summarizes the main findings of the assessment of compensation policies that follow. A reader can always go back to this Table to compare the pros and cons of each strategy on three objectives: distributional effects, economic efficiency and environmental effectiveness. Three important remarks are in order at this point. First, the effect of each package on economic growth depends on several contextual factors (pre-existing market distortions, quality of government, monetary policy, phase of the economic cycle, etc.). To avoid ranking different compensation schemes that requires entering in a theoretical discussion on the fundamental drivers of growth, the expected growth effect is expressed in this Table relative to the simplest compensation policy, a lump-sum redistribution. Second, it is very different to have an increase in inequality when all incomes grow or decline. In fact, use-side effects tend to be negative for all income deciles as they represent a pure cost, while source-side effects are positive for some workers and negative for others. Third, all the discussion of this Section refers to policies that complement an environmental tax or an emission trading scheme. Thus, the assessment is on the entire green policy package.

Table 4.1. Expected effects of different policy packages on various outcomes

Policy package: pollution tax/emission trading combined with	Environmental effectiveness	Economic efficiency	Equity: source-side	Equity: use-side	Equity: nonpecuniary
Benchmark: Lump-sum redistribution	=	=	=	=	=
Environmental tax reforms (ETR)					
- reducing capital taxation	=	+	-	=	=
- reducing tax for unskilled labour	=	+/=	+	=	=
Green deal plan					
- physical infrastructure	+/=	+/=	+/=	?/-	+/=
- training investments	=	+	+	=	=
Place policies in brown communities	+	+/=	+	=	+
Progressive subsidies for green goods	=	?	?	+	=

Note: Effects are compared to the benchmark of a lump-sum redistribution; thus they should be read by column. + means better, - worse, = similar, ? unknown. A range of estimates is indicated using multiple symbols, separated by a “/”. For example, +/=, means that effects can be better or similar to the benchmark of a lump-sum redistribution.
Source: Authors.

4.2.1. Lump-sum revenue redistributions

Redistributing tax revenues in the form of lump-sum rebates to all citizens is the most natural approach to offset distributional effects. A well-known result in the literature is that lump-sum rebates invert the effect of a carbon (or an energy) tax from regressive to progressive (Burtraw, Sweeney and Walls, 2009[101]; Metcalf, 1999[14]; Rausch, Metcalf and Reilly, 2011[66]; Williams et al., 2015[102]).The simple reason is that the rich pay a higher tax bill in absolute terms than the poor (but less taxes in relative terms), thus a lump-sum redistribution makes the whole package progressive.

However, lump-sum redistributions may create a modest rebound effect in emissions.[48] Similar arguments apply to proposals of recycling revenue by indexing social contributions: progressive short-term effects are obtained without providing further incentives to reduce emissions and change the structure of the economy towards greener productions (e.g., Fullerton, Heutel and Metcalf, 2012[136]; Rausch et al., 2010[137]). Finally, both lump-sum rebates or means-tested social contributions fail to address horizontal distributional effects, but this critique applies to all compensation policies reviewed in this section.

Overall, lump-sum redistribution is the less ambitious compensation strategy in terms of environmental benefits and effect on economic efficiency. However, even using the simplest possible compensation policy, a desired level of redistribution can be always achieved at least in the short-run. As we will see in Section 4.3, lump-sum redistributions are very important to increase the political acceptability of environmental policies.

4.2.2. Environmental Tax Reforms

Historically, Environmental Tax Reforms (ETRs)[49] became popular in EU countries as a promising way to tackle high unemployment rates in the 1990s (e.g., Carraro and Siniscalco, 1996[138]). Since tax rates on labour were seen as a constraint to job creation, ETRs represented then a revenue-neutral option to tackle these existing distortions in the tax system. Theory predicts that, in a situation where distortionary taxes exist and markets are imperfect, removing existing tax distortions would result in a win-win outcome in terms of improved environmental quality, job creation and reduced labour market inequalities between insiders and outsiders (Bovenberg, 1999[103]; Goulder, 1995[104]). Early studies concluded that well-designed ETRs improve welfare compare to lump-sum redistributions by increasing the incentives to hire and work, especially in presence of involuntary unemployment (Bovenberg and de Mooij, 1994[105]; Bovenberg, 1999[103]; Goulder, 1995[104]). Moreover, reducing capital taxation entails the largest efficiency gains, but this result is theory dependent (as it may not old in a Keynesian framework) and it is clearly regressive. Conversely, reducing payroll taxes and social security contributions can be both progressive and efficiency-enhancing in imperfect labour markets (e.g., Chiroleu-Assouline and Fodha, 2014[142]). However, the effect on equity rests on the fact that job creation is concentrated among the unskilled workers.

The critical ETR is thus recycling the revenues of an environmental tax by cutting payroll taxes (or social security contribution) for low-skilled workers that, in light of labour research, have more elastic labour supplies both at the intensive (hours worked) and extensive (participation) margins (e.g., OECD, 2011[143]; Roed and Strom, 2002[144]). Such policy has been thoroughly evaluated in the general equilibrium model of Aubert and Assouline (2019[106]), which manages to combine several important elements for the analysis of distributional impacts (non-homothetic preferences,[50] frictional unemployment, skill-unskill heterogeneity and endogenous labour supply). Under the plausible condition that the labour supply elasticity is smaller for high-skilled workers, a progressive ETR reducing labour taxes for the unskilled can achieve the triple dividend of equity, efficiency and environmental quality. An interesting by-product of this proposal, which deserves further attention in a model with green and brown sectors, is that reducing

[48] The lump sum payments can increase overall emissions slightly because households may spend some of the additional income on purchasing additional (polluting) goods (e.g. gasoline) than they would in absence of the lump-sum payments.

[49] Environmental Tax Reforms (ETRs) are reforms of tax systems that shift the burden of taxes to environmentally damaging activities such as pollution. ETRs can for example be implemented by shifting the relative tax burden from income taxes to polluting activities and to allocate additional fiscal resources to innovation in low-carbon technologies.

[50] Preferences are non-homothetic when they depend on income, thus the composition of consumption varies with income.

inequality can increase the aggregated demand of green goods and the WTP for environmental quality (see, e.g., Vona and Patriarca, 2011[146]).

Unfortunately, ex-post empirical evaluations of ETRs are limited by the few historical cases. The notable case is that of the British Columbia carbon tax, part of which is returned in terms of tax reductions. Yamazaki (2017) finds a small 0.74% increase in total employment compared to a credible counterfactual, which combines other regions in Canada. However, Yip (2020[31]) shows that even a carefully designed compensatory policy was not sufficient to overcome source-side distributional effects for low-skilled workers. Note, however, that the British Columbia carbon tax was not designed to increase in the progressivity of labour taxation, which is the critical policy to achieve the triple dividend equity-efficiency-environmental effectiveness.

At present, labour taxation is extremely high compared to taxation on capital and natural resources, with a tax wedge often above 40% (OECD, 2011[107]). Clearly, reforms of the general structure of taxation are essential to address other pressing issues such as poverty and inequality. Discussing ETRs can be the Trojan horse to open a broader political debate on the removal of distortionary subsidies to fossil fuels, energy tax exemptions to large consumers and several fiscal loopholes in general, thus creating valuable political capital to remove the most unfair sources of inequality. However, besides the fact of not providing direct incentives to adjust to green technologies, three additional problems may undermine the efficacy of well-designed ETRs. First, both polluting and non-polluting activities benefit from the tax reductions, thus environmental improvements triggered by the environmental tax would be lower than for compensation policies that directly finance the green economy. Second, to mitigate distributional effects and create jobs tax cuts should be concentrated on the low-skilled, thereby reducing the firm's demand for the high-skilled labour, the incentives to accumulate human capital and long-term economic efficiency. Third, ETRs can be difficult to administer as, if successful, the tax base would be eroded through the induced emission reductions and unexpected fluctuations of tax revenues are likely to occur.

4.2.3. Green Deal Plans

The case for a green deal, namely a plan of coordinated investments in several areas of the green economy, has been made by several countries, the EU *in primis*, and international organisations in response to the COVID-19 crisis (e.g., Agrawala, Dussaux and Monti (2020[108]); IMF (2014[109])). Note, however, that a green deal plan is not justified by a simple macroeconomic argument that fiscal multipliers are large in the aftermath of a recession. According to the theory of the big push (Rosenstein-Rodan, 1943[110]; Murphy, Shleifer and Vishny, 1989[111]), coordinated investments in several sectors create demand spillovers that make the growth process self-sustaining through the exploitation of economies of scale and learning effects. By analogy, this idea can be applied to the low-carbon transition where a series of large-scale, complementary investments in infrastructure, knowledge and training facilities can accelerate the decarbonization of several sectors and help mitigating the regressive effect of environmental policies. The public sector is the only actor with the required size, borrowing capacity and long-term view to make such large scale effort in the green economy possible (Mazzucato, 2015[112]).

There are two market failures that such plan tackles, besides the main ones of climate change and pollution. A small-scale version of a green deal plan can be designed to tackle just a part of these market failures, a policy usually denoted as "green earmarking".

First, direct government spending in knowledge, especially in workforce retraining and R&D for green technologies, is the typical solution to internalize the positive externalities created by such investments. For innovation, the size of the effort and the uncertainty involved calls for a direct role of the government to shape new markets (Mazzucato, 2015[112]). For training, the risk of poaching the trained workers typically reduces investments by private companies, especially when they are small and under-capitalized as green ones. As a result, the public sector plays a key role in training the workers with the right green skills, thereby attracting private investments in the green economy. Training is also a critical investment to create well-paid jobs for the low- and middle-skill workers, thus mitigating distributional effects.

Second, network externalities are a pervasive constraint to the development of green technologies. To illustrate, the recent theoretical analysis of Zhou and Li (2018[113]) highlights the importance of network externalities for the adoption of Electric Vehicles (EV) in a model with chicken-egg critical mass constraint. That is: incentives to invest in EV charging stations depend on the mass of potential adopters, while incentives to adopt depend on the density of charging stations. More in general, complementary investments in smart grids and storage capacity facilities to recycle waste, railways and public transport are all required to make the adoption of several environmental technologies profitable. Given the size of such investments and the weak incentives of private companies to invest in infrastructures, government interventions are required to provide the optimal amount of these critical investments.

The abovementioned paper of Popp et al. (2021[94]) is the closest possible evaluation of a green deal plan as a compensatory policy, albeit green ARRA spending was not enacted in combination with a carbon tax. Two main findings stand out. First, green spending is particularly effective in creating jobs in the long-run, thus a strong political commitment is required to ensure the full benefits of this policy. Second, the effect of green spending is significantly larger in communities with a larger fraction of workers with “green skills”, which are those receiving more green spending per capita.[51] As a result, targeted training investments should be a key component of the green recovery package. The encouraging effect of training investments is consistent with previous findings in the literature (Bartik, 2020[114]), especially when training is targeted to specific sectors (e.g., Katz et al., (2020[115])) and to vocational and technical education that is in high demand in green sectors (Marin and Vona, 2019[42]; Vona, 2019[13]).[52]

In terms of distributional effects, two contrasting patterns emerge. On the one hand, investments in green infrastructures increase relative demand for manual labour, thus offsetting the potential job losses for these workers in polluting industries. On the other hand, areas with a higher share of “green skills” were also wealthier, high-tech and already on a better growth path. This implies that a green deal plan may exacerbate regional inequalities and require substantial workers’ mobility to allow everyone to reap the benefit of these investments.[53]

Overall, using green deal plans in combination with environmental taxes or emission trading schemes can help the economy to achieve a triple dividend. However, as it often happens in economics, there is no free lunch. First, regional inequalities may be exacerbated by green deal plans because rich countries and regions have better capabilities to reap the benefits of green investments becoming the hubs of high-tech green productions. Second, it is clear that the effectiveness of large public spending plans depends on government quality, e.g. corruption, which can be an issue especially for infrastructural investments. Third, green deal plans are relatively cheap in a world with near-zero interest rates, but they will become increasingly expensive with a less accommodating monetary policy.[54] Finally, some infrastructural

[51] In particular, the employment effect is twice larger in regions with a high share of the workforce with appropriate “green skills” compared to the average.

[52] Cross-country differences in training spending on GDP are large. The US spends much less than EU countries, especially Scandinavian ones, in training (on-the-job, support for apprenticeship or institutional). In 2018, the share of public spending in training of GDP was 0.03% in the US, 0.11% for the average OECD country and 0.38% in Finland.

[53] For European countries, Bontadini and Vona (2020[91]) show that rich countries have a persistent comparative advantage in green technologies and thus are likely to benefit disproportionately from the EU green deal plan.

[54] Note also that there is a lively debate among macroeconomists on the effectiveness of fiscal stimulus packages and the size of multiplier effects of fiscal policy, in general. However, while macroeconomists are divided on the effect of expansionary fiscal policies in normal times, there is a wider agreement on the fact that expansionary fiscal policies should be used in exceptional times such as those we are living now with the COVID crisis (IMF, 2014[109]; Chodorow-Reich, 2019[195]).

investments can be highly regressive because the potential users are (and would remain) high-income households (i.e. EVs and speed trains).

4.2.4. Place-based policies for distressed "brown" communities

Green deal plans may exacerbate the gap between green/wealthy/urban communities and brown/poor/rural communities, undermining the political acceptability of environmental policies. The problem of distressed brown communities has been acknowledged in the European green deal plan through a dedicated Just Transition Fund to help coal-intensive regions that will be negatively affected by a deep decarbonization. Recall that coal-intensive regions, or in general regions whose economy depends on polluting industries, will bear the bulk of the policy costs in terms of job and income losses and face the starker trade-off between equity, economic efficiency and environmental effectiveness. These features call for a specific policy intervention.

So far there is scant systematic evidence on which policies work better for communities that rely on polluting industries or the coal industry, with a couple of successful examples in the Ruhr (Germany) and in Netherlands (Vona, 2019[13]). Some insights can be provided in the recent survey of Bartik (2020[114]) on place-based policies for distressed communities, but unavoidable differences across regions make one-size fits all policies ineffective. The key conceptual question here is why compensation should go to regions rather than individuals, facilitating retraining or migration to other regions. Besides for the positive externalities mentioned in the previous section (e.g., network infrastructure and skill base), which have a regional dimension, a high incidence of non-employment produces localized negative externalities in terms of crime, mental and physical health and children's cognitive development. Moreover, the psychological and material costs of migrating to other areas can be significantly larger – yet often difficult to quantify in monetary values – than the subsidy to restart the economy. Finally, the multiplier effects of place-based policies are higher in areas with a larger share of involuntary unemployment, simply because the labour supply is more elastic when the reserve army is larger (Austin, Glaeser and Summers, 2018[116]).

For locations hosting polluting industries, place-based policies are even more important because they fix the pollution externalities that, among other things, increase intergenerational inequality. Further, they are crucial to counterbalance the political opposition against environmental policies, perceived to be responsible for the potential job losses in polluting sectors (e.g. (Weber, 2020[90])). Clean-up of hazardous sites or the shutdown of a coal mine need to be combined with a targeted green spending for that particular community, possibly involving local actors and stakeholders in the decision process. The exact recipe depends on local conditions, but such plan has to go beyond a mere compensation for economic losses and create the conditions for a broader industrial reconversion in those areas. As for the green deal plan, this process will take time, thus requiring long-term spending commitments.

4.2.5. Progressive subsidies for green goods

An alternative to the top-down approach proposed by ETRs, green deal plans and place-based policies is to use a bottom-up approach that directly targets low-income households. In light of the discussion of Section 4.1, the idea is to support households that are more likely to face financial and behavioural constraints to adopt new technologies with subsidies.[55] Theoretically, the creation of a mass consumption effect for green goods can be achieved through a direct stimulus to private demand, rather than through infrastructural investments (Murphy, Shleifer and Vishny, 1989[111]). Vona and Patriarca (2011[117]) show that, with non-homothetic preferences (i.e. green good consumption starts after basic needs are satisfied) and demand externalities, reducing inequality allows to create a positive self-reinforcing feedback between

[55] Recall that, differently from the discussion in Section 2.3.2, subsidies here do not substitute but complement another, more effective, environmental policy such as a pollution tax. Subsidies here address other market failures, e.g. financial constraint, economies of scale and learning effects, etc.

technological improvement and adoption of green goods, but only in rich countries where the potential mass of green consumers is larger. Similarly, in the model of electric vehicle (EV) adoption of Zhou and Li (2018[113]), subsidizing the purchase of EVs is a way to overcome the critical mass constraint by stimulating investments in charging stations.

Clearly, there are strong complementarities between a green deal plan and individual subsidies to green technologies. Such complementarities can be exploited to tackle distributional effects. For instance, if the government builds charging stations for EVs without subsidizing the purchase of the vehicles for households, only the rich would benefit from the new infrastructure. Recent policy experiments, especially in the US, attempted to make green subsidies progressive. In general, this can be done in several ways from giving “organic and local” food stamps to conditional cash transfer for energy efficient behaviour and refundable and progressive tax credits for green technologies. Muehlegger and Rapson (2018[20]) use a triple-difference estimator to evaluate the causal effect of means-tested subsidies for EVs, geographically targeted to disadvantaged and polluting communities. Their results imply that the demand of low- and middle-income households is elastic to the subsidy (with an implied elasticity of -3.9), but subsidizing the mass adoption of EVs would be very costly because the no-subsidy level of adoption among the poor is very low. However, this assessment neglects the role of mass adoption on EV prices, which instead play a key role in theoretical models.[56] Fowlie et al. (2018[19]) conduct a randomized control trial to evaluate the effect of a large scale program for residential energy efficiency targeting low-income households, which was expanded under the ARRA plan. Again, the main conclusion of such evaluation is that the program did not deliver in terms of energy savings, albeit no evidence is found of significant rebound effects and behavioural responses. Clearly, the preliminary accounts of progressive green subsidies are not encouraging, but these “carrots” were not combined with a “stick”, such as a carbon tax, that would have reduced the incentives to consume energy. Further research to understand how behavioural responses vary depending on income is certainly required.

Another approach is to design policies that induce (or ‘nudge’) individual behavioural responses. Gillingham and Bollinger (2020[118]) study a large-scale behavioural intervention to increase the adoption of residential photovoltaic (PV) systems through information campaigns driven by voluntary ambassadors (the so-called Solarize program). The authors find that the program was very effective in increasing PV installation and reducing installation costs in affluent communities. Alcott (2011[119]) finds that an information campaign leveraging peer comparisons have large effects on energy savings, but the effect is concentrated among households consuming more energy (see also Allcott and Kessler, 2019[157]). Furthermore, it remains unclear if these effects are persistent over time or whether the size of the effect diminishes as people become used to the comparison. Overall, the combination of progressive subsidies for green technologies with environmental taxes and soft policies, such as nudges and information campaigns, appears a promising, but still unexplored, avenue for increasing policy effectiveness. For instance, while subsidies to energy efficiency programs rarely reach the efficient level of usage, well-designed information campaigns targeting inattentive users may significantly reduce the energy-efficiency gap even in presence of an energy tax. Similarly, combining subsidies to Solarize-type of information campaigns, which involve the local population can be an effective way to increase adoption of certain green technologies in disadvantaged communities.[57]

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[56] As highlighted by Vona and Patriarca (2011[117]), gradual mass adoption enables economies of scale and stimulates technological change, thus triggering further price reductions and increasing the effectiveness of means-tested green subsidies. Gillingham and Bollinger (2020[118]) provide evidence that increasing the scale of PV adoption lower installation prices. Over the past decades, learning effects decrease the cost of several green technologies, including batteries, wind turbines and EVs.

[57] However, home ownership, a prerequisite to install a PV panel, will remain a more fundamental constraint for the success of such packages in disadvantaged communities.

One problem with means-tested green subsidies is that they are difficult to administer,[58] expensive and, in countries with substantial tax evasion, can be even regressive. Moreover, it is worth stressing again that green subsidies cannot substitute for a pollution tax, which is essential to provide the main incentives to reduce pollution. Unfortunately, in the policy debate, green subsidies receive much more political support than taxes and are often considered as an alternative policy option. The next section will discuss in detail the issues related to the political acceptability of different policy packages.

4.3. Political acceptability of green policy packages

The green policy packages proposed in previous section are not all alike in terms of political acceptability, which ultimately is one of (if not "the") main reason to study distributional effects. The important preliminary point to make is that, while distributional effects shape political preferences and thus political acceptability, other factors are equally important, including ideology, identity, perception biases and trust in governments.[59] Going back to the Yellow Vest protest, the increase in the carbon tax was initially not combined with enough compensatory measures for the low-income households. Still, the opinion survey presented in Douenne and Fabre (2020[12]) highlights substantial misperception of the costs and benefits of the whole plan, with an exaggeration of the real costs, as well as general perception of unfairness towards a government that had just cut wealth taxes. This example reveals how difficult is to empirically isolate the feedbacks from distributional effects to political acceptability and quantify their relative incidence relative to other drivers. Citizens can voice their opposition against environmental policies to manifest their discontent for general unfairness of other public policies.

A burgeoning literature in behavioural and political science has shown that policy design matters to gain political traction for carbon taxation.[60] While the focus of this research was primarily on the acceptability of carbon or energy taxation, some insights can be relevant also to increase the acceptability of broader green policy packages. Examples range from a simple renaming of taxes in another way (Switzerland) and the anticipation the lump-sum redistribution (Canada) to the use of an extensive public dialogue taking care of the procedural aspect of the political process (Sweden) as well as of well-designed improvements in political communication (see Klenert and Mattauch, 2019[158]), for a comprehensive discussion).[61] To gain support to carbon and environmental taxation, there are two clear directions where communication needs to be improved. On the one hand, citizens have to be informed on the distortions of existing energy policies, including fossil fuel subsidies, which are far more regressive than a carbon tax or an auctioned emission trading scheme. On the other hand, health benefits are larger (when properly monetized) than potential income losses, but they are rarely discussed in the public debate on environmental policies.

Importantly, the creation of political constituencies that go beyond the usual right-left political cleavage is another element that enhances the long-term political support for a certain policy package, sheltering it

[58] Also, subsidies can be very hard to remove once they have served their goal.

[59] The importance of these factors is evident in survey studies that seek to identify the willingness to pay for an environmental policy (e.g., Alberini et al., 2018[130]; Campbell and Kay, 2014[193]; Ziegler, 2017[194]).

[60] See the surveys of, e.g., Drews and van den Bergh (2016[200]); Carattini, Carvalho and Fankhauser (2018[122]); Maestre-Andrés, Drews and van den Bergh (2019[124]).

[61] For instance, Kallbekken and Aasen (2010[201]) mention the lack of understanding about environmental policies by survey respondents. The insufficient consultation of social partners is also a problem mentioned by Deroubaix and Lévèque (2006[202]) regarding environmental tax reforms in France. Carattini et al. (2017[203]) and Kallbekken et al. (2011[204]) provide two original views on the importance of behavioral biases and labeling policies.

from the political cycle (Aklin and Urpelainen, 2013[120]). The creation of larger constituencies has to be balanced with the need to compensate the main losers in distressed communities, thereby addressing a typical collective action problem.[62] Participating in international environmental agreements may also prevent policy backlashing, although the nonbinding nature of such agreements does not help increase long-term commitment as the cases of the US with the Paris Agreement or of Canada with Kyoto have shown (Barrett, 2008[121]).

Three recent reviews examine the political acceptability of different compensation packages in a comparative perspective (Carattini, Carvalho and Fankhauser, 2018[122]; Klenert et al., 2018[123]; Maestre-Andrés, Drews and van den Bergh, 2019[124]). Unsurprisingly, environmental tax reforms find a stronger opposition than lump-sum redistribution or spending in green projects, i.e. the small-scale version of a green deal plan. The reason is that the benefits of reducing labour taxation are harder to understand as they are mostly indirect and uncertain, while a carbon dividend paid upfront provides an immediate and direct benefit. The benefits of green public spending on employment and environmental improvements are usually perceived to be larger than those of reducing taxes on labour. Although the salience of green deal plan has increased in the aftermath of the COVID-19 crisis, their scope and scale remain a divisive political subject where green issues are absorbed in a classic right-left cleavage such as in the US. In contrast, lump-sum dividends are more accepted by a wider right-left ideological range, reinforcing the political constituency in favour of this instrument. Also, the public support to large public spending hinges upon government trust and stability as well as on the perception of corruption. In countries with corrupted governments and lack of political stability, decentralized and local solutions, such as lump-sum redistribution and progressive subsidies, may be both the preferred and the best choice to reach a triple dividend.

To increase the salience of green policy packages, a practical solution used by all countries that have taxed carbon emissions (e.g., Switzerland, Sweden, Canada, etc.) is to mix several compensation mechanisms rather than going "all-in" with only one (Klenert and Mattauch, 2019[125]). The idea is splitting the revenues raised with a carbon tax across several uses: a lump-sum redistribution (or progressive tax cuts) for equity, green investments to increase environmental effectiveness and a reduction in business taxes for efficiency and building a larger political constituency. In the EU, where there is a larger constituency in favour of green polices, the scope of the green deal plan is much broader than a massive injection of public investments for the green economy. It indeed entails a revision of the energy taxation directive (going in the direction of increasing the relative cost of carbon-intensive fuels, i.e. carbon tax), a border carbon adjustment (which increase political acceptability and build a larger constituency by granting protection to the most polluting industries) and place-based compensatory policies for carbon-intensive regions (which make the plan acceptable to coal-intensive Eastern members).

Using a wise mix of compensation policies, political deliberation and behaviourally-driven marketing strategies, politicians have somehow succeeded in removing the initial resistance to carbon taxation. However, as Klenert et al. (2018[123]) noted, ambitious carbon taxation is only enacted in countries with a low perception of corruption and a high trust in government. Those countries have significantly lower level of inequality than their peers with similar income levels, e.g. Sweden vs. the US. Magnani (2000[126]) finds that more equal countries invest more in green R&D, which is consistent with a simple median voter model where environmental quality is a normal good. More recently, Gilli et al. (2021[127]) show that, conditional

[62] A collective action problem emerges when losses are concentrated and easy to verify (i.e. job losses in brown communities) and benefits are more diffused and indirect (i.e. health benefits). Losers are more willing to get politically organized to lobby against the policy than winners are to lobby in favour of the policy (Olson, 1965[205]).

on a host of intervening factors, reducing income inequality is associated with a systematic increase in the stringency of several environmental policies in OECD countries.[63]

These findings resonate with a common theme of this survey: the low WTP for environmental quality improvements of the low-income households reduces the acceptability of green policy packages, which goes well beyond misperception, values, identity and trust. While the first part of this claim is well-rooted in a solid body of empirical research (e.g., Banzhaf, Ma and Timmins, 2019[9]; 2019[102]; Greenstone and Jack, 2015[21]), the second is still speculative and deserves further scrutiny. However, a strong and striking example illustrates the point. For households living near steel or coal power plants, the trade-off between health benefits and induced job losses is at its peak. Workers in these places make everyday a choice between: i. work in a polluting factory, facing a very high health risk (also exposing their families to this risk); ii. accept a period of involuntary unemployment, reducing substantially such risk. Case-study evidence indicates that the workers prefer the first option, even if they are perfectly aware of the extreme health risks that they face, thus misperception is controlled for in this example (Vona, 2019[13]).[64] Clearly, these communities are very likely to embrace skeptical views on the threat posed by climate change and on environmental policies in general (see Vona, 2019[12] and, for the case of coal in the US, Weber, 2020). Overall, this example suggests that targeted place-based policies that support distressed communities dependent on fossil fuel industries should be one of the priority of any green policy package.

The bottom line is also that, consistently with the conclusions of Banzhaf et al. (2019[5]; 2019[128]), the level of inequality, and not the expected (perceived or real) effect of the policy package, is one of the (if not "the") major constraint to increase political support to environmental policies and create a critical mass of green consumers that will accelerate the diffusion of environmentally-friendly technologies (Vona and Patriarca, 2011[117]). Reducing inequality may trigger a positive feedback loop between support to climate policies and the gradual recreation of a middle class that is wealthy enough to care more broadly about collective goods, such the environment and the climate (Drupp et al., 2018[15]).[65] The secular increase in income inequality experienced by most countries in last fifty years is certainly not helping in creating a self-reinforcing spiral of political support and technological change for a green transition. Because the increase of inequality went hand-in-hand with a substantial reduction in the progressivity of general taxation, it appears clear that the political capital to remove these distortions is scarce. Also in the spirit of the Sustainable Development Goals of the United Nations, green policy packages should start raising the broader issue of the compatibility between the current level of inequality and the feasibility of a swift reduction in our environmental impacts. Overall, restoring a sense of fairness in the mission of public policy is essential to increase the political acceptability of climate and environmental policies.

[63] Environmental policies are measured using the subcomponents of OECD Environmental Policy Stringency index (Botta and Koźluk, 2014[196]).

[64] For a very interesting documentary on this issue, on the Appalachian coal mines, see: https://german-documentaries.de/en_EN/films/the-black-heart-of-america.10298.

[65] On the other hand, however, a larger middle class may imply more consumption of polluting goods, thus a combination of behavioural interventions and disincentives to over-consume would be needed.

5 Avenues for future research

This survey suggests several areas where research on distributional effects can be fruitfully conducted and useful for policy making.

First, the multidimensionality of the distributional effects calls for improvements in the set of indicators, welfare metrics and data, especially outside the US. A valuable policy-oriented effort would be to collect comparable data on the pollution content of products, jobs and locations, in order to construct a set of indicators of individual exposure to the main costs and benefits induced by an environmental policy. In absence of individual level data, such indicators could be built for regions or different deciles of the income distribution in order to improve our broad understanding of winners and losers.

An interesting exercise to deal with multidimensionality is performed by Muller et al. (2018[129]), who compute the Gini inequality coefficients using an income measure carefully adjusted for air pollution damage. While the fact that this damage is regressive is unsurprising in light of this review, the size of the increase coefficient is striking. When accounting for pollution damage, the Gini coefficient for market income increases from 0.48 to 0.65 that is slightly larger than the effect of progressive taxation on inequality in the average OECD countries. The main implication for the distributional effects discussed here is that the size of potential health benefits, which are progressive, is probably an order of magnitude larger than the size of the potential economic costs, which are mostly regressive but small and highly concentrated. More research is also needed to explore the trade-offs between the three main objectives of the triple dividend (equity, economic efficiency and environmental effectiveness), especially at the micro-level (e.g., establishment, firm, province) to improve the targeting of compensation policies (see, e.g., Marin and Vona, 2021[34]). Moreover, a precise measure of the trade-offs calls for rigorous metrics to track equity improvement in terms of welfare along the income distribution and combining data on data on economic and environmental effects. The recent paper of Mansur and Sheriff (2021[130]) goes in this direction taking stock from the normative literature on income inequality.

Second, the longitudinal dimension of distributional effects is often left aside in existing analyses due to data limitations. Indeed, individual-level exposure to pollutants is often observed over a short time span, while what mostly matters for health is the persistency of pollution exposure over time. Similar considerations apply to the persistency of the labour market shocks induced by environmental policies. Recent research by Voorheis (2017[131]) takes this direction by reconstructing the longitudinal exposure to PM2.5 for each US citizen over the period 2000-2014 using satellite data. While his finding confirms the fact that environmental gentrification reduces the progressivity of environmental improvements, the use of similar data combined with worker-level panel data would allow to expand the scope of the analysis and is feasible in several other countries. For instance, pollution, skill formation and labour market dynamics can be compared for a large portion of the individual history and at different points of the income distribution. The methodological problem here is that the effect of pollution exposure on health is not homogeneous across ages, but highly concentrated in vulnerable groups, especially children.

Third, there is still limited knowledge of several parameters that, as discussed in this survey, are crucial to reach certain policy conclusions and simulate counterfactual scenarios in ex-ante modelling evaluations.

Among these parameters, understanding source-side effects require short- and long-run estimates of the elasticity of factor demand and prices (capital, labour, labour by occupational or educational groups) to changes in environmental policy stringency. Of particular importance is to collect more evidence on factor prices' effects (labour share, profits, wages) within a unique dataset. Moreover, the mechanisms through which source-side effect emerges are unclear because the organizational and technological changes induced by an environmental policy are often unobserved by the econometrician. Exploring different methods can also improve the estimate of key parameters. For example, the willingness to pay for environmental quality is estimated using housing prices, but this approach may suffer from self-selection into the housing market due to binding financial constraints. A promising alternative would be to let labour market choices to reveal the willingness to pay for environmental quality, through the implicit wage-pollution trade-offs faced by the worker in the choice a particular job (see Cole, Elliott and Lindley, 2009[169] as an interesting study on this). More in general, exploring the trade-off between pollution and wage allows to improve our understanding of the tolerance that workers have to take health risks as a function of various socioeconomic, demographic and contextual factors. This survey suggests that these types of analysis are very important to understand extreme form of environmental injustice (i.e. extreme health risk) and how much this injustice is compensated in monetary terms.

Fourth, this survey emphasizes investments in training for green jobs to reconcile equity and efficiency by reducing reallocation costs for workers displaced by an environmental policy. However, the support to this claim is still scant with the exception of Popp et al. (2021[94]). Indeed, little is known on the role played by training in reducing reallocation costs for the specific case of transition from brown to green or other jobs. Throughout this paper, the role of skill gaps has been extensively discussed, but it is not clear which part of the earning losses for a worker displaced by an environmental policy can be quantitatively ascribed to a potential skill gap in alternative jobs, including green ones. Finally, estimating reallocation costs in labour markets with different institutional setups is of paramount importance to design "just transition packages" broadly defined, thus including the duration of unemployment benefits, severance payments and other social contributions.

Fifth, field experiments become popular to evaluate the effects of soft policies, such as information campaigns, on environmental behaviour. However, these approaches have not been directly designed to assess the mediating role of income on the effectiveness of soft policies. If information on specific green technologies (or on how to reduce energy consumption using a given technology) is costlier to obtain for low-income households, soft policies and nudges can be particularly effective in flaking other instruments such as means-tested green subsidies. For instance, in low- and medium-income communities, an open question is whether information campaigns on solar PV installations have an effect beyond that of a generous subsidy scheme (e.g., Gillingham and Bollinger, 2020[155]). Subsidies to weatherization for low-income households represent a fruitful application to test the power of behavioural interventions in contexts where behavioural inertia is extremely important.

Sixth, fairness is an issue that is related, but distinct from distributional effects. Conceptual and statistical efforts are required to assess the extent to which a distributional effect is "fair". This survey has insisted (and implicitly assumed) that progressive effects are fair. However, fairness is a much broader concept than progressivity. The so-called horizontal distributional effects, namely variation in the distributional effects between households with similar incomes, reveal fairness issues along other dimensions (rural vs. urban) and some of those dimensions deserve further assessments (see, e.g., Fischer and Pizer, 2019[94]). Other prominent examples concern the intergenerational effects and the long-term racial disparities in pollution exposure, which are both understudied outside the US. For instance, while it is known that pollution exposure at young age depends on parental income and has a negative effect on child cognitive development (e.g., Currie, 2011[5]), no study has quantified the portion of the parent-child income correlations that is explained by differences in pollution exposure.[66] Speaking about fairness, it is also important to assess the gap between emissions received and emissions implicitly created by one's consumption behaviour (see Tessum et al., 2019[4] for an example in this direction).

Finally, further research is required to understand the other causality nexus: from the level of inequality to the stringency and the ambition of environmental regulation. This causality nexus is extremely important given the dependence of WTP for environmental quality on income. Section 4.3 has discussed the political economy consequences of inequality on environmental policies (e.g., Magnani, 2000[164]; Gilli, Nicolli and Vona, 2021[165]), but more research is needed in this direction at different level of geographical aggregation. Another distributionally-relevant causality nexus is that from climate change and pollution to the accumulation of human capital, labour productivity and thus wages, which has been mentioned in relation to the issue of intergenerational inequality. Heterogeneous effects across workers have not been yet examined by the burgeoning literature on pollution and human capital formation (e.g., Graff Zivin and Neidell, 2013[6]). As long as the incidence of pollution and high temperature is higher in performing manual tasks, environmental policies should mitigate a regressive status quo and thus be progressive. However, this is just a conjecture and more research is required in this direction.

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[66] An interesting experiment would consist in comparing individuals with similar socio-economic family background, but different levels of pollution exposure at young ages.

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