Are Ideas Really Getting Harder To Find? R&D Capital and the Idea Production Function

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Stand with Ukraine

The Idea Production Function in the Growth Literature

- Most R&D-based growth literature assumes that R&D labor is the only input in producing ideas (Romer, 1990; Jones, 1995, 1999; Ha and Howitt, 2007)
- The "lab equipment" specification uses the flow of R&D spending (Rivera-Batiz and Romer, 1991; Kruse-Andersen, 2017)
- Bloom et al. (2020) use effective R&D employment

$$\text{Research Output} = \underbrace{\text{Research Productivity}}_{\alpha_t} \times \text{Researchers}. \tag{1}$$

- Apparently, no role for R&D capital!

Introducing R&D Capital

We introduce **R&D capital** as a factor in producing ideas

- A stock, accumulated through R&D investment
- Arguably, R&D is an increasingly capital-intensive activity: experimentation, numerical computation, prototype testing, etc.
- Practicality and complexity of research equipment has undergone systematic, cumulative changes and productivity improvements over decades and centuries, from Ptolemy's astrolabe or Galileo's telescope to the LHC and VLT
- Modern R&D activity also increasingly uses AI

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Our expectation

- Predictions for idea TFP (Γ_t) will differ if the rate of change in R&D capital systematically differs from that of R&D labor

A First Look at the Data (USA, 1968-2019)

Variables	Symbol	Growth Rate
Patent Applications	ΔA	3.211
Patents-in-Force	A	2.410
Patent Applications Relative to Patents-in-Force	$\Delta A/A$	0.782
R&D Capital	$\mathcal{K}$	3.394
R&D Labor	$\mathcal{R}$	2.099
R&D Wage	w	0.848
R&D Expenditure (Real)	Ω	3.319
R&D Expenditure Relative to R&D Wage	Ω/w	2.450
R&D Capital Relative to Patents-in-Force	$\mathcal{K}/A$	0.961
R&D Labor Relative to Patents-in-Force	$\mathcal{R}/A$	-0.304
Patent Applications Relative to R&D Labor	$\Delta A/\mathcal{R}$	1.090
Patent Applications Relative to Ω/w	$\Delta A/(\Omega/w)$	0.743
Patent Growth Relative to R&D Labor	$(\Delta A/A)/\mathcal{R}$	-1.289
Patent Growth Relative to Ω/w	$(\Delta A/A)/(\Omega/w)$	-1.628

Source: Derived from *WIPO, IPUMS CPS*.

Contribution and Overview of Results

Contribution

- We introduce R&D capital alongside R&D labor into the idea production function (IPF)
- We estimate the IPF allowing for a non-unitary elasticity of substitution and non-neutral productivity changes

$$\Delta \widetilde{A}_t = \left[\eta \left(\Gamma_t^{\mathcal{K}} \widetilde{\mathcal{K}}_t \right)^{\frac{\xi-1}{\xi}} + (1-\eta) \left(\Gamma_t^{\mathcal{R}} \widetilde{\mathcal{R}}_t \right)^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}} \tag{2}$$

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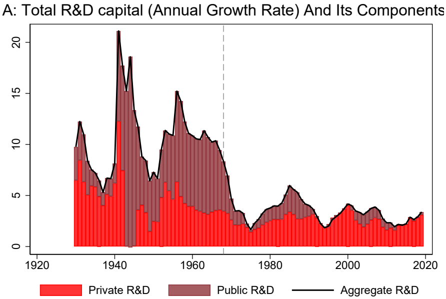
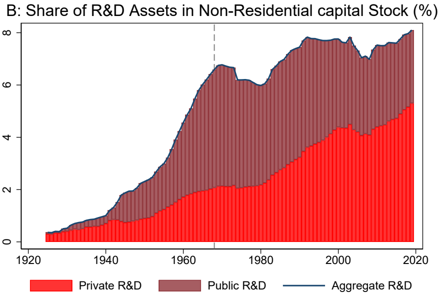
Overview of Results

- We find an elasticity of substitution $\xi \approx 0.6 - 0.8$
- We identify a systematic positive trend in R&D labor productivity at about 1% per year on average...
- ...and a cyclical dynamic in R&D capital productivity
- On average, effective supply of R&D capital was lagging behind that of R&D labor, constraining R&D output
- Idea TFP has not been falling but oscillating around a constant mean

R&D Capital

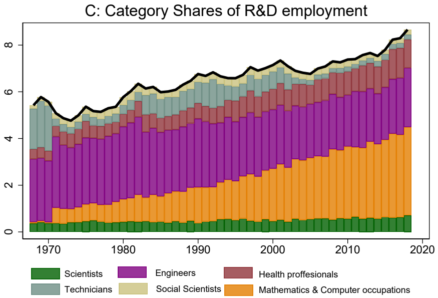
R&D capital is constructed with PIM from BEA data on R&D investment (USA, 1929-2019), $\delta = 15\%$ per annum

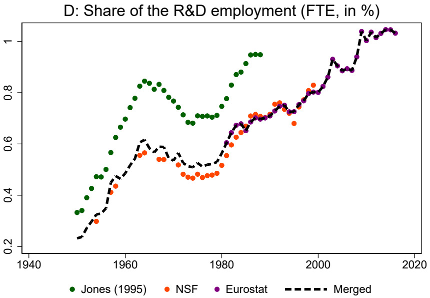




R&D Labor

R&D labor is constructed using IPUMS Current Population Survey (CPS) data. We concentrate on **Scientists**; **Engineers**; **Health Professionals**; **Technicians**; **Social Scientists**; and **Mathematical & Computer Occupations**.





R&D Output and Rental Prices

R&D output

- Patent applications from USPTO/WIPO (Madsen, 2008; Ang and Madsen, 2011; Venturini, 2012)
- *Robustness check:* growth rate of aggregate TFP (Bloom et al., 2020)

Rental prices in the R&D sector

- Capital rental rate: sum of the real interest rate (from Fred) and the R&D capital deprecation rate
- Wage: real hourly wage in R&D (from CPS)

Estimation

We estimate the normalized CES specification in a 2-equation system (Klump et al., 2007; León-Ledesma et al., 2010)

- This approach combines information from different sides of the production framework (costs and volumes) and exploits cross-equation restrictions

$$\Delta \widetilde{A}_t = \left[\eta \left(\Gamma_t^{\mathcal{K}} \widetilde{\mathcal{K}}_t \right)^{\frac{\xi-1}{\xi}} + (1-\eta) \left(\Gamma_t^{\mathcal{R}} \widetilde{\mathcal{R}}_t \right)^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}} \tag{3}$$

$$\ln \left(\frac{r_t^{\mathcal{K}} \mathcal{K}_t}{w_t^{\mathcal{R}} \mathcal{R}_t} \right) = \left(\frac{\xi - 1}{\xi} \right) \ln \left(\frac{\Gamma_t^{\mathcal{K}} \widetilde{\mathcal{K}}_t}{\Gamma_t^{\mathcal{R}} \widetilde{\mathcal{R}}_t} \right) \tag{4}$$

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We consider three assumptions about technical change (growth in $\Gamma_t^{\mathcal{K}}$ and $\Gamma_t^{\mathcal{R}}$)

- Exponential trend
- Box–Cox form $\log\Gamma_t^j = \mathbf{B}(\gamma_j, \lambda_j; t)$
- Fourier form $\log\Gamma_t^j = \mathbf{F}\left(\gamma_j, \kappa_j^{sin}, \kappa_j^{cos}; t\right)$

Baseline Results

Explained variable: normalized patent applications

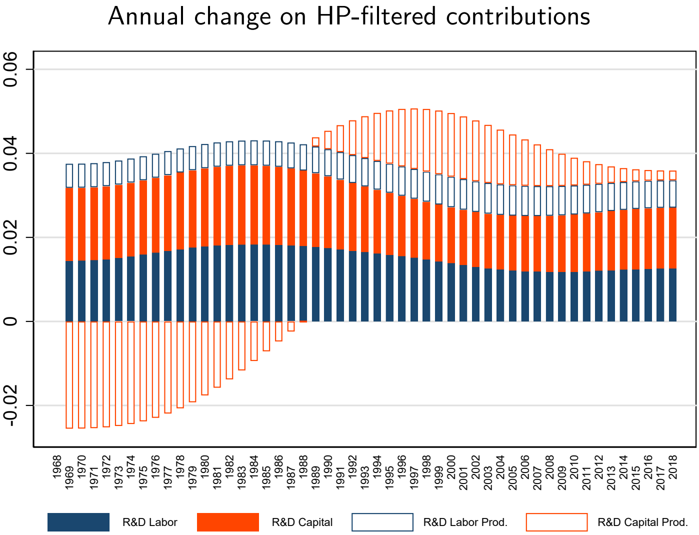
	(3)	(4)	(5)	(6)	(7)	(8)
ξ	0.844***	2.531***	0.737***	0.986***	0.793***	0.760***
$\gamma_{\mathcal{R}}$	0.012***	0.012***	0.011***	−0.013	0.011***	0.011***
$\lambda_{\mathcal{R}}$		2.890***		6.453		
$\gamma_{\mathcal{K}}$			0.004	0.060	−0.016***	−0.013***
$\lambda_{\mathcal{K}}$				5.208		
$\kappa_{\mathcal{K}}^{sin}$					0.556***	0.438***
$\kappa_{\mathcal{K}}^{cos}$					−0.427***	−0.337***
$\mathcal{K}$ share						0.418***
LATC	Exp.	**B**	Exp.	**B**	Exp.	Exp.
KATC	no	no	Exp.	**B**	**F**	**F**
$\xi = 1$	[0.357]	[0.096]	[0.058]	[0.934]	[0.000]	[0.000]
$\lambda_{\mathcal{R}} = 1$		[0.014]		[0.775]		
$\lambda_{\mathcal{K}} = 1$				[0.279]		
$\gamma_{\mathcal{R}} = \gamma_{\mathcal{K}}$			[0.086]	[0.937]	[0.000]	[0.000]
$\kappa_{cos}^{\mathcal{K}} = \kappa_{sin}^{\mathcal{K}} = 0$					[0.000]	[0.006]
res_4	[0.086]	[0.066]	[0.101]	[0.020]	[0.006]	[0.008]
res_3	[0.095]	[0.237]	[0.085]	[0.051]	[0.001]	[0.000]
bic	−141.7	−174.2	−133.3	−173.9	−239.0	−237.0

Robustness Check: Explaining TFP Growth

Explained variable: normalized TFP growth rate

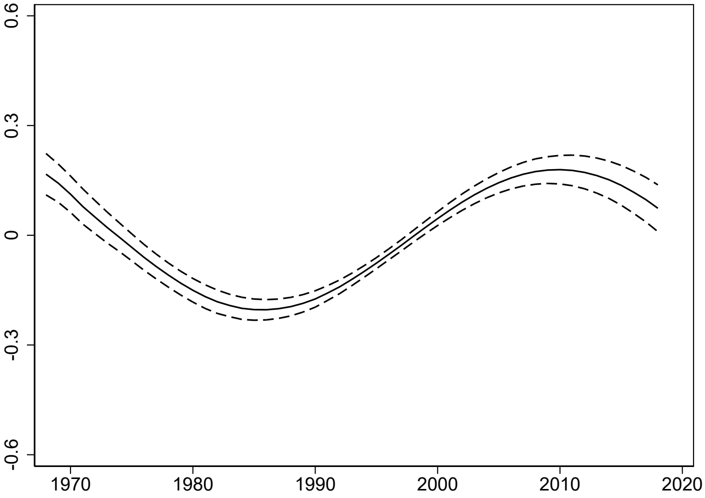
	(2)	(3)	(4)	(5)	(6)
ξ	0.987^{***}	1.001^{***}	0.603^{***}	0.609^{***}	0.601^{***}
$\gamma_{\mathcal{R}}$	-0.040^{***}	0.405	-0.025^{***}	-0.025^{***}	-0.025^{***}
$\lambda_{\mathcal{R}}$	0.861^{***}		1.074^{***}		
$\gamma_{\mathcal{K}}$		-0.892	-0.029^{***}	-0.035^{***}	-0.034^{***}
$\lambda_{\mathcal{K}}$			0.423^{***}		
$\gamma_{\mathcal{K}}^{sin}$				0.035^{*}	0.025
$\gamma_{\mathcal{K}}^{cos}$				-0.126^{***}	-0.108^{***}
$\mathcal{K}$ share					0.562^{***}
LATC	**B**	Exp.	**B**	Exp.	Exp.
KATC	no	Exp.	**B**	**F**	**F**
$\xi = 1$	[0.611]	[0.650]	[0.000]	[0.000]	[0.000]
$\lambda_{\mathcal{R}} = 1$	[0.063]		[0.579]		
$\gamma_{\mathcal{R}} = \gamma_{\mathcal{K}}$		[0.359]	[0.132]	[0.000]	[0.000]
$\kappa_{cos}^{\mathcal{K}} = \kappa_{sin}^{\mathcal{K}} = 0$				[0.000]	[0.000]
$\lambda_{\mathcal{K}} = 1$			[0.000]		
res_3	[0.026]	[0.062]	[0.032]	[0.000]	[0.000]
res_4	[0.053]	[0.030]	[0.004]	[0.004]	[0.005]
bic	-191.2	-197.7	-206.3	-241.3	-237.5

Idea Growth Decomposition (Baseline)

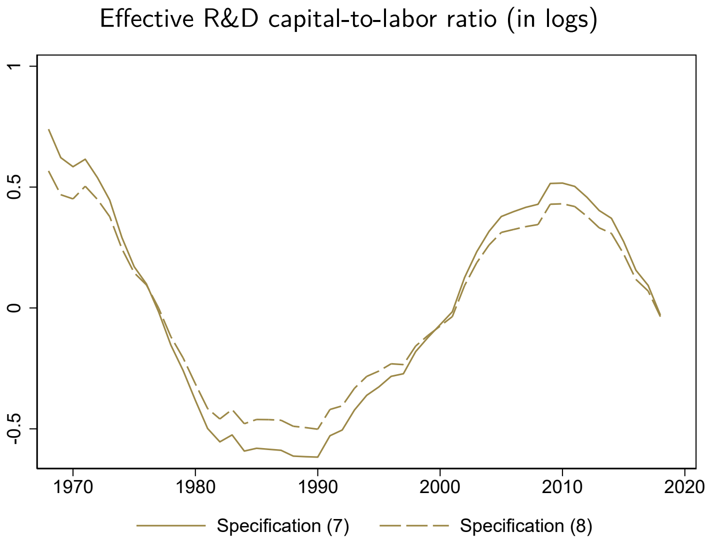


Idea TFP

Hicks-neutral idea TFP backed out from the IPF (in logs, with 95% CI)



Effective Factor Ratio in R&D



Discussion of Baseline Results

Are ideas getting harder to find? Not quite!

- R&D capital is an essential, complementary factor in R&D activity
- In R&D, as in the aggregate economy, capital accumulation outran the growth in labor supply over the long run
- In effective terms, average growth in R&D labor outran that of R&D capital. There is an increasing scarcity of R&D capital required to find the new ideas
- Three main phases of ideas growth
  - (i) sluggish growth in ideas (up to early 1980s)
  - (ii) sharp acceleration in ideas growth (1980s-2000s)
  - (iii) slowdown in ideas growth (since 2000s)

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Perspectives: secular stagnation vs. transition to a mature digital economy

- The current slowdown in R&D output is likely due to a relative shortage of R&D capital, not sharply falling idea TFP

Thank you for your attention.

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