Automation, Human Capital and Welfare: The Stochastic Uzawa-Lucas Approach

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Summing Up: My Paper in One Slide

Q: "What is the effect of automation on human capital and on our macroeconomy?"

Build the continuous-time *stochastic* Uzawa-Lucas model in which the accumulation of human capital follows the stochastic process.

3 Major Findings:

1. With two equality constraints, the (extremely rare) closed-form solution obtains, even in continuous time under uncertainty.
2. Optimal consumption depends on *efficiency/quality* (e.g. index) of human capital, not the *stock/quantity* of human capital.
3. Increasing risk of automation
   - reduces household welfare.
   - leads to human capital contraction.

Outline of the Talk

1. Motivation & Literature Review
    - Key Facts
2. The Model
3. Concluding Remarks

Motivation: Automation Taking Place Globally at Unprecedented Speed (Before and After the Crisis of 2008)

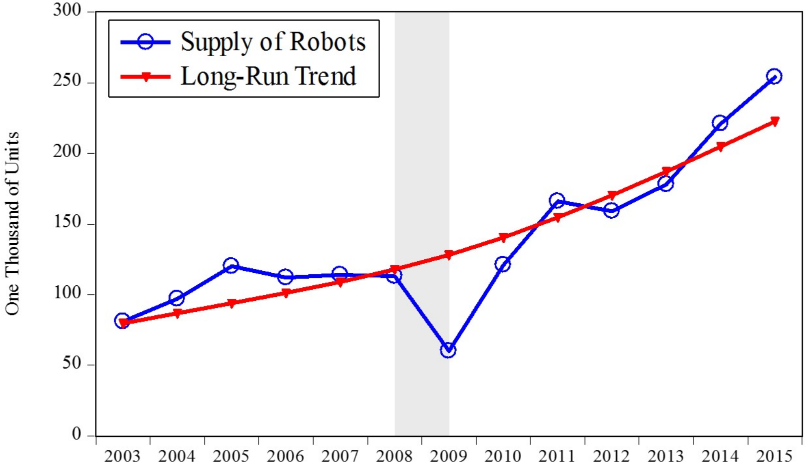


Figure: After the crisis, supply speeding up. *Source*: International Federation of Robotics (2016).

Motivation: Fear of "Technological Unemployment" - List of Selected Jobs that Will be Replaced by Computers

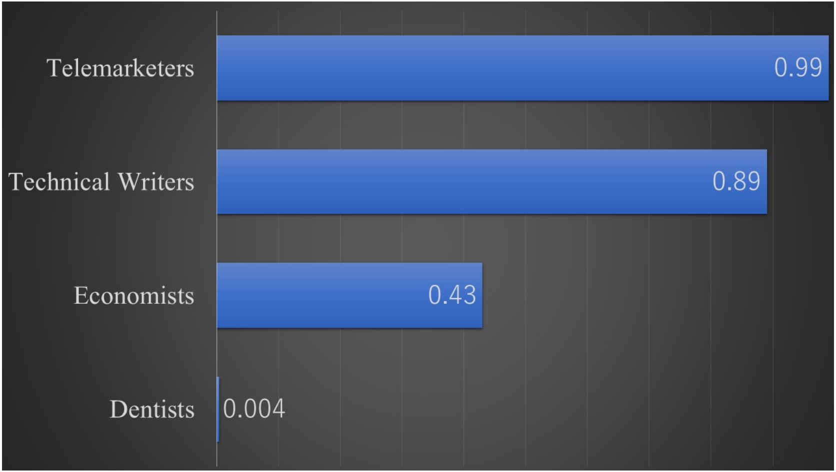


Figure: Probability of computerization... *Source*: Frey and Osborne (2017). 1 = Highest Risk of Automation.

Motivation: Human Capital Lost Only Twice in US History

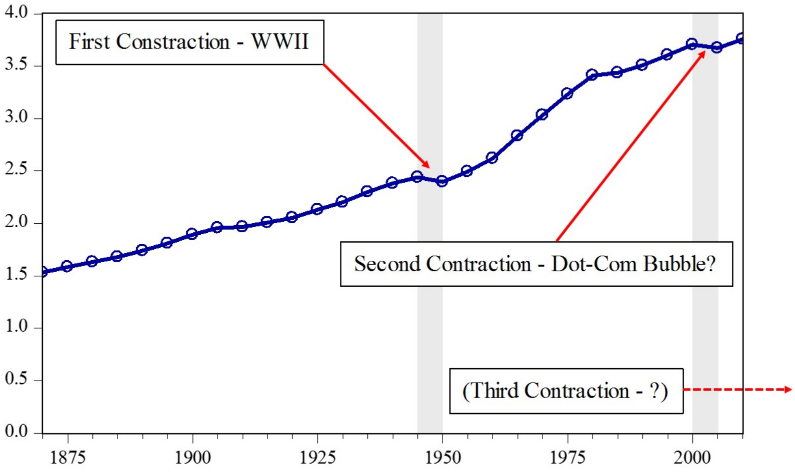


Figure: US human capital index, over the last 14 decades. The mystery circa 2000 despite productivity growth. *Source*: Lee and Lee (2016JDE).

Brief Literature Review: Two Views and My Paper

1. Optimistic View
   - Technology creates new jobs.
   - Some jobs cannot be automated by its nature.
   - Kaku (2012), Deloitte (2015) report, Arntz, Gregory and Zierahn (2016), ...
2. Pessimistic View
   - Labors can be replaced by computers.
   - Labors lose jobs (technological unemployment).
   - Brynjolfsson and McAfee (2012), Acemoglu, Autor, Dorn, Hanson and Price (2014AER), Acemoglu and Restrepo (2017NBER), ...

Literature as a Whole: The effect of automation *only* on the labor mkt (employment, wage inequality, etc).

My paper: The effect of automation on macroeconomy as a whole (specifically, household welfare and human capital).

Analyze the economy where human capital (skills, embodied knowledge) is always and instantaneously at risk of being obsolete, due to rapid automation.

Outline of the Talk

1. Motivation & Literature Review
2. The Model
   - Uzawa-Lucas Model
3. Concluding Remarks

The Uzawa (1965IER) - Lucas (1988JME) Model I

- (Will explain in detail in the next slides.)
- Stylized *deterministic* endogenous growth model in which human capital is an explicit input.

- Recent advance by Bucci et al. (2011JEZN) and Hiraguchi (2013JEZN): *Stochastic* Uzawa-Lucas model in which technology follows a geometric Brownian motion.
- Can answer: "How does the *technology shock* (?) affect economic growth?"
- But they do not consider the welfare. Why not analyze variable X with or without uncertainty?

- Today: Stochastic accumulation of human capital. Increasing automation risk lowers household welfare.

The Uzawa-Lucas Model II: Big Picture

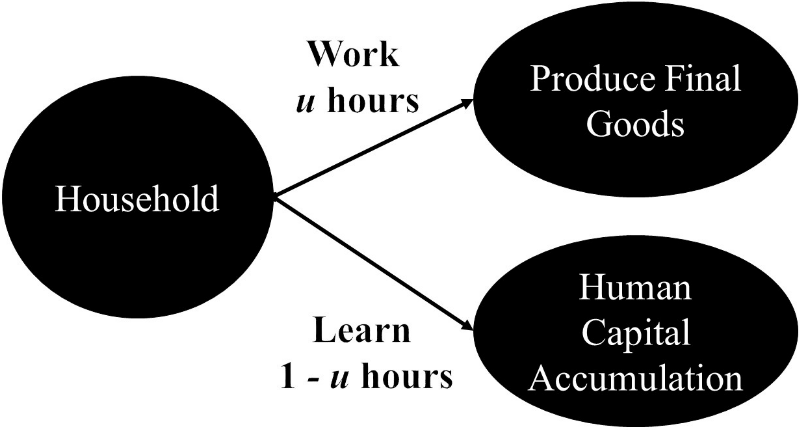


Figure: Note: No Leisure. Household, Production and Education Sector.

The Uzawa-Lucas Model III: Production Sector

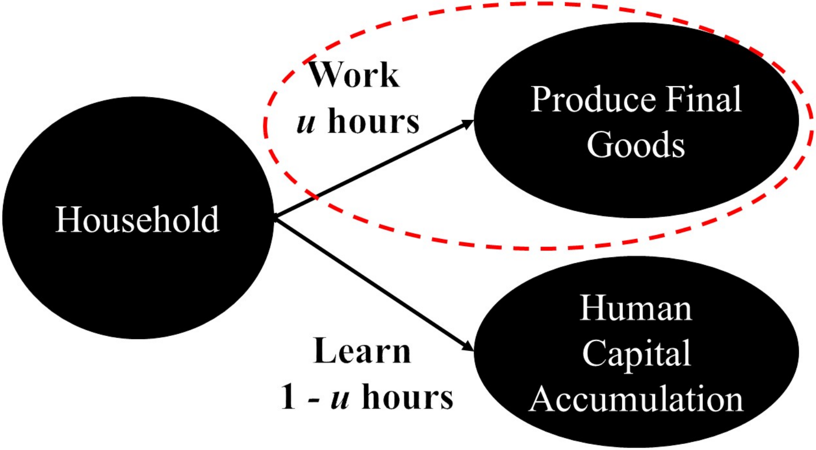


Figure: Begin with the Production Sector.

Production Sector

Goods Mkt Clearing

$$\underbrace{Y(t)}_{Output} = \underbrace{C(t)}_{Consumption} + \underbrace{I(t)}_{Investment} \tag{1}$$

Cobb-Douglas Technology ($\alpha =$ "labor" share)

$$Y(t) = [\underbrace{u(t)}_{WorkTime} \underbrace{H(t)}_{HumanCapital}]^{\alpha} K(t)^{1-\alpha} \tag{2}$$

Law of motion for physical capital K (Note: Abstract from depreciation δ to allow for the explicit solution)

$$dK(t) = I(t)dt \tag{3}$$

Thus

$$dK(t) = \underbrace{[u(t)H(t)]^{\alpha} K(t)^{1-\alpha}}_{\equiv Y(t)} dt - C(t)dt \tag{4}$$

The Uzawa-Lucas Model IV: Household

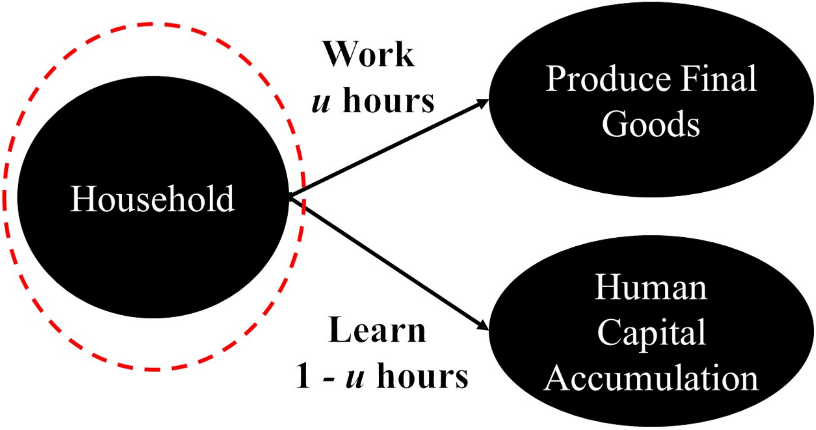


Figure: Next, Household optimization.

Household Optimization under Uncertainty

Preferences of a representative household are given by

$$E \int_0^\infty e^{-\rho t} \frac{C(t)^{1-\phi} - 1}{1-\phi} dt \tag{5}$$

where

$\rho =$ subjective discount rate
$\phi =$ risk aversion

- CRRA utility: People risk averse
- If no E: Textbook Ramsey-Cass-Koopmans Model

The Uzawa-Lucas Model V: Education Sector

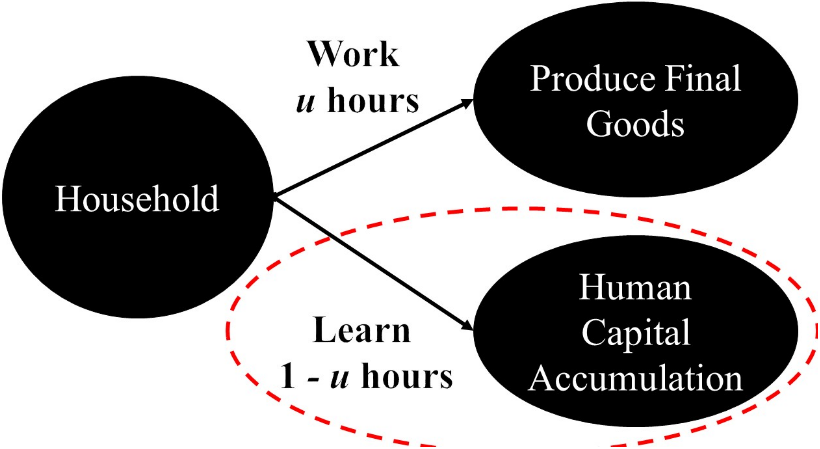
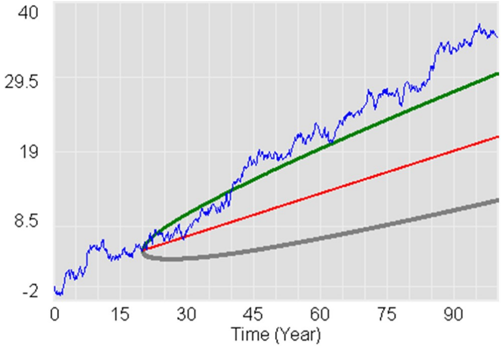


Figure: Finally, the Education Sector.

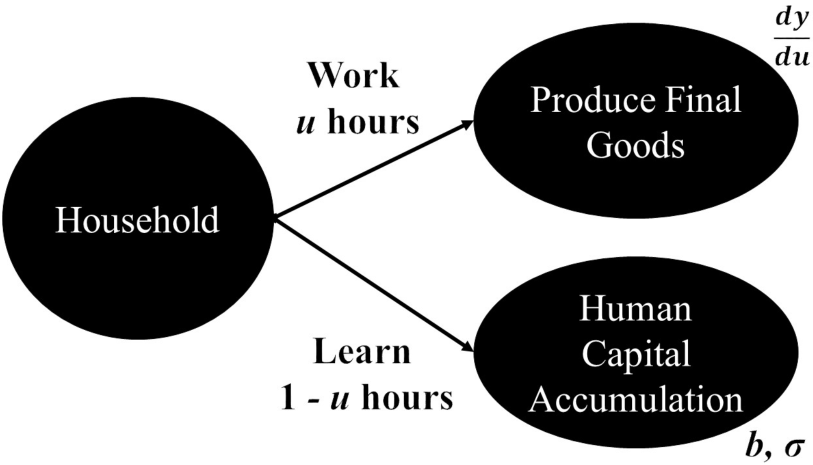
Education Sector: Source of Uncertainty

$$dH(t) = \underbrace{\underbrace{b(t)}_{Efficiency} \underbrace{(1-u(t))}_{LearnTime} \underbrace{H(t)}_{HumanCapital}}_{Drift} dt + \underbrace{\sigma H(t)}_{Diffusion} dz_t \qquad (6)$$

where dz_t is the increment of the *Brownian motion* s.th. $E(dz_t) = 0$ and $Var(dz_t) = dt$! $\sigma =$ degree of automation risk.



The Uzawa-Lucas Model: Picture Summary



Putting All Together: Stochastic Optimization in Continuous Time

Maximize

$$E \int_0^\infty e^{-\rho t} \frac{C(t)^{1-\phi} - 1}{1-\phi} dt \tag{7}$$

subject to

$$dK(t) = \underbrace{[u(t)H(t)]^\alpha K(t)^{1-\alpha}}_{\equiv Y(t)} dt - C(t)dt \tag{8}$$

and

$$dH(t) = b(t)(1-u(t))H(t)dt + \sigma H(t)dz_t \tag{9}$$

- Let $J(H, K)$ be value function.
- Unfortunately (as usual), *no* closed-form solution to this optimization problem...(!) See the Appendix for Turnovsky's thoughtful comments on this.

Aside: "Math Matrix" for Macroeconomic Dynamics: Time and (Un)certainty

	Discrete Time	**Continuous Time**
Deterministic	Solow => Lagrangian	Ramsey => Hamiltonian
Stochastic	RBC, DSGE => Lagrangian, Dynamic Programming	Stochastic Dynamic Programming =>(Generally) no closed-form solution

Figure: "Stochastic Optimization in Continuous Time" is the worst case (see Chang (2004) and Wälde (2011JEDC)).

The Closed-Form Solution Obtained

Proposition: If we impose

$$\underbrace{\phi}_{RiskAversion} = \underbrace{\alpha}_{LaborShare} = \frac{1}{2} \tag{10}$$

$$b = 2\rho \tag{11}$$

then, we *can* get the closed-form solution of the form

$$\underbrace{J(K,H)}_{ValueFunction} = \underbrace{\sqrt{\Lambda_\rho}}_{Const.} \sqrt{K} + \underbrace{\Upsilon_\sigma}_{Const.} \underbrace{\Lambda_\rho}_{Const.} \sqrt{H} - \underbrace{\Lambda_\rho}_{Const.} \tag{12}$$

- The restriction (10) first used by Xie (1994JET). Subsequently, Rebelo and Xie (1999JME), Smith (2007BEJM), and among others...
- J: Measure of household welfare.
- "A picture is worth a thousand words".

Value Function $J(K, H)$ Visualized: Household Welfare under Certainty and Uncertainty

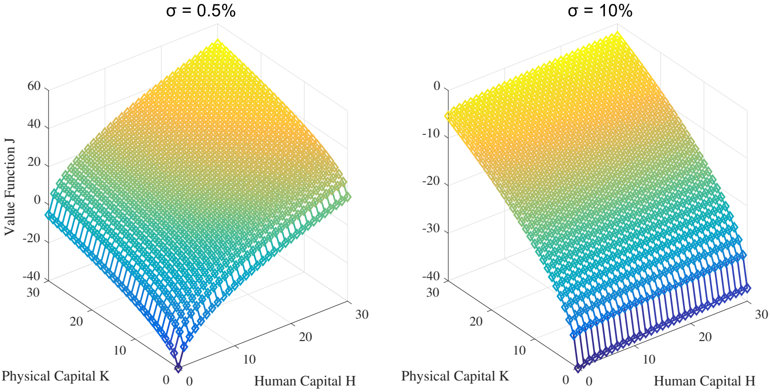


Figure: Value function $J(K, H)$ visualized using $\rho = 0.05$. Left: Virtually deterministic. Right: Stochastic. Key: $\sigma\uparrow\rightarrow$ J$\downarrow$.

Corresponding Policy Functions (= "Optimal Rules")

The value function J implies (Control variables)

$$\underbrace{C}_{Consumption} = \underbrace{b}_{Efficiency} K \tag{13}$$

$$\underbrace{u}_{WorkingTime} = \frac{\overbrace{\sigma^2}^{HumanCapitalUncertainty}}{16b} \tag{14}$$

- Hiraguchi (2013JEZN): "Why C independent of H?"
- Answer: Not $H \uparrow \rightarrow C \uparrow$. But $b \uparrow \rightarrow C \uparrow$.
- Another Key: $\sigma \uparrow \rightarrow u \uparrow$. Visualize these points.

Policy Function I: Human Capital Efficiency b

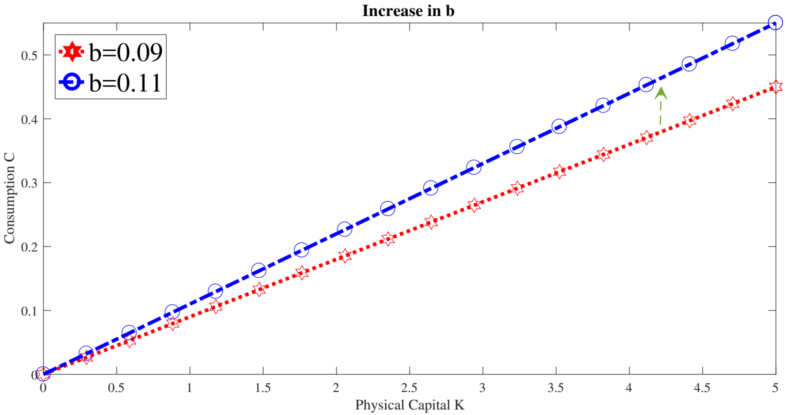


Figure: Policy function. $C = bK$. Yes: b↑→C↑ (*No* :H↑→C↑).

Policy Function II: Increasing Automation Risk σ

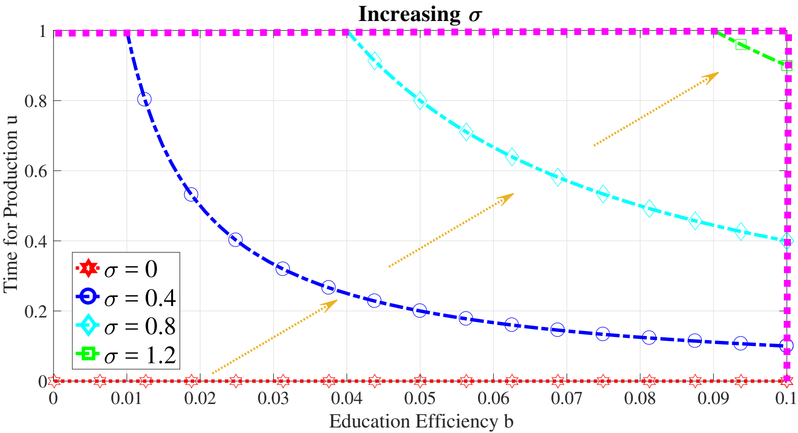


Figure: Increase in σ given b. $\sigma\uparrow\rightarrow u\uparrow$.$\sigma\uparrow\rightarrow$u$\in(0,1)$ harder. When $b=0.1$, $u\in(0,1)$ so long as σ is not too large. Thus, my analysis not restricted to the deterministic neighborhood $\sigma=0$, i.e. when risk of jobs replaced by computers $=0$.

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1. Motivation & Literature Review
2. The Model
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Concluding Remarks

- "What impact does automation have on human capital and our macroeconomy?"
- Build the stochastic Uzawa-Lucas model in which the accumulation of *human capital* follows the stochastic process.

Major Findings:

1. Two equality constraints allows for the (extremely rare) closed-form solution, even in continuous time under uncertainty.
2. Optimal consumption hinges upon *efficiency/quality* of H, not the *stock/quantity* of H ($b \uparrow \rightarrow C \uparrow$).
3. Increase in automation risk $\sigma \uparrow$
   - reduces household welfare $J \downarrow$.
   - leads to human capital contraction $H \downarrow$.

Thanks for Your Attention!

THE END

Appendix: Why Bother with Stochastic Optimization in Continuous Time?

Turnovsky (2000, page 580):

...This is in part a reflection of the fact that they [continuous-time optimization methods under uncertainty] involve a certain amount of technical apparatus, *not that familiar to economists*, and in part a consequence of the fact that *they are often intractable*. However, it is our view that *when they are tractable, continuous-time methods yield transparent solutions that significantly facilitate our understanding of the particular issue.*

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