Distributional Impacts of Climate Mitigation Policies - a Meta-Analysis

Nils Ohlendorf[1,*] Michael Jakob[1,2,3] Jan Christoph Minx[1,2,3] Carsten Schröder[4,5] Jan Christoph Steckel[1,2,3]

[1] Mercator Research Institute on Global Commons and Climate Change, Torgauer Staße 12-15, 10829 Berlin, Germany

[2] Technische Universität Berlin, Department of Economics of Climate Change, Straße des 17. Juni 145, 10623 Berlin, Germany

[3] Potsdam Institute for Climate Impact Research, Telegrafenberg A 31, 14473 Potsdam, Germany

[4] Deutsches Institut für Wirtschaftsforschung, Mohrenstraße 58, 10117 Berlin, Germany

[5] Freie Universität Berlin, Kaiserswerther Straße 16/18, 14195 Berlin, Germany

[*] Corresponding author: ohlendorf@mcc-berlin.net, Torgauer Staße 12-15, 10829 Berlin, Germany

Abstract

The distributional impacts of market-based climate policies are crucial to ensure equitable climate change mitigation that avoids adverse impacts on the poor. Numerous empirical studies that examine the distributional impacts of carbon pricing and subsidy reforms in high- and low-income countries, using various study designs, arrive at ambiguous results. We apply an ordered probit meta-analysis framework to systematically determine the source of variation between these outcomes. The sample comprises 53 empirical studies containing 183 effects in 39 countries. Our analysis indicates a significantly increased likelihood for progressive distributional outcomes for studies on lower income countries and transport sector policies. The same applies to study designs that consider indirect effects, behavioural adjustments of consumers or lifetime income proxies. Lower income countries could use the revenues of progressive market-based climate policies to alleviate poverty or to finance infrastructure investments. Evidence-based policy making however still requires country specific distributional analyses.

Keywords: Meta-analysis, Environmental policies, Distributional impacts, Inequality, Carbon mitigation, Households

JEL Codes: H23, Q52, Q58

1 Introduction

The detrimental consequences of continued global warming require policymakers to proceed enacting climate mitigation policies. The Intergovernmental Panel on Climate Change shows anthropogenic greenhouse gas emissions to increase the likelihood of severe, pervasive and irreversible impacts for people and ecosystems (IPCC, 2014). Especially the poorest people in all countries face higher risks of reduced food security and health problems. With the Paris Agreement policymakers pledged to keep the global average temperature increase well below 2°C compared to pre-industrial levels (United Nations, 2015). The current Nationally Determined Contributions however fall short on meeting the required CO_2 emission reductions (UNEP, 2017). Ambitious climate mitigation targets need to backed by credible and effective policies.

Particularly market-based instruments are suitable and increasingly applied climate mitigation policies. In theory, these policies are environmentally and economically effective and efficient (Pigou, 1920; Nordhaus, 1991; Pearce, 1991) and furthermore recommended by leading economists such as Nicolas Stern and Joseph Stiglitz (High-Level Commission on Carbon Prices, 2017). Market-based climate mitigation policies comprise carbon taxes, cap-and-trade systems and fossil fuel subsidy reforms. In 2018, 51 carbon pricing schemes, such as carbon taxes or cap-and-trade systems have been implemented or planned, covering 20 percent of the global greenhouse gas emissions (World Bank and Ecofys, 2018). The fossil fuel subsidy phase-out has already been committed by the G20 in 2009 at the Pittsburgh summit (G20 Leaders Statement, 2009) with several enacted reforms in the last years[1] (IEA and OECD, 2017).

Distributional impacts strongly influence the political acceptability of environmental policies (Baumol and Oates, 1988; Baranzini et al., 2000; Tiezzi, 2005). Regressive distributional impacts harm vulnerable groups and decrease the policies' likelihood to be implemented and sustained (Parry, 2015). Social equity concerns can thus quickly dominate the public debate if energy prices increase (Shammin and Bullard, 2009). For example, the incidence and the distributional impacts of the repealed Australian carbon tax were subject to the public and the academic debate (Rahman, 2013; Sajeewani et al., 2015). The Nigerian decrease of fuel and petrol subsidies in 2012 even resulted in mass protests and strikes. The public resistance led to a partial reimplementation though Nigerian fuel subsidies are heavily concentrated among high income groups (Soile and Mu, 2015; Lockwood, 2015; Dorband et al., 2017)[2].

The literature on the distributional impacts of climate policies provides ambiguous results. Many studies review an overall tendency for regressive impacts (Araar et al., 2011; Gonzalez, 2012). Other reviews detect mostly regressive findings of studies on developed countries while developing countries show an inconsistent picture with a tendency towards proportional or

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[1]Only in the first half of 2017, energy subsidy reforms were enacted in Argentina, Bangladesh, Indonesia, Kuwait, Mexico, Mozambique, Pakistan and Zambia (IEA, 2017).

[2]Public protests furthermore led to the reimplementation of subsidies in Venezuela (1989), Yemen (2005), Cameroon (2008) and Bolivia (2010) (Clements et al., 2013).

progressive impacts (Verde and Tol, 2009; Wang et al., 2016). Nevertheless, progressive impacts have also been shown for developed countries like Australia (Sajeewani et al., 2015), Canada (Dissou and Siddiqui, 2014) or Spain (Labandeira et al., 2009).

Previous literature reviews provide first insights but do not systematically explain the outcome heterogeneity. Wang et al. (2016) so far conduct the most comprehensive literature review on distributional impacts of carbon prices. They consider distributional impacts across households differing by income, location and demographic characteristics. This broad scope provides valuable insights on various dimensions of distributional impacts. Still, literature reviews usually lack explicit or transparent criteria for their literature selection which exposes them to the critique of subjectivity and lacking validity. Qualitative approaches further deter from obtaining statistically significant and robust insights (Ringquist, 2013).

We focus our analysis on distributional impacts across household income groups. This narrow scope facilitates using a meta-analysis to quantitatively determine the sources of variation in the study outcomes. A meta-analysis in general is a *"systematic, quantitative, replicable process of synthesizing numerous and sometimes conflicting results from a body of original studies"* with the potential to provide scientifically robust results (Ringquist, 2013, p. 3). Thus far, meta-analyses have mainly been applied in the fields of education and medicine. However, there is an increasing amount of meta-analyses in social science including environmental economics (Moeltner et al., 2007; Nelson and Kennedy, 2009; Tunçel and Hammitt, 2014). In this study, we develop and test four major hypotheses which we assume to systematically influence the study outcomes: First, we hypothesise more progressive impacts in countries with lower incomes than in high-income countries. Second, we assume subsidy reforms being more progressive than carbon pricing. Third, we expect more progressive impacts of transport sector policies compared to economy-wide policies. Finally, we assume the research study design to systematically influence the outcomes.

This study applies an ordered probit meta-analysis framework to 53 original studies providing 183 effects in 39 countries. We include moderator variables accounting for different policies, modeled economic effects and countries while controlling for a publication bias and a time trend. We find a significantly increased likelihood for progressive study outcomes for lower income countries and transport policies. The same applies to study designs considering indirect effects, behavioural adjustments of consumers or lifetime income proxies. On the contrary, we find that subsidy reforms are not inherently more progressive than carbon pricing instruments as the many progressive study outcomes can be explained by the low income level of the investigated countries.

We structure the remainder of this paper as follows: Section 2 elaborates our four key hypotheses with respect to theory and literature findings. Section 3 describes the data selection process, explains the variables and introduces the quantitative model. Section 4 presents the main results while section 5 discusses and concludes the findings.

2 Hypotheses

Literature findings and economic theory indicate the countries' level of development, the policy type, the affected sectors and the modeled economic effects to systematically influence the study outcomes. The following paragraphs discuss these potential results drivers and subsequently develop hypotheses about the estimated impact.

First, literature reviews show mostly regressive impacts in developed countries. Developing countries however show an inconsistent picture with a tendency towards proportional or progressive impacts (Verde and Tol, 2009; Wang et al., 2016). The literature findings could be explained by low carbon intensities of the consumption baskets of poor households in lower income countries, resulting from a higher share of subsistence consumption, a low access to modern energy services or the impossibility to afford energy. In fact, Flues and van Dander (2017) even find for 20 OECD countries a negative correlation between the energy affordability risk and the GDP.

Second, literature reviews strongly suggest progressive outcomes for subsidy reforms (Anand et al., 2013; Clements et al., 2013; Coady et al., 2015). Energy subsidies especially benefit well-organised interest groups while disadvantaging low-income households (Inchauste and Victor, 2017). Small groups of powerful and highly profiting actors have a larger incentive to organise and influence a legislation process than a large group of individuals with low payoffs (Oye and Maxwell, 1994). Standard economic theory however describes subsidies as negative taxes, indicating no systematically different distributive impact (Varian, 2009). The income level of the countries provides another potential explanation for the literature findings as energy subsidies have primarily been implemented in developing countries (Coady et al., 2015).

Third, Wang et al. (2016) review a tendency towards progressive outcomes for transport sector policies. Others however show proportional or regressive outcomes in the United States (Casler and Rafiqui, 1993; Chernick and Reschovsky, 1997; Metcalf, 1999; Chernick and Reschovsky, 2000; Williams et al., 2015), Germany (Nikodinoska and Schröder, 2016) and another six European countries (Sterner, 2012). Sterner (2012) argues that the smaller car ownership rate in low-income countries makes fuel a luxury product. Santos and Catchesides (2005) however also find a smaller car ownership rate for low-income household in the United Kingdom, resulting in first progressive and then regressive effects of fuel taxes. The efficiency of the public transport system as well as indirect fuel expenditures on public transport could additionally influence the results (Datta, 2010). Nevertheless, Kpodar (2006) and Ziramba (2009) find no impact of indirect expenditures.

Finally, we consider the modeling of indirect effects, behavioural adjustments of consumers, general equilibrium effects and studies applying lifetime income proxies:

Indirect effects might influence the distributive impact in both directions. Generally, their impact depends on the relative difference of CO_2 intensities in the consumption baskets between low- and high-income households (Anand et al., 2013). Hasset et al. (2009) provide

evidence that indirect effects mitigate regressivity in the United States. Other authors show indirect effects to increase regressivity as low-income households would spend large fractions of their incomes on energy intensive food and public transport (Jacobsen et al., 2003; da Silva Freitas et al., 2016).

Modeling behavioural adjustments of consumers could also ambiguously influence the study outcomes. Their impact depends on differences in the demand elasticities between low- and high-income households. Zhang (2015) shows larger behavioural adjustments for rich households and argues that low-income households were already required to focus on their basic needs. On the contrary, West and Williams (2004) show larger behavioural adjustments for low-income households which results in more progressive outcomes. Their study however only considers transport fuel taxes.

We expect more progressive outcomes for studies that capture general equilibrium effects. Several studies find general equilibrium effects to foster progressive outcomes (Rausch et al., 2011; Dissou and Siddiqui, 2014; Vandyck and Van Regemorter, 2014; Beck et al., 2015; Sajeewani et al., 2015; da Silva Freitas et al., 2016). Dissou and Siddiqui (2014) show that carbon taxes particularly affect the capital-intensive energy industry. This decreases the capital income of rich households and thus makes the distributive effect more progressive. Fullerton and Heutel (2011) however highlight the results' sensitivity on parameter values.

Using lifetime income proxies instead of annual household incomes is hypothesised to increase progressivity. Several literature findings based on lifetime incomes show more progressive outcomes for excise and transport taxes (Poterba, 1989, 1991; Bull et al., 1994; Lyon and Schwab, 1995; Hassett et al., 2009). The permanent income hypothesis (Friedman, 1957) assumes households to smooth their consumption over lifetime. Accordingly, lifetime income proxies consider that low annual incomes in single years do not necessarily correspond to a low welfare as for instance elderly people and students live from savings or loans. The magnitude of the effect (Fullerton and Rogers, 1993) as well as the most suitable lifetime income proxy (Metcalf, 1999; Chernick and Reschovsky, 2000) are however widely debated.

Based on this discussion, we hypothesise an increasing share of progressive study outcomes for first, low-income countries, second, subsidy reforms and third, transport sector policies. We further expect more progressive findings for studies that model general equilibrium effects or use lifetime income proxies. Studies that consider indirect and behavioural effects could either provide more progressive or more regressive findings.

3 Methodology

3.1 Data selection

This paper applies a meta-regression framework analysing literature on the distributional impacts of carbon pricing schemes on households. We follow Ringquist (2013) for the structure of the data selection process. For literature identification we conduct a query search in the *Web of Science* and the *Scopus* literature databases. We connect three groups of keywords

with boolean operators filtering for research on CO_2 related (*carbon, CO_2, gasoline, emission, environment, ecologic, energy*) pricing policies (*tax, allowance, subsidy, policy, price*) investigating the distributional impacts (*distribution, regressive, progressive, incidence, inequality, household income*). We exclude findings from unrelated research fields by permitting characteristic keywords (see appendix A.1 for details). The literature search identified 1023 studies restricted to literature written in English. In the first step, we exclude 856 studies with titles indicating irrelevant research questions, leaving 167 potentially relevant studies.

For the next steps of the selection process we apply the following study selection criteria: First, we exclude 61 studies because of differing research questions, replicating findings of previous studies including double hits, unavailability or insufficient quality. Second, we only select quantitative studies, thus excluding 34 studies that provide qualitative results or apply theoretical models. Third, we exclude 43 studies with an uncomparable scope, i.e. studies pricing multiple pollutants beyond CO_2, imposing sectoral restrictions apart from transport, including revenue recycling schemes or only concentrating on urban or rural households. Last, we only select countries or large regions, thus excluding 8 studies for single cities and supranational unions.

Figure 1: Study selection process
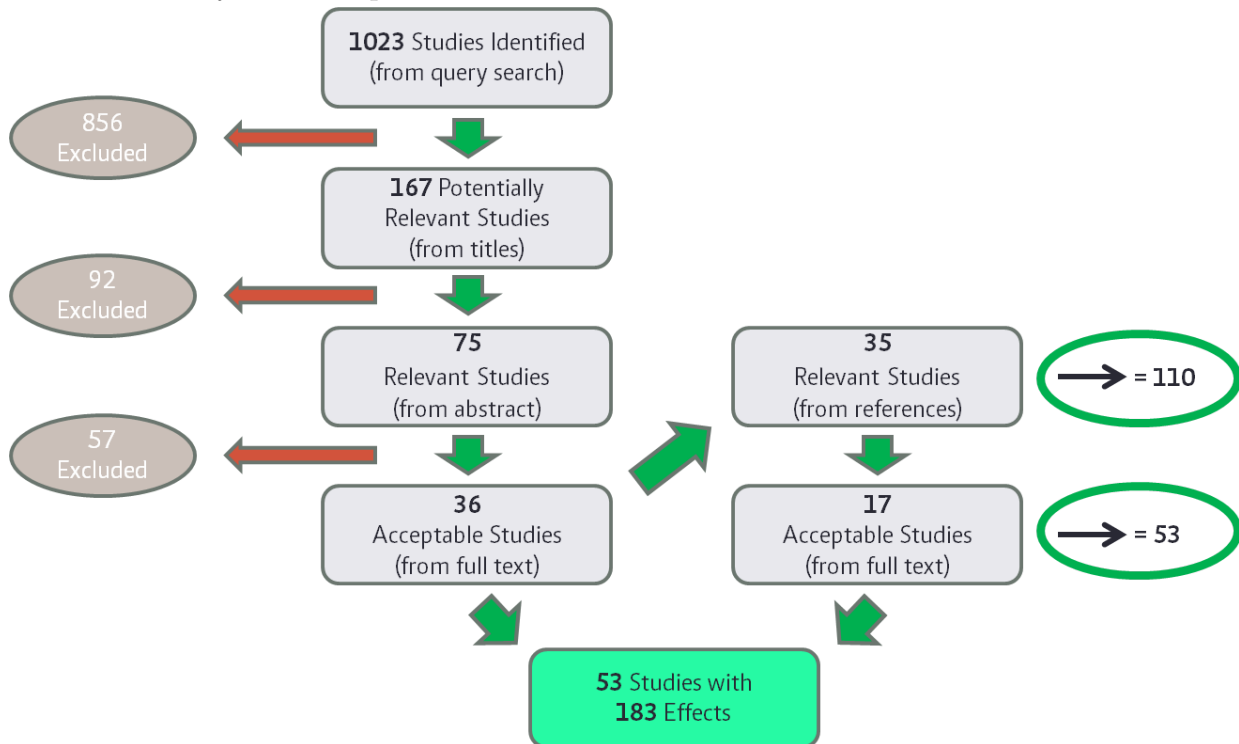
We employ these selection criteria successively to the abstract and the full text of the 167 (potentially) relevant studies, resulting in 36 acceptable studies. Subsequently, we identify another 35 relevant studies by a reference search, resulting in another 17 acceptable studies[3]. The final sample comprises 53 original studies with 183 effects. Figure 1 provides an overview

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[3]The numbers of excluded studies per selection criterion in the previous paragraph already includes these 18 additionally excluded studies.

of the selection process. In total, three researchers were involved to the coding process. One researcher coded all 53 studies. Each of the two additional researchers double coded a subsample in the early coding process to identify potential ambiguities in the variable definitions or coding mistakes. Further details are documented in the codebook which is available upon request.

3.2 Sample overview

The final sample comprises 53 studies with 183 effects in total. Appendix A.2 lists the original study author names, the publication years, the number of included effects per study and the percentage share of included effects per study relative to the 183 total effects. All studies were published between 1991 and 2017 with an average publication year of 2007. Most original studies report several effects which account for alternative policies, different model setups or multiple countries. The number of effects per study are thus unequally balanced with Flues and Thomas (2015) providing 22.4% of the sample, Sterner (2012) 14.2% and Hasset et. al (2009) 6.6% while the other studies contribute less than 5%. The 53 included studies comprise of 46 peer-reviewed journal articles (126 effects) and 7 articles from grey literature (57 effects).

Figure 2 shows the number of effects for each included country. The effects per country are also unequally balanced, with the United States 30.6%, the United Kingdom 6.6% and Germany 4.9% having the largest shares in the sample. Grouping the effects by World Bank country income levels provides 144 effects for high-income countries and 39 effects for low, lower-middle and upper-middle countries.

3.3 Dependent variable

The ordered categorical variable *Distributional impact* captures the progressive, proportional or regressive distributive impact of each included effect. We only aim at explaining whether a policy is progressive, regressive or proportional, without addressing the size of this effect as the inequality measures applied in the original studies are not quantitatively comparable. The methods suggested by the meta-analysis literature to harmonise different effect size metrics are however not applicable to this study[4]. We additionally tried to subsample studies with identical inequality metrics. Unfortunately the sample sizes became too small to conduct an empirical analysis. Section 5 discusses the implications of abstracting from the effect size. Neglecting the effect size allows to examine a larger sample of original studies and thereby to increase the significance and validity of the results. The 183 effects comprise of 52 progressive, 13 proportional and 118 regressive outcomes (see Table 1).

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[4]Quantitatively comparing the change of a country's Gini coefficient with a graphical representation of the relative tax burden for each income decile not feasible. For more details on effect size harmonisation see Ringquist (2013) chapter three "*Calculating and Combining Effect Sizes*".

Figure 2: Country sample overview
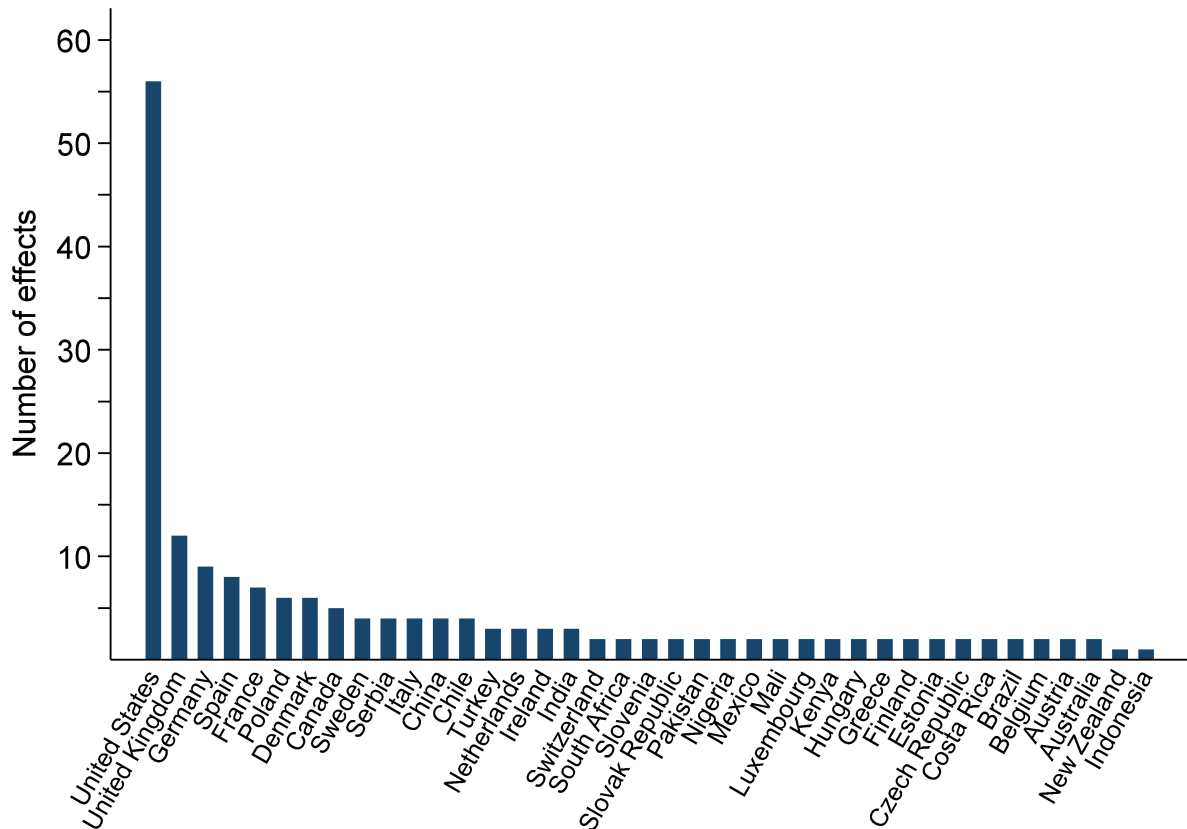
3.4 Moderator variables

Moderator variables are hypothesised to systematically influence the outcomes of the original studies (Ringquist, 2013). We include moderator variables that allow to test the hypotheses developed in section 2. The policy and the country moderator variables account for differences in the presumed distributional impact while the economic effect variables implicitly capture different study designs. We additionally control for a potential publication bias and a time trend. Table 1 summarises the included variables. Furthermore, we test the bivariate relationship between the moderator variables and the dependent variable. For the binary moderator variables we conduct a two-proportion z-test. Analogously, we conduct a correlation analysis for the continuous moderator variables. The results of the two tests indicate a reasonable selection of moderator variables though single variables have no significant bivariate impact on the study outcome. The remainder of this section briefly explains the included moderator variables. Appendix A.3 describes single moderator variables and the bivariate analyses including their results in more detail.

Policy variables: We include two variables controlling for policy differences: The *Subsidy* variable differs between subsidy reforms and carbon pricing schemes. The *Transport* variable compares policies on the transport sector only and economy-wide policies. Generally, we only include effects increasing the burden for the households, i.e. only carbon pricing

Table 1: Variable summary statistics

Dependent variable	Effect category	Frequ.	Pct. share			
	Progressive	52	28.42			
	Proportional	13	7.10			
	Regressive	118	64.48			
Moderator variables	**Description**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	
Policy variables						
Subsidy	Subsidy reducing policy	0.07	0.25	0	1	
Transport	Transport sector only	0.51	0.50	0	1	
Economic effect variables						
Indirect	Indirect effects	0.40	0.49	0	1	
Behavioural	Behavioural adjustments	0.17	0.38	0	1	
General equilibrium	Income side effects	0.07	0.25	0	1	
Lifetime income	Lifetime income proxy	0.51	0.50	0	1	
Context variables						
Publication type	Grey literature	0.31	0.46	0	1	
Publication year	Publication year	2008.36	7.81	1991	2017	
Country variables						
GDP per capita	In 1.000 US$ of 2010	33.06	18.47	0.62	102.40	
Gini	Gini coefficient	36.40	6.94	25.59	64.79	
Poverty gap	At 3.10 US$ of 2011 PPP	3.27	9.50	0.00	41.41	

increases or introductions as well as subsidy decreases or removals.

Economic effect variables: We include four moderator variables which account for different economic effects: *Indirect, Behavioural, General equilibrium* and *Lifetime income*. The first three variables correspond to the model types used in the original studies while lifetime income proxies reflect differences in the underlying data. We explicitly include moderator variables on the modeled economic effects and not on the model type. This method allows to extract more information from the original studies, as, for example, many authors using Input-Output models separately report both, the direct and the indirect distributive impact. We however lose information about the impact of the different model types themselves.

Each model type at least considers direct effects. We identify and include three major groups of more advanced models in the literature: Input-Output models, micro-simulation models and computable general equilibrium (CGE) models[5]. Table 2 provides an overview of the economic effects potentially covered by each model type.

The *Indirect* variable covers the joint impact of direct and indirect effects and comprises findings from Input-Output and CGE models. The *Behavioural* variable covers behavioural changes in the demand of different income groups which are considered by micro-simulations and CGE models. The *General equilibrium* variable covers the long term general equilibrium effects that are only covered by CGE models. The *Lifetime income effects* variable accounts for effects considering lifetime income proxies as opposed to annual household incomes.

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[5]Wang et. al. (2016) further list econometric models as a group. Due to their specific design and their rare occurrence we omit them from this analysis. Further details on the three model types are described in appendix A.4.

Table 2: Models and Economic Effects

Economic Effects:	(Direct)	Indirect	Behavioural	General equilibrium
Basic Approach	X			
Input-Output	X	X		
Micro-Simulation	X		X	
CGE	X	X	X	X

Context variables: The *Publication type* variable differs between peer-reviewed journal articles and grey literature. The *Publication year* variable accounts for a potential time trend of study outcomes.

Country variables: Our main specification considers time fixed and time-variant country characteristics. The main regression thus includes 38 ($N-1, N=39$) single country dummies that account for unobservable time fixed country effects. We further include three time-variant country variables: The *GDP per capita*, the *Gini* and the *Poverty gap* variable. These variables control for the country income and its distribution. For an alternative model specification, we additionally group the countries based on the world bank country income level classifications, namely *high*, *upper-middle*, *lower-middle* and *low-income* countries. The country data stems from the World Bank dataset between the years 1990 and 2014[6] (World Bank, 2017).

3.5 Ordered probit model

The bivariate analyses indicate a significant impact of most moderator variables on the dependent variable (see appendix A.3). Identifying the isolated influence of each moderator variable however requires a regression analysis. The ordered categorical dependent variable with the outcomes progressive, proportional and regressive suggests applying an ordered probit model. The approach is based on Greene (2012) and methodologically similar to the meta-analyses of Waldorf and Byun (2005), Card et al. (2009) and Wehkamp et al. (2018).

This ordered probit model uses a continuous latent variable y^* to measure the unobserved effect size of each original study. We assume y^* to be correlated with the three observed distributional effects: progressive ($y = 0$), proportional ($y = 1$) and regressive ($y = 2$). The relationship between y^* and the moderator variables X is assumed to follow a linear regression model of the form

$$y^* = X\beta + \epsilon \tag{1}$$

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[6]We adjust the data as further described in appendix A.3.

with y^* potentially varying between $-\infty$ and ∞ and ϵ being a normally distributed disturbance term. The observed distributional impact y is linked to the underlying latent variable y^* by

$$
\begin{aligned}
y &= 0 \quad \text{if} \quad y^* < 0 \\
y &= 1 \quad \text{if} \quad 0 < y^* < \mu_1 \\
y &= 2 \quad \text{if} \quad \mu_1 < y^*
\end{aligned}
\tag{2}
$$

where μ_1 is an unknown threshold parameter simultaneously estimated with β.

The probability of estimating a progressive ($y = 0$), proportional ($y = 1$) or regressive ($y = 2$) distributional effect is given by

$$
\begin{aligned}
P(y = 0 | X) &= \Phi(-X\beta) \\
P(y = 1 | X) &= \Phi(\mu_1 - X\beta) - \Phi(-X\beta) \\
P(y = 2 | X) &= 1 - \Phi(\mu_1 - X\beta)
\end{aligned}
\tag{3}
$$

where Φ denotes the standard normal cumulative distribution function. We estimate the parameters by the maximum likelihood method with the previously described probabilities entering the likelihood function. The beta coefficients in combination with the p-value provide the direction and the significance of the effect: A positive β coefficient suggests the respective moderator variable X to increase the probability to obtain a regressive outcome ($P(y = 2)$). A negative β coefficient vice versa suggests the respective moderator variable X to increase the probability of finding a progressive outcome ($P(y = 0)$). The coefficients have an ambiguous effect on the probability of finding a proportional outcome ($P(y = 1)$). The marginal effects at means show the magnitude of the probability change for the three possible outcomes induced by the moderator variables. The pseudo-R^2 is reported as a measure of fit (McFadden, 1974).

We conduct several sensitivity analyses and specification tests as proposed by the best-practice guideline for future meta-analysis by Nelson and Kennedy (2009). First, we impose cluster-robust standard errors by country to address non-independence of observations. Second, to account for the low time variation of single countries we replace the single country dummies by country group dummies based on the country income levels. Another regression without country dummy variables investigates the overall impact of fixed country effects. Third, we test the validity of the ordered probit model specification by conducting significantly progressive and regressive probit regressions. Fourth, we use a jackknife method to identify the impact of single countries on the results (Gould, 1995). Finally, we test for multicollinearity using the variance inflation factors and the joint significance of the variable groups using the likelihood-ratio test. Appendix A.6 provides further information on the sensitivity analyses and specification tests.

4 Main results

Table 3 shows the regression results of our main ordered probit model specification which includes the single country dummies and robust standard errors clustered by countries. The first column provides the estimated coefficients, the subsequent three columns present the marginal effects at mean for the three possible original study outcomes. A negative coefficient indicates an increased probability for a progressive study outcome. Figure 3 additionally plots the coefficients for the most relevant model specifications, i.e. regressions with single country dummies, group country dummies and no country dummies. For all three regression types we show the results with and without the three time-variant country variables ("Baseline" and "No Country Variables"). General findings from all robustness checks are discussed in subsection 4.5. We separately report the 38 coefficients of the single country dummies in the appendix for a better overview (see appendix A.5).

The results confirm our hypotheses of a significantly increased likelihood for progressive study outcomes of transport policies, within lower income countries and for studies applying lifetime income proxies. On the contrary, we show that subsidy reforms are not inherently more progressive than carbon pricing instruments. The regression results further indicate no impact of studies considering general equilibrium effects while modeling indirect effects and behavioural adjustments of consumers provide more progressive study outcomes. The next subsections discuss the results for the different variable groups in detail.

4.1 Policy variables

We hypothesise the two policy variables *Subsidy* and *Transport* to foster progressive outcomes: The *Transport* coefficient indeed indicates a significantly higher likelihood for progressive outcomes while the *Subsidy* coefficient is insignificant. Both findings are highly robust among most other model specifications (see Figure 3).

The insignificant finding for the *Subsidy* coefficient sharply contrasts other literature findings but supports standard economic theory: As subsidies are equal to negative taxes, there should be no systematically different impact of subsidies compared to tax or cap-and-trade systems after controlling for all other influences. The finding is robust over all other specifications besides one notable exception: The regression with no country dummies and no country variables shows a highly significant negative coefficient indicating more progressive results for subsidies as previously expected. Again, energy subsidies have primarily been implemented in developing countries (Coady et al., 2015). Our sample accordingly only includes subsidy policies in non high-income countries, such as India, Mali, Mexico, Nigeria, Poland and Turkey. We thus reason the country variables to capture the progressive impact of subsidy reforms.

The *Transport* coefficient indicates a significantly and highly increased likelihood for progressive outcomes as hypothesised. The marginal effects at mean show an increased likelihood for progressive outcomes of 44.7% and a 55.9% decreased likelihood for regressive outcomes

Table 3: Ordered probit results

| Moderator Variable	Coefficient	Marginal Effect		
		Regressive	Proportional	Progressive
Policy variables				
Subsidy	0.211	0.084	-0.012	-0.072
	(1.671)	(0.665)	(0.095)	(0.570)
Transport	-1.405**	-0.559**	0.081	0.477***
	(0.632)	(0.248)	(0.077)	(0.182)
Economic effect variables				
Indirect	-0.628**	-0.250**	0.036	0.214**
	(0.257)	(0.102)	(0.026)	(0.088)
Behavioural	-0.778*	-0.309*	0.045	0.264*
	(0.464)	(0.185)	(0.038)	(0.159)
General equilibrium	0.028	0.011	-0.002	-0.010
	(0.873)	(0.347)	(0.050)	(0.297)
Lifetime income	-1.254*	-0.499*	0.073	0.426**
	(0.693)	(0.275)	(0.073)	(0.211)
Context variables				
Publication type	-0.558	-0.222	0.032	0.189
	(0.650)	(0.259)	(0.044)	(0.219)
Publication year	0.069	0.027	-0.004	-0.023
	(0.067)	(0.026)	(0.005)	(0.021)
Country variables				
GDP per capita	-0.107	-0.042	0.006	0.036
	(0.095)	(0.038)	(0.008)	(0.030)
Gini	-0.198	-0.079	0.011	0.067
	(0.244)	(0.097)	(0.017)	(0.081)
Poverty gap	-0.879***	-0.349***	0.051*	0.299***
	(0.272)	(0.110)	(0.029)	(0.105)
Single Country Dummies	yes	yes	yes	yes
Cut 1	124.509			
	(126.034)			
Cut 2	124.999			
	(126.069)			
Observations	183			
Pseudo-R^2	0.507			

Cluster-robust standard errors
Dep. var.: Distributional impact: 0=progressive, 1=proportional, 2=regressive
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

and at the 1% and 5% significance levels. Most robustness checks confirm this finding though the magnitude of the effect decreases for regressions without single country dummies. Again, one notable exception is the regression with no country dummies and variables which shows an insignificant coefficient. This finding corresponds to the ambiguous literature outcomes which mostly show progressive but also regressive impacts in mostly high-income countries.

4.2 Economic effect variables

We hypothesise a progressive impact of the *Lifetime income* and the *General equilibrium* variable while being inconclusive about the *Indirect* and the *Behavioural* variable. Table 3 confirms that the application of *Lifetime income* proxies increases the likelihood for pro-

Figure 3: Results overview
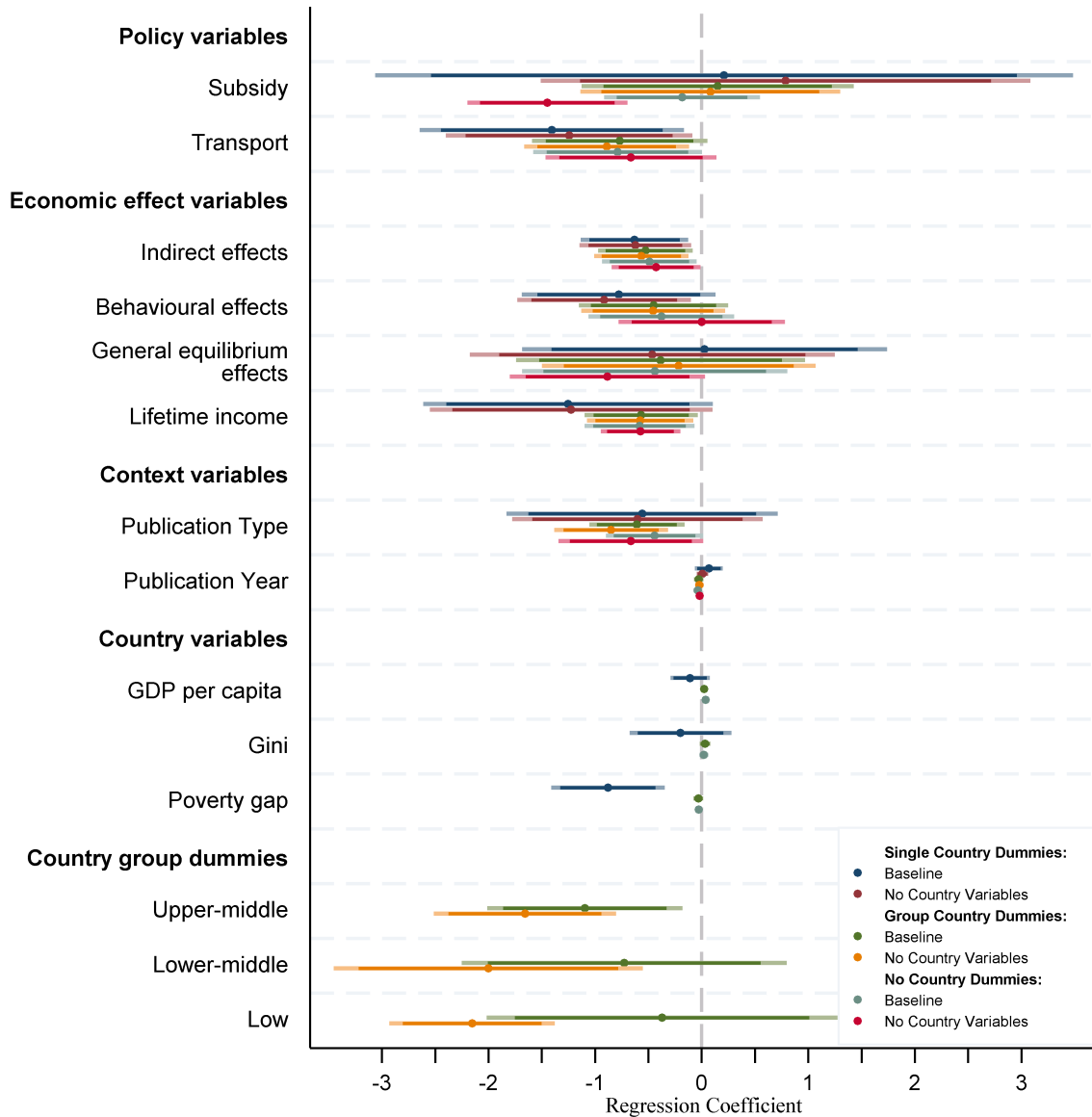
gressive findings. Progressive findings are also more likely for studies including *Indirect* and *Behavioural* effects. The *General equilibrium* coefficient is insignificant which contradicts our hypothesis.

The marginal effects at means for the *Lifetime income* variable indicate an increasing likelihood for progressive outcomes by 42.6%. Regressive outcomes are 49.9% less likely. The results confirm the theory and are supported by the robustness checks. The magnitude of the coefficient however decreases for all regressions without single country dummies though the significance level increases from 10% to 5%.

The marginal effects for the *Indirect* variable indicate an increasing likelihood for progressive outcomes by 21.4%. Regressive outcomes are 25% less likely at the 5% significance level. Other model specifications consistently show coefficients of slightly smaller magnitudes at

mostly the same significance level. Previous literature findings show both, increasing and decreasing regressivity of indirect effects (see section 2). The results suggest more CO_2-intensive consumption baskets of richer households.

The *Behavioural* variable increases the likelihood for progressive outcomes by 26.4% while regressive outcomes are 30.9% less likely. Robustness checks including single dummy variables show mostly significant coefficients at the 5 or 10% level except when standard errors are clustered by studies. Without the single country dummies the coefficients become insignificant. The progressive effect of the *Behavioural* variable is thus sensitive to the modeling of unobserved country characteristics. Though our findings suggest larger elasticities for high-income household, additional and country-specific research is recommended.

The *General equilibrium* coefficient remains insignificant over most model specifications. This finding strictly contradicts our hypothesis. One explanation would be the small number of included general equilibrium effects in combination with our categorical dependent variable: CGE models are the only model type capturing general equilibrium effects. Many CGE models in the literature however include revenue recycling schemes which we exclude from this analysis. Our sample thus only contains 12 effects by CGE models of which 50% show regressive outcomes (see Table 5). The ordered categorical dependent variable only considers the overall outcome, i.e. regressive, proportional or progressive. We thus neglect changes within each category, e.g. from strongly to weakly regressive. Therefore, we do not account for the presumably progressive source side effects within those 6 overall regressive outcomes. We further elaborate the implications of using a categorical dependent variable in section 5.

Summing up, including a wider range of economic effects mostly fosters more progressive outcomes. The economic effects either reflect the application of more sophisticated model types or a different data base using lifetime income proxies.

4.3 Context variables

Table 3 neither shows a publication bias, nor a time trend. The *Publication Type* coefficients remain insignificant over model specifications including single country dummies. The robustness checks without single country dummies however indicate a publication bias towards more progressive outcomes. The *Publication Year* coefficients are insignificant over most model specifications though there are two significant coefficients with opposite signs. The two-proportion z-test results suggest a progressive publication bias and a time trend towards more progressive outcomes (see appendix A.3). In fact, the included grey literature primarily investigates developing countries. Furthermore, research on developing countries has been increasing over the last years. The findings suggest the country variables and especially the single country dummies to account for both trends.

4.4 Country variables

The regression results support our hypothesis of more progressive study outcomes for countries with lower income levels. Our main regression includes 38 single country dummies and three country variables accounting for time-fixed and time-variant country characteristics, respectively. The results interpretation of this variable group requires a particularly detailed investigation of the regression outputs.

Table 3 shows a significantly negative coefficient for the *Poverty gap* variable as expected. The finding indicates a higher likelihood for progressive outcomes for very poor or unequal countries. The coefficient however becomes small or insignificant for regressions without single country dummies. The finding is further sensitive to the included countries (see subsection 4.5). The *Gini* coefficient is insignificant for all regressions. The *GDP per capita* coefficients are mostly insignificant in regressions with single country dummies which contradicts to our hypothesis (see Table 4).

Additional robustness checks however show a large multicollinearity between the time-variant country variables and the time-fixed single country dummies. This can be explained by the small temporal variation of the country variables as the sample comprises only few observations for particularly low-income countries. The coefficients for the single country dummies and the country variables are thus inefficient for main model specification. We address this problem by first, including the country group dummies and second, conducting additional regressions which either exclude the country variables or the country dummies.

Regressions without single country dummies show significantly positive *GDP per capita* coefficients which implies more regressive study outcomes for richer countries. The regression results using group country dummies without country variables confirm this finding: The three group dummies coefficients are negative, highly significant and increase in magnitude for lower country income levels.

4.5 Robustness checks

We conduct several additional analyses to validate our findings. In particular, we address non-independence of observations, unequal numbers of effects and the validity of the ordered probit model specification. Furthermore, we test the robustness of the results with respect to different combinations of country variables. Table 4 provides a comprehensive overview of all regression results. The last two columns show the results of the significantly regressive and progressive probit estimations. Again, the single country dummy coefficients are excluded but shown in the appendix (see appendix A.5).

We address non-independence of observations by imposing cluster-robust standard errors by country for every regression. Additionally we test the sensitivity of the standard errors to the clustering decision by imposing cluster-robust standard errors by study. Clustering by studies shows broadly similar significance levels for most coefficients. Notable exceptions are the insignificant coefficient for the *Behavioural* variable and the significant coefficients for

the *Publication Year* and the *GPD per capita* variable. We conclude the clustering decision to slightly influence the results. The overall findings however remain.

We test the influence of single countries by conducting jackknife regressions. Appendix A.7 shows the distribution of jackknife coefficients for each moderator variable including fitted normal distributions. The coefficients outside the 99% confidence interval unsurprisingly mostly correspond to countries with large numbers of effects, i.e. the United States and the United Kingdom. Most coefficients however remain similar in sign or overall magnitude besides the *Subsidy* and the *Poverty gap* coefficients. Omitting Brazil or Poland strongly influences these two coefficients as the sample contains only few effects from lower income countries while both variables only have few positive observations. Jackknife regressions for model specifications without single country dummies show no impact of these two outlier countries.

We finally investigate the validity of our ordered probit model specification by conducting probit regressions on significantly regressive and progressive outcomes. The coefficients of the significantly regressive probit regression are close to the ordered probit model coefficients. The significantly progressive probit coefficients are broadly opposite in sign. The findings indicate a valid ordered probit model specification.

Table 4: Regression results overview

	Single Country Dummies						Group Country Dummies		No Country Dummies			
	Baseline	**Clustering: Studies**	**No Country Variables**	**Excluding: *Gini* and *Poverty Gap***	**Excluding: *Poverty Gap***	**Excluding: *Gini***	**Baseline**	**No Country Variables**	**Baseline**	**No Country Variables**	**Probit: Significantly Regressive**	**Probit Significantly Progressive**
Policy variables												
Subsidy	0.211	0.211	0.788	0.864	-0.316	1.235	0.151	0.082	-0.183	-1.447***	0.150	0.446
	(1.671)	(1.436)	(1.172)	(1.173)	(1.680)	(1.183)	(0.651)	(0.622)	(0.373)	(0.383)	(0.389)	(0.393)
Transport	-1.405**	-1.405**	-1.242**	-1.304**	-1.446**	-1.282**	-0.769*	-0.890**	-0.789*	-0.663	-0.786*	0.810*
	(0.632)	(0.623)	(0.591)	(0.614)	(0.640)	(0.601)	(0.420)	(0.395)	(0.404)	(0.409)	(0.420)	(0.415)
Economic effect variables												
Indirect	-0.628**	-0.628*	-0.621**	-0.606**	-0.631**	-0.610**	-0.527**	-0.565**	-0.490**	-0.426**	-0.467**	0.519**
	(0.257)	(0.349)	(0.267)	(0.264)	(0.258)	(0.262)	(0.227)	(0.225)	(0.226)	(0.213)	(0.233)	(0.221)
Behavioural	-0.778*	-0.778	-0.914**	-0.913**	-0.792*	-0.868**	-0.450	-0.454	-0.377	0.002	-0.503	0.055
	(0.464)	(0.540)	(0.416)	(0.423)	(0.466)	(0.421)	(0.357)	(0.345)	(0.349)	(0.399)	(0.348)	(0.458)
General equilibrium	0.028	0.028	-0.462	-0.311	-0.121	-0.079	-0.385	-0.214	-0.439	-0.883*	-0.584	0.518
	(0.873)	(0.731)	(0.873)	(0.836)	(0.841)	(0.871)	(0.692)	(0.656)	(0.635)	(0.467)	(0.661)	(0.916)
Lifetime income	-1.254*	-1.254**	-1.224*	-1.245*	-1.271*	-1.233*	-0.567**	-0.577**	-0.582**	-0.573***	-0.686**	0.521*
	(0.693)	(0.569)	(0.677)	(0.684)	(0.702)	(0.677)	(0.271)	(0.255)	(0.264)	(0.190)	(0.297)	(0.284)
Context variables												
Publication Type	-0.558	-0.558	-0.602	-0.588	-0.557	-0.578	-0.607***	-0.848***	-0.441*	-0.664*	-0.503**	0.219
	(0.650)	(0.340)	(0.600)	(0.631)	(0.648)	(0.646)	(0.228)	(0.272)	(0.233)	(0.347)	(0.229)	(0.252)
Publication Year	0.069	0.069**	0.009	0.042	0.065	0.052	-0.027	-0.020	-0.035*	-0.018	-0.036	0.037*
	(0.067)	(0.035)	(0.028)	(0.058)	(0.069)	(0.057)	(0.023)	(0.021)	(0.021)	(0.017)	(0.023)	(0.020)
Country variables												
GDP per capita	-0.107	-0.107*		-0.058	-0.096	-0.081	0.024**		0.037***		0.040***	-0.038***
	(0.095)	(0.062)		(0.076)	(0.095)	(0.079)	(0.010)		(0.009)		(0.009)	(0.011)
Gini	-0.198	-0.198			-0.242		0.032		0.021		0.023	-0.020
	(0.244)	(0.205)			(0.246)		(0.026)		(0.022)		(0.021)	(0.022)
Poverty gap	-0.879***	-0.879***				-1.024***	-0.030		-0.025**		-0.028*	0.022
	(0.272)	(0.241)				(0.261)	(0.024)		(0.013)		(0.017)	(0.013)
Single Country Dummies	yes	yes	yes	yes	yes	yes						
Upper-middle							-1.095**	-1.657***				
							(0.467)	(0.437)				
Lower-middle							-0.726	-2.000***				
							(0.778)	(0.740)				
Low							-0.371	-2.153***				
							(0.840)	(0.396)				
Cut 1 (or Constant)	124.509	124.509*	15.044	78.843	115.412	98.567	-54.580	-43.523	-70.826*	-37.453	72.405	-73.746*
	(126.034)	(66.950)	(54.974)	(112.838)	(129.870)	(111.508)	(46.185)	(41.645)	(41.813)	(34.248)	(45.753)	(40.212)
Cut 2	124.999	124.999*	15.520	79.320	115.895	99.053	-54.259	-43.217	-70.514*	-37.213		
	(126.069)	(66.971)	(54.962)	(112.863)	(129.904)	(111.536)	(46.171)	(41.634)	(41.806)	(34.249)		
N	183	183	183	183	183	183	183	183	183	183	183	183
Pseudo-R^2	0.507	0.507	0.495	0.497	0.503	0.503	0.304	0.278	0.290	0.134	0.364	0.339

Cluster-robust standard errors in parentheses

Dep. var.: Distributional impact: 0=progressive, 1=proportional, 2=regressive

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5 Discussion and conclusion

Market-based climate mitigation policies often raise concerns about potentially adverse distributional impacts. Distributional impacts have therefore been subject to various research papers with regressive, proportional or progressive results. This study applies an ordered probit meta-analysis framework on 53 original studies to systematically determine the source of variation between the outcomes. We find a significantly increased likelihood for progressive study outcomes within lower income countries and for transport policies. The same applies to study designs considering indirect effects, behavioural adjustments of consumers or lifetime income proxies. On the contrary, we show that studies on subsidy removing policies are not inherently more progressive than studies on carbon pricing. The following limitations of the analysis however require particular consideration for the interpretation of the results:

Disregarding the effect size of overall regressive, proportional or progressive distributional impacts influences the regression coefficients. Our methodology neglects differences within outcome categories, for example between strongly and weakly regressive effects. Smaller changes in the distributional impact within single studies which are mostly driven by the economic effect variables are thus ignored, resulting in downward biased and less significant coefficients as illustrated by the *General equilibrium* coefficient in section 4. Analogously, treating similar distributional impacts between studies equally irrespective of their magnitudes might ambiguously influence size and significance of the coefficients. Estimating the effect size using subsamples with common and thus quantitatively comparable inequality metrics however suffers from too few observations for being representative.

The small number of effects for lower income countries decreases the accuracy of our findings. Our analysis shows a large impact of two lower income countries on two variables (see subsection 4.5). A higher share of effects on lower income countries in combination with a larger total sample would reduce the impact of outliers, allow for more refined moderator variables and thus provide more precise insights. The robustness checks however confirm the overall validity of our findings which we discuss in the subsequent paragraphs.

Political economy obstacles to climate mitigation policies could be reduced by suitable revenue recycling schemes. Even progressive policies increase the consumer prices which raises the risk of poverty for low-income households. In the most extreme case this may lead to public resistance as illustrated by the example of Nigeria. The risk of poverty can however be offset by suitable revenue recycling schemes that compensate poor households (van Heerden et al., 2006). Revenue recycling can also provide various other double dividends, for example by reducing distorting income taxes (Pearce, 1991; Goulder, 1995) which potentially results in a higher GDP, more employment or higher individual welfare (Pezzey and Park, 1998).

Low-income countries might thus particularly benefit from progressive market-based climate mitigation policies. Progressive climate policies in combination with a targeted use

of the revenues entail the potential to simultaneously mitigate climate change, reduce inequality and address additional sustainable development goals. Revenues can for example be used for public investments in infrastructure providing access to water, sanitation, electricity, telecommunications and transport (Jakob et al., 2016).

Increased knowledge about the distributional impacts or the potential benefits of climate mitigation policies may further support their implementation. Thus far, there has been a widespread belief that consumption taxes and in particular environmental taxes would particularly impose a burden on the poor. The sample of this meta-analysis however provides more than one third of progressive or proportional effects while the regression analysis identifies the drivers of these outcomes. The narrative of necessarily regressive environmental taxes is however outdated and should be replaced by results from systematic scientific research. Research findings may thus help to prevent actors with vested interests from establishing a public opposition against unwanted policies. Also politicians face incentives to show short run results in order to get reelected while environmental policies on the contrary rather show long-run effects (Sterner, 2007). Market-based climate mitigation policies such as carbon pricing schemes are however mostly beneficial in the long run, particularly when considering double dividends arising from revenue recycling. Future research on the distributional impacts of different categories of revenue recycling schemes would thus add a large value to the literature.

This meta-analysis provides valuable insights explaining the outcome heterogeneity in the distributional literature. Increased knowledge about distributional impacts of market-based climate mitigation policies does not only allow to determine potentially adverse distributional impacts but also lays the foundation for addressing them.

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A Appendix

A.1 Search query

We use different combinations of keywords to comprehensively identify a broad set of original studies for our analysis. Unsuitable categories (for Scopus) and keywords indicating unsuitable categories (for both literature databases) are directly excluded. Adapting the two search queries to the respective syntaxes gives:

Web of Science:

TS = (((carbon OR CO2 OR fuel OR gasoline OR emission* OR environment* OR ecologic* OR energy) NEAR/3 ("tax" OR "taxes" OR "taxation" OR allowance* OR subsid* OR polic* OR pric*)) NEAR/10 (distribut* OR regressive OR progressive OR incidence OR inequality OR (household* NEAR/1 income*))) NOT TS = ("smart grid" OR biomass OR (distribut* NEAR/1 (energ* OR network* OR spatial)) OR "power plant" OR "natural gas" OR health OR solar OR hydropower OR software OR wireless OR "computer" OR forest) NOT WC = ("engineering electrical electronic" OR "thermodynamics" OR zoology OR oceanography OR "engineering civil" OR "computer science theory methods")

Scopus:

TITLE-ABS-KEY(((carbon OR CO2 OR fuel OR gasoline OR emission* OR environment* OR ecologic* OR energy) W/3 (("tax" OR "taxes" OR "taxation" OR allowance* OR subsid* OR polic* OR pric*)) W/10 (distribut* OR regressive OR progressive OR incidence OR inequality OR "household income"))) AND NOT TITLE-ABS-KEY("smart grid" OR biomass OR (distribut* W/1(energ* OR network* OR spatial)) OR "power plant" OR "natural gas" OR health OR solar OR hydropower OR software OR wireless OR "computer" OR forest) AND (EXCLUDE (SUBJAREA,"COMP") OR EXCLUDE (SUBJAREA,"MATH") OR EXCLUDE (SUBJAREA,"CENG"))

A.2 Study overview

Authors	Yr.	Eff.	Pct.
Agostini C.A., Jimenez J	2015	2	1.09
Anand R., Coady D.P., Mohommad A., Thakoor, V.J., Walsh J.P.	2013	1	0.55
Beck M., Rivers N., Wigle R., Yonezawa H.	2015	2	1.09
Bento A.M., Goulder L.H., Jacobsen M.R., von Haefen R.H.	2009	1	0.55
Blackman A., Osakwe R., Alpizar Rodriguez F.	2010	2	1.09
Brenner M., Riddle M., Boyce J.K.	2007	2	1.09
Bull N., Hasset K.A., Metcalf G.E.	1994	4	2.19
Burtraw D., Sweeney R., Walls M.	2009	2	1.09
Casler S.D., Rafiqui A.	1993	6	3.28
Chernick H., Reschovsky A.	1997	2	1.09
Chernick H., Reschovsky A.	2000	2	1.09
Cornwell A., Creedy J.	1996	1	0.55
Creedy, John; Sleeman, Catherine	2006	1	0.55
Datta A.	2010	2	1.09
Dinan T.M., Rogers D.L.	2002	1	0.55
Dissou Y., Siddiqui M.S.	2014	1	0.55
Dresner S., Ekins P.	2006	1	0.55
Feng K.S., Hubacek K., Guan D., Contestabile M., Minx J., Barrett J.	2010	1	0.55
Flues F., Thomas A.	2015	41	22.40
Freund C.L., Wallich C.I.	1996	4	2.19
Fullerton D., Heutel G.	2011	4	2.19
Grainger C.A., Kolstad C.D.	2010	4	2.19
Grottera C., Pereira A.O., La Rovere E.L.	2017	1	0.55
Hamilton K., Cameron G.	1994	2	1.09
Hassett K.A., Mathur A., Metcalf G.E.	2009	12	6.56
Kpodar K.	2006	2	1.09
Labandeira X., Labeaga J.	1999	1	0.55
Mabugu R., Chitiga M., Amusa H.	2009	1	0.55
Mathur A., Morris A.C.	2014	5	2.73
Metcalf G.E.	1999	4	2.19
Metcalf G.E.	2009	1	0.55
Mutua J.M., Börjesson M., Sterner T.	2009	2	1.09
Nikodinoska D., Schröder C.	2016	2	1.09
Parry I.W.H., Williams R.C.	2010	2	1.09
Pearson M., Smith S.	1991	8	4.37
Rausch S., Metcalf G.E., Reilly J.M.	2011	1	0.55
Rosas-Flores J.A., Bakhat M., Rosas-Flores D., Fernández Zayas J.L.	2017	2	1.09
Sajeewani D., Siriwardana M., Mcneill J.	2015	1	0.55
Santos G., Catchesides T.	2005	1	0.55
d. Silva Freitas L.F., d. Santana Ribeiro L.C., d. Souza K.B., Hewings G.J.D.	2016	1	0.55
Shah A., Larsen B.	1992	2	1.09
Shammin M.R., Bullard C.W.	2009	1	0.55
Soile I., Mu X.	2015	2	1.09
Sterner T.	2012	26	14.21
Symons E., Proops J., Gay P.	1994	1	0.55
Teixidó J.J., Verde S.F.	2017	2	1.09
West S.E., Williams R.C.	2004	2	1.09
Wier M., Birr-Pedersen K., Jacobsen H.K., Klok J.	2005	6	3.28
Yang H.Y.	2000	1	0.55
Yang H.Y., Wang T.F.	2002	1	0.55
Yusuf A.A., Resosudarmo B.P.	2015	1	0.55
Zhang F.	2015	1	0.55
Ziramba E., L. Kumo W., Akinboade O.	2009	1	0.55
Total		**183**	**100**

A.3 Detailed moderator variable description

Policy variables: The *Subsidy* variable includes all effects of studies modeling subsidy reforms. For this variable we allow for policies on single fuels while carbon taxes and cap-and-trade systems only consider economy-wide policies. The variable implicitly abstracts from differences between carbon tax policies and cap-and-trade systems. The *Transport* variable includes all effects of studies on the transport sector only. This comprises higher prices for petrol, diesel or liquefied petroleum gas (LPG) explicitly used for transport purposes. To ensure comparability with other policies, we only include distributional impacts on all households irrespective of their car ownership. The two-proportion z-test results for both variables indicate a significantly higher share of progressive outcomes (see Table 5).

Country variables and data: We measure the *GDP per capita* variable in steps of 1,000 US$ in constant 2010 US$. The Gini coefficient as a commonly applied to measure the distribution of income and wealth takes values between 0 and 1. A higher *Gini* coefficient indicates a larger inequality. The *Poverty gap* variable measures the mean shortfall from the poverty line of 3.10 US$ of 2011 PPP. It therefore simultaneously captures the amount of people below the poverty line as well as their distance to it. A higher value indicates a larger absolute poverty.

The four country dummies by income level refer to the GNI per capita in US$ using the Atlas methodology. We use data from the World Bank World Development Indicators for the years 1990-2014 (World Bank, 2017). Further information on the dataset can be retrieved from: *https://data.worldbank.org/data-catalog/world-development-indicators*.

We adjust our coded data or the dataset to consistently match the World Bank data with the included countries. First, we match the country data with the publication year of the original study's underlying household survey data unless the authors provide an explicit reference year. As our dataset only contains data from 1990-2014, we truncate the reference year/household data publication year accordingly. Second, the dataset lacks time-consistent data on the gini coefficients and the poverty gap. We fill the gaps with the next available datapoint. If there is no available datapoint in the future, we instead use the last available datapoint. Third, as there is no available data for British Columbia and Taiwan we instead use data for Canada and China, respectively. Further informations on the coding and the data are documented in the codebook which is available upon request.

Bivariate z-test: We test the bivariate relationship between the moderator variables and the dependent variable. For the binary moderator variables we conduct a two-proportion z-test. The test results indicate, if using the variable significantly changes the proportion of progressive, proportional or regressive study outcomes. Analogously we conduct a correlation analysis for the continuous moderator variables. The results indicate sign and significance of the correlation between the moderator variables and the dependent variable. Table 5 shows the results for both tests.

Table 5: Moderator variables, effect types and correlations

Binary Moderator Variables		Number of estimates	Proportion of estimates		
			Regressive	Proportional	Progressive
Policy variables					
Subsidy	Yes	12	0.333	0.076	0.667
	No	171	0.667	0.000	0.257
	z-test		2.332**	0.991	-3.039***
Transport	Yes	94	0.553	0.085	0.362
	No	89	0.742	0.056	0.202
	z-test		2.661***	-0.761	-2.390**
Economic effect variables					
Indirect	Yes	73	0.699	0.055	0.247
	No	110	0.609	0.082	0.309
	z-test		-1.239	0.697	0.918
Behavioural	Yes	32	0.625	0.125	0.250
	No	151	0.649	0.060	0.291
	z-test		0.258	-1.308	0.472
General equilibrium	Yes	12	0.500	0.167	0.333
	No	171	0.655	0.064	0.281
	z-test		1.084	-1.334	-0.391
Lifetime income	Yes	93	0.538	0.086	0.376
	No	90	0.756	0.056	0.189
	z-test		3.080***	-0.802	-2.811***
Context variables					
Publication type	Yes	57	0.474	0.123	0.404
	No	126	0.722	0.048	0.230
	z-test		3.253***	-1.834*	-2.408**
Additionally: Country Group Dummies					
High	Yes	144	0.771	0.063	0.167
	No	39	0.179	0.103	0.718
	z-test		-6.845***	0.864	6.771***
Upper-middle	Yes	18	0.167	0.111	0.722
	No	165	0.697	0.067	0.236
	z-test		4.464***	-0.697	-4.340***
Lower-middle	Yes	9	0.222	0.111	0.667
	No	174	0.667	0.069	0.264
	z-test		2.717***	-0.480	-2.609***
Low	Yes	12	0.167	0.083	0.750
	No	171	0.678	0.070	0.251
	z-test		3.580***	-0.172	-3.701***

Continous Moderator Variables	Number of estimates	Correlation coefficient	P-value
Publication year	183	-0.217	0.003***
Country variables			
GDP per capita	183	0.509	0.000***
Gini	183	-0.042	0.574
Poverty gap	183	-0.387	0.000***

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The two-proportion z-test results indicate a significant impact of more than half of the binary moderator variables on the proportion of study outcomes. For instance, the share of progressive findings for studies modeling transport policies increases to 36.2% compared to 20.2% for studies on economy-wide policies. The correlation analysis shows a significant correlation between most continuous variables and the dependent variable. The results of the two tests indicate a reasonable selection of moderator variables. The bivariate tests however neglect potential correlations between the moderator variables.

Additional moderator variables We exclude several potentially interesting moderator variables on policies and the study design. In particular, we neglect policy variables on revenue recycling schemes, levels of pricing and the impact of single fuels. The modeled revenue recycling schemes in the literature are too context specific to be aggregated to homogeneous groups. The impact of different pricing levels is especially relevant for CGE models covering behavioural and income side effects. The small number of included CGE models however prevents from determining their quantitative impact. Covering the impact of single fuels would allow conducting a more disaggregated analysis. The distributional impact of single fuels is however too rarely and inconsistently reported to provide robust findings. We further exclude moderator variables on the study design for different household equivalence scales, lifetime income measures and inequality measurement units. The exclusion reasons are: Scarce reporting of equivalence scales, heterogeneous lifetime income proxies and too few literature sources comparing different inequality measures. The following references explicitly discuss or compare the impact of the excluded moderator variables: Revenue recycling schemes (Speck, 1999; Rausch et al., 2011; Mathur and Morris, 2014; Williams et al., 2015), level of pricing (Dissou and Siddiqui, 2014; Grottera et al., 2017), single fuels (Casler and Rafiqui, 1993; Jacobsen et al., 2003), equivalence scales (Grainger and Kolstad, 2010), lifetime income measures (Bull et al., 1994; Hassett et al., 2009) and inequality measurement units (Cornwell and Creedy, 1996; Nikodinoska and Schröder, 2016).

A.4 Original study model details

Input-Output models cover direct and indirect price changes of different product categories. The indirect impact accounts for higher prices of goods and services using carbon intensive intermediate inputs by applying a static input-output matrix. This approach commonly assumes that levies are fully passed through to the final consumers. The assumption of inelastic demand corresponds to the short term incidence of higher prices (Hassett et al., 2009; Feng et al., 2010; Anand et al., 2013).

Micro-simulation models account for behavioural changes by considering consumer choices. The consumer demand is elastic with consumers maximising their utility for given preferences, prices and budgets. Commonly used micro-simulation models are almost ideal demand systems (AIDS) (Deaton and Muellbauer, 1980; West and Williams, 2004; Tiezzi, 2005; Rosas-Flores et al., 2017), its more flexible quadratic specification (QAIDS) (Banks

et al., 1997; Brännlund and Nordström, 2004; Nikodinoska and Schröder, 2016) or more recently the exact affine stone index (EASI) demand system (Lewbel and Pendakur, 2009; Tovar Reaños and Wölfing, 2017).

CGE models cover direct and indirect price changes, behavioural changes of consumers and producers as well as long term general equilibrium effects. This approach considers policy effects on the source side of income additionally to the use side. CGE models assume explicit functional forms of demand and supply functions, use exogenous parameters for demand elasticities and elasticities of substitution between production sectors (Hassett et al., 2009). Linked models, such as Input-Output and micro-simulations or micro-simulations (Creedy and Sleeman, 2006) and CGE models are further extensions (Labandeira et al., 2009; Vandyck and Van Regemorter, 2014).

A.5 Country dummy coefficients

	Baseline	Clustering: Studies	No Country Variables	Excluding: Gini+ Poverty Gap	Excluding: Poverty Gap	Excluding: Gini
Single Country Dummies						
Austria	0.985	0.985	1.443	1.480	0.780	1.573
Belgium	0.024	0.024	1.443	1.266	-0.270	1.279
Brazil	6.468	6.468	-0.550	-2.953	0.760	4.417
Canada	-0.647	-0.647	-0.332	-0.390	-0.723*	-0.367
Chile	-4.895	-4.895	-6.018***	-8.114***	-4.985	-7.265***
China	23.981***	23.981***	-0.157	-2.635	-2.115	27.806***
Costa Rica	3.240	3.240	0.973	-1.211	0.885	1.917
Czech Republic	-9.808**	-9.808***	-5.560***	-7.227***	-10.056**	-7.595***
Denmark	-0.228	-0.228	0.337	0.803	-0.723	1.078
Estonia	-1.602	-1.602	0.610	-1.196	-2.443	-0.535
Finland	-0.700	-0.700	0.610	0.543	-1.039	0.602
France	1.312	1.312	2.139**	1.843*	1.229	1.812*
Germany	0.635	0.635	1.356	1.097	0.552	1.076
Greece	-1.313	-1.313	0.610	-0.828	-0.985	-1.287
Hungary	-9.510**	-9.510***	-5.560***	-7.623***	-9.641**	-7.967***
India	5.421	5.421	-6.878***	-9.736**	-10.214**	8.111
Indonesia	14.426**	14.426***	1.374	-1.466	-2.107	17.572***
Ireland	0.673	0.673	1.028	0.860	0.593	0.890
Italy	1.298	1.298	1.779*	1.363	1.357	1.284
Kenya	15.314**	15.314***	-5.509***	-8.092**	-6.094*	17.190**
Luxembourg	12.964**	12.964***	6.749***	10.025**	12.427**	11.269**
Mali	27.037**	27.037***	-6.346***	-8.962**	-7.931**	31.910***
Mexico	2.305	2.305	0.107	-2.291	0.781	0.064
Netherlands	0.968	0.968	1.618	1.763	0.664	1.896
New Zealand	5.407***	5.407***	6.713***	6.009***	5.538***	5.750***
Nigeria	25.029**	25.029***	-6.966***	-9.762**	-8.081*	29.080***
Pakistan	31.362***	31.362***	-1.270*	-3.307	-4.744	38.393***
Poland	-4.424	-4.424**	-0.614	-2.554	-4.246	-3.181
Serbia	-10.570**	-10.570***	-5.993***	-8.428***	-10.868**	-8.676***
Slovak Republic	-10.012**	-10.012***	-5.560***	-7.380***	-10.311**	-7.715***
Slovenia	2.665	2.665	6.749***	5.372***	2.550	4.872**
South Africa	13.843**	13.843**	-5.501***	-7.795**	-2.172	11.408**
Spain	0.422	0.422	1.964**	1.075	0.533	0.815
Sweden	-0.250	-0.250	0.344	0.721	-0.688	0.949
Switzerland	9.392***	9.392***	6.749***	8.408***	9.007***	9.042***
Turkey	-2.688	-2.688	-0.930	-3.120	-2.585	-3.193
United Kingdom	1.377*	1.377	1.743**	1.359*	1.460*	1.276*
United States	3.257*	3.257*	1.787***	1.819***	3.513*	1.884***

Dep. var.: Distributional impact

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.6 Robustness checks

This part of the appendix gives a comprehensive overview of the sensitivity analyses and specification tests conducted in this study. First, we address non-independence of observations as a common problem in meta-analysis (Ringquist, 2013). Non-independence of observations generally occurs if at least one country or original study provides multiple ef-

fects (Ringquist, 2013) which also applies to our analysis (see appendix subsection A.2 and Figure 2). It potentially causes correlated results within countries or studies. Though estimators are not biased or inconsistent they potentially become inefficient (Waldorf and Byun, 2005). We account for that problem by imposing cluster-robust standard errors by country for the subsequent estimations. Additionally, we conduct one regression with cluster-robust standard errors by study to test the impact of the clustering decision.

Second, we conduct several robustness checks on the country modeling. In particular, we account for the unobservable characteristics in three different ways. Besides using single country dummies we further create country groups based on the level of income. We finally exclude all dummy variables to investigate the influence of unobservable effects. The main regression includes single country dummy variables. Figure 2 however shows five or less effects for 32 countries. Those few observations cast doubt on the explanatory power of our country dummy variables. Our secondary approach thus alternatively groups the countries by the level of income. Grouping the countries increases the number of effects per dummy variable. On the other hand we implicitly assume the group specific unobservable characteristics to be identical for each country within a group. We include three ($N - 1, N = 4$) country group dummies to the regression and thereby omit the high-income dummy. The third approach excludes all dummy variables as a sensitivity check. For all three regression types we show the results with and without the three observable country variables (Figure 3 "Baseline" and "No Country Variables"). For the single country dummies we additionally test different combinations of the three country variables.
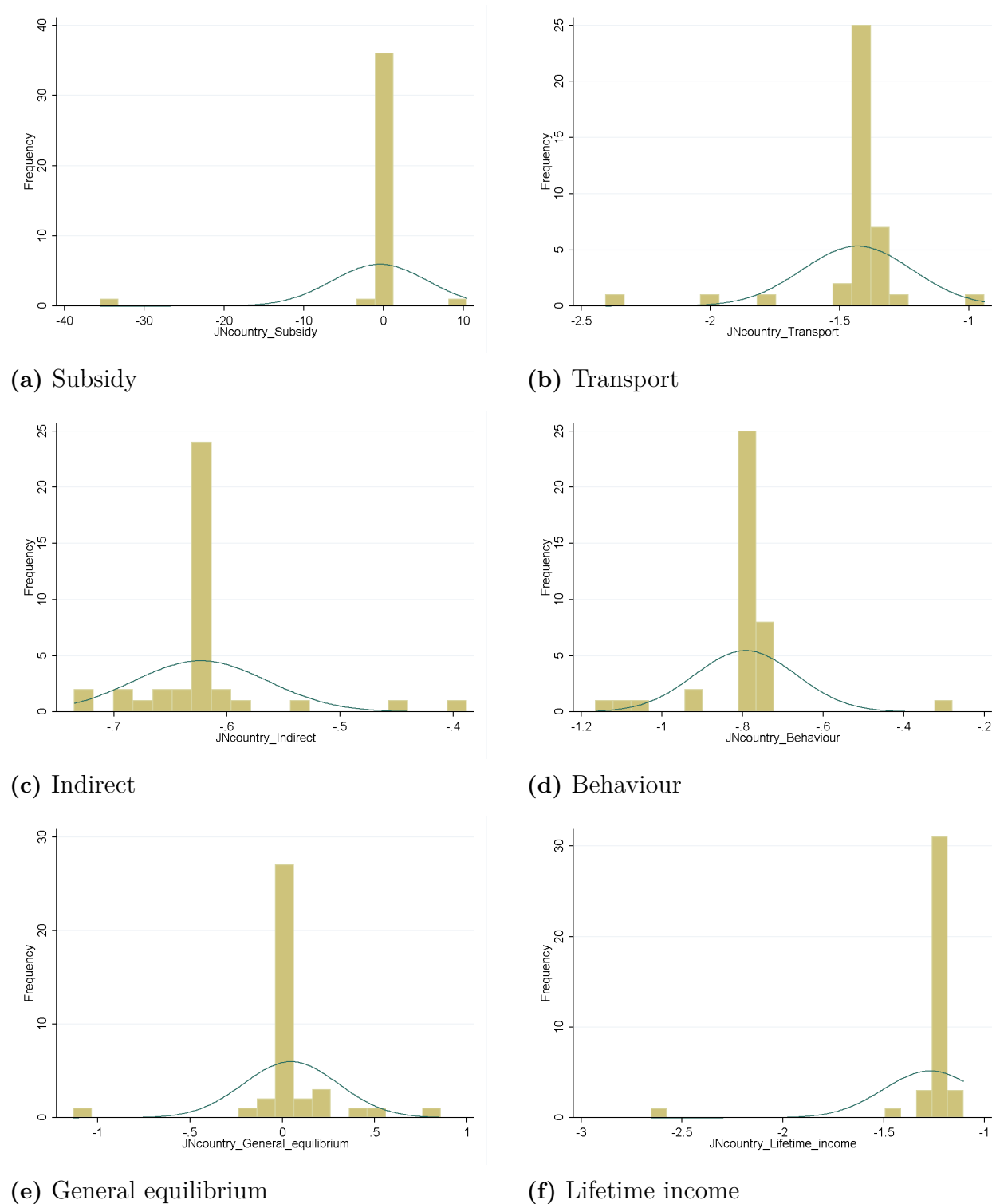
Third, we test the validity of the ordered probit model specification. For a valid ordered probit specification the regression coefficients of a significantly regressive probit regression (1=regressive, 0=proportional or progressive) should be similar to the ordered probit coefficients. The regression coefficients for a significantly progressive probit regression (1=progressive, 0=proportional or regressive) should be similar in magnitude but opposite in sign (Wehkamp et al., 2018). We conduct the two probit regressions without country dummies because including single country dummies results in infinite iterations.
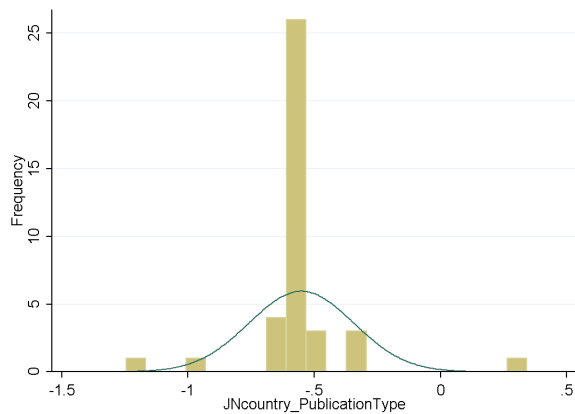
Fourth, we use a jackknife method to identify the impact of single countries on the results (Gould, 1995). The descriptive analysis shows unequally distributed effects per country (see Figure 2) which is a common problem in meta-analyses (Ringquist, 2013). The jackknife method performs N regressions by leaving out the jth observations with $j = 1, 2, ..., N$ being the number of each country ($N = 39$). The method thus provides N coefficients for each moderator variable. Jackknife regression coefficients that largely deviate from the ordered probit coefficient indicate a highly influential country or study.

Finally, we test for multicollinearity using the variance inflation factors and the joint significance of the variable groups using the likelihood-ratio test.
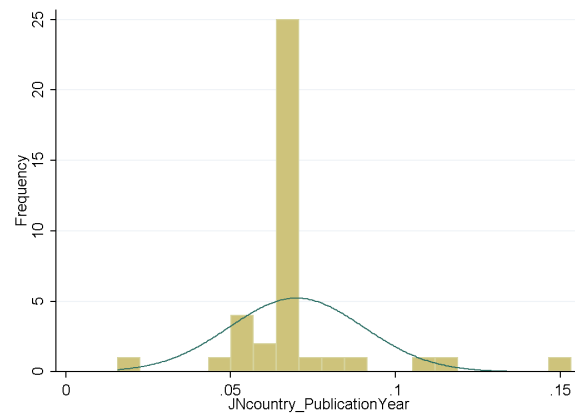
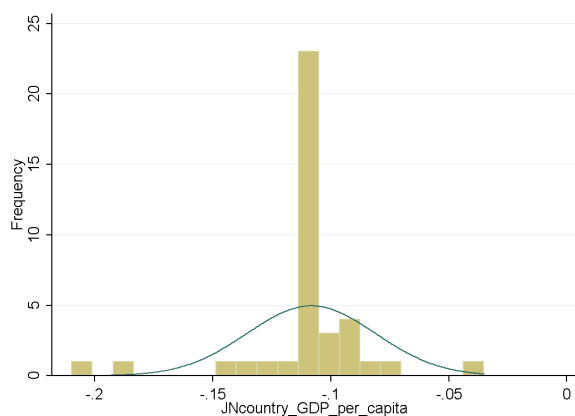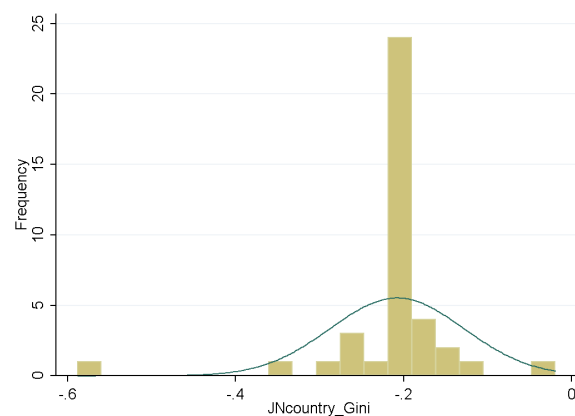## A.7 Jackknife findings

Figure 4: Jackknife country coefficients

(a) Subsidy

(b) Transport

(c) Indirect

(d) Behaviour

(e) General equilibrium

(f) Lifetime income

(g) Publication type

(h) Publication Year

(i) GPD per capita

(j) Gini

(k) Poverty gap