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Climate Inequality: Carbon Capture for Redistribution

Abstract

We study optimal climate policy in a global economy where regions differ in wealth and climate vulnerability. Carbon emissions from production lead to output losses, and there is a technology for emissions absorption. We provide an aggregation result: the model with heterogeneity can be cast into a representative region economy with a different discount factor and damage function. This result offers a simple rule to account for inequality in the design of climate policy. We show that wealthier regions should bear more responsibility for carbon capture to cleanse the atmosphere, and that inequality per se does not entail a compromise on emissions reduction. It is only if regions must contribute uniformly to carbon capture that the optimal climate policy dictates higher global net emissions relative to the first best. An important insight is that carbon capture serves as a redistribution tool when direct lump-sum transfers across regions are unfeasible.

JEL-Codes: Q540, D630, E600, H410, H210.

Keywords: heterogeneous regions, negative emissions, inequality, carbon capture.

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1 Introduction

That countries share a common but differentiated responsibility in addressing global climate change has long been acknowledged and was first stated formally at the 1992 United Nations Conference on Environment and Development. While this principle is grounded on climate justice, its implementation has been elusive. Solutions like the Green Climate Fund, established within the United Nations Framework Convention on Climate Change to assist developing countries with climate policies, have yet to channel sufficient funds. Reaching net zero by 2050, the global target agreed upon in the 2015 United Nations Climate Change Conference in Paris, is compatible with the view of common but differentiated responsibilities only if substantial funds flow into low-income developing countries to assist them with their climate goals. In this paper, we revisit the problem of addressing countries' differentiated responsibilities on climate action, and we provide two insights. First, carbon capture and sequestration can help assigning responsibilities across regions without the apparently politically infeasible need for direct monetary transfers. Second, implementing a global net emissions target - i.e., net zero by 2050 - requires differentiated regional targets, with high-income countries pursuing negative net emissions, and low-income ones being allowed positive net emissions.

To develop this argument, we lay out a neoclassical model with heterogeneous regions and incomplete markets. Carbon emissions from production generate output losses —a negative climate externality— and a technology to absorb these emissions through carbon capture is available to all regions. Carbon capture entails positive global effects at the cost of using up productive resources. In the model, regions differ in their initial wealth and their climate-related output losses. We characterize climate policies by solving the problem of a utilitarian planner that assigns equal weights to all regions and avoids direct transfers of resources across them, much in the spirit of the constrained-efficiency literature proposed in Diamond (1967) and Dávila et al. (2012). In our model, however, there is still some room for redistribution embedded in the choice of each region's contribution to carbon capture. To limit this redistribution, we impose an additional constraint on the planner's problem consisting of a minimum contribution that she can ask from each region. When this minimum is set to zero, contributions are required to be non-negative, precluding direct transfers of resources across regions. As the minimum increases, the planner is forced to ask for positive contributions from all regions and, thus, the scope for redistribution is reduced. The optimal climate policy specifies a global target for net carbon emissions and a schedule of net emissions across regions.

The main result of the paper is an aggregation result. In particular, we show that the solution to the planner's problem in an economy with heterogeneous regions coincides with the planner's solution in a representative region economy in which two key parameters are redefined to summarize the underlying heterogeneity: the discount factor and the elasticity of the damage function with respect to carbon emissions. This result provides a simple way to account for wealth and climate differences across regions in the choice of global emissions and carbon capture. We use it extensively to understand how the planner's solution depends on prevailing inequality and how the burden of cleaning up the atmosphere through carbon capture is distributed across regions.

Our analysis provides several important lessons. First, we show that the constrained efficient outcome requires wealthier regions to bear a larger responsibility for cleaning the atmosphere through carbon capture. Since we explicitly rule out lump-sum transfers, this implies a substantial redistribution of global resources through carbon capture financing. Our preferred interpretation is that, by taking responsibility for capturing carbon, high-income countries indirectly transfer room in the atmosphere to low-income countries to use during their slower transition to a carbon-free economy. The fact that carbon capture can be a mechanism for addressing differential climate responsibilities is a novel insight

of this paper.

We also show that when wealth differences across regions are small, global climate policy coincides with the first best Pareto optimal policy, indicating a complete separation between climate and redistribution motives. As wealth inequality increases, however, an apparent tension between these two motives emerges. In the case in which all regions must contribute uniformly to carbon capture, we show that efficiency calls for a more lenient climate policy as wealth differences increase. However, if it is feasible to assign differentiated carbon capture responsibilities, efficiency dictates a more stringent climate policy as inequality increases, with fewer emissions and more carbon capture relative to the Pareto optimal policy. These results highlight that inequality per se does not entail a compromise on global climate goals.

Finally, we study the effect of differences in climate vulnerability in terms of both heterogeneous and uncertain climate-related output losses. If this source of inequality is sufficiently high, we show that climate heterogeneity in output losses calls for a more stringent policy. Climate uncertainty also calls for a more stringent policy, even if it involves more asset accumulation due to precautionary savings. These extra savings actually constitute a blessing because they finance carbon capture.

This paper belongs to the literature that studies optimal climate policy in a multicountry setting, especially Krusell and Smith (2022), Chichilnisky and Heal (1994), and Hillebrand and Hillebrand (2019). Without lump-sum transfers, Chichilnisky and Heal (1994) shows that abatement efforts are heterogeneous, with high-income countries bearing a higher burden on abatement efforts. Similar to Chichilnisky and Heal (1994), wealthier regions should bear more responsibility for carbon capture in our setup. We differ in our focus on carbon capture and characterize the global climate policy for a broad array of limits to redistribution, from no redistribution (homogeneous carbon capture) to complete redistribution (Pareto optimal benchmark with transfers). This paper relates to Hillebrand and Hillebrand (2019), who study the optimal climate policy of a global economy with multiple regions. Their focus is on characterizing an optimal climate policy, composed of taxes and transfers, that implements the optimal regional emissions and is also incentive-compatible with the laissez-faire equilibrium. In contrast, this paper studies how alternative sources of inequality (stemming from economic and climate factors) across regions affect the optimal allocation and the stance of global climate policy, defined as a global net emissions target. Importantly, we rule out transfers across countries as those characterized by Hillebrand and Hillebrand (2019) and also Chichilnisky and Heal (1994) and introduce a carbon capture technology as a redistribution mechanism across countries.

Krusell and Smith (2022) study the distribution of climate impacts around the world, accounting for heterogeneity in income and temperature increases across regions. We share with that paper that we build upon a standard neoclassical growth model augmented with a climate module and feature regional heterogeneity in economic and climate outcomes. We differ from them in that we study the optimal climate policy of such an unequal world, while the focus in Krusell and Smith (2022) is to quantify the climate impacts. The paper relates to Jacobs and van der Ploeg (2019) for its contribution to optimal climate policy in heterogeneous agents economies. Jacobs and van der Ploeg (2019) studies when the optimal carbon tax differs from the Pigouvian formula to incorporate re-distributive motives. In contrast, this paper studies heterogeneity across regions, not individuals, and characterizes the optimal policy in terms of allocations (i.e., a net emissions target). Also, this paper analyzes how alternative sources of inequality affect the optimal outcome.

While considering existing inequality across regions, the paper focuses on efficiency rather than equity, as we adopt a utilitarian planner and rule out direct transfers of resources across regions. In this regard, the paper differs from the literature that performs welfare analysis on a multi-country economy like Anthoff and Emmerling (2019), Anthoff and Tol (2010) and Budolfson et al. (2021).

Finally, for its focus on optimal policy, this paper differs from existing literature that works with heterogeneous agents climate-economy models aiming to quantify climate change's consequences. Significant contributions to this literature are Fried et al. (2018) and Fried (2021), with whom we share the neoclassical growth model with heterogeneous agents framework, and Cruz and Rossi-Hansberg (2023) and Conte et al. (2022) add climate heterogeneity into spatial economies. These papers consider the impacts of given carbon taxes while, in contrast, we look for the optimal climate policy. In addition, Fried et al. (2018) and Conte et al. (2022) more broadly belong to a rich literature that studies how the incidence of taxes depends on the government's use of carbon taxation revenue, with recent contributions by Goulder et al. (2019) and van der Ploeg et al. (2022) to this line of research.

The rest of the paper is structured as follows. We present the model in Section 2, the laissez-faire equilibrium in Section 3, define constrained-efficient policies in Section 4, and present the main analytical results in Section 5. Section 6 contains a numerical exercise and Section 7 offers some final remarks.

2 The Model Economy

The world consists of a unit measure of regions, each inhabited by a representative household and a representative firm. There is a final good produced using capital and labor, which can be used for consumption or as capital. Households live for two periods, and all production occurs in the last period.

The use of capital in the production of the final good releases carbon to the atmosphere. It is feasible, however, to capture and sequester atmospheric carbon using a technology that uses capital in a linear fashion. Investment in this technology occurs in the first period and it is financed through the contribution of all regions. We use **K** and **M** to denote the global aggregates of capital used in the production of the final good and in carbon capture and sequestration, respectively. The amount of carbon in the atmosphere is determined by global net carbon emissions, $\mathbf{S} = \Pi(\mathbf{K}, \mathbf{M})$, where

$$\Pi(\mathbf{K}, \mathbf{M}) = \xi_d \mathbf{K} - \xi_g \mathbf{M},\tag{1}$$

for positive constants ξ_d and ξ_g .

Carbon in the atmosphere creates a negative externality that results in an output loss in the final good sector, which is specific to each region. More precisely, the total output of the regional-representative firm that uses *K* units of capital and *L* units of labor is $(1 - D(\mathbf{S}, \epsilon))F(K, L)$, where *F* is a constant returns to scale technology, and

$$D(\mathbf{S}, \epsilon) = 1 - \exp(-\gamma(\mathbf{S} + \epsilon)), \tag{2}$$

with $\gamma > 0$, is the damage function. The output loss due to the climate externality is determined by the value of ϵ , which we refer to as *climate vulnerability*, and is the sum of two components. The first component, *z*, captures predetermined differences across regions regarding these losses and we refer to it as *climate inequality*. The second component, *v*, represents region-specific climate shocks that occur in the second period, and we refer to it as *climate uncertainty*. We assume *z* and *v* are mutually independent and normally distributed in the cross section of regions, with standard deviations σ_z and σ_v and means μ_z and μ_v , respectively.

Households are endowed with *y* units of the final good in the first period, and one unit of labor in the second period. We interpret *y* as wealth and assume it is log-normally distributed in the cross-section of regions, with mean equal to one, (normal) standard deviation given by σ_y , and independent from ϵ . In the first period, households decide

how much to consume, to save, and to contribute to finance investment in carbon capture and sequestration. In the second period, they simply consume all their income.

Labor markets operate at a regional level - i.e., no migration -, and there is an international asset market for a non-contingent risk-free bond. This implies that households face labor income uncertainty due to the presence of climate shocks, but the return to their savings is deterministic, as there is no aggregate uncertainty. The budget constraints are

$$c_0 + a \le y - m, \tag{3}$$

$$c_1 \le w(\epsilon) + Ra,\tag{4}$$

where *m* denotes the contribution to carbon capture and sequestration. Households' preferences over consumption are given by the utility function:

$$u(c_0) + \beta \mathbb{E}\left[u(c_1)\right],\tag{5}$$

where the expectation is taken with respect to the region-specific climate shock v. The instantaneous utility function is logarithmic, e.g. $u(c) = \ln(c)$. The problem of each household is to maximize (5), subject to (3) and (4).

In each region, the representative firm solves

$$\max_{K,L} (1 - D(\mathbf{S}, \epsilon)) F(K, L) - w(\epsilon) L - RK,$$
(6)

taking factor prices and the amount of carbon in the atmosphere as given. Firms' optimal behavior requires:

$$(1 - D(\mathbf{S}, \epsilon))F_L(K(\epsilon), L(\epsilon)) = w(\epsilon), \tag{7}$$

$$(1 - D(\mathbf{S}, \epsilon))F_K(K(\epsilon), L(\epsilon)) = R,$$
(8)

for all ϵ .

2.1 Competitive Equilibrium

We use *G* to denote the cross-sectional wealth distribution, with density g(y); and *H* to denote the cross-sectional distribution of exposure across regions, with density $h(\epsilon)$. The function *H* is generated by the cross-sectional distributions of *z* and *v*, which we denote Φ and Ψ , respectively, with corresponding densities $\phi(z)$ and $\psi(v)$. In the first period, market clearing for the asset market is

$$\int \int a(y,z)g(y)\phi(z)\,\mathrm{d}y\,\mathrm{d}z = \int K(\epsilon)h(\epsilon)\,\mathrm{d}\epsilon.$$
(9)

In the second period, labor markets clear if

$$L(\epsilon) = 1, \tag{10}$$

for all ϵ . The global amount of carbon capture is

$$\mathbf{M} = \int \int m(y,\epsilon)g(y)h(\epsilon)\,\mathrm{d}y\,\mathrm{d}\epsilon,\tag{11}$$

which corresponds to the sum of all contributions across regions.

Walras' Law implies that if (9), (10), and (11) are satisfied, then final good market also clears in both periods. For completeness we list here the final good market clearing conditions:

$$\int \int c_0(y,z)g(y)\phi(z)\,\mathrm{d}y\,\mathrm{d}z = \int yg(y)\,\mathrm{d}y - \int K(\epsilon)h(\epsilon)\,\mathrm{d}\epsilon - \mathbf{M},\tag{12}$$

$$\int \int c_1(y,\epsilon)g(y)h(\epsilon)\,\mathrm{d}y\,\mathrm{d}\epsilon = \int (1-D(\mathbf{S},\epsilon))F(K(\epsilon),1)h(\epsilon)\,\mathrm{d}\epsilon.$$
(13)

A *Competitive Equilibrium* consists of households' decision rules $c_0(y, z)$, a(y, z), $c_1(y, \epsilon)$, and $m(y, \epsilon)$; firms' production plan $K(\epsilon)$, and $L(\epsilon)$, global aggregates **K** and **M**; and prices $w(\epsilon)$ and *R* such that policies solve individual agents' problems taking prices as given, global aggregates are consistent with individual decisions, and all markets clear.

3 The Laissez-faire Equilibrium

In a laissez-faire equilibrium, no carbon capture occurs and thus **M** is zero. It will prove convenient to reduce the equilibrium to the following three objects: the amount of productive capital **K**, the distribution of assets holdings across households η , and the distribution of productive capital across regions χ . We must require $\chi(\epsilon) \ge 0$ for all ϵ , and

$$\int \chi(\epsilon) \, \mathrm{d}\epsilon = 1,\tag{15}$$

$$\int \eta(y,z) \,\mathrm{d}y \,\mathrm{d}z = 1. \tag{16}$$

Productive capital in each region is then recovered as $K(\epsilon) = \chi(\epsilon)\mathbf{K}$, household assets as $a(y, z) = \eta(y, z)\mathbf{K}$, and consumption plans from individual budget constraints. We characterize the laissez-faire equilibrium using this notation. The following lemma characterizes the distribution of capital and asset holdings. The proof is in Appendix B.

Lemma 1 In a laissez-faire equilibrium, the distribution of capital across regions is given by

$$\chi(\epsilon) = \exp\left\{-\frac{\gamma}{1-\alpha}\left(\epsilon - \mu_{\epsilon} + \frac{\gamma}{1-\alpha}\frac{\sigma_{\epsilon}^2}{2}\right)\right\}$$
(17)

for all ϵ , and the distribution of asset holdings across households satisfies

$$\beta \alpha \mathbb{E}\left[\frac{y - \eta(y, z)\mathbf{K}}{(1 - \alpha)\chi(\epsilon)\mathbf{K} + \alpha \eta(y, z)\mathbf{K}}\right] = 1,$$
(18)

for all y and ϵ , where the expectation is taken with respect to the climate shock v.

Notice that the distribution of capital depends only on the stochastic properties of ϵ and, thus, it will be the same in any equilibrium. In the absence of climate uncertainty, we can also solve for the distribution of asset holdings in closed form and use it to obtain the following result.

Lemma 2 Suppose $\sigma_v = 0$. Then, the global emissions in a laissez-faire equilibrium are equal to $\xi_d \mathbf{K}^{LF}$, where:

$$\mathbf{K}^{LF} = \frac{\alpha\beta}{1+\alpha\beta}.\tag{19}$$

The proof is in Appendix B. When regions face no *climate uncertainty*, the laissez-faire global emissions are independent of regions' heterogeneity. When there is *climate uncer-tainty*, it is not possible to obtain an expression for global emissions in closed form but we can establish the following result:

Proposition 1 (Laissez-faire Economy) Global emissions in a laissez-faire economy, $\xi_d \mathbf{K}^{LF}$, are increasing in climate uncertainty, σ_v .

This result stems from precautionary savings, which lead to an increase in the capital stock and, ultimately, more emissions. Hence, in laissez-faire, climate uncertainty leads to higher global emissions and exacerbates climate change. Later, in section **??**, we show that precautionary savings do not necessarily lead to higher emissions in a constrained-efficient economy with available carbon capture. The proof of this proposition is in Appendix B.

4 Constrained-Efficient Climate Policies

We now investigate what combination of emissions and carbon capture maximizes social welfare from a utilitarian perspective, and how global net emissions depend on the underlying heterogeneity. To this end, we focus on constrained-efficient allocations: the best a global planner can do when she cannot overcome the constraints on private choices imposed by markets. All she can do is to command a different choice to either households or firms, while respecting individual constraint sets and market clearing conditions. Still, two features of this problem make the planner capable of improving on the market allocation. First, she knows that her choices affect equilibrium prices. Second, she is aware of the climate externalities.

To ensure that carbon capture is desirable from a societal perspective, we impose the following assumption.

Assumption 1 $\beta \gamma(\xi_g + \xi_d) > 1 + \beta \alpha + \frac{\xi_d}{\xi_g}$

As we will see, this assumption is a necessary condition for an interior solution for **M**. Intuitively, diverting one unit of capital from the final good sector into carbon capture and sequestration allows to increase its production by $\frac{\xi_d}{\xi_g}$, which results in $\gamma(\xi_g + \xi_d)$ units of additional output in the second period. Such a decision entails an opportunity cost of one unit of consumption in the first period, and α units of additional output in the second period, since diverted resources could have been used as capital.

4.1 Efficiency and Limits to Redistribution

In this economy, there is in principle a tension between achieving efficiency by fixing the climate externality and addressing existing inequality across regions. To study this tension, we follow **Dávila et al.** (2012) in setting up a utilitarian planner who assigns equal weights to regional welfare and cannot make direct transfers of resources across regions. In our model, however, some redistribution is still embedded in the choice of *m* because capturing carbon takes on productive resources. It is reasonable to expect that redistribution through *m* might also be limited in reality. A simple way to consider this possibility is by imposing an additional constraint on the planner's problem consisting of a minimum contribution that she can ask from each region¹. Moreover, since in practice *climate vulnerability* is a variable difficult to measure, we also preclude the possibility of making the

¹Taking the global **M** as given, requiring a minimum contribution is equivalent to imposing an upper bound on the contribution of each country, which captures the idea of imposing limits to redistribution.

contributions contingent on ϵ . This amounts to impose the following constraint on the global planner's choice:

$$m(y) \ge \underline{m},\tag{20}$$

for each *y*, where $\underline{m} \in [0, \mathbf{M}]$ denotes the minimum carbon capture required from each region. When this minimum is set to zero, it precludes direct transfers of resources across regions. As \underline{m} increases, positive carbon capture is required from all regions and, thus, the scope for redistribution is reduced.

The constrained-efficient allocation is formally defined as follows:

Definition 1 A constrained-efficient allocation solves the global planner 's problem, which is

$$\max_{c_0(y,z), a(y,z),} \int \int \left\{ u(c_0(y,z)) + \beta \mathbb{E} \left[u(c_1(y,z,v)) \right] \right\} g(y), \phi(z) \, \mathrm{d}y \, \mathrm{d}z$$
(21)
$$c_1(y,z,v), m(y),$$

$$L(\epsilon), K(\epsilon), \mathbf{K}, \mathbf{M}$$

subject to $\mathbf{S} = \Pi(\mathbf{K}, \mathbf{M})$, the budget constraints (3) and (4), the market clearing conditions (9) and (10), aggregate consistency (11), firm's optimality conditions (7) and (8), and the lower bound condition (20).

4.2 Characterization

In order to characterize the constrained-efficient allocation in closed form, it is useful to perform a change of variables. Specifically, we characterize the solution to the global social planner's problem in terms of the following five objects: the global stock of capital **K**, global carbon capture **M**, the distribution of capital across regions χ , the distribution of asset holdings across households η , and the distribution of regional carbon capture μ .

Thus, regional carbon capture is given by $m(y) = \mu(y)\mathbf{M}$. Consistent with the lower-bound condition (20), we impose

$$\mu(y) \ge \underline{\mu},\tag{22}$$

for $\underline{\mu} \in [0, 1]$ and $\int \mu(y) \, dy = 1$. A full description of the modified planner's problem is in Appendix **A**.

Using this change of variables, the first order conditions of the planner's problem with respect to **K** and **M** are:

$$1 = \beta R \mathbb{E}_1 \left[\frac{u'(c_1(y,\epsilon))\eta(y,z)}{\mathbb{E}_0 \left[u'(c_0(y,z))\eta(y,z) \right]} \right] - \Lambda^{\mathbf{K}},$$
(23)

$$1 \geq \Lambda^{\mathbf{M}} \tag{24}$$

where the last expression holds with equality if M > 0.

These expressions capture the costs and benefits of carbon emissions and carbon capture at the global scale. In both cases, the left-hand side is the marginal cost of capital in terms of the consumption good in the first period; one more unit of capital represents one unit of global consumption foregone. The right-hand side is the benefit of the additional unit, net of the externality (the social cost of carbon²) captured by the terms $\Lambda^{\mathbf{K}}$ and $\Lambda^{\mathbf{M}}$. Using the functional form assumptions we can write the social cost of carbon as follows:

$$\Lambda^{\mathbf{K}} \equiv \beta \mathbb{E} \left[\frac{u'(c_1)}{\mathbb{E} \left[u'(c_0)\eta(y,z) \right]} \left\{ \gamma \xi_d c_1(y,\epsilon) + F_{L,K}(\eta(y,z)-1) + F_{L,K}(1-\chi(\epsilon)) \right\} \right], \quad (25)$$

$$\Lambda^{\mathbf{M}} \equiv \beta \mathbb{E} \left[\frac{u'(c_1)}{\mathbb{E} \left[u'(c_0) \mu(y) \right]} \left\{ \gamma \xi_g c_1(y, \epsilon) \right\} \right].$$
(26)

The role of heterogeneity shows up in the social cost of carbon in two ways. First, the carbon externality is valued using a utilitarian planner's discount factor in which the

²A social benefit in the case of carbon capture.

marginal utilities of the first period are *weighted* using the distributions η and μ . Second, the social cost of carbon in (25) is the sum of two components: one standard associated with the climate externality and captured in the first term within the curly brackets, and another associated with distributional effects of pecuniary externalities, captured in the second and third terms within curly brackets.

Notice that if the distributions χ and η were degenerate - as they would in a representative region economy - these additional terms disappear, and the social cost of carbon equals the climate externality. Instead, in the economy with inequality, the planner chooses optimal net emissions, $\xi_d \mathbf{K} - \xi_g \mathbf{M}$, considering not only the climate externality but also the distributional consequences of regions' emissions and carbon capture over societal welfare.

To sum up, the constrained-efficient climate policy weighs three different concerns. First is efficiency, as there is an externality. The second is redistribution, as there is heterogeneity. Third is insurance, as the choice of climate policy affects the uncertainty faced by each region. In the next section, we analyze how these three different concerns interact to shape the optimal net emissions of the global economy and its distribution across regions.

5 Analytical Results

In this section, we present the main analytical results. To better grasp the role of inequality in shaping climate policy, we set as a benchmark the optimal policy that would prevail if the planner was allowed to freely redistribute resources across regions. We start by characterizing this benchmark.

5.1 Pareto Optimal Benchmark

The concept of constrained-efficiency, as conceived in Diamond (1967), suggests that it is reasonable to expect that the elements that generate inequality across regions also constrain the ability of the global planner to undo such inequality through lump sum transfers. If we were to ignore this observation, the planner must be able to attain the utilitarian first best Pareto optimum. A simple way to show this is by modifying the regional budget constraints in the planner's problem as follows:

$$c_0 + a \le y - m + T_0(y),$$
 (27)

$$c_1 \le w(\epsilon) + Ra + \mathbb{T}_1(y,\epsilon), \tag{28}$$

where $(T_0(y), T_1(y, \epsilon))$ are cross-regional transfers, with the additional requirement that $\sum_y T_0(y) = 0$ and $\sum_{\epsilon} T_1(y, \epsilon) = 0$. The following result characterizes the solution to a planner's problem in which we replace the budget constraints (3) and (4) with the budget constraints (27) and (28).

Proposition 2 (Pareto Optimal Climate Policy) *The Pareto Optimal Climate Policy in an economy with elasticity of the damage function,* γ *, and discount factor,* β *, is*

$$\mathbf{K}^{FB} = \frac{\alpha}{\gamma(\xi_g + \xi_d)} \tag{29}$$

$$\mathbf{M}^{FB} = 1 - \frac{1 + \alpha\beta + \frac{\xi_d}{\xi_g}}{\beta\gamma(\xi_g + \xi_d)}$$
(30)

It is easy to see that Assumption 1 guarantees that $\mathbf{M}^{FB} > 0$ and $\mathbf{K}^{FB} < \mathbf{K}^{LF}$. Then, the Pareto optimal allocation implies lower emissions (smaller **K**), positive carbon capture (larger **M**), and thus lower global net emissions to curb climate change. Not surprisingly, when transfers are unconstrained, there is a complete separation between climate and redistributive motives, and the optimal climate policy prescribes the same amount of emission cuts and carbon capture as in a representative region economy.³

5.2 Climate Policy and Inequality

We now characterize the solution to the global planner's problem. We first analyze how global carbon capture is distributed across regions through the choice of $\mu(y)$. We then focus on how gross emissions and carbon capture respond to different sources of inequality in the constrained-efficient solution.

As discussed in Section 4.1, the global planner's problem includes a minimum amount of carbon capture required from each region. The optimal choice of $\mu(y)$ takes the form of a cutoff \overline{y} such that the lower bound constraint (22) is indeed binding for all regions with $y \leq \overline{y}$. We obtain $\mu(y)$ in closed form in the following:

Lemma 3 Global carbon capture **M** is distributed among regions according to:

$$\mu(y) = \begin{cases} \mathcal{H}(y,\overline{y}) & \text{if } y > \overline{y} \\ \\ \underline{\mu} & \text{if } y \leq \overline{y} \end{cases}$$

where

$$\mathcal{H}(y,\overline{y}) = \frac{1 - \underline{\mu}G(\overline{y})}{1 - G(\overline{y})} + \frac{1}{\mathbf{M}} \left[y - \mathbb{E} \left[Y \mid Y \ge \overline{y} \right] \right],$$

and \overline{y} satisfies $\mathcal{H}(\overline{y}, \overline{y}) = 0$.

Clearly, $\mathcal{H}(y, \bar{y})$ is increasing in wealth, which indicates that wealthier regions must contribute more to carbon capture, and the burden on the poorest regions is set to the minimum. To understand the circumstances under which the lower bound constraint on $\mu(y)$ binds, suppose $\mu = 0$ and that the planner ignores it so that $\bar{y} = 0$. In such a case, the

³In our framework, this corresponds to the case in which the distributions of *y* and ϵ are degenerate at their mean values.

share of carbon capture in each region becomes

$$\mu(y) = 1 + \frac{y-1}{\mathbf{M}},$$

To the extent that the right-hand side is negative for the poorest regions, the planner will not require contributions from them and make wealthier regions responsible for capturing carbon. Interestingly, this also indicates that if optimal carbon capture, **M**, is not too large, the planner will require contributions only from the wealthier regions and give the poorest regions a free pass on carbon capture responsibilities.

The following proposition presents the main result of the paper. It shows it is possible to obtain the constrained efficient allocation by solving a representative region planner's problem instead and adequately changing the discount factor and the elasticity of the damage function in that problem. These two parameters fully summarize all the heterogeneity in the model. We formally state this result below and provide the proof in the appendix.

Proposition 3 (Aggregation Result) Let {**K**, **M**} be part of the solution to the global planner's problem in an economy with wealth and climate heterogeneity. Then, {**K**, **M**} also solve the planner's problem of a representative region economy where the elasticity of the damage function, $\hat{\gamma}$, and the discount factor, $\hat{\beta}$, are given by

$$\hat{\gamma} = \frac{\alpha}{\alpha - \Omega_0(\mathbf{K}, \mathbf{M})} \gamma$$
$$\hat{\beta} = \frac{\alpha - \Omega_0(\mathbf{K}, \mathbf{M})}{\alpha \Omega_1(\mathbf{K}, \mathbf{M})} \beta$$

respectively, where

$$\begin{split} \Omega_0(\mathbf{K},\mathbf{M}) &= \mathbb{E}\bigg[\frac{(1-\theta)\alpha(\eta(y,z)-\mu(y))}{(1-\alpha)\chi(\epsilon)+\alpha\eta(y,z)}\bigg],\\ \Omega_1(\mathbf{K},\mathbf{M}) &= \mathbb{E}\bigg[\frac{\Lambda+\frac{\alpha\beta}{1-\theta}\mathbb{E}\bigg[\frac{\mu(y)}{(1-\alpha)\chi(\epsilon)+\alpha\eta(y,z)}\bigg]}{\Lambda+\frac{\alpha\beta}{1-\theta}\mathbb{E}_v\bigg[\frac{1}{(1-\alpha)\chi(\epsilon)+\alpha\eta(y,z)}\bigg]}\bigg], \end{split}$$

 $\theta = \mathbf{M}/(\mathbf{K} + \mathbf{M})$, and Λ is the multiplier on the planner's constraint A.6.

The proposition provides an explicit way to solve global emissions and carbon capture in an economy with inequality relative to the (representative region) first best benchmark of Proposition 2. The functions Ω_0 and Ω_1 capture all the heterogeneity in the model as they contain the distributions of capital, χ , asset holdings, η , and carbon capture, μ . In order to know whether emissions and carbon capture are lower or higher than in the Pareto optimum, we need to know the sign of the function Ω_0 and whether Ω_1 is above or below one when evaluated at the constrained-efficient policy. For instance, if $\Omega_0 > 0$, the planner should act "*as if*" the elasticity of the climate damage function were larger and, therefore, pursue a more aggressive climate policy (more emission cuts and more carbon capture). In turn, if $\Omega_1 > 1$, the planner should act "as if" the discount factor were lower and pursue a less aggressive climate policy.

To build intuition about the forces that determine global emissions and carbon capture, in what follows, we consider some special cases activating one source of inequality at a time and then analyzing the interaction between wealth and climate vulnerability.

Wealth Inequality. Consider first the case where there is only wealth inequality. The following result shows that if wealth differences across countries are low enough, the global net emissions coincide with the first best benchmark. When all regions can contribute positively to carbon capture, the planner can equalize consumption in the second period across regions. Thus, we obtain the following result:

Corollary 1 Suppose $\sigma_z = \sigma_v = 0$. Suppose also that $\underline{m} = 0$ and condition (20) is not binding. Then $\hat{\gamma} = \gamma$ and $\hat{\beta} = \beta$. Also, $(\mathbf{K}, \mathbf{M}) = (\mathbf{K}^{FB}, \mathbf{M}^{FB})$.

This corollary implies a separation between climate policy and inequality when wealth differences across regions are low. Constrained efficiency prescribes as much emissions and carbon capture as in the Pareto optimum, and all regions must contribute to carbon capture. Still, wealthier regions bear a larger burden of financing these actions.

The separation between climate policy and inequality breaks down as wealth differences across regions increase, and the poorest regions must get a free pass on climate responsibility. An apparent tension between curbing climate change and sustaining regional equity arises. We obtain the following result:

Corollary 2 Suppose $\sigma_z = \sigma_v = 0$. Suppose also that $\underline{m} = 0$ and condition (20) is binding for some regions. Then $\hat{\gamma} > \gamma$ and $\hat{\beta} > \beta$. Also, $\mathbf{K} < \mathbf{K}^{FB}$ and $\mathbf{M} > \mathbf{M}^{FB}$.

In this case, constrained efficiency surprisingly dictates not a less but a more stringent climate policy: less emissions and more carbon capture are optimal at the global scale. The global economy behaves as a representative region with a lower discount rate and a higher climate damage elasticity - both parameters consistent with a more stringent climate policy relative to the Pareto optimal outcome. Carbon capture effectively acts as a redistribution tool and it is optimally used as such. By taking responsibility for capturing carbon, the richest regions transfer room in the atmosphere to the poorest ones. This result highlights a novel insight: carbon capture can be a mechanism for addressing differential climate responsibilities.

The global planner solution assumes that cooperation across regions is possible. In practice, however, enforcement mechanisms to compel some regions to contribute more

than others to carbon capture may be limited. In fact, when these mechanisms are entirely missing, carbon capture cannot condition on wealth, all regions must equally contribute to it, and the constraint (20) becomes:

$$m(y) = \mathbf{M},\tag{31}$$

for every *y*. Imposing this constraint is akin to requiring uniform contributions from all regions. In this case, $\Omega_0 < 0$ and $\Omega_1 > 1$ and we obtain the following result:

Corollary 3 Suppose $\sigma_z = \sigma_v = 0$. Suppose also that condition (31) holds. Then $\hat{\gamma} < \gamma$ and $\hat{\beta} < \beta$. Also, $\mathbf{K} > \mathbf{K}^{FB}$ and $\mathbf{M} < \mathbf{M}^{FB}$.

Thus, in an economy with wealth inequality across regions, asking for homogeneous contributions to carbon capture leads to a less aggressive climate policy relative to the Pareto optimum. The economy with heterogeneous regions behaves now as a representative region economy with a higher discount factor and a lower climate damage elasticity - both parameters consistent with a less stringent climate policy.

Intuitively, a more aggressive climate policy exacerbates inequality when no redistributive mechanisms are available to mitigate its effects. This is reminiscent of Dávila et al. (2012), who show that when wealth inequality is the main determinant of consumption dispersion, the planner wants to reduce the relative importance of non-labor income, which requires a capital increase (i.e., also an increase in emissions in this economy) and inducing higher wages. In this economy, such compromise reduces the marginal effect of capital, and thus, it also requires a reduction of carbon capture.

Overall, these results show that the stance of global climate policy ultimately depends on the availability of redistributive mechanisms among unequal regions. Importantly, this implies that inequality *per se* does not entail a compromise on global climate policy.

Adding climate heterogeneity. Next, we consider the case in which wealth inequality and climate heterogeneity exist. When all regions contribute to carbon capture, there is an

additional source of dispersion in second-period income due to wage differences across regions. To the extent that more vulnerable regions save more but consume less in the second period, η and c_1 are negatively correlated, and Ω_0 is positive. This mechanism carries through the case in which some regions contribute, and others do not. Thus, we obtain the following result:

Corollary 4 Suppose $\sigma_{\gamma} = 0$. Then $\hat{\gamma} > \gamma$. Also, $\mathbf{K} < \mathbf{K}^{FB}$.

Introducing climate heterogeneity breaks down aggregation, even when all regions contribute to carbon capture. The reason is simple: differences in climate vulnerability translate into differences in labor income and, thus, consumption, which the planner cannot handle because the contributions are not contingent on climate vulnerability. Instead, the planner seeks additional redistribution by reducing the relative importance of labor income. This requires lower capital and emissions. It is not possible to characterize global carbon capture analytically. In Section 6, we explore the effect of climate heterogeneity over emissions and carbon capture in a numerical example.

Adding climate uncertainty. Finally, we consider the case where regional differences stem from wealth inequality and climate uncertainty. The main difference with the previous two cases is that the precautionary motive to save translates into over-accumulation of capital relative to a representative agent economy. When all regions contribute to carbon capture, the planner cannot undo consumption dispersion by choosing the region's contribution to carbon capture. However, any remaining dispersion is unrelated to wealth. This means that Ω_0 equals zero. It is easy to check that this implies Ω_1 equals one. Hence, we obtain the following result:

Corollary 5 Suppose $\sigma_z = 0$. Suppose also that condition (20) is not binding with $\underline{m} = 0$. Then $\hat{\gamma} = \gamma$ and $\hat{\beta} = \beta$. Also, $(\mathbf{K}, \mathbf{M}) = (\mathbf{K}^{FB}, \mathbf{M}^{FB})$.

This result suggests that capital accumulation due to precautionary savings does not necessarily entail a concern for climate goals. The global planner wants regions to save more to finance carbon capture, and precautionary savings are a blessing as long as all regions contribute to it. When some regions do not (condition 20 binds for some *y*), determining analytically how Ω_0 and Ω_1 change is not possible. In the next section, we quantitatively explore the implication of adding climate uncertainty when some regions do not contribute to financing global carbon capture.

6 Numerical Example

In this section, we report the results of a numerical exercise that illustrates the interplay between climate policy and inequality. We first perform comparative statics with respect to wealth inequality, measured by σ_y , and the extent of feasible redistribution across regions, captured in $\bar{\mu}$. In each case, we compare the net global emissions under laissez-faire to those corresponding to the constrained efficient outcome. In addition, we report the schedule of net emissions across the wealth distribution.

6.1 Parameters

Since the discount factor plays a limited role in the results, we set $\beta = 1$. We take $\alpha = 1/3$, which pins down the share of global income that accrues to owners of capital. For the parameter γ in the damage function we take the average considered in Golosov et al. (2014). Since in their paper γ is associated to a given amount of global damage, we then set the degradation rate ξ_d so as to imply a global damage of 3% of global GDP in a business-as-usual scenario (BAU). To do that, we interpret the laissez-faire equilibrium without heterogeneity as BAU. In the case of the restoration rate ξ_g , we set it to the average between the value that satisfies Assumption 1 with equality and the value that makes zero global

net emissions optimal in the representative region economy (see Proposition 2).

We choose the stochastic properties of exposure shocks so that they are TFP-neutral at the global scale, which pins down $\mu_{\epsilon} = \gamma \sigma_{\epsilon}^2/2$. The value of σ_{ϵ} determines how capital is distributed across regions (see equation (17)). We set it equal to 24250, which implies a standard deviation of 0.82 in the distribution of capital $\chi(\epsilon)$. When considering an environment with heterogeneity, we attribute all dispersion to *z*, whereas in an environment with only exposure uncertainty we attribute it to *v*. Finally, for the dispersion in wealth we consider a grid going from 0 to 0.15 and set the benchmark value of σ_y equal to 0.08. Table 1 in the appendix summarizes our parameter choice.

6.2 **Results**

Let us consider first the effect of varying σ_y , assuming there is no climate inequality, but imposing different limits to redistribution. We report the global net emissions as a share of the gross emissions that occur in the laissez-faire equilibrium of an economy with a representative region. In Figure 1, the diamond-marked horizontal lines correspond to outcomes of a representative region economy. In the laissez-faire outcome (*LF-RA*), there is no sequestration and thus net emissions and gross emissions are the same; this corresponds to the line at the top of the figure. In the constrained efficient outcome (*CE-RA*) climate policy calls for reducing global net emissions, in approximately 50%. The fact that net zero is not optimal in this case is not surprising given our choice of the restoration rate ξ_g . Nevertheless, the wedge between these two horizontal lines is a measure of the extent to which mitigation and sequestration are desirable, from a societal perspective, in a representative agent environment.

The figure also depicts the constrained-efficient outcome in a world with different degrees of wealth inequality and in which the global planner faces limits to redistribution (*CE-HA*). We consider two extremes $\mu(y) \ge 0$ and $\mu(y) \ge 0.98$, and the intermediate case



Figure 1: Global Net Emissions with Wealth Inequality.

Notes: The horizontal axis measures the standard deviation of log wealth. *LF RA*: laissez-faire equilibrium with $\sigma_y = \sigma_{\epsilon} = 0$; *CE RA*: constrained efficient solution with $\sigma_y = \sigma_{\epsilon} = 0$; *CE HA*: constrained efficient solution with $\sigma_{\epsilon} = 0$ and $\sigma_y > 0$.

 $\mu(y) \ge 0.8$ as an illustration; all the other cases must be bracketed by the two extreme cases. We observe that when the limits to redistribution are loose ($\mu(y) \ge 0$), more inequality *always* implies a more stringent climate policy, demanding more emission cuts and carbon capture relative to the first best. Moreover, net zero emerges as a natural global objective when inequality is sufficiently large. This is still the case even if conditioning the contributions to each region's economic background becomes more difficult ($\mu(y) \ge 0.8$). Eventually, however, as the limits to redistribution become tighter ($\mu(y) \ge 0.98$), increas-

ing wealth inequality leads to compromising on global climate goals. In fact, as the figure shows, if inequality is too large carbon capture responsibilities are close to uniform, optimal net emissions do not stray too far from the laissez-faire economy.

We turn next to analyze the optimal net emissions schedule. Our benchmark corresponds to the economy with wealth inequality given by $\sigma_y = 0.08$. Figure 2 displays this schedule when regions are partitioned into quartiles of the wealth distribution, along with the burden corresponding to the richest 5% of regions. In the left hand-side, we express net emissions as a fraction of gross emissions under laissez-faire and in the right handside, as a fraction of the average wealth of each group. When limits to redistribution are loose ($\mu(y) \ge 0$), the poorest regions get a "free-pass" on sequestration efforts; their emissions are as large as they would be in the laissez-faire economy. Emissions are still positive for regions in the second quartile, but they engage in some carbon capture. Most of the capture is done, however, by regions in the top of the wealth distribution. As the limits to redistribution tighten ($\mu(y) \ge 0.80$), the net emissions schedule rotates counterclockwise which implies increasing the burden of carbon capture at the bottom of the distribution and alleviating it at the top. In the limit ($\mu(y) \ge 0.98$), the burden is almost uniform across regions but, as discussed previously, the global net emissions goal is far from net-zero.

We now introduce climate inequality. We take as the benchmark the economy in which the limits to redistribution are $\mu(y) \ge 0.8$. While this choice is arbitrary, it provides a good benchmark for two reasons: it prescribes global net-zero emissions when wealth inequality is set at the benchmark value of 0.08, and it acknowledges that while the design of climate policy surely faces limits to redistribution, these might not be too extreme so as to require an homogeneous burden in carbon capture.

In the left-hand side of Figure 3, we display the change in global net emissions with respect to an economy with only wealth inequality when we introduce climate inequality. We note that the interaction between climate and economic inequality depends on the na-



Figure 2: Net Emissions Schedule with Wealth Inequality.

Notes: The horizontal axis measures the implied global damage in production for each value of ξ_d considered. *LF RA*: laissez-faire equilibrium with $\sigma_z = \sigma_\epsilon$; *CE RA*: constrained efficient solution with $\sigma_\epsilon = \sigma_y = 0$; *CE HA*: constrained efficient solution with $\sigma_\epsilon \ge 0$ and $\sigma_y > 0$.

ture of differences in climate vulnerability. When these constitute pre-existing differences, whether the global target of net emissions is higher or lower will depend on the degree of wealth inequality. Specifically, climate policy is more lenient if wealth inequality is low and more stringent if it is high. When the difference in climate vulnerability is due to climate uncertainty, however, the constrained-efficient policy always prescribes a lower objective for global net emissions, and the policy is more stringent the higher the wealth inequality.

At the benchmark level of wealth inequality $\sigma_y = 0.08$, both the economy with climate heterogeneity and the one with climate uncertainty prescribe global net emissions to be reduced by approximately 10%. In the right-hand side of Figure 3, we fix σ_y to its benchmark and examine the change in the net emission schedule relative to the economy with only wealth inequality that prescribes global net zero. A key difference between hetero-



Figure 3: Global Net Emissions with Wealth and Climate Inequality.

Notes: The figure in the left shows the change in global net emissions relative prescribed by an economy with climate inequality relative to an economy without it. The figure in the right shows the change in the net emissions schedule of the policy that corresponds to $\sigma_y = 0.08$, which calls for the same global net emissions target under the two forms of climate inequality. *CE HA YH*: constrained efficient solution with $\sigma_z > 0$, $\sigma_y > 0$ and $\sigma_v = 0$; *CE HA YU*: constrained efficient solution with $\sigma_z = 0$, $\sigma_y > 0$ and $\sigma_v > 0$.

geneity and uncertainty emerges. In relative terms, the constrained efficient net emission schedule puts the burden of adjustment on the bottom of the distribution when climate inequality comes from pre-existing differences in climate vulnerability. The opposite is true when the climate inequality emerges from uncertain climate shocks. The reason for this difference lies on what is the margin of adjustment to attain the global net emissions goal; in the case of heterogeneity is trough more emission cuts while in the case of uncertainty is through more global carbon capture.

7 Conclusions

We lay out a model with heterogeneous regions and a carbon capture technology to study the effect that inequality has on the design of climate policy. Our focus is on the choice of the global net emissions target, and the net emissions schedule across regions. We show that inequality has in fact a non-trivial effect on climate policy, which ultimately depends both on its source and on its magnitude.

We highlight two takeaways from our analysis. First, in an unequal world, the choice of a net emissions schedule across countries can be an effective tool to attain global climate goals. This requires the ability to make the contributions of each country to global carboncapture conditional on their wealth. Second, if all nations are mandated to contribute uniformly to financing carbon capture, wealth inequality acts as a hindrance to collective climate efforts. In such a scenario, global emissions will remain high, and carbon offsetting will be low.

From a positive perspective, the results in this paper resonate with some of the global climate goals in the Paris Agreement. One of the commitments is to reach global net zero emissions by the year 2050. Following the agreement, countries have been evaluated individually regarding their progress towards net zero (see ClimateTracker. Nevertheless, whether it is optimal to attain the target country by country or in the aggregate remains an open question. In this paper, we show that the constrained-efficient policy in an economy with heterogeneous regions is to reach a homogeneous global net emissions target (i.e., "net-zero by 2050" from the Paris Agreement) with *net negative* emissions in high-income countries and *net positive* emissions in low-income ones.

Our model can be extended to an infinite horizon setup, more suitable to a quantitative exploration that considers the relative importance of different sources of inequality. We leave this extension for future work.

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Appendix

A Modified Planner's Problem

With the change of variables, the utilitarian planner's problem can be written as follows:

$$\max_{\substack{c_0(y,z), \eta(y,z), c_1(y,\epsilon) \\ \mu(y), \chi(\epsilon), \mathbf{K}, \mathbf{M}}} \int \int \left\{ u(c_0(y,z)) + \beta \mathbb{E}_{\nu} \left[u(c_1(y,\epsilon)) \right] \right\} g(y) \phi(z) \, \mathrm{d}y \, \mathrm{d}z$$

subject to budget constraints:

$$c_0(y,z) = y - \eta(y,z)\mathbf{K} - \mu(y)\mathbf{M} \qquad \forall (y,z),$$
(A.1)

$$c_1(y,\epsilon) = w(\epsilon) + R\eta(y,z)\mathbf{K} \quad \forall (y,\epsilon),$$
 (A.2)

optimal conditions for regional-representative firms:

$$R = \alpha \exp\left(-\gamma \left(\mathbf{S} + \epsilon\right)\right) \left(\chi(\epsilon) \mathbf{K}\right)^{\alpha - 1} \quad \forall \epsilon,$$
(A.3)

$$w(\epsilon) = (1-\alpha) \exp\left(-\gamma \left(\mathbf{S}+\epsilon\right)\right) \left(\chi(\epsilon)\mathbf{K}\right)^{\alpha} \quad \forall \epsilon.$$
(A.4)

and the constraints on the distributions

$$\int \chi(\epsilon)h(\epsilon) \,\mathrm{d}\epsilon = 1 \tag{A.5}$$

$$\int \eta(y,z)g(y)\phi(z)\,\mathrm{d}y\,\mathrm{d}z = 1 \tag{A.6}$$

$$\int \mu(y)g(y)\,\mathrm{d}y = 1 \tag{A.7}$$

We note that $\chi(\epsilon)$ is pinned down by constraints and it will coincide with the laissez-faire outcome.

B Proofs

Proof of Lemma 1

Using the functional forms, first order condition with respect to capital is:

$$R = \alpha \exp(-\gamma (\mathbf{S} + \epsilon)) K(\epsilon)^{\alpha - 1} L(\epsilon)^{1 - \alpha}).$$
(B.1)

Since labor market clearing implies that $L(\epsilon) = 1$ in all regions, we can write

$$K(\epsilon) = \left(\frac{\alpha}{R}\right)^{\frac{1}{1-\alpha}} \exp\left(-\frac{\gamma}{1-\alpha}(\mathbf{S}+\epsilon)\right),\tag{B.2}$$

for all ϵ . Integrating across all regions:

$$\mathbf{K} = \left(\frac{\alpha}{R}\right)^{\frac{1}{1-\alpha}} \exp\left(-\frac{\gamma}{1-\alpha} \left(\mathbf{S} + \mu_{\epsilon} - \frac{\gamma}{1-\alpha} \frac{\sigma_{\epsilon}^2}{2}\right)\right),\tag{B.3}$$

where we have used the fact that if z and v are normally distributed and independent, ϵ is also normally distributed. Hence, the share of global capital allocated to each region is

$$\chi(\epsilon) = \exp\left(-\frac{\gamma}{1-\alpha}\left(\epsilon - \mu_{\epsilon} + \frac{\gamma}{1-\alpha}\frac{\sigma_{\epsilon}^2}{2}\right)\right),\tag{B.4}$$

for all ϵ . For later use in the numerical example, note also that if $\mu_{\epsilon} = \gamma \sigma_{\epsilon}^2/2$, then the share of global capital allocated to each region is

$$\chi(\epsilon) = \exp\left(-\frac{\gamma}{1-\alpha}\left(\epsilon + \gamma \frac{\alpha}{1-\alpha} \frac{\sigma_{\epsilon}^2}{2}\right)\right),\tag{B.5}$$

for all ϵ .

To obtain the expression that characterizes the distribution of asset holdings, we use the Euler equation of each household in each region

$$\frac{1}{c_0(y,z)} = \beta R \mathbb{E}\left[\frac{1}{c_1(y,z,\nu)}\right],\tag{B.6}$$

for all *y*, *z*, and *v*. Since the public good is not provided in equilibrium, household assets are $a(y, z) = \eta(y, z)\mathbf{K}$. Using this in the first period budget constraint budget constraints yields

$$c_0(y,z) = y - \eta(y,z)\mathbf{K},\tag{B.7}$$

for all y, and z. Household consumption in the second period can be written as follows

$$c_1(y,\epsilon) = w(\epsilon) + \eta(y,z)R\mathbf{K},\tag{B.8}$$

and thus

$$\frac{c_1(y,\epsilon)}{R} = \frac{w(\epsilon)}{R} + \eta(y,\epsilon)\mathbf{K},$$
(B.9)

for all *y*, and ϵ . First order conditions of the final good firm 's problem imply

$$\frac{w(\epsilon)}{R} = \frac{1-\alpha}{\alpha} \chi(\epsilon) \mathbf{K},\tag{B.10}$$

for all ϵ . Plugging this into (B.9), and using (B.7) and (B.6), yields (18).

Proof of Lemma 2

Without exposure uncertainty, $\sigma_v = 0$ and thus, $\epsilon = z$. Since the expectation operator in (18) becomes redundant because households do not face any uncertainty, we verify that

$$\eta(y,z) = \frac{1}{1+\beta} \left[\beta \frac{y}{\mathbf{K}} - \frac{1-\alpha}{\alpha} \chi(z) \right], \tag{B.11}$$

for all *y* and *z*, satisfies the Euler equation of each household. Integrating across all regions and using (15) and (16), we can solve for the global capital stock and obtain (19).

Proof of Proposition 1

Integrating both sides of (B.6) across all regions and using the expressions for household consumption deliver

$$\int \frac{1}{y - \eta(y, z)\mathbf{K}} g(y)\phi(z) \, \mathrm{d}y \, \mathrm{d}z = \beta \alpha \int \mathbb{E}\left[\frac{1}{(1 - \alpha)\chi(\epsilon)\mathbf{K} + \alpha \eta(y, z)\mathbf{K}}\right] g(y)\phi(z) \, \mathrm{d}y \, \mathrm{d}z,$$

which determines the global stock of productive capital. The left-hand side increases with **K** and the right-hand side does the opposite. A solution is guaranteed because of properties of marginal utility when preferences are logarithmic. The expectation in the right-hand side is taken with respect to v, which only affects the distribution of productive capital across regions, e.g., $\chi(\epsilon)$. Since marginal utility is convex with respect to $\chi(\epsilon)$, Jensen's inequality implies that the right-hand side is larger in the presence of uncertainty, for any **K**. This implies that the solution to the previous expression increases as the variance of σ_v does.

Proof of Proposition 2

The ability to make transfers allows the planner to make marginal utilities equal across regions. Taking this into account, we can write 23 and 24 as follows:

$$1 = \beta \alpha \frac{1 - \mathbf{K} - \mathbf{M}}{\mathbf{K}} - \beta \left(1 - \mathbf{K} - \mathbf{M} \right) \gamma \xi_d, \tag{B.12}$$

$$1 = \beta (1 - \mathbf{K} - \mathbf{M}) \gamma \xi_g, \tag{B.13}$$

where we assume an interior solution for **M** and we use the fact that second period consumption must be constant and equal to global output **Y**₁, which satisfies $R\mathbf{K} = \alpha \mathbf{Y}_1$. This is a system of two equations and two unknowns. The solution is:

$$\mathbf{K} = \frac{\alpha}{\gamma(\xi_d + \xi_g)},\tag{B.14}$$

$$\mathbf{M} = 1 - \mathbf{K} - \frac{1}{\beta \gamma \xi_g} = 1 - \frac{1 + \alpha \beta + \frac{\xi_d}{\xi_g}}{\beta \gamma (\xi_d + \xi_g)}.$$
(B.15)

Proof of Lemma 3

We conjecture that for any contributing region, the savings choice takes the form:

$$\eta(y,z)\mathbf{K} = (\tilde{\eta}(y) + \tilde{\eta}(z))\mathbf{K}.$$

Using this guess, the first order condition with respect to $\mu(y)$ is

$$\mathbb{E}\left[\frac{\mathbf{M}}{y - (\tilde{\eta}(y) + \tilde{\eta}(z))\mathbf{K} - \mu(y)\mathbf{M}}\right] = \Lambda^{\mu},\tag{B.16}$$

for any contributing region, where the expectation in the left hand side is taken with respect to *z*, and Λ^{μ} is the Lagrange multiplier that corresponds to the constraint (A.7) in the modified planner's problem. Since the right hand side does not depend on differences across regions, the terms that depend on *y* on the left hand side must be constant. From this observation, we obtain

$$\mu(\mathbf{y}) = \frac{1 - \overline{\mu}G(\overline{\mathbf{y}})}{1 - G(\overline{\mathbf{y}})} + \frac{\mathbf{y} - \mathbb{E}[\mathbf{Y} \mid \mathbf{Y} \ge \overline{\mathbf{y}}]}{\mathbf{M}} - \frac{\widetilde{\eta}(\mathbf{y}) - \mathbb{E}[\widetilde{\eta}(\mathbf{Y}) \mid \mathbf{Y} \ge \overline{\mathbf{y}}]}{\mathbf{M}},$$

for any contributing region. Now, the first order condition with respect to $\eta(y, z)$ delivers

$$\frac{1}{y - (\tilde{\eta}(y) + \tilde{\eta}(z))\mathbf{K} - \mu(y)\mathbf{M}} = \beta R \mathbb{E} \left[\frac{1}{w(z, v) + R(\tilde{\eta}(y) + \tilde{\eta}(v))\mathbf{K}} \right] + \Lambda^{\eta}$$
(B.17)

for contributing regions, where the expectation in the right hand side is taken with respect to ν , and Λ^{η} denotes the multiplier corresponding to the constraint (A.6). Note that for a

contributing region, the left-hand side depends on *z* but not on *y*. Therefore, the same must be true for the right-hand side. This implies that $\tilde{\eta}(y)$ is constant for contributing regions and thus:

$$\mu(\mathbf{y}) = \frac{1 - \overline{\mu}G(\overline{\mathbf{y}})}{1 - G(\overline{\mathbf{y}})} + \frac{\mathbf{y} - \mathbb{E}[\mathbf{y} \mid \mathbf{y} \ge \overline{\mathbf{y}}]}{\mathbf{M}},$$

and $\tilde{\eta}(z)$ is defined implicitly in (B.17) for contributing regions. For regions with $y < \bar{y}$ we must have $\mu(y) = \bar{\mu}$.

Proof of Proposition 3

We perform the two change of variables. First we define $\tilde{a} = a + m$ and write the individual budget constraints as follows:

$$c_0 + \tilde{a} \leq y, \tag{B.18}$$

$$c_1 \leq R(\tilde{a} - m) + w(\epsilon). \tag{B.19}$$

Next, we let the planner choose **A** and θ where:

and the distribution of asset holdings across regions $\tilde{\eta}$, which satisfies $\tilde{a} = \tilde{\eta}(y, z)\mathbf{A}$. The distribution η of the original problem can then be recovered from the definition of \tilde{a} , which implies

$$\eta(y, z)\mathbf{K} = \tilde{\eta}(y, z)\mathbf{A} - \mu(y)\mathbf{M},\tag{B.20}$$

for all *y* and *z*. We characterize the solution to the planner's problem using these changes.

First order condition with respect to θ :

$$\beta \mathbb{E}\left[\frac{-R\mu(y)\mathbf{A} - \frac{\partial R}{\partial K}\chi(\epsilon)(\eta(y,z) - \theta\mu(y))\mathbf{A}\mathbf{A} - \frac{\partial w}{\partial K}\chi(\epsilon)\mathbf{A} + \gamma(\xi_d + \xi_g)\mathbf{A}c_1(y,\epsilon)}{c_1(y,\epsilon)}\right] = 0$$

where the expectation is taken using the distributions of *y*, *z* and *v*. We simplify this to

$$\mathbb{E}\left[\frac{R\mu(y) + \frac{\partial R}{\partial K}\chi(\epsilon)(\eta(y,z) - \theta\mu(y))\mathbf{A} + \frac{\partial w}{\partial K}\chi(\epsilon) - \gamma(\xi_d + \xi_g)c_1(y,\epsilon)}{c_1(y,\epsilon)}\right] = 0$$

Using the pricing functions and properties of the production function:

$$\mathbb{E}\left[\frac{(1-\theta)R\mu(y) - F_{LK}(\eta(y,z) - \theta\mu(y)) + (1-\theta)F_{LK}\chi(\epsilon) - (1-\theta)\gamma(\xi_d + \xi_g)c_1(y,\epsilon)}{(1-\theta)c_1(y,\epsilon)}\right] = 0$$

Now, we note that we can write:

$$\frac{\alpha c_1(y,\epsilon)}{\mathbf{A}} = (1-\theta)\chi(\epsilon)F_{LK} - F_{LK}(\eta(y,\epsilon) - \theta\mu(y)) + R(\eta(y,\epsilon) - \theta\mu(y))$$

Using this in the previous first order condition yields

$$\frac{\alpha}{(1-\theta)\mathbf{A}} - \mathbb{E}\left[\frac{R(\eta(y,\epsilon) - \mu(y))}{(1-\theta)c_1}\right] = \gamma(\xi_d + \xi_g)$$

Noting again that

$$\frac{\alpha c_1(y,\epsilon)}{R} = \chi(\epsilon)(1-\theta)\mathbf{A} + \alpha(\eta(y,\epsilon) - \chi(\epsilon))\mathbf{A} - \alpha(\mu(y) - \chi(\epsilon))\theta\mathbf{A}$$

We obtain

$$(1-\theta)\mathbf{A} = \frac{\alpha - \Omega_0}{\gamma(\xi_d + \xi_g)} \tag{B.21}$$

where

$$\Omega_0 = \mathbb{E}\left[\frac{\alpha(1-\theta)(\eta(y,\epsilon)-\mu(y))}{(1-\alpha)\chi(\epsilon)(1-\theta)+\alpha\eta(y,\epsilon)-\alpha\mu(y)\theta}\right]$$

Therefore, **K** depends purely on the sign of Ω_0 .

Next, the first order condition with respect to A delivers

$$\mathbb{E}\left[\frac{\eta(y,\epsilon)}{y-\eta(y,\epsilon)\mathbf{A}}\right] = \beta \mathbb{E}\left[\frac{R(\eta(y,\epsilon) - \theta\mu(y)) - \gamma \frac{\Pi(\mathbf{A},\theta)}{\mathbf{A}}c_1 - F_{LK}(\eta(y,\epsilon) - \theta\mu(y)) + F_{LK}\chi(\epsilon)(1-\theta)}{c_1(y,\epsilon)}\right]$$

which once more simplifies to

$$\mathbb{E}\left[\frac{\eta(y,\epsilon)}{y-\eta(y,\epsilon)\mathbf{A}}\right] = \beta \frac{\alpha - \gamma \Pi(\mathbf{A},\theta)}{\mathbf{A}}$$

We define

$$Q \equiv \mathbb{E}\left[\frac{\eta(y,\epsilon)\mathbf{A}}{y - \eta(y,\epsilon)\mathbf{A}}\right]$$

which implies

$$Q = \beta(\alpha - \gamma \Pi(\mathbf{A}, \theta))$$

We then use (B.21) to write

$$\gamma \Pi(\mathbf{A}, \theta) = \gamma \left(\xi_d \frac{\alpha - \Omega_0}{\gamma(\xi_d + \xi_g)} - \xi_g \left(\mathbf{A} - \frac{\alpha - \Omega_0}{\gamma(\xi_d + \xi_g)} \right) \right)$$

which delivers

$$\mathbf{A} = \frac{Q - \beta \Omega_0}{\beta \gamma \xi_g}$$

We now look now for an expression for $Q - \beta \Omega_0$. The first order condition with respect to

 $\eta(y,z)$ is

$$\frac{\mathbf{A}}{y - \eta(y, z)\mathbf{A}} = \beta \mathbb{E}\left[\frac{R\mathbf{A}}{c_1(y, \epsilon)}\right] + \Lambda$$

where Λ is the Lagrange multiplier on the constraint $\int \eta(y, z)g(y)\phi(z) \, dy \, dz \ge 1$, and the expectation in the right-hand side is taken with respect to the exposure shock ν . Multiplying both sides by $\eta(y, z)$ and aggregating across regions delivers

$$\mathbb{E}\left[\frac{\eta(y,z)\mathbf{A}}{y-\eta(y,z)\mathbf{A}}\right] = \beta \mathbb{E}\left[\frac{R\mathbf{A}\eta(y,z)}{c_1(y,\epsilon)}\right] + \Lambda$$

Using the expression for $c_1(y, \epsilon)/RA$ allows us to write

$$Q = \Lambda + \frac{\alpha\beta}{1-\theta} \mathbb{E}\left[\frac{(1-\theta)\eta(y,z)}{(1-\alpha)(1-\theta)\chi(\epsilon) + \alpha(\eta(y,z) - \theta\mu(y))}\right]$$
$$Q - \beta\Omega_0 = \Lambda + \frac{\alpha\beta}{1-\theta} \mathbb{E}\left[\frac{(1-\theta)\mu(y)}{(1-\alpha)(1-\theta)\chi(\epsilon) + \alpha(\eta(y,z) - \theta\mu(y))}\right]$$

To save on notation, we let $\tilde{\mathbb{E}}[x]$ stand for

$$\tilde{\mathbb{E}}[x] = \mathbb{E}\left[\frac{(1-\theta)x}{(1-\alpha)(1-\theta)\chi(z) + \alpha(\eta(y,z) - \theta\mu(y))}\right]$$

Plugging these expressions in (B.22) and then in the first order condition with respect to η allows us to write

$$\frac{\Lambda + \frac{\alpha\beta}{1-\theta}\tilde{\mathbb{E}}\left[\mu(y)\right]}{\beta\gamma\xi_{g}y - \eta(y,z)(Q - \beta\Omega_{0})} = \Lambda + \frac{\alpha\beta}{1-\theta}\tilde{\mathbb{E}}_{\nu}\left[1\right]$$

Rearranging and aggregating across regions delivers

$$Q - \beta \Omega_0 = \beta \gamma \xi_g - \mathbb{E} \left[\frac{\Lambda + \frac{\alpha \beta}{1 - \theta} \tilde{\mathbb{E}} \left[\mu(y) \right]}{\Lambda + \frac{\alpha \beta}{1 - \theta} \tilde{\mathbb{E}}_{\nu} \left[1 \right]} \right]$$

We define then

$$\Omega_{1} = \mathbb{E}\left[\frac{\Lambda + \frac{\alpha\beta}{1-\theta}\tilde{\mathbb{E}}\left[\mu(y)\right]}{\Lambda + \frac{\alpha\beta}{1-\theta}\tilde{\mathbb{E}}_{\nu}\left[1\right]}\right],\tag{B.22}$$

and note that in the absence of any source of inequality, $\Omega_1 = 1$.

We finally obtain:

$$\mathbf{K} = \frac{\alpha - \Omega_0}{\gamma(\xi_d + \xi_g)},\tag{B.23}$$

$$\mathbf{M} = 1 - \frac{\alpha - \Omega_0}{\gamma(\xi_d + \xi_g)} - \frac{\Omega_1}{\beta \gamma \xi_g}, \tag{B.24}$$

$$\mathbf{A} = \frac{\beta \gamma \xi_g - \Omega_1}{\beta \gamma \xi_g}. \tag{B.25}$$

Finally, we recover the expressions in the main text by noticing that we can use (B.20) to write:

$$\tilde{\eta}(y,z) - \mu(y) = (1 - \theta)(\eta(y,z) - \mu(y)),$$
(B.26)

$$\tilde{\eta}(y,z) - \theta \mu(y) = (1-\theta)\eta(y,z), \tag{B.27}$$

(B.28)

for all *y* and *z*.

Proof of Corollary 2

The dispersion in second-period consumption among regions and Jensen's inequality imply that Ω_1 is below one. We establish that as long as aggregate savings are positive for non-contributing regions, the sign of the between-group covariance dominates and Ω_0 is positive. To show this, it is useful to classify regions in two groups: contributing and noncontributing. According to this classification, while the within-group covariance between $\eta(y) - \mu(y)$ and marginal utility is negative, the between-group one is actually positive, as the conditional expectation of $\eta(y) - \mu(y)$ is smaller than zero for contributing regions. It is sufficient to show that Ω_0 is positive. Let

$$N(y) = \eta(y) - \mu(y)$$

$$D(y) = ((1 - \alpha)(1 - \theta) + (\eta(y) - \theta\mu(y)))^{-1}$$

Then the sign of Ω_0 is the same as the sign of $\mathbb{E} [\mathbb{N}(y) \cdot \mathbb{D}(y)]$. We can write:

$$\begin{split} \mathbb{E}\left[\mathbb{N}(y) \cdot \mathbb{D}(y)\right] &= \mathbb{E}\left[\mathbb{C} \circ v\left(\mathbb{N}(y), \mathbb{D}(y) \mid y\right)\right] + \mathbb{C} \circ v\left(\mathbb{E}\left[\mathbb{N}(y) \mid y\right], \mathbb{E}\left[\mathbb{D}(y) \mid y\right]\right) \\ &= \mathbb{C} \circ v\left(\mathbb{N}(y), \mathbb{D}(y) \mid y\right) \Pr[y \ge \overline{y}] + \mathbb{C} \circ v\left(\mathbb{N}(y), \mathbb{D}(y) \mid y\right) \Pr(y < \overline{y}) \\ &+ \mathbb{C} \circ v\left(\mathbb{E}\left[\mathbb{N}(y) \mid y\right], \mathbb{E}\left[\mathbb{D}(y) \mid y\right]\right) \end{split}$$

Since D(y) is constant across contributing regions, the first term in the right-hand side equals zero. Using properties of the covariance, we use:

$$\operatorname{Cov}\left(\mathbb{N}(y), \mathbb{D}(y) \mid y < \overline{y}\right) = \operatorname{Cov}\left(\mathbb{N}(y), \mathbb{D}(y) - \mathbb{E}[\mathbb{D}(y)] \mid y < \overline{y}\right)$$

and then write

$$\mathbb{E}\left[\mathbb{N}(y) \cdot \mathbb{D}(y)\right] = \mathbb{Cov}\left(\mathbb{N}(y), \mathbb{D}(y) - \mathbb{E}[\mathbb{D}(y)] \mid y < \overline{y}\right) \Pr(y < \overline{y}) \\ + \left(\mathbb{E}\left[\mathbb{N}(y) \mid y \ge \overline{y}\right] - \mathbb{E}[\mathbb{N}(y)]\right) \left(\mathbb{E}\left[\mathbb{D}(y) \mid y \ge \overline{y}\right] - \mathbb{E}[\mathbb{D}(y)]\right) \Pr(y \ge \overline{y}) \\ + \left(\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right] - \mathbb{E}[\mathbb{N}(y)]\right) \left(\mathbb{E}\left[\mathbb{D}(y) \mid y < \overline{y}\right] - \mathbb{E}[\mathbb{D}(y)]\right) \Pr(y < \overline{y})$$

Using the fact that $\mathbb{E}[N(y)] = 0$ and since

$$Cov(N(y), D(y) - \mathbb{E}[D(y)] | y < \overline{y}) = \mathbb{E}[N(y)(D(y) - \mathbb{E}[D(y)]) | y < \overline{y}]$$
$$- \mathbb{E}[N(y) | y < \overline{y}]\mathbb{E}[(D(y) - \mathbb{E}[D(y)]) | y < \overline{y}]$$

we obtain

$$\mathbb{E}\left[\mathbb{N}(y) \cdot \mathbb{D}(y)\right] = \mathbb{E}\left[\mathbb{N}(y)(\mathbb{D}(y) - \mathbb{E}[\mathbb{D}(y)]) \mid y < \overline{y}\right] \Pr(y < \overline{y}) \\ + \mathbb{E}\left[\mathbb{N}(y) \mid y \ge \overline{y}\right] \left(\mathbb{E}\left[\mathbb{D}(y) \mid y \ge \overline{y}\right] - \mathbb{E}[\mathbb{D}(y)]\right) \Pr(y \ge \overline{y})$$

Using again $\mathbb{E}[\mathbb{N}(y)] = 0$ we rewrite

$$\mathbb{E}\left[\mathbb{N}(y) \cdot \mathbb{D}(y)\right] = \mathbb{E}\left[\mathbb{N}(y)(\mathbb{D}(y) - \mathbb{E}[\mathbb{D}(y)]) \mid y < \overline{y}\right] \Pr(y < \overline{y}) \\ -\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right] \left(\mathbb{E}\left[\mathbb{D}(y) \mid y \ge \overline{y}\right] - \mathbb{E}[\mathbb{D}(y)]\right) \Pr(y < \overline{y})$$

We operate in the first term in the right hand side without altering the equation

$$\mathbb{E}\left[\mathbb{N}(y) \cdot \mathbb{D}(y)\right] = \mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right] \mathbb{E}\left[\frac{\mathbb{N}(y)}{\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right]} (\mathbb{D}(y) - \mathbb{E}[\mathbb{D}(y)]) \mid y < \overline{y}\right] \Pr(y < \overline{y}) \\ -\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right] \left(\mathbb{E}\left[\mathbb{D}(y) \mid y \ge \overline{y}\right] - \mathbb{E}[\mathbb{D}(y)]\right) \Pr(y < \overline{y})$$

And thus

$$\mathbb{E}\left[\mathbb{N}(y) \cdot \mathbb{D}(y)\right] = \mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right] \left(\mathbb{E}\left[\frac{\mathbb{N}(y)}{\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right]} (\mathbb{D}(y)) \mid y < \overline{y}\right] - \mathbb{E}[\mathbb{D}(y)]\right) \Pr(y < \overline{y}) - \mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right] \left(\mathbb{E}\left[\mathbb{D}(y) \mid y \ge \overline{y}\right] - \mathbb{E}[\mathbb{D}(y)]\right) \Pr(y < \overline{y})$$

Which implies:

$$\mathbb{E}\left[\mathbb{N}(y) \cdot \mathbb{D}(y)\right] = \mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right] \left(\mathbb{E}\left[\frac{\mathbb{N}(y)}{\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right]} \mathbb{D}(y) \mid y < \overline{y}\right] - \mathbb{E}\left[\mathbb{D}(y) \mid y \ge \overline{y}\right]\right) \Pr(y < \overline{y})$$

To the extent taht $\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right]$ is positive for non-contributing regions, the sign of Ω is determined by whether

$$\mathbb{E}\left[\frac{\mathbb{N}(y)}{\mathbb{E}\left[\mathbb{N}(y) \mid y < \overline{y}\right]} \mathbb{D}(y) \mid y < \overline{y}\right] - \mathbb{E}\left[\mathbb{D}(y) \mid y \ge \overline{y}\right]$$

is positive or negative. Since D(y) is basically the marginal utility of each region, the first term is the weighted average marginal utility of non-contributing regions, while the second is the average marginal utility of contributing regions. We know that the former is larger than the latter if it weren't by the fact that it has weights. However, we should note that the marginal utility of *each* non-contributing regions is larger than that of a contributing region, which means that the weighting is innocuous. Therefore, Ω_0 is positive.

C Algorithm for Computation

- 1. Guess **K** and **M**, and translate it into θ and **A**. A good initial guess is the representative agent solution.
- 2. Check if all regions contribute for this initial guess. If not, find the last contributing region. This sets \overline{y}
- 3. Solve for $\{\Lambda, \eta, \mu\}$ as follows:
 - (a) Guess Λ and use this guess to obtain η from Euler equation both for contributing and non contributing regions.
 - (b) Obtain μ give \overline{y} .
 - (c) Check if η adds up to one. If not, adjust Λ
 - (d) Iterate until convergence.
- 4. Use { Λ , η , μ } to obtain { Ω_0 , Ω_1 } according to the expressions of Proposition 3.

- 5. Compute new values for **K** and **M** using Proposition 3.
- 6. Iterate until convergence

D Parameter values

Parameter	Symbol	Benchmark	Comment
Discount factor	β	1	
Capital intensity	α	0.33	
Damage Function			
Elasticity	γ	2.4e-05	\$
Degradation rate	ξ_d	5.1e+02	Ť
Restoration rate	ξ_g	5.6e+04	+
Dispersion			
Wealth	σ_y	0.08	*
Exposure	σ_ϵ	24250	

Table 1: Parameter values

Notes: (\diamond) average reported in Golosov et al. (2014); (\dagger) implied global production damage of 3%; (\ddagger) guarantees slackness of Assumption 1 and positive global net emissions in the representative region case; (\circledast) sensitivity performed with a grid going from 0.01 to 0.15.