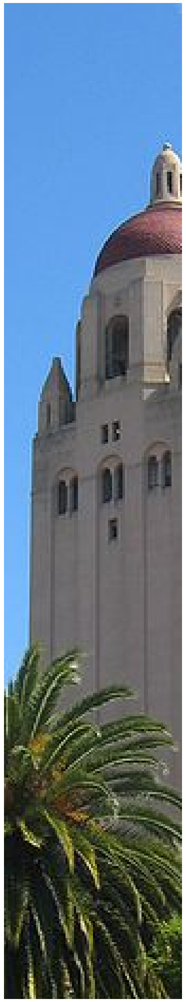

Life and Growth

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R. Posner (2004) *Catastrophe: Risk and Response*

"Certain events quite within the realm of possibility, such as a major asteroid collision, global bioterrorism, abrupt global warming — even certain lab accidents— could have unimaginably terrible consequences up to and including the extinction of the human race... I am not a Green, an alarmist, an apocalyptic visionary, a catastrophist, a Chicken Little, a Luddite, an anticapitalist, or even a pessimist. But... I have come to believe that what I shall be calling the 'catastrophic risks' are real and growing..."

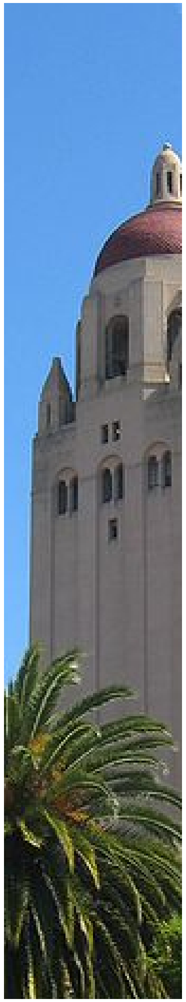
Should we switch on the Large Hadron Collider?

- Physicists have considered the possibility that colliding particles together at energies not seen since the Big Bang could cause a major disaster (mini black hole, strangelets).
- Conclude that the probability is tiny.
- But how large does it have to be before we would not take the risk?
- As economic growth makes us richer, should our decision change?

Growth involves costs as well as benefits

- Benefits | Costs
  - Nuclear power | Nuclear holocaust
  - Biotechnology | Bioterror
  - Nanotechnology | Nano-weapons
  - Coal power | Global warming
  - Internal combustion engine | Pollution
  - Radium, thalidomide, lead paint, asbestos
- Technologies (new pharmaceuticals, medical equipment, airbags, pollution scrubbers) can also save lives

How do considerations of life and death affect the theory of economic growth and technological change?



The “Russian Roulette” Model

New ideas raise consumption,

but a tiny probability of a disaster...

Simple Model

- Single agent born at the start of each period
- Endowed with stock of ideas $\Rightarrow$ consumption c, utilty $u(c)$
- Only decision: to research or not to research
  - Research:

    With (high) probability $1-\pi$, get a new idea that raises consumption by growth rate $\bar{g}$.

    But, with small probability π, disaster kills the agent.
  - Stop: Consumption stays at c, no disaster.

- Expected utility for the two options:

$$U^{\text{Research}} = (1-\pi)u(c_1) + \pi \cdot 0 = (1-\pi)u(c_1), \quad c_1 = c(1+\bar{g})$$
$$U^{\text{Stop}} = u(c)$$

- Taking a first-order Taylor expansion around $u(c)$, agent undertakes research if

$$(1-\pi)u'(c)\bar{g}c > \pi u(c)$$

- Rearranging:

$$\bar{g} > \frac{\pi}{1-\pi} \cdot \frac{u(c)}{u'(c)c}$$

Three Cases

- Consider CRRA utility:

$$u(c) = \bar{u} + \frac{c^{1-\gamma}}{1-\gamma}$$

$\bar{u}$ is a key parameter

- Three cases:
  - $0 < \gamma < 1$
  - $\gamma > 1$
  - log utility ($\gamma = 1$)

Case 1: $0 < \gamma < 1$

$$\bar{g} > \frac{\pi}{1-\pi} \cdot \frac{u(c)}{u'(c)c}$$

- The value of life relative to consumption:

$$\frac{u(c)}{u'(c)c} = \bar{u}c^{\gamma-1} + \frac{1}{1-\gamma}.$$

- $\bar{u}$ not important, so set $\bar{u} = 0$

$$\Rightarrow \frac{u(c)}{u'(c)c} = 1/(1-\gamma)$$

Exponential growth, with rare disasters.

Case 2: $\gamma > 1$

- Notice that we've implicitly normalized the utility from death to be zero (in writing the lifetime expected utility function)
  - So flow utility must be positive for consumer to prefer life
- But $\gamma > 1$ implies $u(c)$ negative if $\bar{u} = 0$:

$$u(c) = \bar{u} + \frac{c^{1-\gamma}}{1-\gamma}$$

  Example: $\gamma = 2$ implies $u(c) = -1/c$.

- Therefore $\bar{u} > 0$ is required in this case.

Case 2: $\gamma > 1$ (continued)

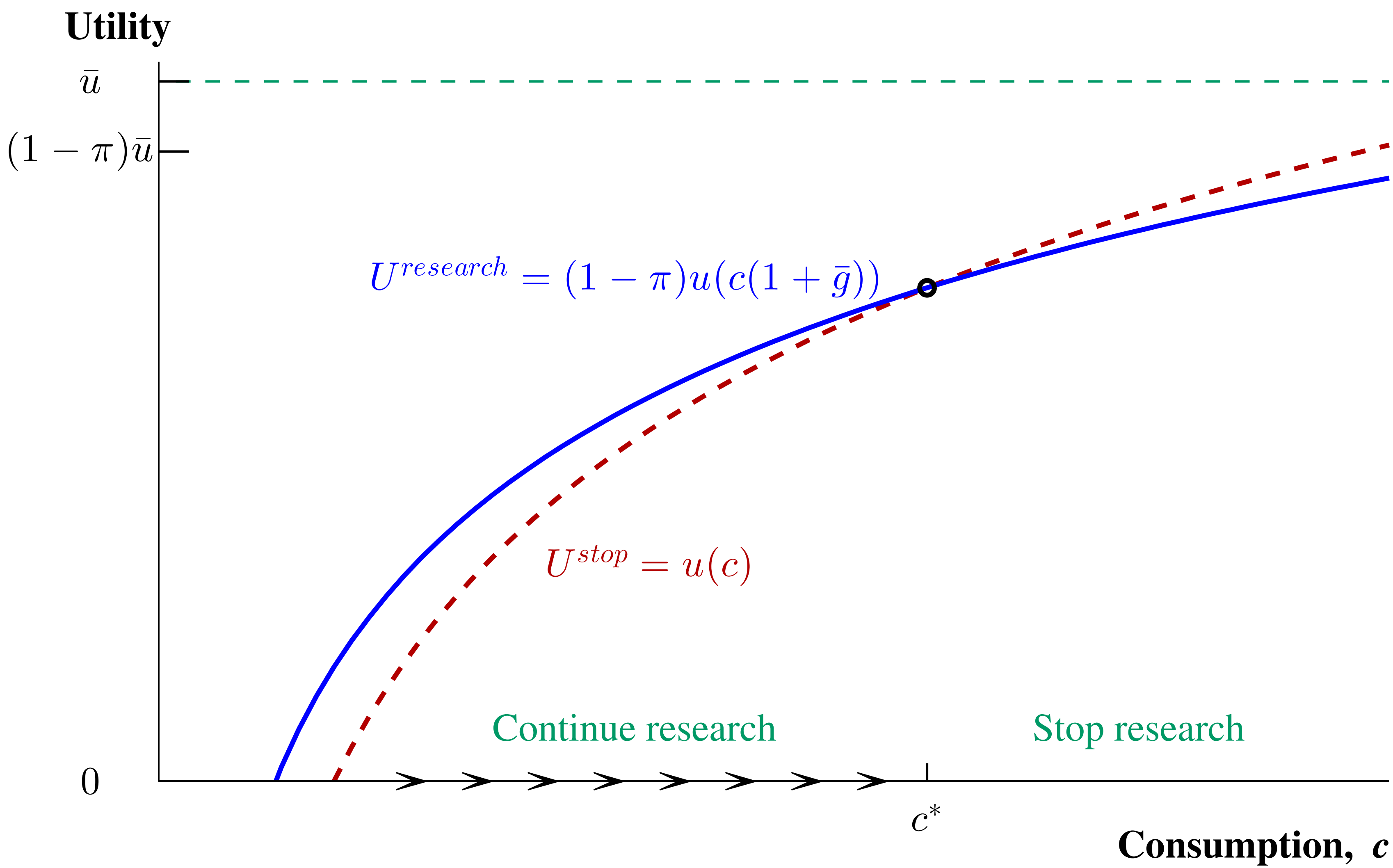
$$\bar{g} > \frac{\pi}{1-\pi} \cdot \frac{u(c)}{u'(c)c}$$

- With $\gamma > 1$, the value of life rises relative to consumption!

$$\frac{u(c)}{u'(c)c} = \bar{u}c^{\gamma-1} + \frac{1}{1-\gamma}.$$

Eventually, people are rich enough that the risk to life of Russian Roulette is too great and growth ceases.

The Research Decision when $\gamma > 1$

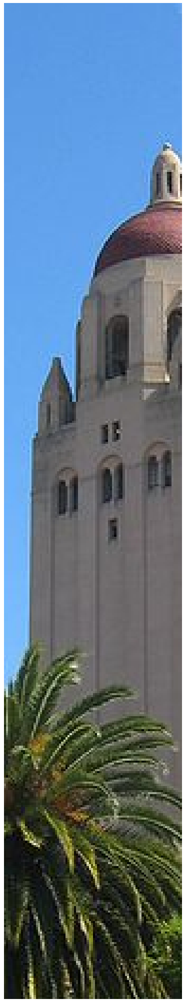


Case 3: log utility ($\gamma = 1$)

- Flow utility is unbounded in this case
- But the value of life relative to consumption still rises

$$u(c)/u'(c)c = \bar{u} + \log c$$

- So growth eventually ceases in this case as well.



Microfoundations in a Growth Model

Hall and Jones (2007) meet Acemoglu (Direction TechChg)

Production	$C_t = (\int_0^{A_t} x_{it}^{1/\alpha} di)^\alpha, \quad H_t = (\int_0^{B_t} z_{it}^{1/\alpha} di)^\alpha$
Ideas	$\dot{A}_t = \bar{a} S_{at}^\lambda A_t^\phi, \quad \dot{B}_t = \bar{b} S_{bt}^\lambda B_t^\phi$
RC (labor)	$L_{ct} + L_{ht} \leq L_t, \;\; L_{ct} \equiv \int_0^{A_t} x_{it} di, \;\; L_{ht} \equiv \int_0^{B_t} z_{it} di$
RC (scientists, pop)	$S_{at} + S_{bt} \leq S_t, \quad S_t + L_t \leq N_t$
Mortality	$\delta_t = h_t^{-\beta}, \;\; h_t \equiv H_t / N_t$
Utility	$U = \int_0^\infty e^{-\rho t} u(c_t) M_t dt, \quad \dot{M}_t = -\delta_t M_t$
Flow util.	$u(c_t) = \bar{u} + \frac{c_t^{1-\gamma}}{1-\gamma}, \quad c_t \equiv C_t / N_t$
Pop growth	$\dot{N}_t = \bar{n} N_t$

Allocating Resources

- 14 unknowns, 11 equations (not counting utility)
  - $C_t, H_t, c_t, h_t, A_t, B_t, x_{it}, z_{it}, S_{at}, S_{bt}, S_t, L_t, N_t, \delta_t$
- Three allocative decisions to be made
  - (s_t) Scientists: $S_{at} = s_t S_t$
  - (ℓ_t) Workers: $L_{ct} = \ell_t L_t$
  - (σ_t) People: $S_t = \sigma_t N_t$
- Rule of Thumb allocation: $s_t = \bar{s}$, $\ell_t = \bar{\ell}$, and $\sigma_t = \bar{\sigma}$

BGP under the Rule of Thumb

PROPOSITION 1: As $t \to \infty$, there exists an asymptotic balanced growth path such that growth is given by

$$g_A^* = g_B^* = \frac{\lambda \bar{n}}{1-\phi}$$

$$\delta^* = 0$$

$$g_c^* = g_h^* = \alpha g_A^* = \alpha g_B^* = \bar{g} \equiv \frac{\alpha \lambda \bar{n}}{1-\phi}.$$

The Optimal Allocation

$$\max_{\{s_t,\ell_t,\sigma_t\}} U = \int_0^\infty M_t u(c_t) e^{-\rho t} dt \quad s.t.$$

$$c_t = A_t^\alpha \ell_t (1-\sigma_t)$$

$$h_t = B_t^\alpha (1-\ell_t)(1-\sigma_t)$$

$$\dot{A}_t = \bar{a} s_t^\lambda \sigma_t^\lambda N_t^\lambda A_t^\phi$$

$$\dot{B}_t = \bar{b} (1-s_t)^\lambda \sigma_t^\lambda N_t^\lambda B_t^\phi$$

$$\dot{M}_t = -\delta_t M_t, \quad \delta_t = h_t^{-\beta}$$

Hamiltonian

- In solving, useful to define

$$\mathcal{H} = M_t u(c_t) + p_{at}\bar{a}s_t^\lambda \sigma_t^\lambda N_t^\lambda A_t^\phi + p_{bt}\bar{b}(1-s_t)^\lambda \sigma_t^\lambda N_t^\lambda B_t^\phi$$

$$-v_t \delta_t M_t$$

- Co-state variables:
  - p_{at}: shadow value of a consumption idea
  - p_{bt}: shadow value of a life-saving idea
  - v_t: shadow value of an extra person

Optimal Growth with $\gamma > 1 + \beta$

PROPOSITION 2: Assume $\gamma > 1 + \beta$. There is an asymptotic balanced growth path such that ℓ_t and s_t both fall to zero at constant exponential rates, and

$$g_s^* = g_\ell^* = \frac{-\bar{g}(\gamma - 1 - \beta)}{1 + (\gamma - 1)(1 + \frac{\alpha\lambda}{1-\phi})} < 0$$

$$g_A^* = \frac{\lambda(\bar{n} + g_s^*)}{1 - \phi}, \quad g_B^* = \frac{\lambda\bar{n}}{1 - \phi} > g_A^*$$

$$g_\delta^* = -\beta\bar{g}, \quad g_h^* = \bar{g}$$

$$g_c^* = \alpha g_A^* + g_\ell^* = \bar{g} \cdot \frac{1 + \beta(1 + \frac{\alpha\lambda}{1-\phi})}{1 + (\gamma - 1)(1 + \frac{\alpha\lambda}{1-\phi})}$$

Intuition

$$\dot{A}_t = \bar{a} s_t^{\lambda} \sigma_t^{\lambda} N_t^{\lambda} A_t^{\phi} \text{ and } \dot{B}_t = \bar{b}(1 - s_t)^{\lambda} \sigma_t^{\lambda} N_t^{\lambda} B_t^{\phi}.$$

- $1 - s_t \to 1$, but s_t falls exponentially, slowing growth in A_t.
- Why? The FOC for allocating ℓ_t is

$$\frac{1 - \ell_t}{\ell_t} = \beta \frac{\delta_t v_t}{u'(c_t) c_t} = \delta_t \tilde{v}_t$$

  where v_t is the shadow value of a life, from the Hamiltonian.
- Numerator is extra lives that can be saved, denominator is extra consumption that can be produced
- Race!

Optimal Growth with $\gamma < 1 + \beta$

PROPOSITION 3: Assume $1 < \gamma < 1 + \beta$. There is an asymptotic balanced growth path such that $\tilde{\ell}_t \equiv 1 - \ell_t$ and $\tilde{s}_t \equiv 1 - s_t$ both fall to zero at constant exponential rates, and

$$g_A^* = \frac{\lambda \bar{n}}{1-\phi}, \quad g_B^* = \frac{\lambda(\bar{n} + g_{\tilde{s}}^*)}{1-\phi} < g_A^*$$

$$g_c^* = \bar{g}, \quad g_\delta^* = -\beta g_h^*.$$

$$g_{\tilde{s}}^* = g_{\tilde{\ell}}^* = \frac{-\bar{g}(\beta + 1 - \gamma)}{1 + \beta(1 + \frac{\alpha\lambda}{1-\phi})} < 0$$

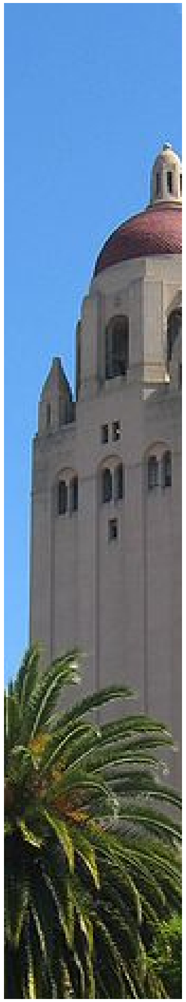
$$g_h^* = g_c^* \cdot \left(\frac{1 + (\gamma - 1)(1 + \frac{\alpha\lambda}{1-\phi})}{1 + \beta(1 + \frac{\alpha\lambda}{1-\phi})} \right) < g_c^*.$$

Optimal Growth with $\gamma = 1 + \beta$

PROPOSITION 4: Assume $1 < \gamma = 1 + \beta$. There is an asymptotic balanced growth path such that ℓ_t and s_t settle down to constants strictly between 0 and 1, and

$$g_A^* = g_B^* = \frac{\lambda \bar{n}}{1 - \phi}$$

$$g_c^* = g_h^* = \bar{g}, \quad g_\delta^* = -\beta \bar{g}.$$



Empirical Evidence

Empirical Evidence

- $\gamma - 1$ versus β
  - $\gamma > 1$ is the "normal" case
  - Evidence from health "production functions" suggests β is relatively small
- Trends in R&D: Toward health
- Quantifying the "growth slowdown"

Evidence on β (Recall: $\delta_t = h_t^{-\beta}$)

- Plausible upper bound compares trends in mortality to trends in health spending
  - Attributes all decline in mortality to real health spending
  - Minimal quality adjustment reinforces "upper bound" view for β
- Numbers for 1960 – 2007
  - Age-adjusted mortality rates fell at 1.2% per year
  - CPI-deflated health spending grew at 4.1% per year

$$\Rightarrow \beta^{\text{upper bound}} \approx \frac{1.2}{4.1} \approx .3$$

- Hall and Jones (2007) more careful analysis along these lines finds age-specific estimates of between .10 and .25.

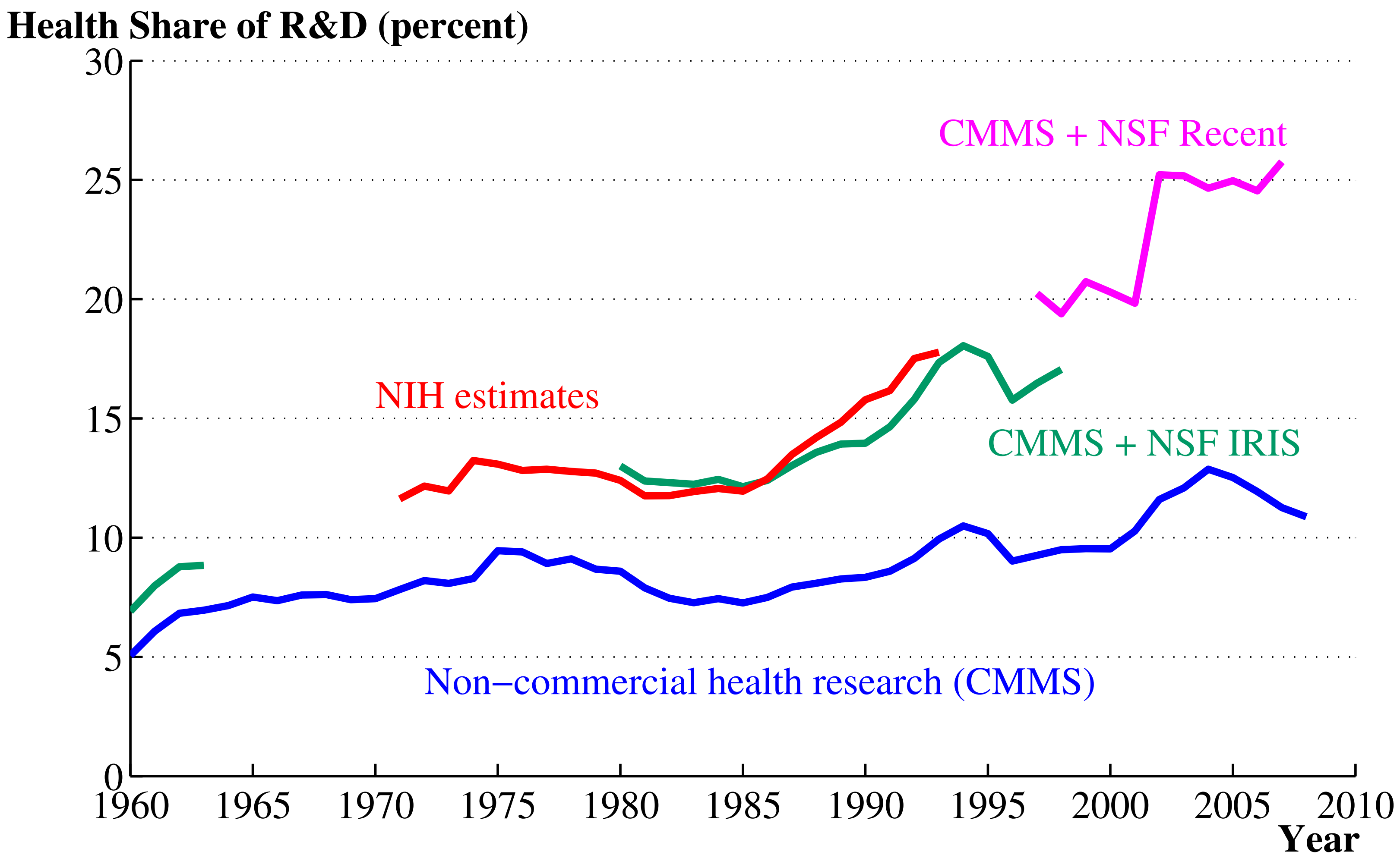
Evidence on γ

- Risk aversion evidence suggests $\gamma > 1$
  - Asset pricing (Lucas 1994), Labor supply (Chetty 2006)
- Intertemporal substitution elasticity $1/\gamma$
  - Traditional view is EIS<1 $\Rightarrow \gamma > 1$ (Hall 1988)
  - Careful micro work supporting this view: Attanasio and Weber (1995), Barsky et al (1997), Guvenen (2006), Hall (2009)
  - Other recent work finds some evidence for EIS>1 $\Rightarrow \gamma < 1$ (Vissing-Jorgensen and Attanasio 2003, Gruber 2006)
- Mixed evidence.

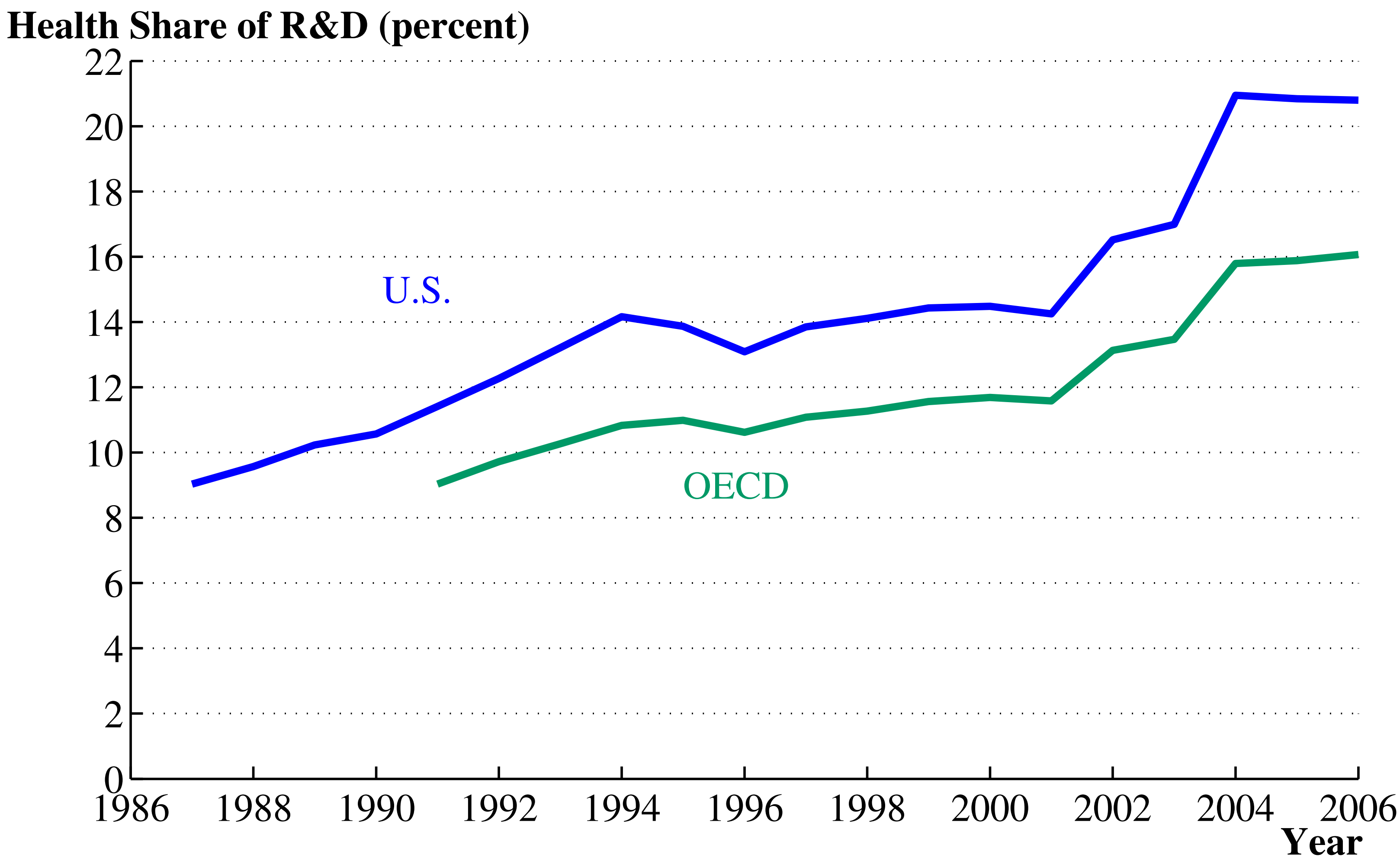
Evidence on the Value of Life

- Same force as in Hall and Jones (2007) on health spending
  - Consumption runs into sharply diminishing returns: $u'(c)$
  - While life becomes increasingly valuable: $u(c)$
- Evidence on value of life?
  - Nearly all is cross sectional
  - Costa and Kahn (2004), Hammitt, Liu, and Liu (2000)
- Other evidence? Safety standards?

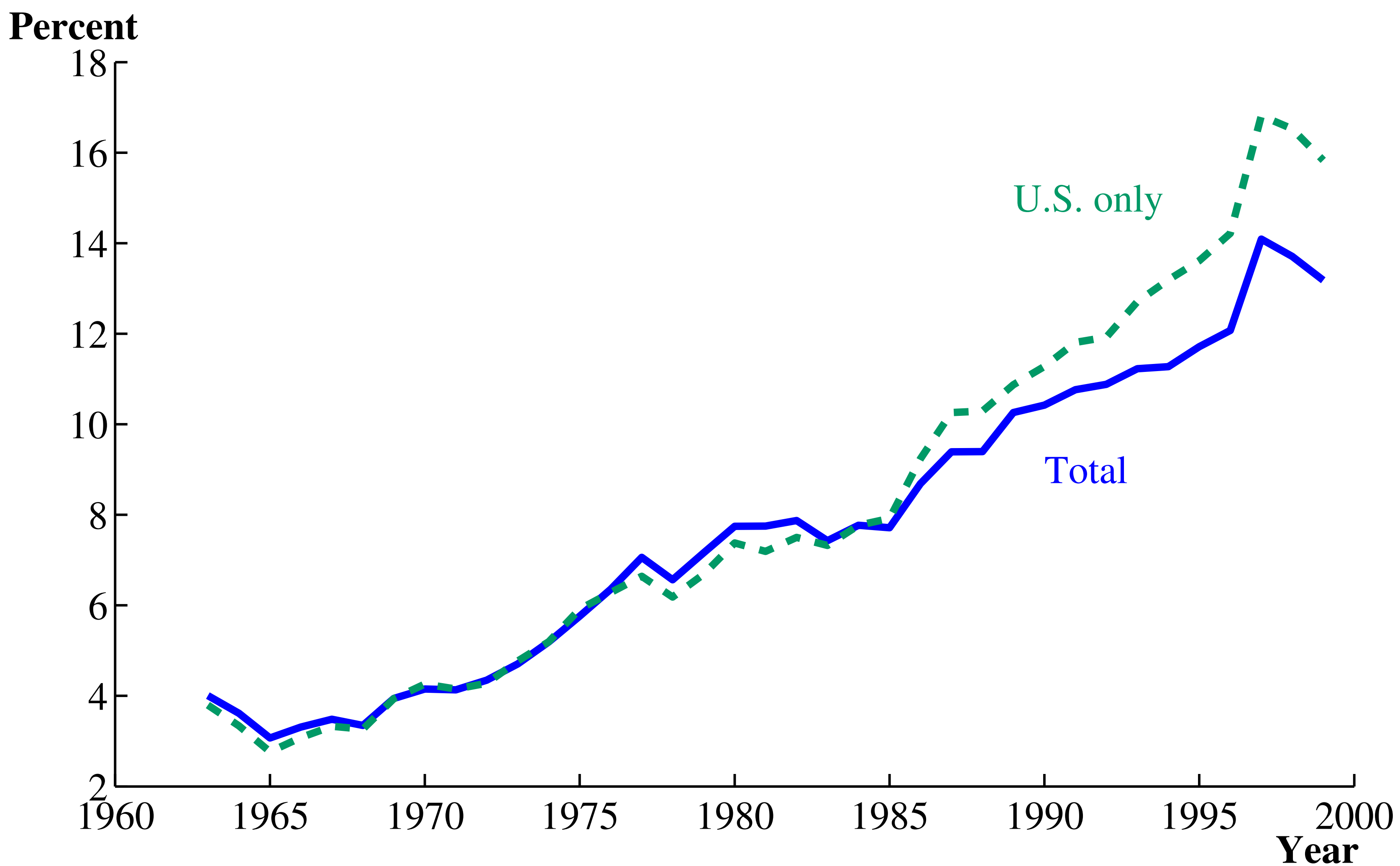
The Changing Composition of U.S. R&D Spending



The Changing Composition of OECD R&D Spending

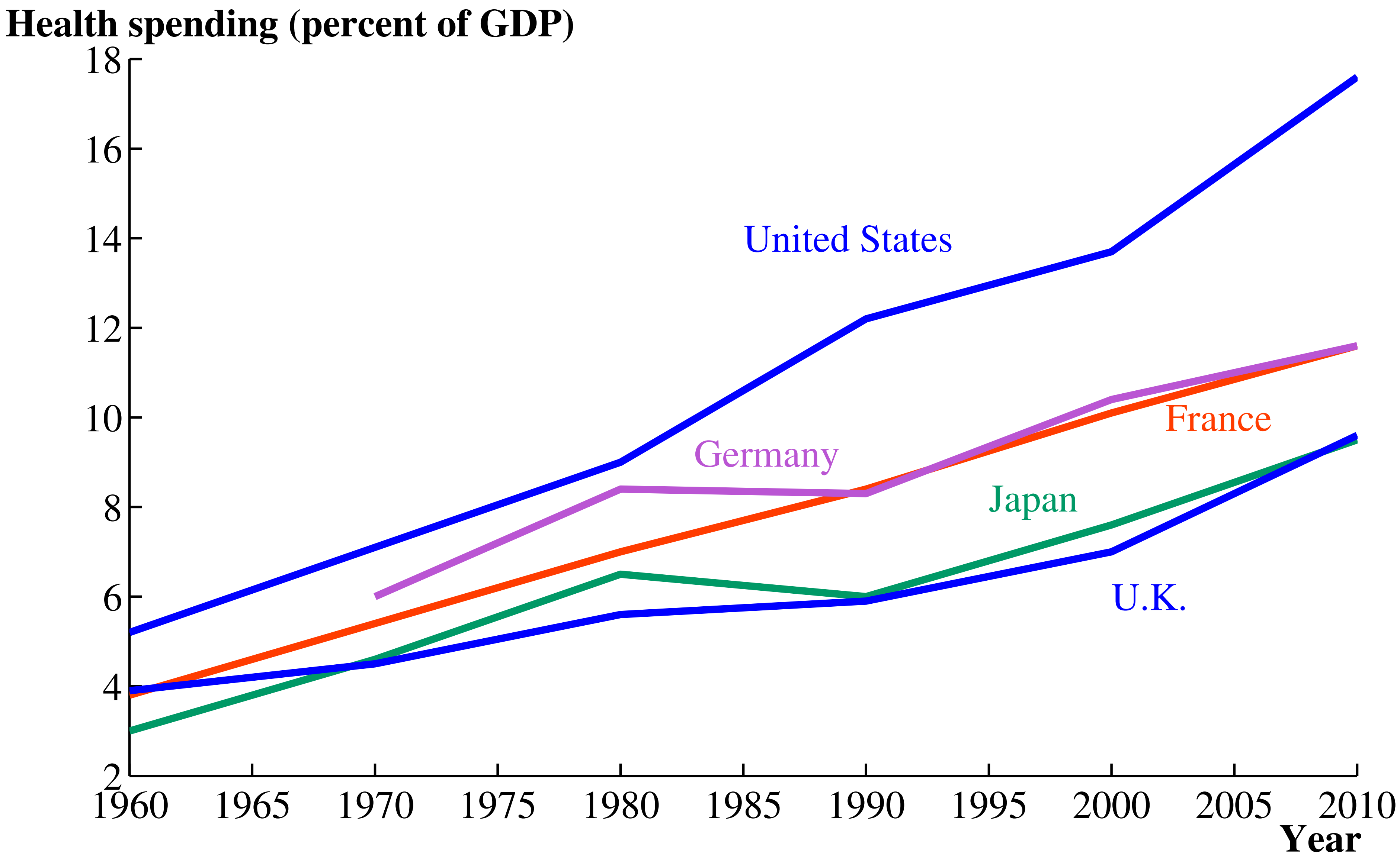


Fraction of Patents for Medical Eq. or Pharma

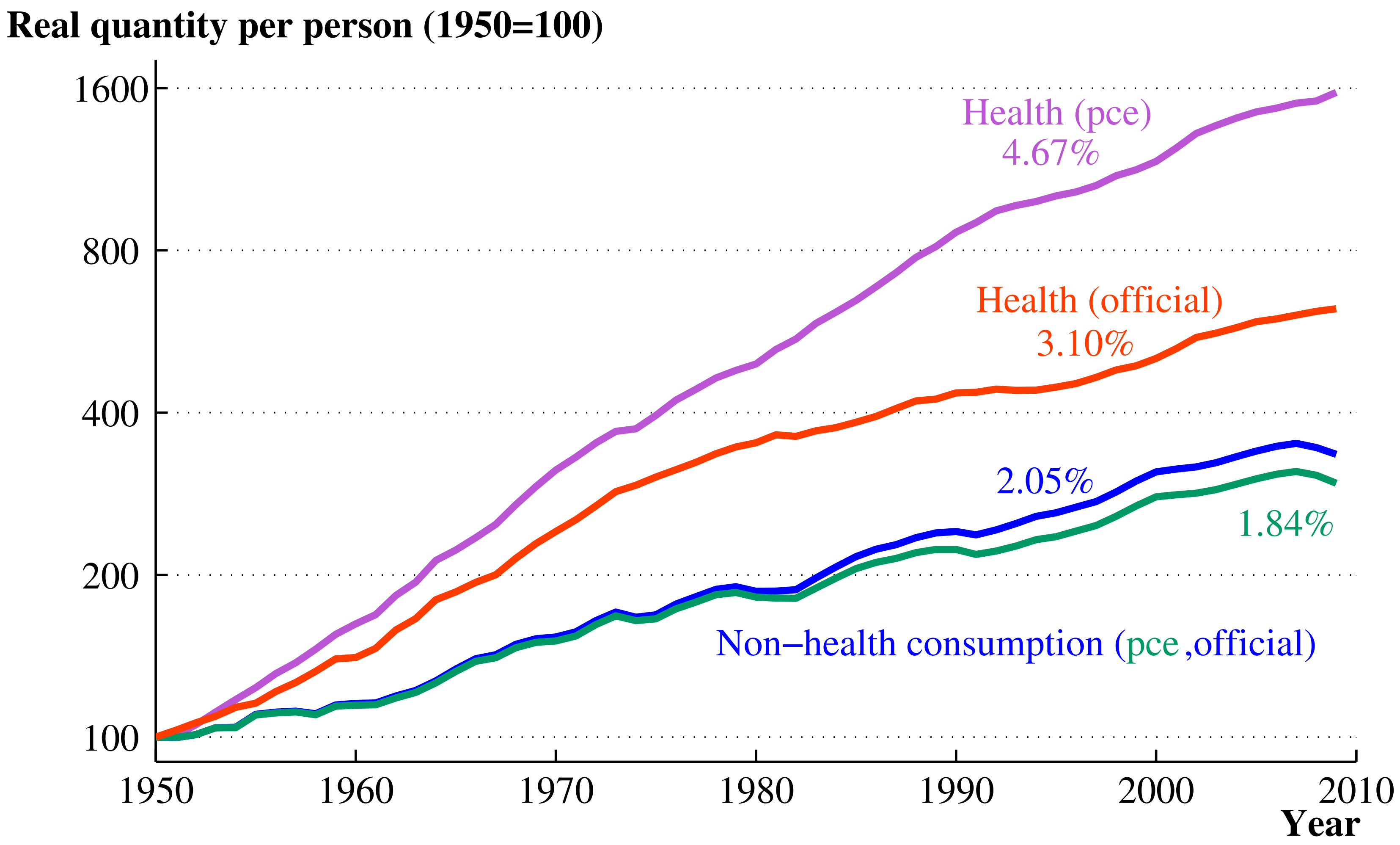


Source: Jeffrey Clemens

An Income Effect in Health Spending



Health and Consumption



The Growth Drag: Ratio of g_c to g_h

	$\beta = .25$		$\beta = .10$	
$\frac{\alpha\lambda}{1-\phi}$	$\gamma = 1.5$	$\gamma = 2$	$\gamma = 1.5$	$\gamma = 2$
0.50	0.79	0.55	0.66	0.46
1.00	0.75	0.50	0.60	0.40
2.00	0.70	0.44	0.52	0.33

A Future Slowdown?

- Calibration to past growth suggests $\frac{\alpha\lambda}{1-\phi} < 2$, so that $\bar{g} < 2\%$.
  - Therefore growth in h must slowdown significantly from its $4+\%$ rate.
  - And $g_c \approx \frac{1}{2} g_h < 1\%$ suggests a slowdown of consumption growth as well.
- Intuition: h has been growing much faster than its steady state rate because of the rising share of research devoted to life-saving technologies.

Conclusions

- Including “life and death” considerations in growth models can have first order consequences.
- For a large class of preferences, safety is a luxury good.
  - Diminishing returns to consumption on any given day means that additional days of life become increasingly valuable.
  - R&D may tilt toward life-saving technologies and away from standard consumption goods.
  - Consumption growth may be substantially slower than what is feasible, possibly even slowing all the way to zero.