Who should pay for the transition? Climate change, debt and inequalities in a demand-driven stock-flow consistent macrodynamic model

September 28, 2021

Abstract

There is a widespread agreement within the literature that climate change mitigation policies will worsen existing inequality issues. To address this issue, propositions have arisen regarding the recycling of carbon tax revenues through transfers aimed at mitigating the regressive impact of carbon pricing on the most vulnerable. However, a limit of this literature is that it often fails to consider the macroeconomic impact of redistributive policies. How and to whom carbon tax receipts are redistributed will affect consumption and investment patterns, thus retro-feedbacking on the macroeconomy. Building a demand-driven stock-flow-consistent macroeconomic model of global warming, this paper fills this gap by looking at how different carbon tax redistribution policies affect the achievement of the three key policy goals of climate change mitigation, financial stability and equality. Our key finding is the existence of a trade-off between redistributing to households and handling subsidies to low-carbon technologies in achieving our three joint goals. Tax recycling to households not only reduces inequality but also improves financial stability, although it increases aggregate demand and therefore emissions. Low-carbon subsidies, by contrast, results in lower carbon emissions, but at the cost of higher income inequalities and financial instability.

1 Introduction

There are strong interconnections between climate change mitigation and inequalities. It is now widely acknowledged that global warming will affect more severely the poorest segments of the population (Burke et al., 2015; IPCC, 2019). In addition, policies aimed at mitigating climate change are also likely to worsen poverty and inequality issues. In particular, there is a large empirical literature which highlights how carbon pricing, the most commonly considered policy instrument to tackle global warming, would disproportionately impact poor households (Callan et al., 2009; Dennig et al., 2015; Fremstad and Paul, 2019; Malerba et al., 2021; Mathur and Morris, 2014; Saelim, 2019; Zachmann et al., 2018). In order to dampen the regressive impact of carbon taxation, a solution would be to recycle the carbon tax receipts into a lump-sum dividend directed towards low income households. However, this proposition has not yet reached a consensus within the literature, as some authors rather suggest to use the carbon tax income to finance environmental policies in order to accelerate the transition (Baranzini et al., 2017).

The main argument in favor of a carbon tax income redistribution towards poor households is that achieving equality and eradicating poverty are by themselves essential policy goals. In addition, some authors highlight how an excessively regressive environmental policy might be considered as unfair by the most affected citizens, thus raising the issue of the political acceptability of the policy (Fay et al., 2015). Opponents rather argue that the carbon tax income could be a useful source of incomes to finance research and development in low carbon technologies, or to subsidize green economic sectors such as public transportation (Fremstad and Paul, 2019). Another argument against a progressive carbon tax relates to the risk of a rebound effect: by increasing households' purchasing power, direct transfers might increase consumption and hence total carbon emissions. However, we argue in this paper that a limit of this literature is that it often fails to consider the macroeconomic consequences of carbon tax recycling policies. How and to whom carbon tax receipts are redistributed will affect consumption and investment patterns, thus retro-feedbacking on the macroeconomy, and having consequences that go beyond the issue of inequalities and climate change mitigation.

To bridge this gap, we build in this paper a demand-driven stock-flow-consistent macroeconomic model of global warming in continuous time that endogenously represents the interconnections and feedback effects between income distribution, global warming and financial instability. The model is built on the Coping with the collapse model introduced in Bovari et al. (2018). This model has the interesting property of having multiple locally stable equilibria, including a "collapse" equilibrium characterized by infinite debt accumulation, high deflation, and falling output, employment and wages. This framework thus permits to study how different parameters can increase or reduce the probability that the economy successfully overcome the challenge of climate change, or rather fails and set on a path towards the collapse equilibrium. In order to correctly represent the impact of carbon tax recycling policies on macroeconomic and financial variables, our key contribution is to turn the supply-side framework of the original model into a demand-driven model. To do so, we add a disequilibrium goods market with inventory management where firms adjust their production to aggregate demand. In addition, we introduce the possibility of inflationary tensions arising on the goods market when the economy is pushed towards full capacity utilization by excess demand or if climate damages disrupt production. Finally, we add the possibility for workers to oppose to income losses in order to represent the political opposition to regressive environmental polices.

Simulations are performed to look at how different carbon tax redistribution policies affect the achievement of the three key policy goals of climate change mitigation, financial stability and equality and poverty. Our key finding is the existence of a trade-off between redistributing to households and handling subsidies to low-carbon technologies in achieving our three joint goals. Tax recycling to households not only reduces inequality but also improves financial stability, although it increases aggregate demand and therefore emissions. Low-carbon subsidies, by contrast, results in lower carbon emissions, but increase corporate debt and worsen income distribution in the medium run. However, robustness checks indicate that this result might not always hold, and that it is strongly dependent on the intensity of climate damages and the sensitivity of the economy to changes in demand conditions.

2 The Model

We build a continuous time IAM that presents the cross interactions between economic and climate dynamics. The macroeconomic model is introduced in subsection 2.1. It is composed of four main aggregated sectors: firms, banks, capitalists and workers. We assume the economy produces a single good which is used for both consumption and investment purposes. The climate model is presented in subsection 2.2, while subsection 2.3 shows how the two models are connected. We do not explicitely model the government sector, although we assume the core interest rate follows a Taylor rule, and the government handles the redistribution of the carbon tax income.

We use the following notations: Let x be a variable, $\dot{x} = \frac{dx}{dt}$ is the time derivative of x, and $\hat{x} = \frac{\dot{x}}{x}$ is its growth rate. If X is a nominal (respectively real) aggregate variable, then x stands for the ratio of X to nominal (respectively real) capital: $x = \frac{X}{pK}$ (respectively $x = \frac{X}{K}$)).

2.1 The Macroeconomic Module

2.1.1 Output

Firms produce using a Leontieff production function combining labor E and capital K with a (constant) capital-to-output ratio ν and (endogenous) labor productivity α. We assume that capital is abundant compared to employment:

$$Y_g^p = min(\alpha E,\ \frac{K}{\nu}) = \alpha E. \tag{1}$$

In order to reduce carbon tax payments, firms use a share A of their gross output Y_g^p to finance abatement efforts that reduce their CO2-e emissions per unit of output. In addition, a fraction D^y of the remaining output is destroyed by climate damages. Output net of damages and abatement costs Y_n^p, namely output available for sales or inventory accumulation, is given by:

$$Y_n^p = (1 - A)(1 - D^y)Y_g^p. \tag{2}$$

2.1.2 Inventory dynamic and production decision

As in Franke (1996), we assume a disequilibrium goods market where inventories N absorb the discrepancy between net supply Y_n^p and aggregate demand Y^d. In addition, inventories depreciate at a constant rate δ^N. Firms have a target inventory level N^T defined as a fraction of their normal output $Y^N = u^N \frac{K}{\nu}$, with u^N the (constant) normal rate of utilization. In order to reach their target inventory level, firms try to produce more than (expected) demand. They have a desired supplementary output J^T, defined as the output sufficient to compensate for inventory depreciation, plus a fraction of the discrepancy between their realized and target inventory. Firms have a desired sales level defined by their net output minus desired supplementary output. Firms adjust their gross output Y_g^p following a double adjustment process that depends on growth anticipations and the discrepancy between their realized and target sales

$$\dot{Y_g^p} = g_k Y_g^p + \beta(S - S^T). \tag{3}$$

2.1.3 Pricing

Firms have a target price level defined as a markup m over unit costs c. Due to price stickiness, realized prices adjust towards this desired level with a relaxation time $1/\eta$, so that inflation is defined by:

$$\hat{p} = \eta(mc - 1). \tag{4}$$

Equation 3 is fully in line with the Post-Keynesian view that output is primarily determined by demand, although some minor deviations can arise due to firms' inventory management decisions and/or the sluggishness of production adjustment. However, this does not mean that supply conditions do not matter. In particular, global warming will put a significant pressure on the supply side. On the one hand, firms' abatement efforts will mobilize a significant share of available resources, while carbon tax recycling policies will increase demand. On the other hand, climate damages on output and capital will reduce the economy's productive capacity. As a result, the economy is likely to approach from its maximum productive capacity within the end of the century, which would cause inflationary tensions due to (a fear of) a shortage of supply on the good market. To model this effect, we follow Rowthorn (1977) or Seppecher et al. (2018) and assume an endogenous markup that positively depends on demand conditions.

$$m = m_0 + m_1(u - u_0), \tag{5}$$

Where u is the rate of utilization of capital,

$$u = \frac{Y_g^p}{Y_g^{max}} = \frac{\nu Y_g^p}{K}, \tag{6}$$

with Y_g^{max} the economy's potential production.

2.1.4 investment and profits

Economic production causes industrial emissions of CO2 E_{ind}. Firms have to pay a real tax p_c for each ton of CO2-e they emit, so that the total nominal carbon tax flow is:

$$T_c = p.p_c E_{ind}. \tag{7}$$

Firms' profits Π are the difference between their nominal income, namely realized sales pY^d, and their expenditures that are the wage bill wE, interest payments on debt $i_d D$ and payment of the carbon tax net of government transfers $T_c - G_f$

$$\Pi = pY^d - \{wE + i_d D + T_c - G_f\}. \tag{8}$$

Firms distribute a share s_f of their profits to capitalists as dividends Div_f, so that their undistributed gross profits are:

$$\Pi_u = s_f \Pi. \tag{9}$$

Firms draw expectations of their future profits Π^e by assuming that aggregate demand will be equal to their target sales

$$\Pi^e = pS^T - \{wE + i_d D + T_c - G_f\}, \tag{10}$$

$$r^e = \frac{\Pi^e}{pK}. \tag{11}$$

Firms' investment is a linear function of their expected profit rate net of inflation, utilization rate and debt to capital ratio d

$$I = K.(\mu_0 + \mu_1(r^e - \hat{p} + \mu_2 u - \mu_3 d). \tag{12}$$

Firms finance their investments in excess of internal capacities by borrowing to the banking sector. Contrarily to Bovari et al. (2020), we assume that there is no credit rationing. However, we include the possibility for firms to default on their debt at a rate τ_D that depends on their debt-to-capital ratio d

$$\dot{D} = pI - \Pi_u - \tau_D D, \tag{13}$$

2.1.5 The banking sector

Banks provide credit to firms on demand. To limit solvency risks, they wish to keep a precautionary cushion of own funds OF_b^T, defined as a fraction μ_b of their lending. Banks profits Π_b are defined by firms' interest payments on corporate debt, with i_d the nominal interest rate. Banks retain a fraction of their profit Π_b^u, which depends on the mismatch between their realized and target own funds, and distribute the rest as dividends Div_b. Their realized own funds OF_b are determined by the discrepancy between losses incurred by debt default and their retained earnings.

The central bank sets the core interest rate following a Taylor rule; private banks define their target interest rate as an endogenous markup on the core rate, and the real rate adjusts linearly towards the target:

$$i_{cb} = max(0, r^* + \hat{p} + \phi(\hat{p} - infl^T), \tag{14}$$

$$i_d^T = i_{cb} + \lambda_{i_d^T} \frac{OF_b - OF_b^T}{OF_b^T}, \tag{15}$$

$$\dot{i}_d = \lambda_{i_d}(i_d^T - i_d), \tag{16}$$

with r^* and $infl^T$ the central bank's targeted real interest and inflation rates.

2.1.6 Households and the labor market

Following Coping With the Collapse Bovari et al. (2018), The world workforce POP grows at a rate defined by a sigmoïd function

$$\gamma(POP) = \hat{POP} = q(1 - \frac{POP}{P^{POP}}), \tag{17}$$

where P^{POP} is the upper bound of the world's labor force and q is the speed of convergence.

We define the employment rate e and workers' share of gross and net output u_w^g and y_w as follows:

$$e = \frac{E}{POP}, \tag{18}$$

$$y_w^g = \omega + \frac{g_h \nu}{u}, \tag{19}$$

$$y_w = \frac{y_w^g}{1 - D^y}, \tag{20}$$

where g_h is the ratio of carbon tax receipts redistributed to workers (G_w) to capital stock

$$g_w = \frac{G_w}{pK}. \tag{21}$$

Workers exchange their labor for a nominal wage w, which is determined following a Goodwinian process depending on employment, prices and past historical workers' incomes. We assume workers do not save, so that their consumption C_w is equal to their available income. Capitalists' incomes are the sum of dividend payments by firms and banks. Capitalists save a fraction s_c of this income and use the rest to finance their consumption expenditures C_c:

2.2 The Climate Module

We use the same climate module as the one in coping with the collapse (Bovari et al. (2018)), which is mostly an adaptation to continuous time of the framework proposed in Nordhaus (2018).

The carbon cycle is described using a three layers model: the atmosphere (AT), the upper ocean and the biosphere (UP) and the deep ocean (LO). Carbon emissions E are released in the atmosphere, and the three layers can exchange carbon, so that CO2 accumulation in the three layers evolve according to

$$\begin{pmatrix} \dot{CO_2}^{AT} \\ \dot{CO_2}^{UP} \\ \dot{CO_2}^{LO} \end{pmatrix} = \begin{pmatrix} E \\ 0 \\ 0 \end{pmatrix} + \phi \begin{pmatrix} CO_2{}^{AT} \\ CO_2{}^{UP} \\ CO_2{}^{LO} \end{pmatrix}, \tag{22}$$

$$\phi = \begin{pmatrix} -\phi_{12} & \phi_{12} C_{UP}^{AT} & 0 \\ \phi_{12} & -\phi_{12} C_{UP}^{AT} - \phi_{23} & \phi_{23} C_{LO}^{UP} \\ 0 & \phi 23 & -\phi_{23} C_{LO}^{UP} \end{pmatrix}. \tag{23}$$

CO2-e accumulation in the atmosphere modifies its chemical properties and thus its ability to accumulate heat, triggering a rise in the radiative forcing of the atmosphere F. A distinction is made between the residual forcing F_{exo} and forcing caused by CO2-e emissions F_{ind}:

$$F = F_{ind} + F_{exo}, \tag{24}$$

$$F_{ind} = \frac{F_{2xCO2}}{log(2)} log(\frac{CO_2^{AT}}{C_{AT_{pind}}}). \tag{25}$$

Temperature dynamics is modeled by a two layer system, the first layer corresponds to the atmosphere, land and the upper ocean, that have a temperature T, and the second one is the lower ocean, that has a temperature T_0. The first layer is heated up by the radiative forcing F, looses heat due to radiations ρT, and exchanges heat with the lower ocean, with γ_T the heat exchange coefficient between the two layers. C and C_0 are the respective heat capacities of the two layers.

$$C\dot{T} = F - \rho T - \gamma_T(T - T_0), \tag{26}$$

$$C_0\dot{T}_0 = \gamma(T - T_0). \tag{27}$$

2.3 Connecting the two modules: Damages and Mitigation

2.3.1 Carbon emissions

Total CO2-e emissions, E_{tot} are the sum of emissions caused by industrial production E_{ind} and land-use E_{land}. Land-use emissions decrease at an exogenous rate $\delta^{land} < 0$

$$E = E_{ind} + E_{land}, \tag{28}$$

$$\hat{E}_{land} = \delta^{land}. \tag{29}$$

Industrial emissions depends on gross output Y_g^p, the emission intensity of the economy σ_1 and the emission reduction rate σ_2. The emission intensity of the economy decreases at an exogenous rate g_sigma_1 that evolves following equation (32). The emission reduction rate depends on firms abatement efforts A, that we define below

$$E_{ind} = Y_g^p \sigma_1(1 - \sigma_2), \tag{30}$$

$$\hat{\sigma}_1 = g_{\sigma_1}, \tag{31}$$

$$\hat{g}_{\sigma_1} = \delta_{\sigma_1}. \tag{32}$$

2.3.2 Environmental Damages

The damages function represents the total impact of global warming on the economy, and is defined as a non linear function of atmospheric temperature deviation T. Total damages D are distributed as either damages on capital D_k or on output D_y

$$\begin{cases} D = 1 - \frac{1}{1+\pi_1 T + \pi_2 T^2 + \pi_3 T^\zeta} \\ D_k = f_k D_k \\ D_y = 1 - \frac{1-D}{1-D_k} \end{cases}.$$

2.3.3 Carbon tax and emissions reduction

The carbon price p_c is set exogenously and increases through time at a steady growth rate δ_{p_c}

$$\hat{p}_c = \delta_{p_c} > 0. \tag{33}$$

The backstop technology, which allows firms to reduce their CO2 emissions, is available at an exogenously decreasing price p_{bs}:

$$\hat{p}_{bs} = \delta_{bs} < 0. \tag{34}$$

The government finances a fraction s_a of all abatement efforts by firms through a subsidy. Firms decide of their emission reduction rate σ_2 based on an arbitrage between the carbon price and the price of the backstop technology (net of government subsidies). The emission reduction rate, the price of the backstop technology and the emission intensity σ_1 define the abatement efforts necessary to reach the desired emission reduction rate, represented by the share of output A that they consume:

$$\sigma_2 = min((\frac{p_c}{(1-s_A)p_{bs}})^{\frac{1}{\theta-1}}, 1), \tag{35}$$

$$A = \frac{\sigma_1 p_{bs}}{\theta} {\sigma_2}^{\theta}, \tag{36}$$

where θ is a parameter controlling the convexity of the cost. Note that when the carbon price is equal to the price of the backstop technology, $\sigma_2 = 1$ and we have a completely green economy with zero industrial emissions. In practice, the carbon price stops increasing as soon as it reaches the price of the backstop technology.

Governments' total carbon tax receipts are defined as $T_c = p.p_c E_{ind}$. The government can save a fraction of the carbon tax income, redistribute it to workers through, use it to finance a green subsidy on abatement efforts, or redistribute it to firms as an unconditional transfer.

3 main results

3.1 Calibration and scenarios

Whenever possible, we used the calibration of the original Coping with the Collapse model (Bovari et al. (2018, 2020)). In addition, we performed a partial model calibration on a steady state[1]. Regarding the climate module, we also used the calibration from Coping with the Collapse, which is mostly an adaptation to continuous time of the framework developed in Nordhaus (2018).

To account for the uncertainties regarding the precise materialization of climate damages, we consider three major climate scenario that correspond to different curvatures of the damage function. The "low" climate scenario corresponds to Nordhaus-type climate damages (Nordhaus (2007)). The "medium" scenario uses a slightly more convex damage function following Weitzman (2012). Finally, the "high" damages case uses the calibration from Dietz and Stern (2015), with even higher climate damages for high temperatures. In addition, for each scenario, we consider a case where damages are allocated to output only ($f_k = 0$), and a case where they affect both output and capital ($f_k = 1/3$).

Another source of uncertainties relates to the carbon tax pass through. Most of the empirical literature estimates the pass through for specific economic sectors, such as for instance electricity (Dagoumas and Polemis (2020);

[1] More precisely, we calibrate firms' retention ratio s_f, capitalists' propensity to save s_c, the constant term of the investment function μ_0 and the constant term of the Phillips' curve ω_{e_0}. The calibration was obtained by solving a distance-minimization problem with a covariance matrix adaptation evolution strategy (CMA-ES).

Fabra and Reguant (2014); Nazifi et al. (2021)) or cement (Miller et al. (2017)). These papers find a full or almost full pass through (i.e. $pt = 1$). However, the pass through might differ for other sectors. Indeed, in Ganapati et al. (2017)), the authors estimate energy cost pass through for six different economic sectors and find highly variegated results, as consumers can bear between 50% and 100% of the cost. To account for these uncertainties, we consider three cases: a full pass through case $pt = 100\%$, a low pass through case $pt = 50\%$ and a medium case $pt = 75\%$[2].

Simulations are performed over the time period 2015-2100. Because we are interested in the impact of carbon tax recycling policies, we use an initially high carbon price $p_c(t = 2015) = US\$50t/CO_2$. Different growth rates of the carbon price are considered, with values ranging from 0 to 10%. For the baseline, we use $g_{p_c} = 6.33\%$, which is the rate that leads to net zero GhG emissions in 2050. We test three major different policy scenarios regarding carbon tax incomes redistribution. (i) a *workers redistribution scenario*, where the carbon tax is recycled through direct transfers to workers in order to alleviate the regressive impact of carbon taxation on the poorest segments of the population. (ii) a *firms subsidy scenario*, where the government uses the carbon tax receipts to finance a green subsidy, thus encouraging firms to increase their abatement efforts. (iii) a *firms redistribution scenario*, where the government fully redistributes the carbon tax income to the firms sector through unconditional transfers. In this case, government transfers directly increase firms' profits but have no direct impact on abatement efforts.

3.2 Transitional dynamics

We begin our analysis by drawing the trajectory of the economy for the three redistributive scenarios. Results are presented in 3.2. Note that there is a break in the curves in 2050, which is caused by the achievement of net zero GhG emissions. Beyond this date, carbon tax incomes are equal to zero and the different redistributive flows vanish as well.

We first note that our results significantly differ from the ones in Bovari et al. (2018). Indeed, in their supply framework, production is solely determined by the stock of capital. In addition, workers' consumption adjusts perfectly to available output so that there can be no inflationary tensions on

[2]We found that the carbon price pass through only has a minor impact on the results, so we show results for the low pass through case only. Results with a different pass through are available on demand.

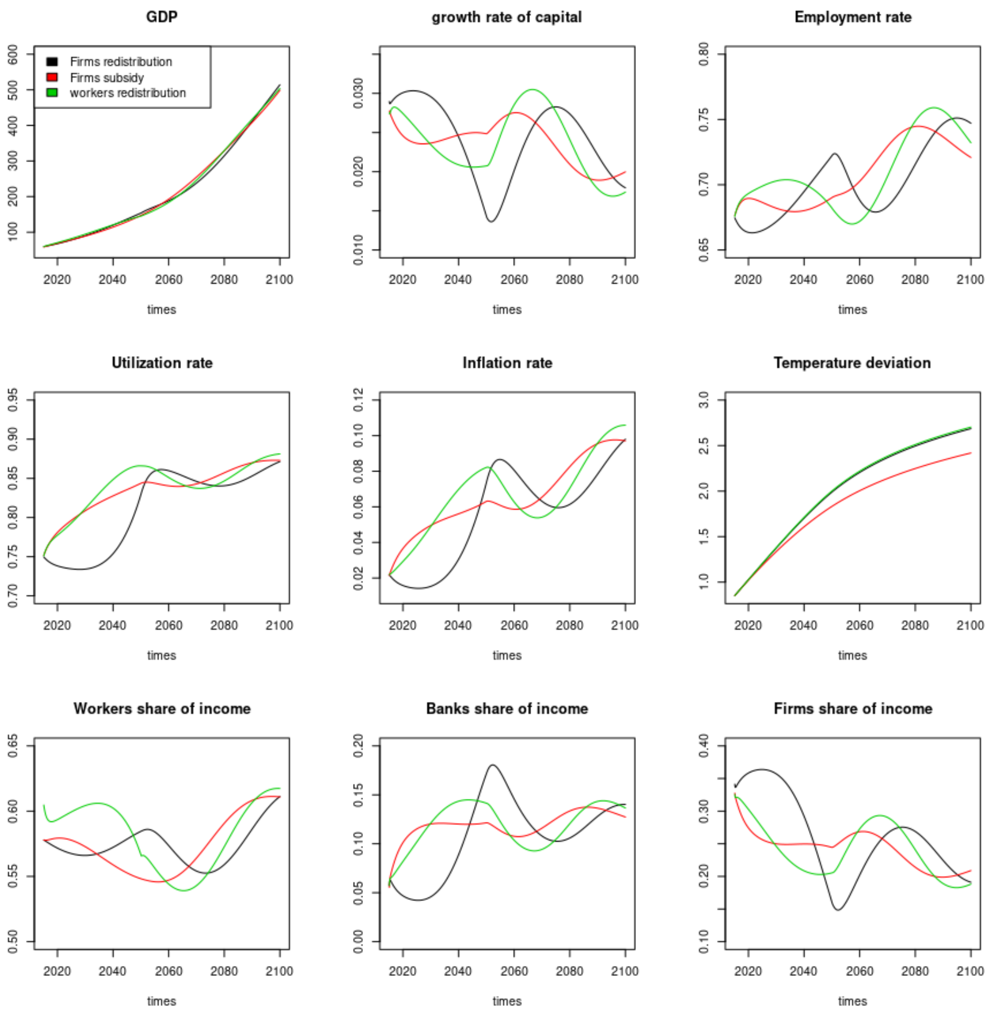

Figure 1: Macroeconomic trajectories for the three redistributive scenarios. Results are for the "medium" climate damages case, with no damages on capital ($f_k = 0$) and low pass-through ($pt = 0.5$).

the goods market. Said differently inflation is exclusively cost-push. As a result, they find a relatively stable inflation rate, which remains below 2%, and the employment rate remains roughly constant as well. But, in our demand framework, global warming has an inflationary impact on the economy, and the inflation rate reaches 10% in 2100 in all scenarios. This is because firms try to compensate output losses caused by climate damages and abatement efforts by increasing their rate of utilization, which increases from 75% in 2015 to almost 90% in 2100. This increase in utilization pushes up employment and, through equation 5, causes a strong inflationary pressure on the economy. Second, we note that global warming increases the economy's potential financial instability. Indeed, in all scenarios, the banking sector's share of income increases, at the expanse of the firms sector. Third, over the period 2015-2050, the *firms redistribution scenario* and *workers redistribution scenario* significantly depart from the *firms subsidy scenario*. Indeed, the growth rate of capital and firms' share of income are higher in the two former cases, and then rapidly fall after 2040, while inflation and banks' share of income are initially lower and rise rapidly around 2040. This happens because firms initially spend less in abatement efforts in the two redistributive scenarios, resulting in faster economic growth, lower tensions on the goods market and less demand for credit in the short run. But the economy then suffers from having to rapidly catch up to achieve carbon neutrality by 2050, while the adjustment is more gradual in the *firms subsidy scenario*. Finally, the *firms subsidy scenario* is optimal regarding climate change mitigation, as the temperature in 2100 is of +2.41 in this case, instead of respectively +2.70 and +2.68 in the *workers redistribution* and *firms redistribution* scenarios. However, this scenario is also characterized by a significantly lower workers' share of income prior to 2050.

3.3 Environmental policies and trade-offs

To pursue the analysis in a more thorough way, our goal in this section is to measure the impact of different climate policy parameters on the three policy goals that are: (i) Poverty, (ii) Climate change mitigation and (iii) economic stability.

We use average workers' real income over the period 2015-2050 as an indicator of goal (i). More precisely, it measures by how much climate change mitigation policies affect workers' purchasing power. We also look at the economy's average growth rate over the period 2015-2050 to get a measure of the overall impact of climate mitigation policies on the economy. For goal (ii), we look at the temperature deviation in 2100. Finally, measuring the achievement of goal (iii), economic stability, is less straightforward. The economy is subject to two potential sources of instability. On the one hand, transition risks might threaten financial stability in case of a too fast transition financed by credit creation. But, on the other hand, insufficient mitigation efforts have a destabilizing impact in the long run due to physical risks. Indeed, excessive climate damages might harm production (and possibly capital) up to a point where firms can no longer compensate their losses out of their own profits, and have to cut investment expenditures or rely on external financing. In both cases, excessive debt accumulation and low firms' profitability might trigger a debt-deflation crisis, thus pushing the economy away from its desirable growth path.

To measure how these two instability channels might disrupt the economy, we follow Bovari et al. (2018) and estimate basins of attraction. The basin of attraction of an equilibrium is defined by the set of initial positions such as the model, if it is initialized at one of these points, converge towards the equilibrium. A large basin of attraction means that the model is more likely to reach the equilibrium even in the presence of adverse shocks, so that it can be used as a measure of stability. Here, the model is characterized by path dependency and does not have a unique "good" equilibrium. Thus, we define a set of variables values, called the convergence set, outside of which economic outcomes are clearly undesirable. We consider that an initial position belongs to the "good" basin of attraction if it leads to a trajectory whose final point stands within the convergence set[34]. To estimate the "good" basin of attraction, we test points belonging to a regular grid of nearly 200000 points within the set of initial conditions $\{\omega, u, e, d\} \in [0.2; 1]^3 \times [0; 1]$. Finally, we take the size of the basin of attraction, namely the proportion of explored points that belong to the "good" basin, as our indicator of economic stability.

Figure 2 shows the four indicators as a function of the annual growth rate of the carbon price and of the share of the carbon tax income used to finance a green subsidy (we assume that what remains of the carbon tax income is redistributed to workers). We first see that a higher growth rate of the carbon price or a higher green subsidy reduces temperature deviation in

[3]The convergence set is defined as $\{\omega, u, e, d\} \in [0.2; 1]^3 \times [0; 1]$.

[4]In order to ensure that we measure the economy's stability in the long run, we use a long simulation period of 500years.

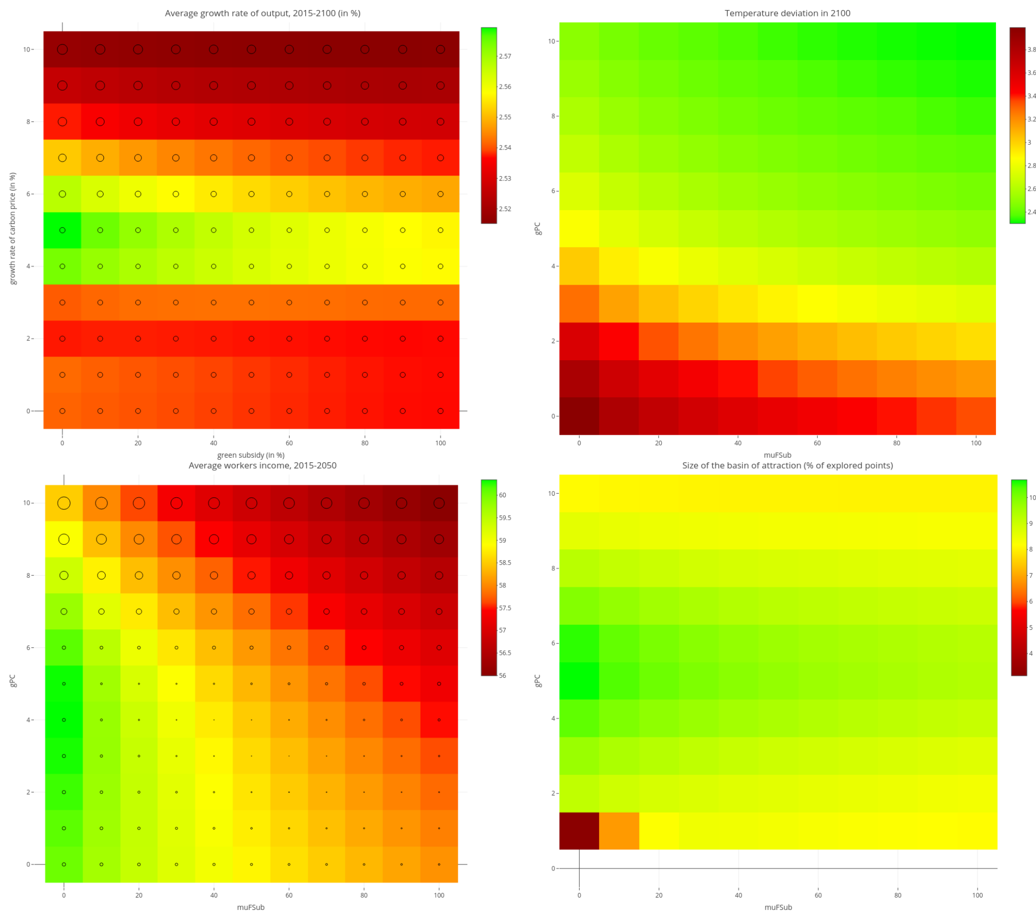

Figure 2: Heatmaps for the average growth rate of the economy in the medium-run (2015-2050), average workers real income in the medium-run, temperature anomaly in 2100($^{\circ}C$) and economic stability (defined by size of the basin of attraction), as a function of $\mu_{f,sub}$ (x-axis) and g_{pc} (y-axis). Results are for the no damages on capital ($f_k = 0$) and low pass-through ($pt = 0.5$) case. The black circles in the two upper graphs indicate the standard deviation over the considered time period. Results are for medium climate damages on output only and with a low pass through.

2100 (lower-left panel). However, this improvement regarding climate change mitigation comes at the cost of lower and more volatile households income in the medium run(upper right panel).

Regarding economic stability, there is an arbitrage to find between transition and physical risks. We see that both a very high and a very low growth rate of the carbon tax can be destabilizing, and there is an "optimal" carbon tax (for the economic stability goal only) for an intermediate level of taxation of $g_{pc} = 5\%$. Regarding the carbon tax recycling policy, we see that a higher redistribution towards workers is highly effective to improve stability (except for a very low growth rate of the carbon price). For $g_{pc} = 5\%$, Redistributing the carbon tax receipts to workers rather than to finance a green subsidy increases the economy's stability by 14%. This is an interesting result as it is, to our knowledge, the first time that a link between the redistributive impact of environmental policies and economic stability is established.

These results indicate that there is a trade-off between the climate mitigation goal on the one hand and the poverty and stability goals on the other hand. Ensuring a just and fair low carbon transition is already an important goal in itself. But we we find is that reducing the regressive impact of climate change mitigation policies on the poorest segments of the population is not the only effect of redistributive policies. A high redistribution rate towards workers also fosters aggregate demand through higher consumption, thus increasing firms' investment and profitability. In turn, this stronger macroeconomic environment reduces the economy's vulnerability to adverse shocks. By contrast, financing a climate subsidy allows to increase abatement efforts by firms, resulting in lower temperature deviation in 2100, but at the cost of higher inequalities and instability due to excessive transition risks.

3.4 testing different climate damages

Our goal in this section is to test the robustness of the trade-offs identified above to different climate scenarios. In practice, the trade-off between climate change mitigation and poverty is highly robust and holds for all specifications. Indeed, a higher green subsidy will always increase abatement efforts and lead to lower temperature deviation. Conversely, a higher redistribution towards workers will always reduce poverty and inequality. However, this might not always be the case for the stability goal.The relation between the policy variables and economic stability depends on the impact of physical risks relative to transition risks, so that higher climate damages, or a higher allocation of damages to capital, might affect the results.

Figure 3 shows the heatmaps of the size of the basin of attraction for different climate scenarios. We first see that adding damages on capital has a significant adverse impact on stability. Even in the low damage on capital scenario, the economy is almost fully unstable (meaning that there are no or almost no stable points within the explored domain) for a growth rate of the carbon price below 4%. Next, for low or medium climate damages on output only (upper panels), a higher redistribution towards workers improves stability. However, when adding climate damages on capital (lower panels), the result reverses: a higher green subsidy improves the economy's stability, and there is no longer a trade-off between stability and climate change mitigation. This is due to the fact that, in the two scenarios with damages on capital, physical risks become prevalent over transition risks, which strongly increases the benefits of early and ambitious mitigation efforts relative to redistributive policies.

3.5 The role of the investment function

The economy's sensitivity to demand conditions is another critical factor that might affect the positive relationship between a higher carbon tax recycling towards workers and economic stability. There are different parameters that determine how the economy responds to workers' consumption demand, such as firms' retention ratio, the propensity to consume of capitalists, inflation dynamics or the Phillips curve. But the most crucial parameters are those of the investment function (12). Indeed, if firms' investment decision is strongly responsive to demand (high μ_2), the expansive effect of a redistribution towards workers will be associated with a higher multiplier effect that will reinforce its positive impact. But,if firms are more concerned about their profitability (high μ_1), their response to higher aggregate demand will be more moderate, and the gains in terms of lower transition risks will be lower as well.

Based on the above, we test two different investment functions. First, we model a demand-led economy, with $\mu_1 = 0.208$ and $\mu_2 = 0.06$. For the second scenario, we use $mu_1 = 0.408$ and $mu_2 = 0.04$, which corresponds to a more profit-led economy. The heatmaps of economic stability for the two investment functions are presented in figure 4. We see immediately that, with a more supply-led economy, the stabilizing impact of a higher

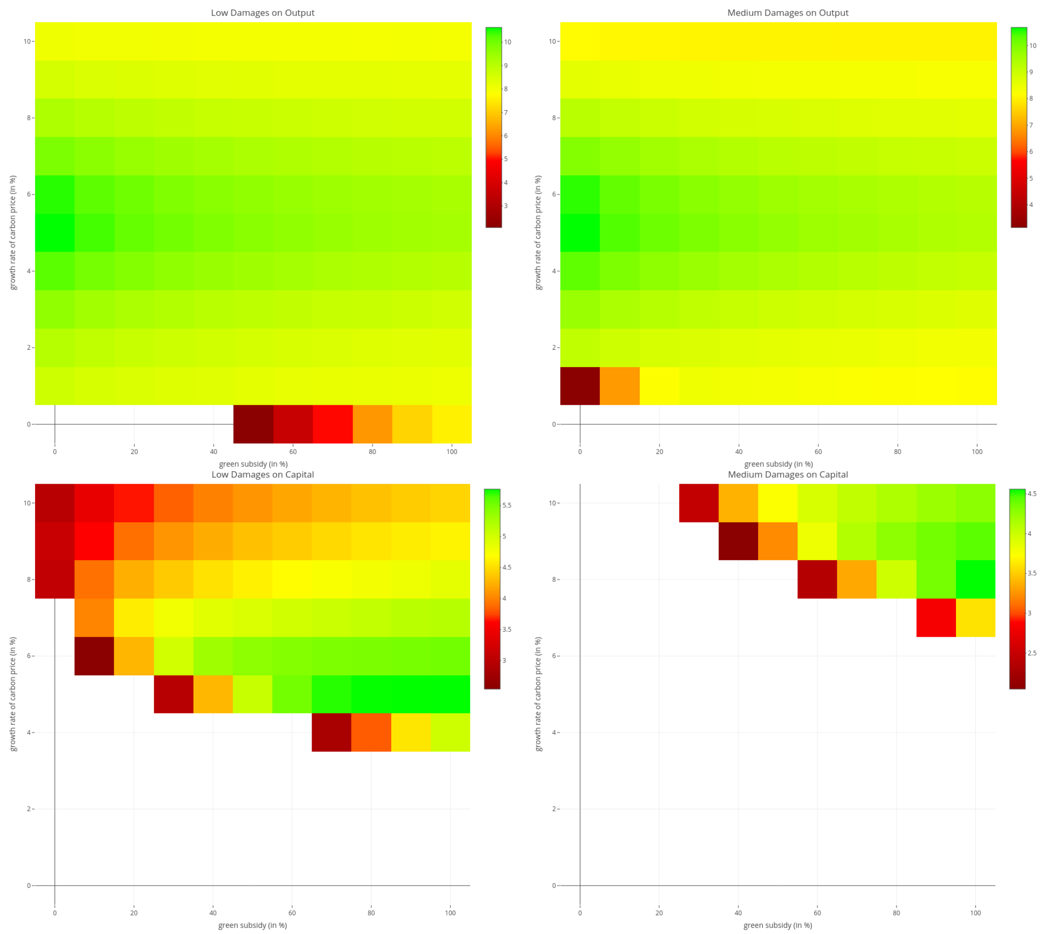

Figure 3: Heatmaps for the size of the basin of attraction as a function of $\mu_{f,sub}$ (x-axis) and g_{pc} (y-axis), for low and medium climate damages with and without damages on capital and low pass-through ($pt = 0.5$) case. We do not show graphs for high climate damages because in this case the economy is highly unstable.

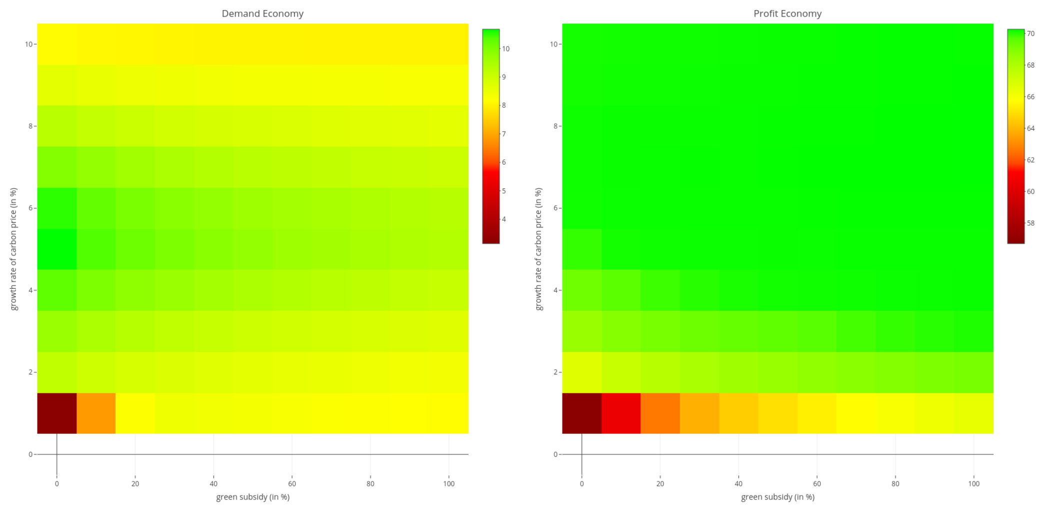

Figure 4: Heatmaps for the size of the basin of attraction as a function of $\mu_{f,sub}$ (x-axis) and g_{pc} (y-axis), for a demand-led or a supply-led economy. Results are for the no damages on capital ($f_k = 0$) and low pass-through ($pt = 0.5$) case.

redistribution towards workers identified above vanishes. Firms' investment do not sufficiently responds to higher consumption demand by workers, so that it is more effective to focus on mitigating physical risks by financing a low-carbon subsidy.

4 Conclusion

By turning the supply model presented in Bovari et al. (2018) into a demand framework, this paper presents a stock-flow consistent macroeconomic model able to assess the effectiveness of different policies on climate change mitigation, income distributions or macroeconomic stability. Our analysis focused on the question of recycling the carbon tax receipts either to finance additional mitigation efforts or to dampen the regressive impact of the carbon tax policy on low income households.

Our main finding is that we showed the possibility of existence of a positive relationship between a progressive carbon tax recycling policy and economic stability. This result emerges from the fact that increasing workers' income leads to higher consumption demand, to which firms respond by increasing their investment expenditures, thus resulting in a stronger and more resilient macroeconomic environment.

This result, however, should be taken cautiously as it relies on two major assumptions. First, although it is true that a higher redistribution rate towards workers can help the economy to cope with transition risks, it does not affect physical risks caused by global warming. Thus, financing additional mitigation efforts might be more effective to prevent the collapse of the economy if physical risks are predominant over transition risks. Second, the effectiveness of the redistributive policy is highly dependent on how responsive the economy is to changes in aggregate demand. In a profit-led economy where firms consider primarily their profits and tend to neglect demand conditions for their investment decisions, a more progressive carbon tax would have a more moderate impact.

Despite these limitations, we believe that this paper brings a useful perspective on the debate on the distributional consequences of environmental policies. In particular, we provide additional arguments in support of more progressive environmental policies by showing that, at least under some circumstances, ensuring that the burden of financing the low carbon transition do not disproportionately fall on lower income households can provide additional co-benefits in terms of economic stability.

References

Baranzini, A., van den Bergh, J. C. J. M., Carattini, S., Howarth, R. B., Padilla, E., and Roca, J. (2017). Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations. *WIREs Climate Change*, 8(4):e462. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/wcc.462.

Bovari, E., Giraud, G., and Mc Isaac, F. (2018). Coping With Collapse: A Stock-Flow Consistent Monetary Macrodynamics of Global Warming. *Ecological Economics*, 147:383–398.

Bovari, E., Giraud, G., and McIsaac, F. (2020). Financial impacts of climate change mitigation policies and their macroeconomic implications: a stock-flow consistent approach. *Climate Policy*, 20(2):179–198.

Burke, M., Hsiang, S. M., and Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527(7577):235–239. Bandiera_abtest: a Cg_type: Nature Research Journals Number: 7577 Primary_atype: Research Publisher: Nature Publishing Group Subject_term: Climate-change impacts Subject_term_id: climate-change-impacts.

Callan, T., Lyons, S., Scott, S., Tol, R. S. J., and Verde, S. (2009). The distributional implications of a carbon tax in Ireland. *Energy Policy*, 37(2):407–412.

Dagoumas, A. S. and Polemis, M. L. (2020). Carbon pass-through in the electricity sector: An econometric analysis. *Energy Economics*, 86:104621.

Dennig, F., Budolfson, M. B., Fleurbaey, M., Siebert, A., and Socolow, R. H. (2015). Inequality, climate impacts on the future poor, and carbon prices. *Proceedings of the National Academy of Sciences*, 112(52):15827–15832. Publisher: National Academy of Sciences Section: Social Sciences.

Dietz, S. and Stern, N. (2015). Endogenous Growth, Convexity of Damage and Climate Risk: How Nordhaus' Framework Supports Deep Cuts in Carbon Emissions. *The Economic Journal*, 125(583):574–620.

Fabra, N. and Reguant, M. (2014). Pass-Through of Emissions Costs in Electricity Markets. *American Economic Review*, 104(9):2872–2899.

Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., and Kerr, T. (2015). *Decarbonizing Development: Three Steps to a Zero-Carbon Future*. The World Bank. Publication Title: World Bank Publications.

Franke, R. (1996). A Metzlerian model of inventory growth cycles. *Structural Change and Economic Dynamics*, 7(2):243–262.

Fremstad, A. and Paul, M. (2019). The Impact of a Carbon Tax on Inequality. *Ecological Economics*, 163:88–97.

Ganapati, S., Shapiro, J. S., and Walker, R. (2017). The Incidence of Carbon Taxes in U.S. Manufacturing: Lessons from Energy Cost Pass-Through. SSRN Scholarly Paper ID 2953941, Social Science Research Network, Rochester, NY.

IPCC (2019). Global Warming of 1.5 ºC —.

Malerba, D., Gaentzsch, A., and Ward, H. (2021). Mitigating poverty: The patterns of multiple carbon tax and recycling regimes for Peru. *Energy Policy*, 149:111961.

Mathur, A. and Morris, A. C. (2014). Distributional effects of a carbon tax in broader U.S. fiscal reform. *Energy Policy*, 66:326–334.

Miller, N. H., Osborne, M., and Sheu, G. (2017). Pass-through in a concentrated industry: empirical evidence and regulatory implications. *The RAND Journal of Economics*, 48(1):69–93. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1756-2171.12168.

Nazifi, F., Trück, S., and Zhu, L. (2021). Carbon pass-through rates on spot electricity prices in Australia. *Energy Economics*, 96:105178.

Nordhaus, W. (2018). Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies. *American Economic Journal: Economic Policy*, 10(3):333–360.

Nordhaus, W. D. (2007). A Review of the Stern Review on the Economics of Climate Change. *Journal of Economic Literature*, 45(3):686–702.

Rowthorn, R. E. (1977). Conflict, inflation and money. *Cambridge Journal of Economics*, 1(3):215–239. Publisher: Oxford University Press.

Saelim, S. (2019). Carbon tax incidence on household demand: Effects on welfare, income inequality and poverty incidence in Thailand. *Journal of Cleaner Production*, 234:521–533.

Seppecher, P., Salle, I. L., and Lavoie, M. (2018). What drives markups? Evolutionary pricing in an agent-based stock-flow consistent macroeconomic model. *Industrial and Corporate Change*, 27(6):1045–1067.

Weitzman, M. L. (2012). GHG Targets as Insurance Against Catastrophic Climate Damages. *Journal of Public Economic Theory*, 14(2):221–244. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-9779.2011.01539.x.

Zachmann, G., Fredriksson, G., and Clayes, G. (2018). The distributional effects of climate policies. *Bruegel Blueprint series 28*.