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Abstract

Mitigation of the potential impacts of climate change is one of the leading policy concerns of the 21st century. However, there continues to be heated debate about the nature, the content and, most importantly, the impact of the policy actions needed to limit greenhouse gas emissions. One contributing factor is the lack of systematic evidence on the impact of mitigation policy on the welfare of the poor in developing countries. In this letter we consider two alternative policy scenarios, one in which only the Annex I countries take action, and the second in which the first policy is accompanied by a forest carbon sequestration policy in the non-Annex regions. Using an economic climate policy analysis framework, we assess the poverty impacts of the above policy scenarios on seven socio-economic groups in 14 developing countries. We find that the Annex-I-only policy is poverty friendly, since it enhances the competitiveness of non-Annex countries—particularly in agricultural production. However, once forest carbon sequestration incentives in the non-Annex regions are added to the policy package, the overall effect is to raise poverty in the majority of our sample countries. The reason for this outcome is that the dominant impacts of this policy are to raise returns to land, reduce agricultural output and raise food prices. Since poor households rely primarily on their own labor for income, and generally own little land, and since they also spend a large share of their income on food, they are generally hurt on both the earning and the spending fronts. This result is troubling, since forest carbon sequestration—particularly through avoided deforestation—is a promising, low cost option for climate change mitigation.

Keywords: climate change, mitigation policies, computable general equilibrium, poverty, developing countries

S Online supplementary data available from stacks.iop.org/ERL/8/035009/mmedia

1. Introduction

Climate change is a global problem and successful mitigation will require the concerted efforts of many governments (IPCC 2007). Generating a global plan of action, however, is easier said than done. There continues to be heated debate about the nature, content and, most importantly, about the impact of the policy actions needed to limit greenhouse gas emissions. Macro-economic outcomes of climate change mitigation policies often take center stage in international negotiations and the impact of these policies on the general economy has been extensively investigated in the literature. However, these macro-economic effects may mask significant distributional consequences. This letter is the first attempt to provide quantitative evidence on the poverty impacts of climate change mitigation polices across a sample of 14 developing countries in Africa, Asia and Latin America.

Establishing a causal link between climate change mitigation policies and poverty presents a rather complex challenge.

There are many different types of mitigation policies and each has different impacts on production and consumption decisions in countries where the policies are implemented. Historically, mitigation studies have focused heavily on reductions in emissions from fossil fuel combustion in high income countries. So assessing the impact on poverty in poor countries entails tracing the impact on world markets and then following the transmission of changes in international prices to domestic prices, thereupon linking these to poverty. Predicting these price transmission effects is notably difficult (Winters 2002). Recently, there has been increasing interest in the potential for abatement of non-CO_2 emissions from agriculture, as well as reduced carbon emissions through avoided deforestation in developing countries, in order to contribute to global GHG emissions reduction (Smith *et al* 2008, Rose *et al* 2012, Wollenberg *et al* 2012). Each of these policies has different impacts on prices faced and wages received by poor households. While climate change mitigation policies in rich countries have only an indirect effect on low income households in the developing world, policies aimed to reduce deforestation in poor countries strike much closer to 'home' for the majority of the world's poor. Analysis of the poverty impacts of Annex I mitigation policies taken alone, as well as such policies combined with non-Annex carbon sequestration incentives is the goal of this letter.

Climate change mitigation polices can affect poverty in developing countries either directly or indirectly. A good example of the direct channel is when farmers get paid for avoided deforestation. Other things remaining the same, one would expect that such payments for environmental services should help reduce poverty. The indirect channel operates through markets via changes in world prices, domestic prices and factor earnings (e.g., land rents and wages). The fact that there are differing channels of influence suggests that the poverty impacts of climate change mitigation policy are likely to vary by region and by household type.

While the literature documenting the distributional impacts of climate change mitigation policy in developed countries is growing (Jorgenson *et al* 2011), there is a lack of systematic evidence linking policies implemented in Annex I countries to poverty in developing countries. Much of the recent work examines the impact of Annex I policies on global production and consumption. However, it is usually left to the imagination of the reader to figure out how such changes might translate into changes in welfare of the poor in developing countries. There are some important exceptions, most notably in the area of biofuels policies which are often justified on the basis of their potential contribution to climate change mitigation. A recent study (Cororaton *et al* 2010) finds that biofuels lead to higher prices for basic agricultural commodities with the adverse impact on the poor being partially offset by increased returns to unskilled rural labor. Their analysis suggests that current biofuel policies increase poverty in South Asia and sub-Saharan Africa, while reducing poverty in East Asia and Latin America. However, existing biofuels policies are quite different in nature from most policies currently being proposed for climate change mitigation. This letter will focus on a package of policies

aimed at reducing GHG emissions, including fossil fuels taxes, taxes on non-CO_2 emissions from agriculture, and forest carbon sequestration incentives. By linking these results to household survey-based poverty modules for 14 developing countries, we seek to shed light on the likely poverty impacts of climate change mitigation policies.

In section 2 we describe the modeling framework and data base, as well as the two policy scenarios considered. The materials and methods section is followed by the results section where we first look at trade related impacts of the policy package, and then investigate individual and cumulative impacts of the package components on poverty. We conclude with the discussion of the results and limitations of the analysis.

2. Materials, methods and policy scenarios

Analyzing the poverty impacts of climate change mitigation policies requires understanding not only how climate change mitigation policies affect domestic and international commodity prices, but also how these changes affect wages and other factor returns in developing countries. In order to obtain estimates of factor price changes, a computable general equilibrium (CGE) model is required. In this letter, we combine a modified version of the standard GTAP model, GTAP-AEZ-GHG (Golub *et al* 2010), with the recently developed poverty module, GTAP-POV (Hertel *et al* 2011a). GTAP-POV has been used for climate studies before. Hertel *et al* (2010) used the GTAP-POV model to document the impact of climate induced agricultural yield changes on poverty in developing countries while Hertel *et al* (2011b) used the model to disentangle the contributions of biophysical and economic forces in the uncertainty in climate change analysis. The combined GTAP-AEZ-GHG-POV model incorporates detailed non-CO_2 GHG and CO_2 emissions mapped to specific countries, economic sectors and drivers (Rose and Lee 2008, Lee 2008). The forestry component of the model is calibrated to outputs from an updated version of a partial equilibrium global forestry model (Sohngen and Mendelsohn 2003) documented in Choi *et al* (2011).

We use the World Bank's $1 per day Purchasing Power Parity definition of poverty to ensure comparability across countries (Chen and Ravallion 2000). Our sample comprises 14 countries in Africa, Asia and Latin America. These countries were selected based on data availability and intersections between household surveys and individual countries in the GTAP database. While the selection of countries is not random, it does encompass a wide range of developing countries with greatly differing patterns of poverty (Hertel *et al* 2011a). Within each country, poverty is broken down into socio-economic strata based on a household's primary source of income (95% or more of income from the following sources): agricultural self-employed (farm income), non-agricultural self-employed (non-agricultural self-employment earnings), urban labor (urban household, wage labor income), rural labor (rural household, wage labor

income), Transfer payment dependent, urban diverse, and rural diverse (Hertel *et al* 2004).

The poverty consequences of climate change mitigation policy are transmitted through three channels: changes in earnings, changes in taxes, and changes in the real cost of living at the poverty line (Hertel *et al* 2011a). The following equation from (Hertel *et al* 2011a) details the relationship between these three components and the poverty headcount in each country r, $\hat{H}_r$, where the 'hat' denotes percentage change in the underlying variable:

$$\hat{H}_r = -\sum_s \beta_{rs} \cdot \varepsilon_{rs} \cdot \sum_j \alpha_{rsj}^{\mathrm{p}} (\hat{W}_{rj} - \hat{T}_r - \hat{C}_r^{\mathrm{p}}). \qquad (1)$$

The parameter β_{rs} represents the share of a given stratum, s, in national poverty in country r, while $\alpha_{rsj}^{\mathrm{p}}$ is the share of income obtained from factor j in that particular stratum, for households in the neighborhood of the poverty line. The parameter ε_{rs} is the stratum-specific poverty elasticity with respect to real, after-tax income and describes how a given percentage change in household income at the poverty line translates into poverty change in that stratum. All three of these parameters have been estimated from the household survey data for each of the fourteen countries in our sample. The first term within the brackets on the right hand side of equation (1), $\hat{W}_{rj}$ is the percentage change in income from factor endowment j in region r. This captures the fact that a rise in earnings will reduce poverty. The second term $(\hat{T}_r)$ is the 'tax replacement effect' which arises from our assumption that any policy change must be fiscally neutral. This is achieved by adjusting the income tax on primary factors of production[1,2]. The third term within the brackets captures the 'spending effect' i.e. the change in cost of living C_r^{p} at the poverty line. Both higher taxes and a higher cost of living tend to offset the impact of higher earnings and so the earnings effect must be viewed in light of these other changes. The entire term within the brackets in equation (1) represents the percentage change in real, after-tax earnings from each of the household's income sources.

As we can see from equation (1), the impact of climate change mitigation policy on total household earnings depends importantly on the share of the income sources for a given household group: $\alpha_{rsj}^{\mathrm{p}}$. If unskilled farm wages, adjusted for taxes and cost of living changes, rise as a result of the policy, then the rural wage labor households will benefit, given the predominance of unskilled wages in their earnings profile. This will lower the stratum poverty headcount, with the extent of the decline depending on the density of the stratum population in the neighborhood of the poverty line, ε_{rs}. Whether or not this leads to a national poverty reduction depends on the relative importance of rural wage labor households in national poverty, β_{rs}, as well what happens to the other strata.

With seven strata, and 14 developing countries, there are 98 poverty change results for each experiment. Therefore, some sort of summary statistics are needed to ascertain what has happened to poverty *in general*. We adopt the metrics used in Hertel *et al* (2007). These include the 'sign consistency' statistic (SC) and the 'average absolute value' (AAV) for the critical variables. The AAV statistic is used as a measure of magnitude for a given effect. The SC statistic is the ratio of the average change in a variable to its average absolute value. By construction, it falls within the $[-1, 1]$ range. For example, if the impact of a given policy scenario on a particular stratum of the population is always poverty reducing, then SC $= -1$, and we conclude that the policy is always poverty reducing in our sample of countries[3].

The Annex-I-only policy experiment involves the application of an economically efficient climate change mitigation policy whereby a carbon price of \$27/tCO$_2$eq is applied to all sectors in the Annex I regions along with a forest carbon sequestration incentive of the same magnitude. The second experiment combines this Annex I policy with a carbon sequestration incentive policy in the developing countries, paid for by Annex II regions[4]. The level of this payment is tied to abatement attained by non-Annex regions[5]. We restrict ourselves to the carbon sequestration policy in non-Annex regions since this has been shown to be very effective at reducing the cost of climate stabilization (Sohngen 2010), and several hundred carbon sequestration policies are already underway in many developing countries (Peters-Stanley *et al* 2012). (Other policy options are explored in the SOM available at stacks. iop.org/ERL/8/035009/mmedia.)

3. Results

3.1. Annex-I-only mitigation policy

In order to understand the poverty impacts of global climate change mitigation policies, we must first examine the macro-economic effects. The effects of policies implemented in developed countries will be transmitted to developing countries through world markets. An important element of the Annex I climate policy suite is the Annex I fossil fuel tax. This type of tax has been widely studied over the past two decades, and the broad effects are well understood. By sharply reducing consumption of petroleum and coal in the Annex I economies, the main international impact of this tax is to reduce the world price of fossil fuels. Therefore, regions that are net exporters of fossil fuels are expected to lose, while net importers will

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[1] We explore alternative tax replacement rules in sections 5.3 and 5.4 of the SOM (available at stacks.iop.org/ERL/8/035009/mmedia).

[2] We follow Hertel *et al* (2009) in employing a macro-economic closure which fixes government spending, tax revenue, net national saving, the trade balance, and, by implication, transfer payments, all relative to net national income. This avoids changes in poverty due to spurious macro-economic effects.

[3] When we discuss the impact on economy-wide factor returns, however, we interpret a negative SC to mean a decline in the factor returns to the household. Interpretation of the magnitude of the SC value does not change.

[4] Under the United Nations Framework Convention on Climate Change (UNFCCC), non-Annex I countries have no mitigation obligations and Annex II regions are expected to finance the mitigation activities that non-Annex I regions might undertake.

[5] Table A8.2 of the SOM (available at stacks.iop.org/ERL/8/035009/mmedia) presents regional classification of the countries in our model. Annex II is Annex I without Russia.
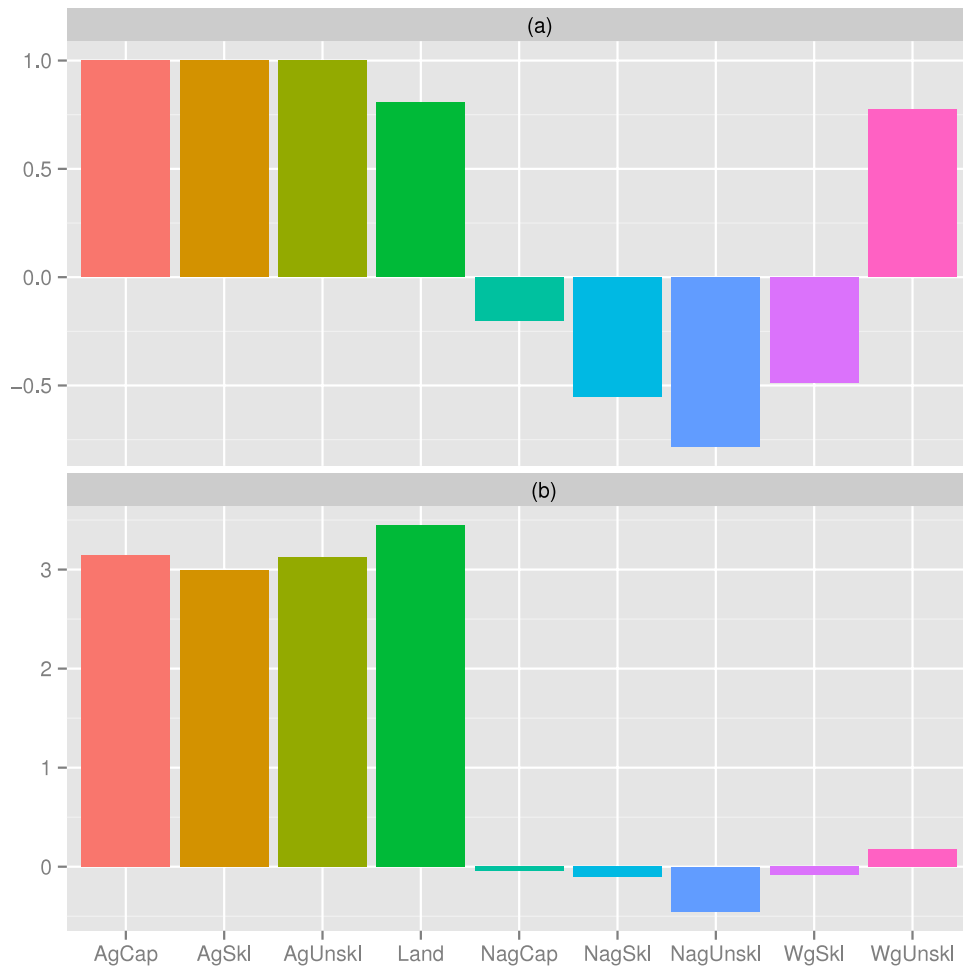
Figure 1. Drivers of changes in earnings from the Annex-I-only policy scenario. Definition of sources of income is as follows: AgCap = agricultural capital, AgSkl = skilled labor self-employed in agriculture, AgUnskl = unskilled labor self-employed in agriculture, Land = agricultural land, NagCap = non-agricultural capital, NagSkl = skilled labor self-employed in non-agriculture, WgSkl = skilled wage labor, WgUnskl = unskilled wage labor. (a) Sign consistency (SC). (b) Average absolute value (AAV).

gain. In the case of our poverty sample, the net oil exporting countries like Mexico, Columbia, Venezuela and Indonesia suffer significant losses in export revenues, while the net fossil fuel importing countries benefit from the lower world prices[6]. In addition, since energy is a critical input into manufacturing, higher energy prices boost industrial costs and reduce the competitiveness of Annex I countries in world markets. This benefits non-Annex I countries generally, as they gain market share globally.

There has been less extensive analysis of the tax on other GHG emissions in Annex I countries, in part due to the fact that the bulk of these emissions come from the farm sector (Baumert *et al* 2009) and this sector has received less attention in past studies of climate change mitigation policy. However, when the carbon tax is extended to methane and nitrous oxide emissions, and forest carbon sequestration incentives are added to this mix, the Annex I climate policy leads to a substantial decline in domestic output and agricultural export volume from Annex I countries, thereby leading to a rise in the

world price of these products. Non-Annex I net exporters of agricultural commodities stand to benefit. For example, since Brazil is a net exporter of agricultural commodities while Mexico is a net importer vis-à-vis the Annex I region (most notably NAFTA), Brazil benefits while the opposite is true for Mexico. Malawi and Vietnam also benefit from the higher agricultural prices, while Venezuela and Mozambique lose from this component of the Annex I climate change mitigation policy[7].

Following the logic of equation (1), we proceed to analyze the poverty impacts of the Annex-I-only policy by focusing on the sign consistency and average absolute value of the changes in real, after-tax income, by earnings source. These are reported in figure 1, with SC in the top panel (1a) and AAV in the lower panel (1b). From the SC results reported in figure 1(a), we note that the Annex I climate change mitigation policy leads to an increase in real, after-tax returns to factors employed in the agricultural sectors of the developing countries. This is because the combination of the
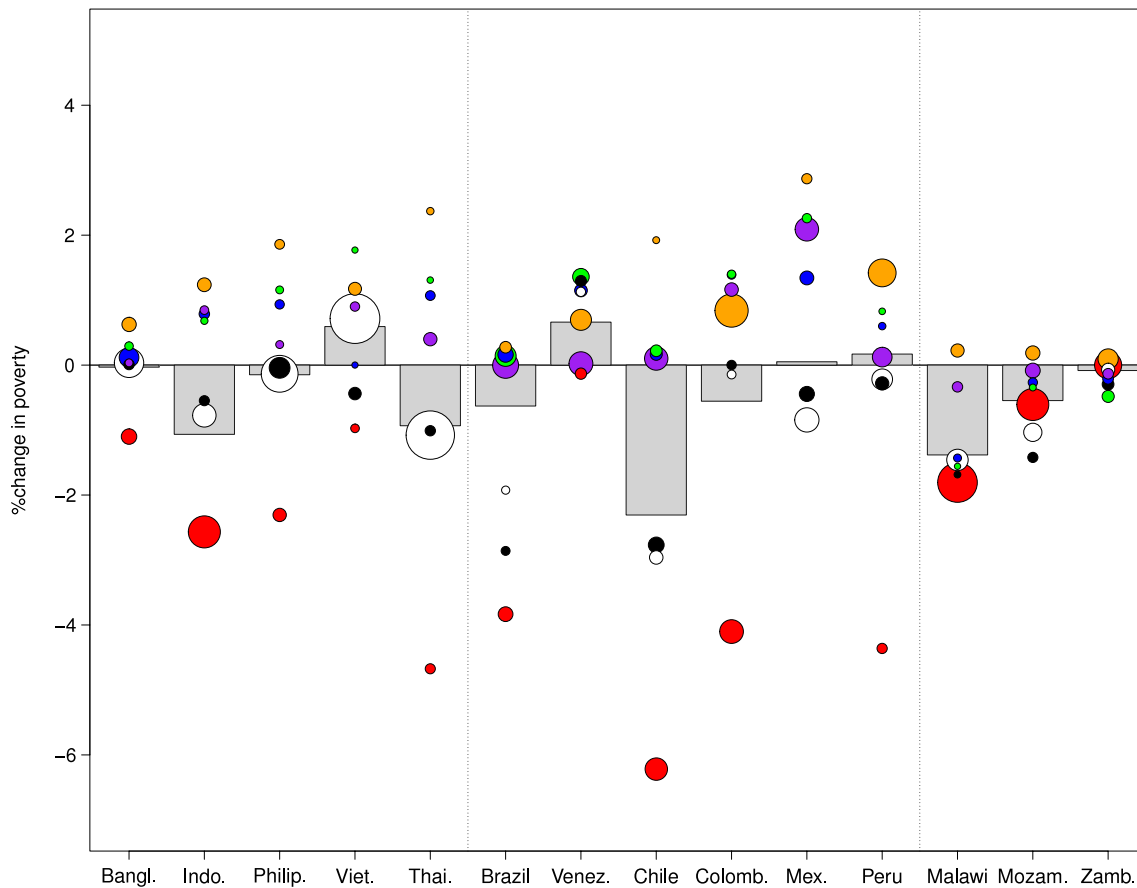
Figure 2. Poverty headcount changes (%) following Annex-I-only policy. Negative numbers imply reductions in poverty. The gray bars represent total poverty impact. Bubbles represent effects in individual stratum, with red = agriculture, orange = non-agriculture, green = urban labor, blue = rural labor, purple = transfer dependent, black = urban diversified, white = rural diversified. Note also that the bubbles are scaled by the proportion of a country's poor living in that stratum.

taxes on methane and nitrous oxide and the forest carbon incentive raise crop and livestock production costs in the Annex I region. This shifts production towards the other sectors of the economy, which expand modestly, despite the effects of the fossil fuels tax. As a result, production and exports of agricultural commodities from Annex I decrease. The trade effect is such that developing countries find new opportunities in the international agricultural commodity markets. This leads to higher domestic output and increased demand for factors of production in the agricultural sector in the non-Annex I countries. Indeed, the values of SC = 1 for agricultural labor and capital suggest that this effect is dominant in all of the sample countries. Economy-wide unskilled wages also rise in nearly all cases, lending further impetus to poverty reduction. Not surprisingly, real, after-tax returns fall for some earnings categories in some countries, as resources are drawn away from non-agricultural activities. This is reflected in the negative SC for the three categories of non-agricultural, self-employed earnings as well as for skilled labor.

In addition to the sign of the earnings impacts of Annex I climate change mitigation policies in our sample of poverty countries, it is important to also examine the magnitude of these effects. This is captured by the AAV statistic reported in figure 1(b). This shows that the impact of the policy on agricultural factor returns and land is dominant. The absolute

size of the impact on non-agricultural factor returns and economy-wide wages is much smaller, so that the earnings driven poverty impacts from the Annex I policy will be stronger in the strata where income from factors employed in the agricultural sector are relatively more important.

We are now in a position to assess the national poverty impacts of the Annex I policy package (figure 2). The net change in national poverty (gray bar in figure 2) depends on the stratum changes, weighted by the contribution of each stratum to overall poverty and summed over all strata as in equation (1). This poverty share (β_{rs}) is denoted by the area of each circle in figure 2. As can be seen by the relative areas, in most regions, the agriculture dependent (red circles) and rural diversified (white circles) strata tend to contain a large share of the poor, so what happens to these strata will have a bigger impact on the overall national poverty changes than the urban wage labor households which tend to contribute a much smaller share to national poverty. In every region, poverty falls in the agricultural stratum (SC = −1.0). And it also falls in most of the rural diversified (SC = −0.7) and urban diversified households (SC = −0.8). Given the predominance of these households in national poverty, we find that poverty declines in ten out of the 14 focus countries (SC = −0.7).[8]

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[8] See tables A4.10 and A4.11 of the SOM for details (available at stacks.iop. org/ERL/8/035009/mmedia).

In summary, when Annex I countries undertake comprehensive climate change mitigation policies, inclusive of non-CO_2 mitigation and forest carbon sequestration incentive payments, the agricultural sector in developing countries expands, thereby boosting earnings in agriculture, as well as for unskilled wage labor. This, in turn, reduces poverty in most of the sample countries. However, the mechanism behind this poverty reduction also directs attention to the biggest complaint which Annex I nations have to this kind of 'go-it-alone' climate policy—namely emissions leakage. Agricultural production in the developing countries is generally more emissions intensive (Avetisyan *et al* 2011), so any policy that shifts production from the rich to the poor countries has the potential to raise emissions, as opposed to lowering them. Of course the migration of production is not complete, and leakage rates are generally much less than 100%. In their analysis of the experiment considered above, Golub *et al* (2012) find that there is a 35% leakage rate in livestock, and 25% for the overall agricultural sector, when Annex I countries pursue mitigation policies in the absence of developing country participation. Interestingly, those authors find that, when the Annex I policies are combined with carbon sequestration incentives in the non-Annex regions, such leakage is eliminated. The reason for this is that the sequestration incentives generate a competing use for land, which raises costs for agricultural production, thereby eliminating the incentive to expand in the wake of Annex I mitigation policies. For this reason, it is particularly interesting to pair the Annex I policies with carbon sequestration incentives in the developing countries.

3.2. Adding a non-Annex I forest carbon sequestration incentive to the Annex I policy

We now implement, alongside the Annex I mitigation policies, a forest carbon sequestration incentive of equal value ($27/$tCO_2$) in the non-Annex regions. This proves to be quite effective in reducing global GHG emissions. In our analysis, non-Annex I forest carbon sequestration delivers 51% of the 7.8 $GtCO_2eq$[9] annual emissions reductions at the $27/$tCO_2eq$ carbon price. Most of this is avoided deforestation in the tropics. This is an indication of the great mitigation potential of such a policy, and this highlights why the REDD+ policies have received so much attention recently. The production, consumption, and price changes from policies that alter land use may turn out to be non-trivial. For example, Popp *et al* (2011) use a coupled dynamic land use energy–climate–economy model and show that restricting land use for bioenergy conversion can lead to substantial rise in food prices in Africa (82%) and Latin America (73%) by the year 2095.

As specified under UNFCCC guidelines, this incentive is paid for by Annex II regions and the financial transfer a non-Annex I country receives depends on the level of abatement attained under the policy. For countries in Africa

and Latin America, the transfer from Annex II regions is substantial, as there is a great deal of abatement potential at the subsidy rate of $27/$tCO_2$. For example, the associated transfer amounts to about 4% of national income in Brazil and Colombia, and about 6% for Malawi. Such a large inflow of transfers is expected to lead to an appreciation of the real exchange rate, drawing labor and capital out of the tradable sectors and raising export prices relative to import prices (Pearson 2011)[10]. Indeed, with the exception of Mozambique, Chile and Bangladesh all focus countries experience a real appreciation. And the countries that receive the largest proportionate subsidy experience the highest appreciation in their real exchange rate[11].

Figure 3 reports our summary statistics for the impact of the non-Annex I sequestration subsidy on real, after-tax factor returns. The first order impact of the sequestration subsidy is to lower the cost of land used in forestry and increase the return to land owners, bidding land away from other uses. As a result, land devoted to forestry increases, while land available to agricultural activities declines, leading to reduced farm output. This strong, new source of demand for land bids up the real returns to land, which increase sharply in all 14 countries (SC = 1—see figure 3(a)). The relative returns to other factors of production decline. The AAV statistics (figure 3(b)) indicate the magnitude of the policy impact is felt most strongly in the returns to land[12]. Meanwhile, higher food prices raise the cost of living for households at the poverty line ($\hat{C}_r^p > 0$) as these households spend a disproportionate share of their income on food. This rise in the cost of living for the poor, in turn, lowers the deflated returns to all other factors of production (recall equation (1)). Indeed, for the non-agricultural factors, this outcome is universal across all sample countries (SC = −1.0).

The poverty impacts by stratum for the experiment including forest carbon sequestration incentive in the non-Annex regions are reported in the bubble graph in figure 4. Here, we see that, rather than lowering poverty in the rural strata, the favorable impacts of Annex I mitigation are now dominated by the poverty increasing nature of the forest carbon sequestration incentive. The reason is that the poor are poor because they generally do not own many assets. So, while the strong increase in real, after-tax land rents benefits rural households in general, it does little to benefit the poor in rural areas, who rely much more heavily on their own labor for income. There are some exceptions in countries where earnings from land represent a larger share of income for households at the poverty line in the agricultural stratum, including Chile (23% of total income) and Philippines (65% share of total income). Rural and urban diversified households

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[9] See table A1.1 of the SOM (available at stacks.iop.org/ERL/8/035009/mmedia) for detailed results of this paragraph.

[10] To ascertain the impact of the resource inflow associated with the third component, we run a separate experiment whereby the model was shocked by an amount that is equal to the sequestration subsidy non-Annex I region received. There is no mitigation activity associated with this simulation. See part III of the SOM for the discussion on the TOT effects from this separate exercise (available at stacks.iop.org/ERL/8/035009/mmedia).

[11] Table A3.2 of the SOM (available at stacks.iop.org/ERL/8/035009/mmedia).

[12] Indeed, the AAV value for land reported in figure 3(b) has been truncated to allow the other values to be visible. Its value in this experiment is 184!
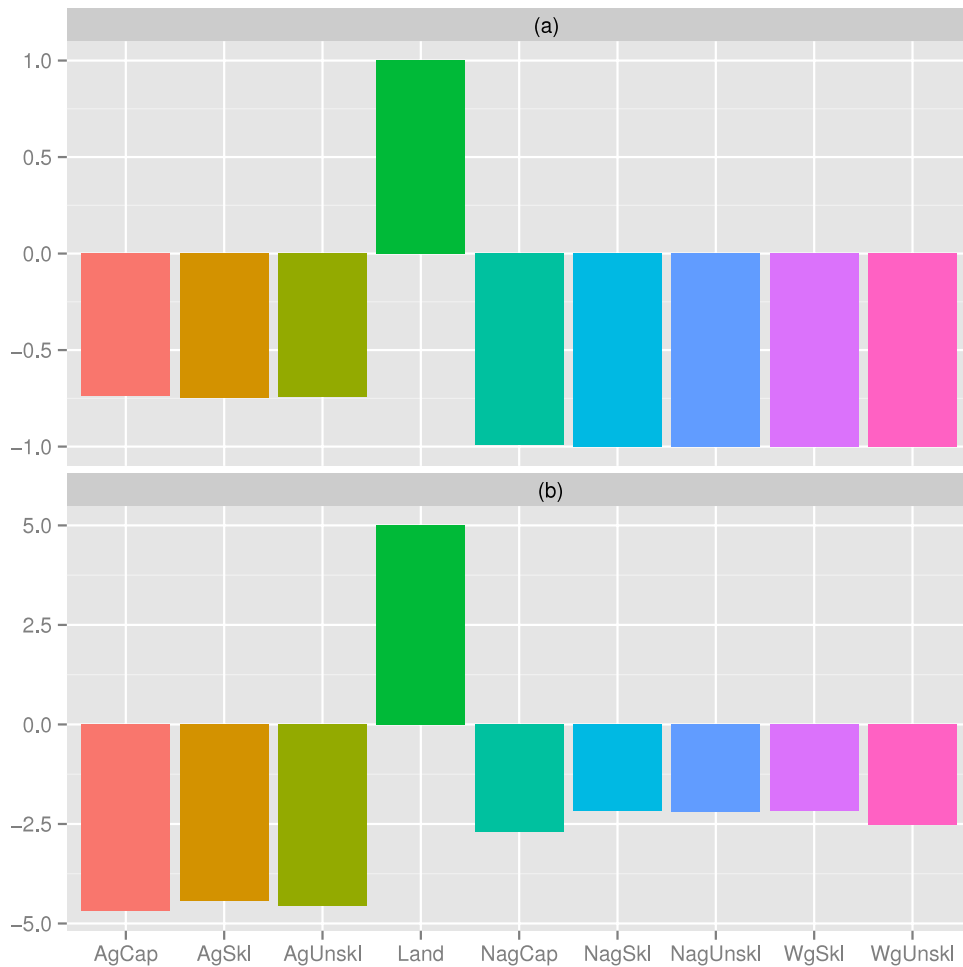
Figure 3. Drivers of changes in earnings from Annex I policies plus non-Annex I forest carbon sequestration incentive. Definition of sources of income is as follows: AgCap = agricultural capital, AgSkl = skilled labor self-employed in agriculture, AgUnskl = unskilled labor self-employed in agriculture, Land = agricultural land, NagCap = non-agricultural capital, NagSkl = skilled labor self-employed in non-agriculture, WgSkl = skilled wage labor, WgUnskl = unskilled wage labor. Note that the AAV for land has been truncated at 5.0 for visual purposes. Its actual value is 184. (a) Sign consistency (SC). (b) Average absolute value (AAV).

also derive income from agricultural activities and the pattern of poverty reduction we see here is quite similar. However, the predominant impact of the lower real returns for non-land factors is to raise poverty across our sample of countries (SC = 0.4, AAV = 3.0). In table A6.1 of the SOM (available at stacks.iop.org/ERL/8/035009/mmedia), we report the 95% confidence interval of these estimates, taking into account uncertainty in key parameters. These results suggest that seven of the national poverty increases are robust to parameter uncertainty, as are three of the poverty decreases. The sign of the outcome is indeterminate in the remaining four cases.

We conclude this section by exploring a few individual country cases in more detail in order to highlight some important principles. The first of these is that gains at the macro-economic level do not necessarily translate into poverty reduction. Brazil illustrates this principle. It is a country which experiences a significant macro-economic improvement following the policy shock and yet poverty increases. The country is a net exporter of agricultural products, but also has huge potential to sequester carbon in forests. The latter leads to a financial transfer of about 4% of national income in the form of sequestration payments.

This financial inflow induces 'Dutch disease' wherein costs rise and domestic output in the tradable sectors contracts, with imports rising. This raises the cost of living for the poor, who do not participate significantly in the rise in earnings.

A second important principle is illustrated by the case of Chile. This highlights the importance of earnings shares in determining the overall poverty outcome. The income share from land is particularly important. Since this income share is imputed and not observed directly, this measure applies both to cases where the land is communally held and where it is privately owned[13]. In Chile, households at the poverty line in the self-employed agricultural stratum are estimated to derive about 23% their income from land, 44% from unskilled labor and the remaining from capital ownership. As presented above, the sequestration incentive, which dominates the overall result, increases land rents. This benefits the agricultural stratum, through their ownership of land, and

[13] More precisely, household returns to land and capital are obtained by deducting from farm household income imputed wages for farm labor. The latter are obtained by referring to the wage of market-employed individuals with similar educational attainment, gender, age, sector and geographic location.
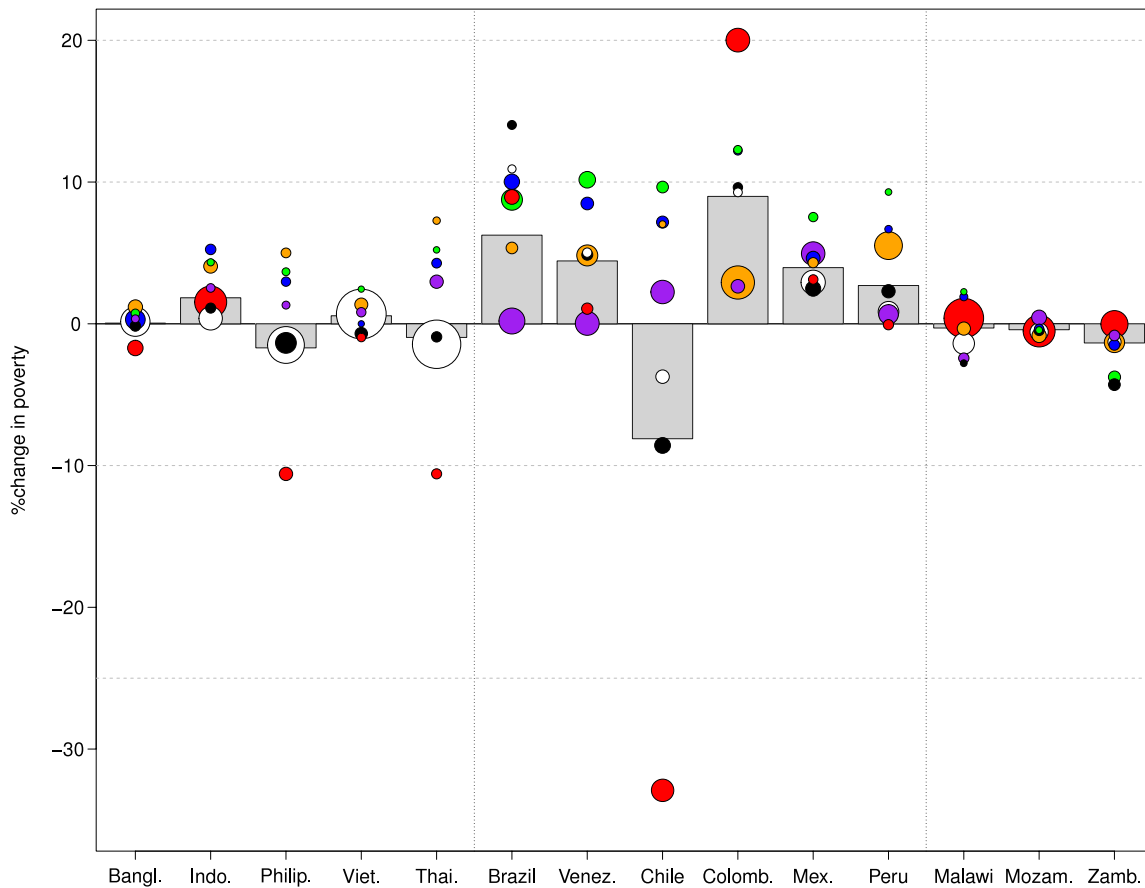
Figure 4. Poverty Headcount changes (%) from Annex I policies plus non-Annex I forest carbon sequestration incentive. Negative numbers imply reductions in poverty. The gray bars represent total poverty impact. Bubbles represent effects in individual stratum, with red = agriculture, orange = non-agriculture, green = urban labor, blue = rural labor, purple = transfer dependent, black = urban diversified, white = rural diversified. Note also that the bubbles are scaled by the proportion of a country's poor living in that stratum.

thereby helps to reduce poverty. The Chilean case shows that, for the carbon sequestration payments to reduce poverty, the income share from land for the poor households must be large.

4. Discussion and limitations

The policy scenarios we consider in this letter assume that the developing countries are passive participants in the global climate change mitigation policy, only participating to the extent that Annex II payments motivate forest carbon sequestration. This begs the question: what would be the poverty impact if there was global participation in the mitigation policy. Accordingly, we undertook another experiment whereby the carbon tax is imposed globally such that not only developed, but also developing countries mitigate their emissions. Unlike our second experiment (Annex I policies plus non-Annex I forest carbon sequestration incentive), developing countries do not get paid for the amount of sequestration they achieve and will have to finance the incentive payments from domestic sources, as is the case in the Annex I region. The result of this experiment is clear-cut: poverty increases strongly in all the 14 focus countries. Relatively high economic emissions factors in the developing countries make the carbon tax particularly costly for most sectors and the policy reduces domestic output

substantially, leading to declines in factor returns and rises in consumer prices[14].

Of course it is highly unlikely that most developing countries would participate in such a carbon tax. Therefore, we considered yet another experiment in which, like our second experiment, no developing country participates beyond the Annex II financed forest carbon sequestration incentive, however, now Annex I members respond by imposing carbon-based border tax adjustments (BTAs) to shield their economy from the associated loss of competitiveness. Once again, this alternative policy leads to greater poverty increases in the developing countries than in the core policy package. In the wake of the BTAs, the developing countries substantially reduce exports of agricultural commodities and other energy intensive products. This has the undesirable effect of reducing domestic production, which in turn affects factor returns negatively. As a result, poverty increases in 10 of the 14 focuses countries in our sample[15].

So far our analysis has said nothing about the dynamics of climate change, economy, and mitigation policy. While there

[14] See section 5.1 of the SOM for detailed results (available at stacks.iop.org/ERL/8/035009/mmedia).

[15] See section 5.2 of the SOM for detailed results (available at stacks.iop.org/ERL/8/035009/mmedia).

are many dynamic analyses of climate policy and the economy in general, when it comes to poverty impacts, the analysis is much more complicated. The reason is that it is very hard to predict how the patterns of poverty and associated income sources will change in the future. Modeling such dynamics is beyond the scope of this letter. However, we do undertake a simple robustness check in which we update the rural/urban composition of populations in our sample countries to reflect the greater share of the poor likely to reside in urban strata in 2030. When we redo our analysis of the second climate policy experiment with this new population profile, we find that poverty increases are even more prevalent, with the SC measure rising from 0.38 to 0.84. Chile, in particular shows the largest change wherein the poverty reduction changes from a 6% reduction to an increase of 0.3%, as the importance of the rural poor in national poverty diminishes[16].

This is one of the first studies to look at the poverty impacts of climate change mitigation policy at global scale, and as such it also suffers from significant limitations. Perhaps most important is the stylized nature of the policies examined here. In practice climate mitigation policies involve significant transactions costs, and monitoring outcomes is a challenge (Wollenberg *et al* 2012). Furthermore, in many countries climate policy is being implemented as a patchwork of regulations and standards which are not economically efficient in the way we have modeled them here. To the extent that such policies dictate the manner in which abatement is achieved, rather than leaving it for individual households and firms to decide on the method (as is the case with a tax on emissions), economic theory predicts that costs will rise more than shown here. We expect this to adversely affect all households on average—although the distributional impacts of such economic inefficiencies cannot be anticipated in advance. A further simplification is that we assume that the price of carbon is equalized across Annex I regions, as would be achieved in an international emissions trading scheme. However, the price of carbon currently varies greatly across regions, ranging from zero in the countries such that the United States, which has failed to implement a climate policy, to (until recently) prices comparable to those imposed in our analysis in the EU and Australia. The differential restrictiveness of climate policies across regions will also raise global mitigation costs. However, again the incidence of such differences is a matter for further analysis.

Another important limitation of our analysis derives from our characterization of household income. Here, we are constrained by the underlying household survey data which typically focus on market-based earnings. However, poor households in many developing countries rely heavily on naturally occurring consumption and production of goods which are not recorded by such surveys. These include: wild foods, medicines, construction materials, energy sources such as firewood, furnishings, etc. Indeed, where researchers have sought to measure the importance of these environmental goods, they have been shown to account for as much as

40% of household income in some of the poorest countries (Cavendish 2000). To the extent that an aggressive forest carbon sequestration policy enhances the ecosystem services upon which such households rely, it will be more beneficial than here portrayed. On the other hand, such policies may also limit the supply of fuel and wood products for household use, which could have the opposite effect. Another important consideration pertains to localities where land is communally owned. In such cases, low income households may participate directly in forest carbon sequestration. One such example is offered by the Juma Sustainable Development Reserve in the Brazilian Amazon, where households receive regular monthly payments on a debit card, provided aerial inspections do not turn up signs of deforestation in this communally owned area (The Economist, 24 September 2009). These payments offer a direct form of poverty reduction. However, to date such policies have only been implemented on a relatively small scale.

The final limitation which we would like to highlight is the modest sample of countries included in this study. Ideally, we would like to include every developing country in the world. Lacking that, we would like to have a representative sample of countries. Unfortunately, as previously noted, we are constrained by data availability on both the household survey side (surveys with full earnings detail are the exception rather than the rule) as well as on the economy-wide data side (GTAP). In future work, we hope to significantly increase the size of our country coverage.

5. Conclusions

Both climate change and the policy responses aimed at mitigating these impacts are fraught with uncertainties (Webster *et al* 2003). Of particular concern is the lack of systematic evidence about the impact of mitigation policy on the welfare of the poor in developing countries. This letter analyzes the poverty impacts of a comprehensive, economically efficient, climate mitigation policy with the following elements: (a) a fossil fuel tax in Annex I; (b) a tax on non-CO_2 emissions along with forest carbon sequestration incentive payments in Annex I countries, and (c) forest carbon sequestration incentive payments in non-Annex I regions. We first examine the impact of the Annex I policies alone, then add (c) to the mix. We find that the Annex-I-only policies, on balance, have a favorable poverty impact on our sample of countries, as they tend to result in the migration of production (particularly agriculture) to developing countries. However, it is this very threat of production shifting—and the associated emissions leakage—which has doomed Annex-I-only policies.

When these same Annex I policies are combined with the forest carbon sequestration subsidy, the leakage of emissions from agricultural production is eliminated. This follows from the stiff competition for land which results. But it is this very competition for land which also turns the mitigation policy package from poverty reducing to poverty increasing. This adverse result is due to the fact that the most important impacts of the non-Annex I forest carbon sequestration policy

[16] See section 5.5 of the SOM for detailed results (available at stacks.iop.org/ ERL/8/035009/mmedia). Tables A4.14 and A5.21 of the SOM present the SC values reported above.

are to raise returns to land, reduce agricultural output and raise food prices. Since poor households rely primarily on their own labor for income and generally control little land, and since they also spend a large share of their income on food, they are often hurt on both counts. This doesn't mean that the interests of the poor are ill served by climate mitigation. Many of these same households are likely to be disproportionately hurt by climate change as they are more exposed to climate change impacts and associated extreme events which are likely to increase in frequency and intensity in the future. As such, these same poor households stand to benefit disproportionately from the mitigation of such climatic change, particularly in the long run. However, for most poor households, the long run is an abstraction which they can ill-afford to contemplate, and those crafting climate change mitigation policies need to be aware of the potential adverse impacts on these households, designing policies to limit such negative effects.

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