Virtual Seminar on Climate Economics

Federal Reserve Bank of San Francisco

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Climate, technology, family size; on the crossroad between two ultimate externalities

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- You're welcome to unmute and ask questions during presentation
- ... or use the chat box for questions/comments.

First Ultimate Externality

“[CC is] the greatest market failure the world has seen” (Stern 2006)

Key features (DICE, William Nordhaus 1993, Nobel prize 2018):

- Fossil fuels for energy $\rightarrow$ CO_2 emissions
- atmospheric CO_2 $\rightarrow$ global warming
- Global warming $\rightarrow$ reduced output
- atmospheric CO_2 depreciates extremely slowly $\Rightarrow$ present individuals need to reduce fossil fuel use for the benefit of future generations around the world

Recent developments: closed-form SCC proxies.

Central variable:
Social Costs of Carbon (SCC) = NPV of damages caused by 1 tCO_2.

- GHKT2014: add climate to the Brock-Mirman 1972 structure $\Rightarrow$ closed-form solutions for SCC.
- most simple version: $SCC_t = \frac{\delta c}{\rho+\eta} Y_t$
  δ = relative damage per degree Celsius; c = climate sensitivity; ρ = pure impatience; η = CO_2 depreciation
- vdBGL2016, RvdP2016: GHKT2014 closed-form analytical solutions can be generalized to SCC formulas that proxy IAMs (e.g. DICE) very well

This paper builds on the BM72+GHKT2014 model.

Recent developments: global warming & economic growth

New Empirical Climate-Growth literature:

- The ideal temperature for the economy seems to be 14°C annual average.
- Global warming leads to a (permanent) reduction of economic growth (not level)
- macro-economic growth evidence: Dell et al. 2012, Burke et al. 2015
- micro-economic learning evidence: Graff Zivin et all (2018)
- micro-macro connection: Masters and McMillan (2001), Park et al. (2020)

This paper adds climate-growth-damaging mechanisms into the BM72+GHKT2014 model.

New Empirical Climate-Growth literature (summary)

Table: Dependent variable: economic growth

	(1)	(2)
Temperature	0.261	1.27***
Temp. × Poor	-1.66***	
Temp. sq.		-0.05***
Country FE	YES	YES
Year FE	YES	YES
N	4924	6584

Sources: (1) Dell, Jones & Olken, AEJmacro 2012, Table 2. (2) Burke, Hsiang & Miguel, Nature 2015, Table 1 (x100). Various controls, lags, and FEs included.

Estimate uses panel data with annual variation in weather and growth between countries. Interpreting as sensitivity to climate...

This paper contribution 1

- Build an analytic IAM (BM72-GHKT14)
- incorporate endogenous growth mechanisms
- include global warming induced growth reduction
- derive SCC analytically

Provides basis for study of second 'Ultimate externality'

Second Ultimate Externality

- Jon Harford AER 1998: Parent's fertility decisions are the ultimate externality [because the number of people negatively impacts on resources available per person]
- Kuznets 1960: People are the ultimate source: more people $\rightarrow$ more ideas $\rightarrow$ higher welfare per capita (also Simon 1981, Romer 1986)
  "[we should view] human beings not as producers of commodities and services, but as producers of new knowledge"

Finding the balance: People as source or sink of welfare?

This paper

- tractable model: BM72 + GHKT14 + Endogenous Growth + Endogenous Fertility
- support a structured discussion on (more) people as the source, or solution, for scarcity of natural resources (specifically climate change).

Research questions

1. $ETC \in SCC$: Climate change and endogenous growth
    - If climate change affects growth, as estimated in recent empirical literature, does that increase the social costs of carbon (carbon tax) substantially?
2. $W(POP|CLIM, ETC)$: Reason to worry or to celebrate the future 10-12bn world population?
    - Do more people increase or reduce environmental damages and welfare?

Method

Basis: Brock Mirman model (1972): Ramsey-Cass-Koopmans with discrete time, stochastic TFP, full capital depreciation → closed-form solution for all decision variables (investment in capital).

Endogenous population extension:

- human capital
- endogenous fertility

Semi-endogenous growth extension:

- variety expansion with standing on shoulders & toes

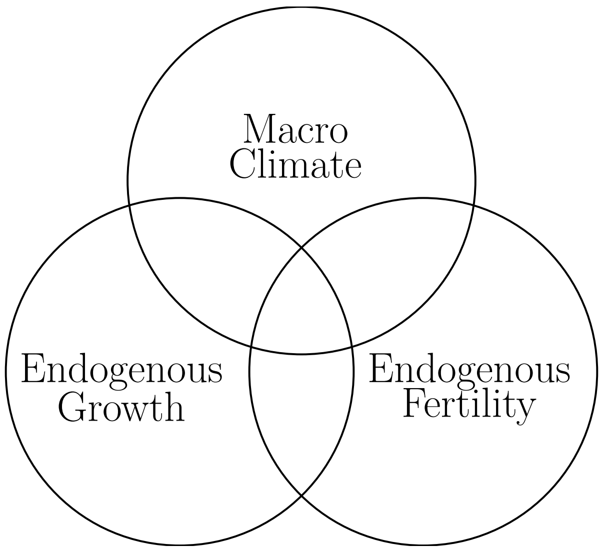
Climate extension:

- emissions as production factor (GHKT14)
- higher temperatures decreases TFP (GHKT14)
- higher temperatures decreases innovation

Scope: limitations

- World model
  - no heterogeneous regions
  - no migration
- Dynasties as units of decision making
  - no value of individual life / optimal population size
  - externalities between dynasties (cf. aggregate versus average welfare)
  - Interpretation: Am I ok with my neighbor's third child?
- Undirected technical change
  - No renewables versus fossil fuels (no fossil fuel markets)

Connecting 3 strands of literature



I borrow from

- Macro-Climate (NP 2018 Nordhaus)
- Endogenous Growth (NP 2018 Romer)
- Endogenous Fertility (NP 1992 Becker)

Intersections

- Climate-Endogenous Growth (Gradus and Smulders 1993) If pollution reduces learning abilities, environmental policy increases long-term growth.
- Macro-Climate-Population
- Unified Growth theory

Inner section

- Climate-Endogenous Growth & Population But not new growth theory.

Literature: population $\cap$ endogenous growth $\cap$ climate

Literature

- Schou (ITPF 2002)
- Gerlagh, Lupi, Galeotti (WP 2018, but no ETC)
- Kruse-Andersen (WP 2019)
- Bretscher (EER 2020)

This paper innovations:

- Closed-form SCC when global warming reduces growth
- Discussion on independence between policy domains (second-best)
- Connecting population externality to returns to scale

Households

Dynasties $i \in [0, 1]$ of size $n_{i,t}$ maximize (average) welfare

$$w_{i,t}(s_{i,t}, n_{i,t}, h_{i,t}) = \sum_{j=0}^{\infty} \beta^j \left[\ln(c_{i,t+j}/n_{i,t+j}) + \gamma \ln(f_{i,t+j})\right] \qquad (1)$$

with consumption $c_{it,}$, fertility $f_{i,t}$, subject to the budget constraint, labour supply, population dynamics and human capital dynamics

$$c_{i,t} + s_{i,t+1} = \sigma_t^y (w_t h_{i,t} l_{i,t} + r_t s_{i,t}) - \tau_{f,t} f_{i,t} n_{i,t} + \tau_{n,t} n_{i,t} \qquad (2)$$

$$l_{i,t} = (1 - \phi f_{i,t} - x_{i,t} f_{i,t}) n_{i,t} \qquad (3)$$

$$n_{i,t+1} = (1 + f_{i,t} - \delta_N) n_{i,t} \qquad (4)$$

$$h_{i,t+1} = x_{i,t}^{\eta_s} h_{i,t}^{\eta_h} \qquad (5)$$

where $l_{i,t}$ labour supply, w_t are wages, r_t returns to investments, $1 - \sigma_t^y$ income tax, $\tau_{f,t}$ fertility tax, $\tau_{n,t}$ per capita lump-sum government transfers, ϕ time for raising children, and $x_{i,t}$ time spent on schooling.

Symmetry $\rightarrow$ drop and reuse i.

Final goods production

The final good is produced by use of intermediates indexed $i \in [0, A_t]$

$$Y_t = \Omega_t \left(\int_{i=0}^{A_t} (y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}}) \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{6}$$

where Ω_t is climate-related productivity (Nordhaus 1993,...).
Intermediates are produced by monopolists

$$\max_{k_{i,t}, l_{i,t}, e_{i,t}} [p_{i,t}y_{i,t} - r_t k_{i,t} - w_t h_{i,t} l_{i,t} - \tau_{z,t} z_{i,t} - \tau_{e,t} e_{i,t} - \pi_{i,t}] \tag{7}$$

$$\text{s.t. } y_{i,t} = k_{i,t}^{\alpha} \left(q_t(z_{i,t}, e_{i,t})\right)^{\kappa} \left(h_{i,t} l_{i,t}\right)^{1-\alpha-\kappa} \tag{8}$$

with $\pi_{i,t}$ royalties paid to the patent owner, $e_{i,t}$ is the use of natural resources associated with greenhouse gas emissions (mostly fossil fuels), $z_{i,t}$ is the use of other natural resources in fixed supply $\int_i z_{i,t} = 1$ owned by government, $\tau_{e,t}$ is a carbon tax, and $q(.)$ describes renewables substitution (Gerlagh&Liski 2018).

Innovation

Varieties $i \in [0, A_t]$ are produced by innovators indexed j. Each innovator produces a mass $a_{j,t+1}$ of new ideas, and the current stock of knowledge is

$$A_t = \int_j a_{j,t} \quad (9)$$

Innovator j maximizes

$$\max_{k_{j,t}, l_{j,t}} [\pi_{j,t+1} a_{j,t+1}/r_{t+1} - r_t k_{j,t} - w_t l_{j,t} - \tau_{z,t} z_{j,t} - \tau_{e,t} e_{j,t}] \quad (10)$$

$$\text{st. } a_{j,t+1} = \zeta_t \Gamma_t x^a_{j,t} (X^A_t)^{-\psi} A^{\varphi}_t. \quad (11)$$

where ζ_t common shocks, Γ_t is a climate factor (Dell et al.2012/Burke et al.2015), $x^a_{j,t} = k^{\alpha}_{j,t} f^{\kappa}_{j,t} (h_t l_{j,t})^{1-\alpha-\kappa}$ is individual effort, $X^A_t = \int_j x^a_{j,t}$ is the aggregate effort, $(X^A_t)^{-\psi}$ standing on toes, A^{φ}_t standing on shoulders.
Note: Creative destruction for compatibility with BM72: varieties complementary to capital, fully depreciate after each period.

Climate Change

Past emissions increase global temperatures:

$$T_t = \sum_{i=1}^{\infty} \theta_i E_{t-i} \tag{12}$$

Temperature rise reduces output, a level-effect, but also hamper growth (Dell et al. 2012, Burke et al. 2015).
Borrow functional form from Golosov et al. (2014):

$$\Omega(T_t) = e^{-\delta_Y T_t}, \tag{13}$$

$$\Gamma(T_t) = e^{-\delta_A(\varepsilon-1) T_t}. \tag{14}$$

The term $(\varepsilon - 1)$ scales both δ to have the same immediate effects.
Main implication: welfare linearly decreasing in cumulative emissions
(stronger assumptions used by Schou 2002, Kruse-Andersen 2019, Bretschger 2020).

Summary of agents

- Households choose consumption and savings (c_t, s_t), human capital and fertility (f_t, h_t), that maximize welfare, given wages (w_t), interest (r_t), lump-sum transfers $(\tau_{n,t})$, fertility taxes $(\tau_{f,t})$.
- Final sector produces final good (Y_t) using intermediates $(y_{i,t})$, implying demand function for intermediates.
- Intermediates sector sets prices (p_t) that maximize profits given wages (w_t), interests (r_t), prices for emissions and renewables $(\tau_{f,t}, \tau_{z,t})$, royalties for blueprints $(\pi_{i,t})$
- Innovators produce varieties (a_t), choosing capital, labor, emissions (k_t, l_t, e_t) that maximize profits given royalties for blueprints $(\pi_{i,t})$, wages (w_t), interests (r_t), prices for emissions and renewables $(\tau_{f,t}, \tau_{z,t})$.
- Government may maximize welfare or use fiscal rule of thumb. Sets carbon taxes $(\tau_{e,t})$, fertility taxes $(\tau_{f,t})$, and lump-sum transfers $(\tau_{n,t})$ and maintains closed budget.

Aggregate Economy

$$W_t = \sum_{j=0}^{\infty} \beta^j \left[\ln(C_{t+j}/N_{t+j}) + \gamma \ln(f_{t+j})\right] \tag{15}$$

$$C_t + K_{t+1} = \Omega_t(T_t) A_t^{\frac{1}{\varepsilon-1}} (1 - s_A) X_t(.) \tag{16}$$

$$A_{t+1} = \zeta_t \Gamma_t(T_t)(s_A X_t(.))^{1-\psi} A_t^{\varphi} \tag{17}$$

$$N_{t+1} = (1 + f_t - \delta_N) N_t \tag{18}$$

$$h_{t+1} = {x_t}^{\eta_s} h_t^{\eta_h} \tag{19}$$

$$T_t = \sum_i \theta_i E_{t-i} \tag{20}$$

with $X_t(.) = K_t^{\alpha}[q_t(E_t, Z_t)]^{\kappa}(h_t(1 - \phi f_t - x_t f_t)N_t)^{1-\alpha-\kappa}$ total effort
Control variables: investment share of output $s_{K,t}$, share of effort into innovation $s_{A,t}$, share of time into education x_t, fertility f_t, emissions E_t
Note that h_t is an intensive state variable, while K_t, A_t, N_t are aggregate stocks.

Calibration: Growth accounting

$$y^* \approx \left(\frac{K}{Y}\right)^{\beta} \cdot h \cdot (\text{R\&D intensity})^{\gamma} \cdot L^{\gamma}$$

	Solow	Lucas	Romer/AH/GH	J/K/S
2.0	0.0	0.4	1.2	0.4
(100%)	(0%)	(20%)	(58%)	(21%)

- Important for our growth calibration: how much (historic) growth is attributed to population growth?
- Jones (2002,2014): most of post WWII growth has been transitional dynamics; only 0.4 per cent point attributable to population growth (transitional dynamics: increasing R&D intensity and schooling)

Calibration: all parameters

Table: Parameters and Macro Targets

Parameter	Description	Value	Source / Targeted Moment
α	Capital-output elasticity	(0.12,0.26,0.39)	Savings share
β	Pure discount	(0.74,0.82,0.90)	Return on capital
δ_Y	Climate damage for output [/K]	(0.005,0.01,0.015)	Hsiang et al. 2017
δ_A	Climate damage for growth [/K]	(0.01,0.03,0.05)	Dell et al. 2012,Burke et al. 2015
ε	Elasticity of demand	(3,5,7)	Industry mark up
φ	Standing on shoulders	(0.71,0.79,0.88)	Convergence of 1-3% p.y.
κ	Natural resource share in output	(0.05,0.1,0.15)	Resource shares
ψ	Standing on toes	(0.49,0.80,0.93)	Income growth, $g_Y/g_L = 1.2 - 1.6$
θ_i	Climate sensitivity [K/TtCO2]	(0.4,0.7,1.0)	Climate literature

The triples for $\beta, \delta_Y, \delta_A, \varepsilon, \kappa, \theta$ present the lower bound, median, and upper bound for chosen uniform distributions, while the triples for α, φ, ψ present 5,50,95 percentiles that come out of the calibration process.

I copied the BM72 - GHKT14 trick

The BM72 and GHKT14 model structure:

- Decision domains (investment + climate policy) become separable
  - 'outcome by assumption' (SS)
  - analysis of 'first order' effects (interactions are second-order)
- Decision variables in intensive form become history-independent
  - BM72: investment share: $s_t = I_t / Y_t = s^*$.
  - GHKT14: Climate policies (E_t) are characterized through the intensive variable g_t, which defines carbon taxes proportional to output (cf GHKT14).

$$g_t \equiv \frac{\partial Y_t / \partial E_t}{Y_t} \tag{21}$$

- Full (transitionary) dynamics, but with 'simple' and independent intensive control variables

BM72 - GHKT14 trick: formalization

Definition (history-independent policies)

A policy (or the allocation produced by the policy), is said to be in the class $\mathcal{P}(s_K)$, $\mathcal{P}(s_A)$, $\mathcal{P}(g)$, $\mathcal{P}(f)$, $\mathcal{P}(x)$, when the corresponding policy choice variable $s_{K,t}, s_{A,t}, g_t, f_t, x_t$ is a sequence (over time) independent of the (current) state of world $(K_{t_0},\ A_t,\ (E_{t-i})_{i=1}^{\infty},\ N_t,\ h_t)$.

- The definition does not require the intensive controls to be constant.
- The definition does not impose a steady state. It characterizes 'behavior' (intensive control variables), e.g. savings rate and innovation share, fertility, time for education, independent of income.
- we can define intersections: $\mathcal{P}(s_K, s_A) = \mathcal{P}(s_K) \cap \mathcal{P}(s_A)$

First formal Result 1: $SO \in \mathcal{P}(s_K, s_A, g, f, h)$

Proposition (Social optimum characterization)

$$s_K^* = \alpha\beta \left[1 + \frac{\beta(1-\psi)}{(\varepsilon-1)(1-\beta\varphi)}\right] \tag{22}$$

$$s_A^* = \frac{\beta(1-\psi)}{(\varepsilon-1)(1-\beta\varphi)+\beta(1-\psi)} \tag{23}$$

$$g^* = \left[\delta_Y + \frac{\beta\delta_A}{1-\beta\varphi}\right] \sum_{i=1}^{\infty} \beta^i \theta_i \tag{24}$$

$$\frac{\phi f^* + x_t f^*}{1-\phi f^* - s^* f^*} = \frac{\gamma + \beta\widetilde{\lambda}_N \widetilde{f}}{(1-\alpha-\kappa)\widetilde{\lambda}}, \tag{25}$$

$$\frac{s^* f^*}{1-\phi f^* - s^* f^*} = \frac{\eta_s \beta}{1-\beta\eta_h}, \tag{26}$$

BM72 + GHKT14

The BM72 - GHKT14 - GL16 feature, extended

Lemma (separable log-linear welfare)

Within the class of equilibria $\mathcal{P}(s_K, s_A, g, f, h)$, welfare depends on the state variables log-linearly:

$$W_t = \zeta_K \ln(K_t) + \zeta_A \ln(A_t) + \zeta_h \ln(h_t) + \zeta_N \ln(N_t) - \sum_{i=1}^{\infty} \Theta_i E_{t-i} + \overline{W}_t. \tag{27}$$

The weights $\zeta_K, \zeta_A, \zeta_h, \zeta_N$ and parameters describing the social costs of past emissions Θ_i are constant over time, and do not depend on the the level of (past, present and future) savings rates $s_{K,t}$, innovation shares $s_{A,t}$, or climate policies g_t, fertility decisions f_t, and schooling x_t. These policy choices are captured by the sequence of constants $(\overline{W}_t)_t$.

R1(a) Broad validity of carbon pricing rule

- Social Optimum $\in \mathcal{P}^* \equiv \mathcal{P}(s_K, s_A, g, f, x)$
- BAU defined as muted climate policy, $g = g^{BAU} < g^*$ is also in $\mathcal{P}^*$
- Any Solow-type equilibrium with behavioral savings rules s_K, innovation investment shares s_A, fertility f_t, time for education x_t are in $\mathcal{P}(s_K, s_A, f, x)$.
  Possible mechanisms: distortions in decision making or incomplete information about true values of parameters such as ψ, φ.

Corollary (Climate policy in second best)

For any reference savings, innovation, fertility and education policy sequence $\mathcal{P}(s_{K,t}, s_{A,t}, f_t, x_t)$, the second-best optimal climate policy implements g^*.

Stern vs Nordhaus

Corollary (Climate policy in second best)

For any reference savings, innovation, fertility and education policy sequence $\mathcal{P}(s_{K,t}, s_{A,t}, f_t, x_t)$, the second-best optimal climate policy implements g^*.

Consider that one argues ethically that time preferences should be based on equal weights for the future (Broome 1994, Stern 2006), $\beta = 0.999$, and that savings etc. are set by other forces orthogonal to ethical climate change decisions ...
we can use the same formula and find a very high SCC.

R1(b) Social costs of carbon has 2 parts

- Output reduction similar to previous literature (GHKT14)

$$g^* = \left[\delta_Y + \frac{\beta\delta_A}{1-\beta\varphi}\right]\sum_{i=1}^{\infty}\beta^i\theta_i \tag{28}$$

- Growth reduction, which has more persistent effects

$$g^* = \left[\delta_Y + \frac{\beta\delta_A}{1-\beta\varphi}\right]\sum_{i=1}^{\infty}\beta^i\theta_i \tag{29}$$

The term $1/(1-\beta\varphi)$ measures the persistence of a growth-reducing negative shock.
If conditional convergence is 2%/yr, and pure discounting is 2%/yr, then any growth reduction shock is valued at $1/(0.02+0.02) = 25$ times the one-year damage.

First quantitative results, carbon prices

We do not need to simulate (!), but can calibrate to long-run economic behavior (population and economic growth)

Table: Outcomes for calibrated model

Variable	**Description**	**Value**
s_K	Capital Investment share	$(0.12, 0.24, 0.34)$
s_A	Research share	$(0.06, 0.11, 0.18)$
τ_E	SCC [€/tCO2]	$(11, 20, 38) + (54, 144, 300)$

The triples present 5,50,95 percentiles. The Social Cost of Carbon is partitioned in its two components

Discussion: Our interpretation of Dell et al (2012) and Burke et al (2015) results in very high Social Costs of Carbon related to growth damages (144 vs 20).

Intermezzo

Nordhaus 2017 finds 31 USD/tCO2, Pindyck 90 USD/tCO2 (experts view on extreme events prevention), Burke et al (2015, Fig5d) don't state SCC but find climate damages order of magnitude larger than other IAMs.

Papers on population-climate interaction effect on welfare remain abstract: do not calculate SCC
(Schou 2002, Kruse-Andersen 2019, Bretschger 2020)

1^{st} perspective: Welfare

$$W_t = \zeta_K \ln(K_t) + \zeta_A \ln(A_t) + \zeta_h \ln(h_t) + \zeta_N \ln(N_t) - \sum_{i=1}^{\infty} \Theta_i E_{t-i} + \overline{W}_t.$$

Table: Returns to scale; outcomes for calibrated model

$(1-\beta)\zeta_K$	capital-permanent income elasticity	$(0.03, 0.07, 0.12)$
$(1-\beta)(1-\psi)\zeta_A$	technology-permanent income elasticity	$(0.02, 0.04, 0.06)$
$(1-\beta)\zeta_N$	population-permanent income elasticity	$(-0.18, -0.05, 0.09)$
$-\beta(\zeta_K + (1-\psi)\zeta_A + \zeta_N)$	birth tax rate	$(-0.84, -0.25, 0.28)$

The triples present 5,50,95 percentiles.

- savings $\nearrow$ 10% $\Rightarrow$ permanent income $\nearrow$ 0.7%
- R&D $\nearrow$ 10% $\Rightarrow$ permanent income $\nearrow$ 0.4%
- population $\nearrow$ 10% $\Rightarrow$ permanent income $\searrow$ 0.5%

2^{nd} perspective: returns to scale

Negative welfare effect of population is short-run: fixed capital and technology.

Long-run: in any semi-endogenous growth: larger population increases long-run per capita income. Resource scarcity is too small to counter.

$$\frac{\widehat{Y}}{\widehat{L}} = \frac{-\kappa(\varepsilon-1)(1-\varphi)+(1-\kappa)(1-\psi)}{(1-\alpha)(\varepsilon-1)(1-\varphi)-\alpha(1-\psi)}\widehat{L} = 0.22\widehat{L} \tag{30}$$

3^{rd} perspective: birth externality

Birth externality: parents internalize the dilution of their savings with the increase in number of children. They do not internalize the other positive innovation + climate effects.

Proposition (optimal fertility tax)

$$\tau^*_{f,t} N_{t+1} = -(\zeta_K + (1-\psi)\zeta_A + \zeta_N) C_t \quad (31)$$

- A positive birth externality $\beta(\zeta_K + (1-\psi)\zeta_A + \zeta_N) = 0.25 > 0$.
- Positive innovation externality > negative climate externality

4^{th} perspective: optimal growth

Whether population growth is optimal or not, does not depend only on returns to scale effects...

- A preference for many children γ results in optimal population growth

Population and welfare

- More children reduce capital per capita (short-run effect $-$)
- More children reduce natural resources per cap (permanent effect $-$)
- More children increase pool of ideas (long-run effect $+$)
- Parents internalize capital dilution effect $\Rightarrow$ birth externality $+$
  Parents also internalize the scarce resource effect iff owned as private property.

Comparison with literature

- Schou (ITPF 2002): No endogenous TFP; small positive birth externality for new abatement technology, major negative externality for resource scarcity
- Gerlagh, Lupi, Galeotti (WP 2018): No endogenous TFP; negative birth externality for natural resource scarcity
- Kruse-Andersen (WP 2019): No optimal climate policy; more people tend to pollute more
- Bretscher (EER 2020): Resource scarcity mainly as exhaustible fossil fuels; fossil fuels markets provide key mechanisms, and do not suffer from negative externalities. Has benefits of new ideas.

Summary: outcomes depend on whether you assume climate change to be a major scarcity problem ($\neq$ fossil fuels), and whether you assume benefit of increasing pool of ideas.

Results reflect assumptions, these reflect view of world?

Model validity

What is the empirical basis for our models?

The model produces a long-run balanced growth for population:

- increases without bound (beyond 12 billion, 100 billion,...) when calibrated to past patterns
- or collapses, when calibrated to Japan's preferences that may represent the future state of world?

The property is shared with other models, but... it is a problem.

- Such models lack validity to study long-run costs & benefits of larger population
- We need some serious negative or positive feedback from the level of population to optimal fertility.

Rebuttal I: demographic transition

We can adjust the model, but...

- SO long-run still converges to either zero population, or infinite population

Rebuttal II: more serious utility (i)

- We tend to focus on tangible economic costs and benefits. ('love for nature' is hard to measure, also with CV)
- Excluding intangibles, the calibration suffers from a structural measurement error.
- Disutility of more people, pollution, congestion, does not necessary transmit through (economically measurable) output.
- Crowding in utility? People have bodies, they value and need space (e.g. land = substantial share of value of houses).

$$w_{i,t} = \sum_{j=0}^{\infty} \beta^j \left[\ln(c_{i,t+j}/n_{i,t+j}) + \gamma_f \ln(f_{i,t+j}) + v(N_{t+j})\right] \tag{32}$$

add physical needs: $v'(\infty) < 0$.

Rebuttal II: more serious utility (ii)

- At the other end: we like company. People are social and like choice when making friends.

$$w_{i,t} = \sum_{j=0}^{\infty} \beta^j \left[\ln(c_{i,t+j}/n_{i,t+j}) + \gamma_f \ln(f_{i,t+j}) + v(N_{t+j}) \right] \tag{33}$$

  add social needs: $v'(0) = \infty$
- Negative feedback from the level of population to optimal fertility.

Optimal population II

Proposition (SO with population socializing and congestion)

The Social Optimum for the economy with a socializing and congestion effect (33) is characterized through the same policy rules as before with respect to capital investments $s^*_{K,t}$ (22), innovation efforts $s^*_{A,t}$ (23), the social costs of carbon g^* (24), and education efforts x^* (26).

The economy converges to a steady state with constant population. For population starting below the steady state level $N_0 < N^*_\infty$, optimal fertility f^*_t strictly decreases with increasing population size N_t.

But no hope yet, for empirical calibration of $v(N_t)$.

Research answers 1 (Innovation & SCC)

1 Climate change and endogenous growth

   a If climate change affects growth, as estimated in recent empirical literature, does that increase the social costs of carbon (carbon tax) substantially?

After you understand the model, the results become obvious.

- Yes and substantially so, due to slow recovery of lost TFP
- Provided a simple intuitive closed-form solution

Research answers 2 (Climate and population)

2 Reason to worry or to celebrate the future 10-12bn world population?
   a Do more people increase or reduce environmental damages and welfare?

Social Optimum

- More people means more man-made varieties, a positive externality.
- More people means less space, less nature, a negative externality.
- In social optimum, positive exceeds negative externality, when measured in per capita consumption.

But empirically

- History shows that pollution increases with population, and space for nature decreases with population
- Policy does not adapt optimally.
- Our models structurally omit social preferences for friends & living space

12 bn people are good for economic output, but your welfare depends on your subjective individually heterogeneous preferences.

Thank You

Comments appreciated