ECON 164: Theory of Economic Growth

Week 9A: Natural Resources and the Environment

Levi Crews

Winter 2026

Introduction

- **last time**: added factor in **fixed supply** (**land X**) $\rightarrow$ declining GDPpc unless...
  - ...endogenous technological change A wins the race against declining X/L
  - but we treated land as a **renewable resource**: can use the same land over and over

Introduction

- **last time**: added factor in **fixed supply** (**land** X) $\rightarrow$ declining GDPpc unless...
  - ...endogenous technological change A wins the race against declining X/L
  - but we treated land as a **renewable resource**: can use the same land over and over
- **today**: nonrenewable resources (petroleum, coal, natural gas, minerals, ...)
  - like last time: race between A vs. X/L *and* E/L
  - quantify the **drag on growth** from **resource extraction**
  - consider relationship between **GDP per capita** and **pollution**

Production with nonrenewables

Production now also requires **land $\boldsymbol{X}$** and **energy $\boldsymbol{E}$**:

$$Y_t = K_t^{\alpha} \boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}$$

notice: **constant returns to scale** in $\{K, \boldsymbol{E}, \boldsymbol{X}, L\}$

Capital, labor, and technology growth as in the **Solow** model:

$$\dot{K}_t = s_I Y_t - \delta K_t$$
$$\dot{L}_t = g_L L_t$$
$$\dot{A}_t = g_A A_t$$

Resource extraction

To get **energy $\boldsymbol{E}$**, need to extract **nonrenewable resource** w/ initial stock $\boldsymbol{R_0}$:

$$\dot{\boldsymbol{R}}_t = -\boldsymbol{E}_t$$

$\longrightarrow$ no way to ***increase*** $\boldsymbol{R_t}$!

Resource extraction

To get **energy $\boldsymbol{E}$**, need to extract **nonrenewable resource** w/ initial stock $\boldsymbol{R_0}$:

$$\dot{\boldsymbol{R}}_t = -\boldsymbol{E}_t$$

$\longrightarrow$ no way to ***increase*** $\boldsymbol{R_t}$!

How much to extract?

Resource extraction

To get **energy** $\boldsymbol{E}$, need to extract **nonrenewable resource** w/ initial stock $\boldsymbol{R_0}$:

$$\dot{\boldsymbol{R}}_t = -\boldsymbol{E}_t$$

$\longrightarrow$ no way to ***increase*** $\boldsymbol{R_t}$!

How much to extract? For now, just set fraction $\boldsymbol{s_E}$, so... (Dasgupta and Heal, 1974)

$$\frac{\dot{\boldsymbol{R}}_t}{\boldsymbol{R}_t} = -\frac{\boldsymbol{E}_t}{\boldsymbol{R}_t}$$

Resource extraction

To get **energy $\boldsymbol{E}$**, need to extract **nonrenewable resource** w/ initial stock $\boldsymbol{R_0}$:

$$\dot{R}_t = -E_t$$

$\rightarrow$ no way to ***increase*** $\boldsymbol{R_t}$!

How much to extract? For now, just set fraction s_E, so... (Dasgupta and Heal, 1974)

$$g_R = -s_E$$

Resource extraction

To get **energy** E, need to extract **nonrenewable resource** w/ initial stock R_0:

$$\dot{R}_t = -E_t$$

$\rightarrow$ no way to ***increase*** R_t!

How much to extract? For now, just set fraction s_E, so. . . (Dasgupta and Heal, 1974)

$$g_R = -s_E \quad \rightarrow \quad g_E = -s_E$$

because $E_t = s_E R_t$

How do we solve this model?

Recall the production function:

$$Y_t = K_t^{\alpha} \boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}$$

If we could instead write...

$$Y_t = K_t^{\alpha} (\boldsymbol{B_t} L_t)^{1-\alpha}$$

... **would we know what to do?**

How do we solve this model?

Recall the production function:

$$Y_t = K_t^{\alpha} \boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}$$

If we could instead write...

$$Y_t = K_t^{\alpha} (\boldsymbol{B_t} L_t)^{1-\alpha}$$

...**would we know what to do?**

Yes! This is just the **Solow model** with **labor-augmenting productivity $\boldsymbol{B_t}$**...

- steady state where $g_{\tilde{k}} \equiv g_K - \boldsymbol{g_B} - g_L = 0 \to$ **phase diagram**

$$\tilde{k}^{\text{ss}} = \left(\frac{s_I}{\boldsymbol{g_B} + g_L + \delta} \right)^{\frac{1}{1-\alpha}}$$

- slope of BGP: $g_y^{\text{ss}} = \boldsymbol{g_B}$

What is B_t?

Taking ratios of the two possible forms of the production function...

$$1 = \frac{K_t^{\alpha} \boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}}{K_t^{\alpha} (\boldsymbol{B_t} L_t)^{1-\alpha}} = \frac{\boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} A_t^{1-\alpha-\beta-\gamma} L_t^{-(\beta+\gamma)}}{\boldsymbol{B_t}^{1-\alpha}}$$

What is B_t?

Taking ratios of the two possible forms of the production function...

$$1 = \frac{K_t^{\alpha} \boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}}{K_t^{\alpha} (\boldsymbol{B_t} L_t)^{1-\alpha}} = \frac{\boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} A_t^{1-\alpha-\beta-\gamma} L_t^{-(\beta+\gamma)}}{\boldsymbol{B_t}^{1-\alpha}}$$

...so we can define $\boldsymbol{B_t}$ as

$$\boldsymbol{B_t} \equiv A_t^{\frac{1-\alpha-\beta-\gamma}{1-\alpha}} \left(\frac{\boldsymbol{E_t}}{L_t}\right)^{\frac{\beta}{1-\alpha}} \left(\frac{\boldsymbol{X}}{L_t}\right)^{\frac{\gamma}{1-\alpha}}$$

What is B_t?

Taking ratios of the two possible forms of the production function...

$$1 = \frac{K_t^{\alpha} \boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}}{K_t^{\alpha} (\boldsymbol{B_t} L_t)^{1-\alpha}} = \frac{\boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} A_t^{1-\alpha-\beta-\gamma} L_t^{-(\beta+\gamma)}}{\boldsymbol{B_t}^{1-\alpha}}$$

...so we can define $\boldsymbol{B_t}$ as

$$\boldsymbol{B_t} \equiv A_t^{\frac{1-\alpha-\beta-\gamma}{1-\alpha}} \left(\frac{\boldsymbol{E_t}}{L_t}\right)^{\frac{\beta}{1-\alpha}} \left(\frac{\boldsymbol{X}}{L_t}\right)^{\frac{\gamma}{1-\alpha}}$$

...and its growth rate is then

$$\boldsymbol{g_B} = \frac{1-\alpha-\beta-\gamma}{1-\alpha} g_A + \frac{\beta}{1-\alpha}(\boldsymbol{g_E} - g_L) + \frac{\gamma}{1-\alpha}(\boldsymbol{g_X} - g_L)$$

What is B_t?

Taking ratios of the two possible forms of the production function...

$$1 = \frac{K_t^{\alpha} \boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} (A_t L_t)^{1-\alpha-\beta-\gamma}}{K_t^{\alpha} (\boldsymbol{B_t} L_t)^{1-\alpha}} = \frac{\boldsymbol{E_t}^{\beta} \boldsymbol{X}^{\gamma} A_t^{1-\alpha-\beta-\gamma} L_t^{-(\beta+\gamma)}}{\boldsymbol{B_t}^{1-\alpha}}$$

...so we can define $\boldsymbol{B_t}$ as

$$\boldsymbol{B_t} \equiv A_t^{\frac{1-\alpha-\beta-\gamma}{1-\alpha}} \left(\frac{\boldsymbol{E_t}}{L_t}\right)^{\frac{\beta}{1-\alpha}} \left(\frac{\boldsymbol{X}}{L_t}\right)^{\frac{\gamma}{1-\alpha}}$$

...and its growth rate is then

$$\begin{aligned} \boldsymbol{g_B} &= \frac{1-\alpha-\beta-\gamma}{1-\alpha} g_A + \frac{\beta}{1-\alpha}(\boldsymbol{g_E} - g_L) + \frac{\gamma}{1-\alpha}(\boldsymbol{g_X} - g_L) \\ &= \left(1 - \frac{\beta+\gamma}{1-\alpha}\right) g_A - \frac{\beta}{1-\alpha} \boldsymbol{s_E} - \frac{\beta+\gamma}{1-\alpha} g_L \end{aligned}$$

Defining the resource drag on growth

We can rearrange the expression for the growth rate of $\boldsymbol{B_t}$ to get...

$$g_y^{\text{ss}} = \boldsymbol{g_B} = \left(1 - \frac{\beta + \gamma}{1 - \alpha}\right) g_A - \underbrace{\frac{\beta}{1 - \alpha}(\boldsymbol{s_E} + g_L)}_{\text{drag from \textbf{energy} } \boldsymbol{E}} - \underbrace{\frac{\gamma}{1 - \alpha} g_L}_{\text{drag from \textbf{land} } \boldsymbol{X}}$$

- both include spreading finite resources over more people...
- ...but the drag from **energy** $\boldsymbol{E}$ also includes the depletion of the resource

Defining the resource drag on growth

We can rearrange the expression for the growth rate of $\boldsymbol{B_t}$ to get...

$$g_y^{\text{ss}} = \boldsymbol{g_B} = \left(1 - \frac{\beta+\gamma}{1-\alpha}\right) g_A - \underbrace{\frac{\beta}{1-\alpha}(\boldsymbol{s_E} + g_L)}_{\text{drag from energy } \boldsymbol{E}} - \underbrace{\frac{\gamma}{1-\alpha} g_L}_{\text{drag from land } \boldsymbol{X}}$$

- both include spreading finite resources over more people...
- ...but the drag from **energy** $\boldsymbol{E}$ also includes the depletion of the resource

Recall: We saw this kind of resource drag at the end of the Malthusian model, too

$$g_y^{\text{ss}} = \beta(g_A^{\text{ss}} - g_L^{\text{ss}}) = (1-\beta)\frac{\lambda}{1-\phi} g_L^{\text{ss}} - \underbrace{\boldsymbol{\beta g_L^{\text{ss}}}}_{\substack{\text{drag from} \\ \text{land } \boldsymbol{X}}}$$

Quantifying the resource drag on growth (Nordhaus, 1992)

- $\alpha \equiv$ share of total factor payments to **capital** $K \approx 0.2$
- $\beta \equiv$ share of total factor payments to **energy** $E \approx 0.1$
- $\gamma \equiv$ share of total factor payments to **land** $X \approx 0.1$

$\longrightarrow$ the **labor share** is then ≈ 0.6 like the Kaldor facts!

Quantifying the resource drag on growth (Nordhaus, 1992)

- $\alpha \equiv$ share of total factor payments to **capital** $K \approx 0.2$
- $\beta \equiv$ share of total factor payments to **energy** $E \approx 0.1$
- $\gamma \equiv$ share of total factor payments to **land** $X \approx 0.1$

$\rightarrow$ the **labor share** is then ≈ 0.6 like the Kaldor facts!

- for the US, population growth $g_L \approx 0.01$ and nonrenewable usage rate $s_E \approx 0.005$

Quantifying the resource drag on growth (Nordhaus, 1992)

- $\alpha \equiv$ share of total factor payments to **capital** $K \approx 0.2$
- $\beta \equiv$ share of total factor payments to **energy** $E \approx 0.1$
- $\gamma \equiv$ share of total factor payments to **land** $X \approx 0.1$

$\longrightarrow$ the **labor share** is then ≈ 0.6 like the Kaldor facts!

- for the US, population growth $g_L \approx 0.01$ and nonrenewable usage rate $s_E \approx 0.005$

$$-\frac{\beta}{1-\alpha}(s_E + g_L) - \frac{\gamma}{1-\alpha} g_L = -\left(\frac{0.1}{1-0.2}\right)(\mathbf{0.005} + 0.01) - \left(\frac{0.1}{1-0.2}\right) 0.01$$

$$= (1/8) \times 0.015 + (1/8) \times 0.01 \approx \mathbf{0.003}$$

Quantifying the resource drag on growth (Nordhaus, 1992)

- $\alpha \equiv$ share of total factor payments to **capital** $K \approx 0.2$
- $\beta \equiv$ share of total factor payments to **energy** $E \approx 0.1$
- $\gamma \equiv$ share of total factor payments to **land** $X \approx 0.1$

$\rightarrow$ the **labor share** is then ≈ 0.6 like the Kaldor facts!

- for the US, population growth $g_L \approx 0.01$ and nonrenewable usage rate $s_E \approx 0.005$

$$-\frac{\beta}{1-\alpha}(s_E + g_L) - \frac{\gamma}{1-\alpha} g_L = -\left(\frac{0.1}{1-0.2}\right)(\mathbf{0.005} + 0.01) - \left(\frac{0.1}{1-0.2}\right) 0.01$$

$$= (1/8) \times 0.015 + (1/8) \times 0.01 \approx \mathbf{0.003}$$

$\rightarrow$ **1.8% observed growth** includes **0.3% drag** from **energy** and **land**

Comparative statics with respect to s_E

Say we permanently decrease s_E at time T

Comparative statics with respect to s_E

Say we permanently decrease s_E at time $T \longrightarrow$ simul. permanent $g_B \uparrow$ + temp. $B_t \downarrow$

Comparative statics with respect to s_E

Say we permanently decrease s_E at time $T \to$ simul. permanent $g_B \uparrow$ + temp. $B_t \downarrow$

1. What happens to $\tilde{k}^{\text{ss}}$? **(draw the phase diagram!)**
2. What happens to g_y^{ss} at T? In the long run?
3. What happens to $\ln y_t^{\text{BGP}}$ at T? In the long run?

So should we just set $s_E = 0$?

- last slide suggests lower $s_E \rightarrow$ higher g_B

So should we just set $s_E = 0$?

- last slide suggests lower s_E $\rightarrow$ higher g_B
- but $s_E = 0$ means $E_t = 0$, so **no output**: $Y_t = K_t^{\alpha}(\mathbf{0})^{\beta}X^{\gamma}(A_tL_t)^{1-\alpha-\beta-\gamma} = 0$
  - saw this with s_I in Solow: $s_I = 0$ means no capital in the long run

So should we just set $s_E = 0$?

- last slide suggests lower $s_E \rightarrow$ higher g_B
- but $s_E = 0$ means $E_t = 0$, so **no output**: $Y_t = K_t^{\alpha}(\mathbf{0})^{\beta}\boldsymbol{X}^{\gamma}(A_tL_t)^{1-\alpha-\beta-\gamma} = 0$
  - saw this with s_I in Solow: $s_I = 0$ means no capital in the long run
- **what's the optimal s_E?** think about analogy w/ s_I and s_R:
  - s_I in **NGM**: more consumption today vs. more consumption tomorrow
  - s_R in **(semi-)endogenous**: more output today vs. more/better ideas for tomorrow

So should we just set $s_E = 0$?

- last slide suggests lower s_E $\rightarrow$ higher g_B
- but $s_E = 0$ means $E_t = 0$, so **no output**: $Y_t = K_t^{\alpha}(\mathbf{0})^{\beta}\boldsymbol{X}^{\gamma}(A_t L_t)^{1-\alpha-\beta-\gamma} = 0$
  - saw this with s_I in Solow: $s_I = 0$ means no capital in the long run
- **what's the optimal s_E?** think about analogy w/ s_I and s_R:
  - s_I in **NGM**: more consumption today vs. more consumption tomorrow
  - s_R in **(semi-)endogenous**: more output today vs. more/better ideas for tomorrow
  - s_E in **this model**: more energy today vs. more resources for tomorrow

So should we just set $s_E = 0$?

- last slide suggests lower s_E $\rightarrow$ higher g_B
- but $s_E = 0$ means $E_t = 0$, so **no output**: $Y_t = K_t^\alpha (0)^\beta X^\gamma (A_t L_t)^{1-\alpha-\beta-\gamma} = 0$
  - saw this with s_I in Solow: $s_I = 0$ means no capital in the long run
- **what's the optimal s_E?** think about analogy w/ s_I and s_R:
  - s_I in **NGM**: more consumption today vs. more consumption tomorrow
  - s_R in **(semi-)endogenous**: more output today vs. more/better ideas for tomorrow
  - s_E in **this model**: more energy today vs. more resources for tomorrow
- **but something's different**: s_E, unlike s_I and s_R, *does* affect the growth rate g_y^{ss}

So should we just set $s_E = 0$?

- last slide suggests lower $s_E \rightarrow$ higher g_B
- but $s_E = 0$ means $E_t = 0$, so **no output**: $Y_t = K_t^{\alpha}(\mathbf{0})^{\beta} X^{\gamma}(A_t L_t)^{1-\alpha-\beta-\gamma} = 0$
  - saw this with s_I in Solow: $s_I = 0$ means no capital in the long run
- **what's the optimal s_E?** think about analogy w/ s_I and s_R:
  - s_I in **NGM**: more consumption today vs. more consumption tomorrow
  - s_R in **(semi-)endogenous**: more output today vs. more/better ideas for tomorrow
  - s_E in **this model**: more energy today vs. more resources for tomorrow
- **but something's different**: s_E, unlike s_I and s_R, *does* affect the growth rate g_y^{ss}
- **why?** depletion of R is a linear differential equation $\rightarrow$ like **AK models**

How to value "energy today" vs. "resources for tomorrow"

Suppose the representative household has preferences

$$U_t = (c_t - \bar{c})^{1-\rho} R_t^{\rho}$$

and faces the *implicit* budget constraint

$$y_t = c_t + p_{Rt} R_t$$

- $\bar{c}$ is **subsistence consumption**, like in the Malthusian model
- household cares directly about the **stock of resources** R_t
  - if **resource extraction** implies **pollution** $\rightarrow$ captures the value of clean environment
  - can reinterpret E_t as **emissions**
- p_{Rt} is the **relative price** of resources vs. consumption

How to value "energy today" vs. "resources for tomorrow"

Suppose the representative household has preferences

$$U_t = (c_t - \bar{c})^{1-\rho} R_t^{\rho}$$

and faces the *implicit* budget constraint

$$y_t = c_t \; \cancel{+ p_{Rt} R_t}$$

- $\bar{c}$ is **subsistence consumption**, like in the Malthusian model
- household cares directly about the **stock of resources** R_t
    - if **resource extraction** implies **pollution** $\rightarrow$ captures the value of clean environment
    - can reinterpret E_t as **emissions**
- p_{Rt} is the **relative price** of resources vs. consumption

Solving the household's problem

Compute the marginal utility of consumption...

$$\mathsf{MU}_c = \frac{(1-\rho)U_t}{c_t - \bar{c}} = (1-\rho)\left(\frac{R_t}{c_t - \bar{c}}\right)^{\rho}$$

Solving the household's problem

Compute the marginal utility of consumption...

$$\mathsf{MU}_c = \frac{(1-\rho)U_t}{c_t - \bar{c}} = (1-\rho)\left(\frac{R_t}{c_t - \bar{c}}\right)^{\rho}$$

...and the marginal utility of resources

$$\mathsf{MU}_R = \frac{\rho U_t}{R_t} = \rho\left(\frac{c_t - \bar{c}}{R_t}\right)^{1-\rho},$$

Solving the household's problem

Compute the marginal utility of consumption...

$$\mathsf{MU}_c = \frac{(1-\rho)U_t}{c_t - \bar{c}} = (1-\rho)\left(\frac{R_t}{c_t - \bar{c}}\right)^{\rho}$$

...and the marginal utility of resources

$$\mathsf{MU}_R = \frac{\rho U_t}{R_t} = \rho\left(\frac{c_t - \bar{c}}{R_t}\right)^{1-\rho},$$

then note that the household will choose c_t and R_t to satisfy (check Lagrangian)

$$\frac{\mathsf{MU}_R}{\mathsf{MU}_c} = p_{Rt}$$

Solving the household's problem

Compute the marginal utility of consumption...

$$\mathsf{MU}_c = \frac{(1-\rho)U_t}{c_t - \bar{c}} = (1-\rho)\left(\frac{R_t}{c_t - \bar{c}}\right)^{\rho}$$

...and the marginal utility of resources

$$\mathsf{MU}_R = \frac{\rho U_t}{R_t} = \rho\left(\frac{c_t - \bar{c}}{R_t}\right)^{1-\rho},$$

then note that the household will choose c_t and R_t to satisfy (check Lagrangian)

$$\frac{\mathsf{MU}_R}{\mathsf{MU}_c} = \frac{\rho}{1-\rho}\left(\frac{c_t - \bar{c}}{R_t}\right) = p_{Rt}$$

Production and prices

To simplify, let's set $\alpha = \gamma = 0$ to eliminate **capital** (no saving) and **land**...

$$Y_t = \boldsymbol{E_t}^{\beta} (A_t L_t)^{1-\beta} \quad \rightarrow \quad y_t = A_t \left(\frac{\boldsymbol{E_t}}{A_t L_t} \right)^{\beta}$$

Production and prices

To simplify, let's set $\alpha = \gamma = 0$ to eliminate **capital** (no saving) and **land**...

$$Y_t = \boldsymbol{E_t}^{\beta}(A_t L_t)^{1-\beta} \quad \rightarrow \quad y_t = A_t \left(\frac{\boldsymbol{E_t}}{A_t L_t} \right)^{\beta}$$

...but keep the same resource extraction rule:

$$\dot{R}_t = -\boldsymbol{E_t}$$

Production and prices

To simplify, let's set $\alpha = \gamma = 0$ to eliminate **capital** (no saving) and **land**...

$$Y_t = \boldsymbol{E_t}^{\beta} (A_t L_t)^{1-\beta} \quad \rightarrow \quad y_t = A_t \left(\frac{\boldsymbol{E_t}}{A_t L_t} \right)^{\beta}$$

...but keep the same resource extraction rule:

$$\dot{R}_t = -\boldsymbol{E_t}$$

Note the tradeoff: more **energy** $\rightarrow$ more **output** $\boldsymbol{y_t}$ but lower **resources** $\boldsymbol{R_t}$

$$p_{Rt} = \frac{\partial y_t}{\partial E_t}$$

The optimal choice of s_E

Take the household's optimality condition and the price of resources...

$$\frac{\mathsf{MU}_R}{\mathsf{MU}_c} = p_{Rt}$$

The optimal choice of s_E

Take the household's optimality condition and the price of resources...

$$\frac{\rho}{1-\rho}\left(\frac{c_t-\bar{c}}{R_t}\right)=\beta\frac{y_t}{E_t}$$

The optimal choice of s_E

Take the household's optimality condition and the price of resources…

$$\frac{\rho}{1-\rho}\left(\frac{c_t-\bar{c}}{R_t}\right)=\beta\frac{y_t}{E_t}$$

…then rearrange to get the optimal choice of s_E:

$$s_{Et}\equiv\frac{E_t}{R_t}=\beta\left(\frac{1-\rho}{\rho}\right)\frac{y_t}{y_t-\bar{c}}$$

Economic growth leads to better environmental quality

$$s_{Et} = \beta \left(\frac{1-\rho}{\rho} \right) \frac{y_t}{y_t - \bar{c}}$$

- when y_t is close to subsistence level $\bar{c}$...
    - $y_t/(y_t - \bar{c})$ is high
    - willing to sacrifice environmental quality for more consumption

Economic growth leads to better environmental quality

$$s_{Et} = \beta \left(\frac{1-\rho}{\rho} \right) \frac{y_t}{y_t - \bar{c}}$$

- when y_t is close to subsistence level $\bar{c}$...
  - $y_t/(y_t - \bar{c})$ is high
  - willing to sacrifice environmental quality for more consumption
- ...but as y_t grows (at rate g_B)
  - $y_t/(y_t - \bar{c})$ is falling
  - rising willingness to pay for environmental quality rel. to consumption
  - **think**: electric cars, recycling, low-impact products, ...

Economic growth leads to better environmental quality

$$s_{Et} = \beta \left(\frac{1-\rho}{\rho} \right) \frac{y_t}{y_t - \bar{c}}$$

- when y_t is close to subsistence level $\bar{c}$...
  - $y_t/(y_t - \bar{c})$ is high
  - willing to sacrifice environmental quality for more consumption
- ...but as y_t grows (at rate g_B)
  - $y_t/(y_t - \bar{c})$ is falling
  - rising willingness to pay for environmental quality rel. to consumption
  - **think**: electric cars, recycling, low-impact products, ...
- requires $\bar{c} > 0$ (nonhomothetic preferences)
  - s_E is constant if $\bar{c} = 0 \rightarrow$ what we assumed to start today

Economic growth leads to better environmental quality

$$s_{Et} = \beta \left(\frac{1-\rho}{\rho} \right) \frac{y_t}{y_t - \bar{c}}$$

- when y_t is close to subsistence level $\bar{c}$...
  - $y_t/(y_t - \bar{c})$ is high
  - willing to sacrifice environmental quality for more consumption
- ...but as y_t grows (at rate g_B)
  - $y_t/(y_t - \bar{c})$ is falling
  - rising willingness to pay for environmental quality rel. to consumption
  - **think**: electric cars, recycling, low-impact products, ...
- requires $\bar{c} > 0$ (nonhomothetic preferences)
  - s_E is constant if $\bar{c} = 0 \longrightarrow$ what we assumed to start today
- better model would predict "environmental Kuznets curve" (Brock and Taylor, 2010)
  - s_{Et} rises with y_t at low levels, then falls at high levels

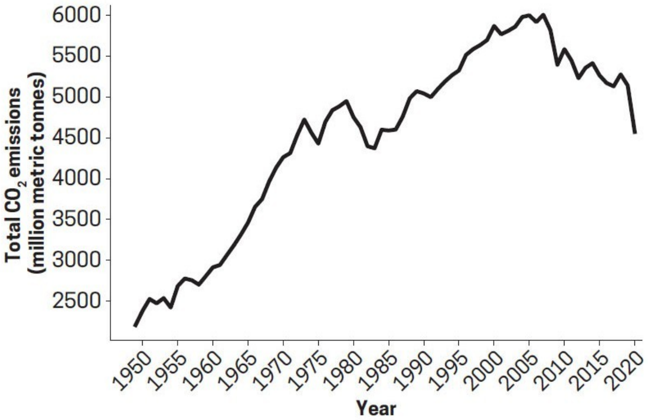
Does economic growth lead to lower resource extraction?

Figure 10.5 Energy Use per Capita in the United States, 1950–2019

SOURCE: Authors' calculations from U.S. Energy Information Administration (2021*a*).

Does economic growth lead to lower pollution?

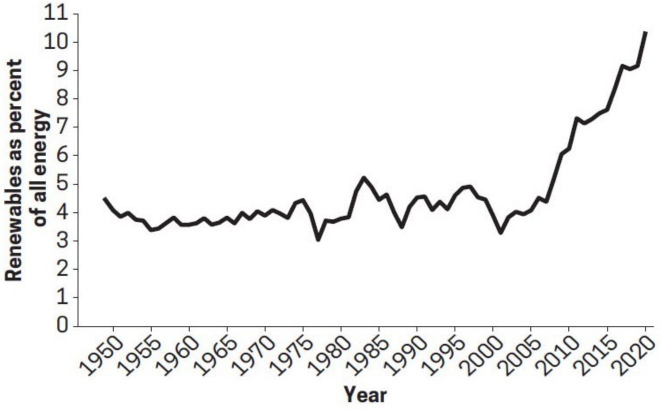
Figure 10.6 Total CO_2 Emissions in the United States, 1950–2019



SOURCE: Authors' calculations from U.S. Energy Information Administration (2021*a*).

Does economic growth lead to lower pollution?

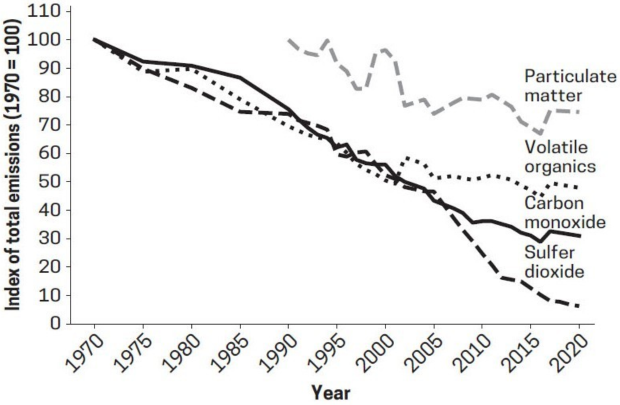
Figure 10.7 Renewables as a Percent of Energy in the United States, 1950–2019



SOURCE: Authors' calculations from U.S. Energy Information Administration (2021*a*).

Does economic growth lead to lower pollution?

Figure 10.8 Air Pollutants in the United States, 1970–2019



SOURCE: Authors' calculations from U.S. Environmental Protection Agency (2021).

NOTE: The indices for particulate matter are indexed to 100 in 1990, given a lack of prior data. All other series are indexed to 100 in 1970.

Summary

- **last time**: added factor in **fixed supply** (**land** X) $\rightarrow$ declining GDPpc unless...
  - ...endogenous technological change A wins the race against declining X/L
  - but we treated land as a **renewable resource**: can use the same land over and over
- **today**: **nonrenewable resources** (petroleum, coal, natural gas, minerals, ...)
  - like last time: race between A vs. X/L *and* E/L
  - can analyze like **Solow model** with **labor-augmenting productivity** B_t
  - find **0.3% drag on growth** from **land** and **resource extraction**
  - some evidence that higher **GDP per capita** leads to lower **emissions** s_E

References

Brock, William A. and M. Scott Taylor. 2010. "The green Solow model." *Journal of Economic Growth* 15 (2):127–153.

Dasgupta, Partha and Geoffrey Heal. 1974. "The optimal depletion of exhaustible resources." *Review of Economic Studies* 41 (5):3–28.

Nordhaus, William D. 1992. "Lethal Model 2: The limits to growth revisited." *Brookings Papers on Economic Activity* 1992 (2):1.