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THE MACROECONOMICS OF CLIMATE CHANGE‡

Climate Change and Long-Run Factor Shares†

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Understanding who bears the cost of climate change is a central focus of economists. Much work has focused on the distribution of climate impacts across space and countries, or across the income distribution (e.g., Dell, Jones, and Olken 2012; Diffenbaugh and Burke 2019; Carleton et al. 2022; Nath 2025). Far less attention has been paid to how climate change disproportionately affects labor versus capital, despite the distribution of income between these factors being central to aggregate inequality in the macroeconomics literature (Karabarbounis and Neiman 2014; Grossman and Oberfield 2022). A limited body of empirical work has found that climate change will reduce the labor share in the United States because of automation in response to higher temperatures (Qiu and Yoshida 2024), as well as globally because climate damages are biased toward harming capital productivity more than labor productivity (Liu, Rudik, and Xu 2026).

In this paper, we analyze how climate change affects the long-run distribution of income between labor and capital under a general class of balanced growth models. We do so by mapping temperature into factor-augmenting productivities and leveraging insights from factor-augmenting technical change literature.[1] In our model, households supply labor and capital to firms that produce output using a constant returns to scale production function. Production is subject to labor- and capital-augmenting productivities, which are affected by temperature. Under this setup, we show that temperature's long-run effect on the division of income only depends on the elasticity of substitution between labor and capital and how temperature affects capital-augmenting productivity. Labor-augmenting productivity and the elasticity of labor supply do not directly affect temperature's long-run impact on factor shares. In the long run, only capital productivity effects matter for the climate's distributional effects. If labor and capital are complements, as found in the empirical literature (Raval 2019; Oberfield and Raval 2021; Liu, Rudik, and Xu 2026), then the labor share declines if and only if higher temperatures reduce capital-augmenting productivity.

I. Model

A. *Representative Firm*

A profit-maximizing representative firm produces output by combining capital K_t and labor L_t using a standard neoclassical production function with constant returns to scale in its two arguments:

$$Y_t = F(A_t K_t, B_t L_t), \tag{1}$$

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[1] See Acemoglu (2003) on labor- versus capital-augmenting technical change in growth models, and Acemoglu and Restrepo (2018) for factor-share comparative statics with fixed factor supply under capital-augmenting technology governed by the elasticity of substitution.

where $F(\cdot)$ is continuously differentiable and concave. The elasticity of substitution between capital and labor is defined as $\sigma_{KL} \equiv \frac{F_K F_L}{F \cdot F_{KL}}$, where subscripts denote derivatives of $F(A_t K_t, B_t L_t)$ with respect to (K_t, L_t). A_t is capital-augmenting productivity and B_t is labor-augmenting productivity. We parameterize factor-augmenting productivities so they are log separable into a temperature and a nontemperature component:

$$A_t = A_T(T_t) A_t^e, \quad B_t = B_T(T_t) B_t^e, \tag{2}$$

where T_t is temperature and is taken to be exogenous by the firm.

Input markets are competitive with rental rate r_t and wage w_t. We let the price of output be the numeraire. Lemma 1 derives factor prices and factor shares.

LEMMA 1: *Assume that factor markets are competitive. Under equation (1), the marginal products are*

$$r_t \equiv \frac{\partial Y_t}{\partial K_t} = A_t F_1(A_t K_t, B_t L_t), \quad w_t \equiv \frac{\partial Y_t}{\partial L_t} = B_t F_2(A_t K_t, B_t L_t), \tag{3}$$

where F_i denotes the partial derivative of F with respect to its ith argument. The factor shares of income are

$$s_{K,t} \equiv \frac{r_t K_t}{Y_t} = \frac{(A_t K_t) F_1(A_t K_t, B_t L_t)}{F(A_t K_t, B_t L_t)}, \tag{4}$$

$$s_{L,t} \equiv \frac{w_t L_t}{Y_t} = \frac{(B_t L_t) F_2(A_t K_t, B_t L_t)}{F(A_t K_t, B_t L_t)}, \tag{5}$$

and $s_{K,t} + s_{L,t} = 1$.

PROOF:

See Supplemental Appendix. ∎

B. *Representative Dynasty*

Each household member supplies one unit of labor inelastically, so population equals total labor input L_t. Denote $c_t \equiv C_t / L_t$ as consumption per capita. The representative dynasty chooses a stream of consumption and investment $\{c_t, I_t\}_{t \geq 0}$ to maximize $\sum_{t=0}^{\infty} \beta^t L_t \frac{c_t^{1-\theta}}{1-\theta}$, subject to the resource constraint and capital transition:

$$C_t = Y_t - I_t, \qquad K_{t+1} = (1-\delta) K_t + I_t, \tag{6}$$

where $\beta \in (0,1)$ is the discount factor; $\theta > 0$ is the inverse of the intertemporal elasticity of substitution; and $\delta \in (0,1)$ is the capital depreciation rate.[2] Combining the resource constraint and capital transition yields a single intertemporal budget constraint in terms of consumption, output, and capital:

$$c_t L_t = Y_t - K_{t+1} + (1-\delta) K_t. \tag{7}$$

The household's optimal consumption trajectory is pinned down by its Euler equation:

$$\left(\frac{c_{t+1}}{c_t}\right)^{\theta} = \beta(1 + r_{t+1} - \delta). \tag{8}$$

[2] When $\theta = 1$, the dynasty's objective becomes $\sum_{t=0}^{\infty} \beta^t L_t \log c_t$.

C. *Balanced Growth, Temperature, and Factor Shares*

We assume that the nontemperature component of labor-augmenting productivity B_t^e and the stock of labor L_t grow exogenously at constant rates, $B_{t+1}^e = g_B B_t^e$ and $L_{t+1} = g_L L_t$ with $g_B > 1$ and $g_L > 1$. To be compatible with Uzawa's balanced-growth restriction when $\sigma_{KL} \neq 1$, we assume the nontemperature component of capital-augmenting productivity is constant, $A_t^e = A^e$ for all t.

We detrend (aggregate) output, consumption, and capital as $y_t \equiv \frac{Y_t}{B_t^e L_t}$, $\tilde{c}_t \equiv \frac{C_t}{B_t^e L_t}$, and $k_t \equiv \frac{A_t^e K_t}{B_t^e L_t}$. Along a balanced growth path (BGP) with stationary $(y_t, \tilde{c}_t, k_t)$, the levels (Y_t, C_t, K_t) all grow at the exogenous rate $g_{BL} \equiv \frac{B_{t+1}^e L_{t+1}}{B_t^e L_t} = g_B g_L$.

Fix temperature T and suppose $T_t \equiv T$ in the long run, so $A_T(T)$ and $B_T(T)$ are constant. Under equation (2), the detrended production function can be written as

$$y_t = F\big(A_T(T)\, k_t, \quad B_T(T)\big). \tag{9}$$

Unless otherwise noted, we drop time subscripts when referring to BGP steady-state values.

Rearrange the household Euler equation in equation (8) along a BGP (where per-capita consumption growth is $c_{t+1}/c_t = g_B$) to obtain the steady-state rental rate:

$$r^* = \frac{g_B^\theta}{\beta} - 1 + \delta, \tag{10}$$

which implies that r^* is invariant to the levels of $A_T(T)$ and $B_T(T)$ and thus invariant to climate change in the steady-state comparative statics. Lemma 2 provides an alternative expression from the firm's problem: In equilibrium, the rental rate equals the marginal product of capital, which is a function of detrended quantities and the temperature component of capital-augmenting productivity.

LEMMA 2: *On the balanced growth path, the rental rate satisfies*

$$r^* = A_T(T)\, A^e F_1\big(A_T(T) k, B_T(T)\big). \tag{11}$$

PROOF:

See Supplemental Appendix. ∎

With Lemmas 1 and 2 in hand, we state our main result in Proposition 1 as a steady-state comparative static across constant-temperature BGPs.

PROPOSITION 1: *Suppose the economy is on a BGP with constant temperature T. Assume the nontemperature component of capital-augmenting productivity is constant ($A_t^e \equiv A^e$), so Uzawa (1961)'s balanced-growth conditions hold when $\sigma_{KL} \neq 1$. Then the temperature semi-elasticities of the steady-state factor shares are*

$$\frac{d\log s_K}{dT} = (\sigma_{KL} - 1)\frac{d\log A_T(T)}{dT}, \quad \frac{d\log s_L}{dT} = -\frac{s_K}{s_L}(\sigma_{KL} - 1)\frac{d\log A_T(T)}{dT}, \tag{12}$$

where all objects in equation (12) are evaluated at the BGP steady state.

PROOF:

See Supplemental Appendix. ∎

Proposition 1 highlights several key facts about the long-run effect of temperature on factor income shares. The first is that, assuming that higher temperature reduces capital-augmenting productivity, whether climate change will increase or decrease the labor share depends on the elasticity of substitution between labor and capital, σ_{KL}. The second is that, holding the elasticity of substitution fixed, it is independent of how temperature affects labor-augmenting productivity, $B_T(T)$.

The intuition is as follows. Equation (10) shows that on a BGP, the household Euler equation pins down a unique steady-state rental rate r^* that is invariant to the levels of $A_T(T)$ and $B_T(T)$. Since r^* is pinned down, capital's share is proportional to the capital-output ratio $s_K = \frac{r^* K}{Y} \propto \frac{K}{Y}$. At a steady state, Lemma 1 implies that the rental rate satisfies $r^* = AF_1(AK, BL)$, where F_1 is the marginal product of effective capital services AK. Because F has constant returns to scale, $F_1(AK, BL)$ is homogeneous of degree 0 and depends only on how scarce effective capital AK is relative to effective labor BL. Therefore, holding r^* fixed, a change in $A_T(T)$ must be offset by a change in long-run capital intensity (and hence K/Y) until $AF_1(AK, BL)$ is restored to r^*, which in turn changes $s_K = r^* K/Y$.

Whether s_K rises or falls when $A_T(T)$ falls depends on σ_{KL}. Suppose higher temperature reduces $A_T(T)$, so that effective capital services AK decline for a given physical capital stock. If $\sigma_{KL} < 1$, capital and labor are complements, so this reduction makes effective capital relatively scarcer and pushes up the marginal product of capital. Since the Euler equation pins down the required return at r^*, the economy restores $MPK = r^*$ by accumulating capital, raising the capital-output ratio K/Y. Since $s_K = r^* K/Y$, the increase in K/Y raises the capital share (and lowers the labor share). If instead $\sigma_{KL} > 1$, the long-run adjustment of capital intensity goes in the opposite direction, and the labor share rises.

Why does the effect of temperature on long-run factor shares not depend on its effect on labor-augmenting productivity $B_T(T)$? The central reason is that capital is an endogenous stock variable that can be reallocated across time, while labor is not. Because capital is an intertemporal choice, any shift in MPK must be absorbed by a change in capital intensity to maintain r^*, which is why $A_T(T)$ can move long-run factor shares. However, unlike capital, labor is not intertemporally chosen, so there is no intertemporal condition that pins down the marginal product of labor. As a result, wages respond to changes in $B_T(T)$ so that even though the levels of output and labor-augmenting productivity change, factor shares do not. To see this another way, suppose $B_T(T)$ falls and $\sigma_{KL} < 1$. Effective labor services decline, and output falls. Since the target rental rate remains r^*, capital must adjust so that the effective capital $AK/(BL)$ returns to its steady-state value. This implies that K falls proportionally with BL, so K/Y and factor shares are unchanged even though wages move with the level of output.

The Special Case of CES.—To make the mechanism transparent, consider the firm operating a CES technology $Y_t = \left[\gamma(A_t K_t)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)\,(B_t L_t)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$, where $\sigma_{KL} = \sigma$ is constant. On the balanced growth path, the rental rate is $r^* = \gamma A_T(T)^{\frac{\sigma-1}{\sigma}} A^e \left(\frac{y}{k}\right)^{\frac{1}{\sigma}}$. At a steady state, we can solve the capital-output ratio and capital share as $s_K = \frac{r^* K}{Y} = \gamma^\sigma A_T(T)^{\sigma-1}\left(\frac{A^e}{r^*}\right)^{\sigma-1}$. It's now clearer to see that temperature affects long-run factor shares only through capital-augmenting productivity $A_T(T)$ since the elasticity of substitution is fixed. If higher temperature lowers $A_T(T)$, then effective capital becomes scarcer; when $\sigma < 1$, this raises MPK at a given K/Y, so the economy increases K/Y—and hence s_K—until MPK returns to r^*. When $\sigma > 1$, the adjustment goes in the opposite direction.

D. *A Model with Elastic Labor Supply*

One concern with the prior result is that it may be mechanically driven by an inelastic labor supply. We now extend the baseline model by allowing labor supply to adjust along the intensive margin in the most general case of balanced growth preferences in Boppart and Krusell (2020).

Let total labor input be $L_t \equiv h_t N_t$, where N_t denotes exogenous population growing at g_N and $h_t > 0$ denotes endogenously chosen hours worked per capita.[3] In this case, the production

[3] The inelastic benchmark corresponds to setting $h_t \equiv 1$, so $L_t = N_t$.

technology can now be written as $Y_t = F(A_t K_t, B_t L_t) = F(A_t K_t, B_t h_t N_t)$. The representative dynasty chooses $\{c_t, h_t, K_{t+1}\}_{t\geq 0}$ to maximize

$$\sum_{t=0}^{\infty} \beta^t N_t u(c_t, h_t),$$

subject to the combined resource constraint and capital transition:

$$c_t N_t = Y_t - K_{t+1} + (1-\delta) K_t. \tag{13}$$

We assume period utility $u(c,h)$ belongs to the general class of balanced-growth preferences in Boppart and Krusell (2020). Up to affine transformations, this is characterized by

$$u(c_t, h_t) = \frac{\left(c_t \cdot v\left(h_t c_t^{\frac{\nu}{1-\nu}}\right)\right)^{1-\theta} - 1}{1-\theta} \tag{14}$$

for some twice continuously differentiable function $v(\cdot)$ and $\nu < 1$ governing how the income effect dominates the substitution effect on hours supplied along the BGP.[4,5] A well-known subcase with $\nu = 0$ is the King, Plosser, and Rebelo (1988) preferences, which leave the labor-leisure trade-off unchanged with productivity-driven wage growth.

The household first-order conditions are

$$-\frac{u_h(c_t, h_t)}{u_c(c_t, h_t)} = w_t, \tag{15}$$

$$\frac{u_c(c_t, h_t)}{u_c(c_{t+1}, h_{t+1})} = \beta(1 + r_{t+1} - \delta). \tag{16}$$

Lemma 3 states the balanced-growth implication of the intratemporal condition under (14).

LEMMA 3: *Along a BGP where wage per hour grows at a constant rate* $g_w \equiv \frac{w_{t+1}}{w_t} = g_B$. *If preferences satisfy equation* (14) *for some* $\nu < 1$, *then along the BGP*

$$\frac{h_{t+1}}{h_t} = g_B^{-\nu}, \quad \frac{c_{t+1}}{c_t} = g_B^{1-\nu}. \tag{17}$$

In particular, if $\nu = 0$ (*the King, Plosser, and Rebelo 1988 case*), *then* $h_{t+1} = h_t$ *for all t.*

PROOF:

See Supplemental Appendix. ∎

Lemma 3 shows that in general, for $g_B > 1$, consumption c_t is increasing. Whether the hours supply h_t rises or declines over time depends on whether $\nu < 0$. However, in either case, $h_t c_t^{\frac{\nu}{1-\nu}}$ is constant over time and so is the labor disutility term $v\left(h_t c_t^{\frac{\nu}{1-\nu}}\right)$. Under equation (14), marginal utility

[4] For $\theta = 1$, we let $u(c_t, h_t) = \log(c_t) + \log v\left(h_t c_t^{\frac{\nu}{1-\nu}}\right)$.

[5] It is straightforward to show that our results extend to a broader class of preferences in which temperature directly shifts the labor-leisure margin. In particular, the long-run factor-share conclusions in Proposition 2 continue to hold under preferences of the form $u(c_t, h_t; T_t) = \left[\left(c_t v\left(\psi(T_t)\, h_t c_t^{\nu/(1-\nu)}\right)\right)^{1-\theta} - 1\right] / (1-\theta)$, with $\psi(T) > 0$ governing temperature-induced shifts in labor (dis)utility.

of consumption can be written as $u_c(c,h) = c^{-\theta} m\left(hc^{\frac{\nu}{1-\nu}}\right)$ for some function $m(\cdot)$.[6] The constancy of $hc^{\frac{\nu}{1-\nu}}$ suggests that

$$\frac{u_c(c_t,h_t)}{u_c(c_{t+1},h_{t+1})} = \left(\frac{c_{t+1}}{c_t}\right)^{\theta} = g_B^{\theta(1-\nu)}.$$

Substituting into equation (16) yields the steady-state rental rate:

$$r^* = \frac{g_B^{\theta(1-\nu)}}{\beta} - 1 + \delta, \tag{18}$$

which is similar to equation (10) and is still invariant to the levels of $A_T(T)$ and $B_T(T)$.

Proposition 2 shows that, even when allowing labor supply to adjust endogenously in any balanced-growth-consistent way, we arrive at the same temperature semi-elasticity of factor shares as in the inelastic-labor benchmark.

PROPOSITION 2: *Suppose the economy described above with Boppart and Krusell (2020) preferences is on a BGP at constant temperature T and that* $A_t^e \equiv A^e$. *Then the temperature semi-elasticities of steady-state factor shares satisfy*

$$\frac{d\log s_K}{dT} = (\sigma_{KL} - 1)\frac{d\log A_T(T)}{dT}, \quad \frac{d\log s_L}{dT} = -\frac{s_K}{s_L}(\sigma_{KL} - 1)\frac{d\log A_T(T)}{dT}, \tag{19}$$

where all objects in equation (19) are evaluated at the BGP steady state.

PROOF:

See Supplemental Appendix. ∎

Introducing elastic labor supply does not change the result because balanced-growth preferences imply the leisure term in marginal utility is constant on the BGP, so labor supply does not affect interest rate. The baseline logic therefore continues to apply.

II. Conclusion

With a general neoclassical technology featuring factor-augmenting productivity and balanced-growth-consistent preferences, the long-run effects of climate change on factor shares only depend on how temperature affects capital-augmenting productivity and the elasticity of substitution between labor and capital. In particular, when the aggregate elasticity is below one, temperature-induced damage to capital-augmenting productivity is therefore central to explaining a declining labor share.

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[6] Specifically, $m(z) = v(z)^{-\theta}\left[v(z) + \frac{\nu}{1-\nu} z v'(z)\right]$, where $z = hc^{\frac{\nu}{1-\nu}}$.

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