Technology Adoption, Innovation, and Inequality in a Global World

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Really a paper about Scale Effects

- How come no link between country size and productivity (across countries)
- How come no growth miracle after globalization push in the 90s? (across time)
- Modelling and appreciating the role of technology adoption in growth theory

Really a theory paper, but let me remind you of three striking facts of global growth since the 1990s that the theory will address

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1. Global convergence in avg income **across countries** (Cross Country Gini $\downarrow$)
2. Rising income inequality **within-country** (Within Country Gini $\uparrow$)
3. Fast growth in East (5%) vs. **slow growth in advanced econ's** (Germany 1%)

Wanna think about this jointly but hard given growth slowdown Global Growth Patterns

Develop a Semi-Endogenous Growth Model that Captures all Three Facts

- Romer/Jones two-sector model of growth
  - Two types of labor: production vs. high skill
  - Research sector **develops frontier technology**
    - Innovators pay fixed cost in skilled labor to create new idea
  - Production sector **adopts technology** & produces output
    - Adoption margin: Takes effort & skill to adopt new ideas
- Results in a model where innovation and adoption are
  - forward-looking **endogenous** outcomes
  - **skill-intensive** activities
  - **both** essential for long run growth
    - Frontier technology A_F **and** adoption $z \in [0, 1]$
    - GDP: $Y = K^{\alpha} (zA_F L)^{1-\alpha}$

Thinking about Innovation and Adoption Jointly

- Innovation & adoption related in equilibrium
    - Fast adoption raises incentive to innovate (**Complementary**)
    - But both activities compete for skilled labor (**Rivalry**)
    - Endogenous allocation of skilled labor
- **In autarky** innovation and domestic adoption move together

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- **In autarky** innovation and domestic adoption move together
- **Goods market integration** between GER and East drives them apart
  - Fast adoption in Eastern Europe
  - Rising returns to innovation (comp. advantage)
  - Reallocation of skilled labor toward innovation: $A_F \uparrow$, skill premium $\uparrow$, $z \downarrow$
  - So what happens to $A_F z$? Main Results Literature

Theory

Production Sector of the Economy

- Competitive final good producer combines intermediate goods in CES fashion
- Intermediate goods firms $i \in \Omega_M$ produce unique good
  - Combine differentiated capital goods $x_{ij} \in \Omega_{A_i}$ at price p_{xj} and labor l_i at wage w
  - Variety effect: increasing the size of the set A_i raises overall productivity

$$
\begin{aligned}
\text{Production of final good} \qquad Y_t &= A_t^Y \cdot \left(\int_{\Omega_M} (y_{it})^{\frac{\sigma-1}{\sigma}} \, di \right)^{\frac{\sigma}{\sigma-1}} \\
\text{Production of intermediate goods} \qquad y_{it} &= \left(\int_{\Omega_{A_i}} \left(\frac{x_{ijt}}{\alpha} \right)^{\alpha} dj \right) \left(\frac{l_{it}}{1-\alpha} \right)^{1-\alpha} \\
\text{Free entry + fixed cost} \qquad V_{it} &\leq f_e w_t
\end{aligned}
$$

  - Monopolistic competition + CES + symmetric capital good

$$
p_i = \frac{\sigma}{\sigma - 1} \underbrace{(p_x)^{\alpha} \left(\frac{w}{A_i} \right)^{1-\alpha}}_{mc_i} \tag{1}
$$

Dynamic Adoption Problem of an Intermediate Goods Firms

- Denote with A_F the measure of capital goods (ideas) that have been invented
  - A_i qualitatively the same as A_F but quantitatively different

$$A_i \leq A_F \qquad \text{(Current vs. Frontier Level)}$$

- Firm hires skilled labor h_i at skilled wage w_H to increase A_i
  - Trade-off between **cost of hiring skilled labor vs. improving productivity**
  - Discounting due to random death shock δ_{ex} and interest rate r
  - Operating profits $\pi_i^o = (p_i - mc_i) \cdot y_i$

HJB $$(r + \delta_{ex}) V(A_i, t) = \pi^o(A_i, t) + \dot{V} + \max_{h_i} \left[\partial_{A_i} V(A_i, t) \left[\dot{A}_i \right] - w_H h_i \right]$$

Foc $$\underbrace{\partial_{A_i} V(A_i, t) \left[\partial_{h_i} \dot{A}_i(h_i) \right]}_{\text{benefit of marginal increase in skill}} = \underbrace{w_H}_{\text{marginal cost}}$$

Ideal Adoption Technology $\dot{A}_i$

- Admit balanced growth path with constant adoption gap to the frontier
  - Define $z_i := \frac{A_i}{A_F}$ as relative productivity, and adoption gap $\Gamma := -\log z_i$
- Should lead to realistic convergence dynamics

$$\frac{\dot{A}_i}{A_i} = \zeta \cdot \left(\frac{A_F}{A_i}\right)^{1-\theta} h_i^{\beta} - \delta_I$$

- Broadly following Nelson/Phelps (66) but h_i endogenous
  - Depends on $\partial_A V, w_H, \frac{A_F}{A}$ and parameters $\beta, \theta, \zeta > 0, \delta_I \geq 0$
    - $(1-\theta)$ captures advantage of backwardness (Gerschenkron, 1962)
    - $\beta \in (0,1)$ characterizes diminishing returns in adoption conditional on $\frac{A_F}{A_i}$
    - Drop i but take account of adoption technology and spillover

Result: Technology adoption falls in the skill premium

- Derive firm i's demand for skilled labor in steady state
  - κ picks up constant things
  - Existence and Uniqueness & Adoption Dynamics
  - cost w_H v.s. benefit $\partial_A V(A) \propto w$

$$h_{ss} = \frac{1}{s}\kappa_h \tag{2}$$

$$z_{ss} = h_{ss}^{\frac{\beta}{1-\theta}}\kappa_z \tag{3}$$

- Link between **skill premium and productivity** emerges (recall $A := zA_F$)

$$\frac{\partial \log z}{\partial \log s} = -\frac{\beta}{1-\theta} < 0$$

Research Sector based on Expanding Variety Growth Model

- Romer-Jones model: pay fixed cost f_R in skilled labor to produce flow of new ideas

$$\dot{A}_F^N = \frac{A_F^{\phi} H_F}{f_R}, \quad \phi < 1 \text{ is a dynamic knowledge spillover}$$

- **Departure**: innovation impacted by adoption friction
  - Idea developed first adopted first
  - Waiting time τ untill idea is adopted and generates flow profit π_I $(\propto \frac{Y}{A})$

PDV
$$V_I = \int_{t+\boxed{\tau_t}}^{\infty} \exp\left(-\int_t^u (r_v + \delta_I)\, dv\right) \pi_{I,u} du$$

Free entry
$$V_I \leq f_R A_F^{-\phi} w_H$$

Resource constraint
$$\dot{A}_F = \frac{A_F^{\phi} H_F}{f_R} - \underbrace{\delta_I A_F}_{\text{death shock}}$$

Result: Innovation on the BGP

- Endogenous waiting time τ depends on adoption effort
  - Define gross adoption rate: $\frac{\dot{A}}{A} + \delta_I = g_A + \delta_I$
  - Define effective discounting $\tilde{\rho} = \rho - g_L > 0$ and derive V_I

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- Constant waiting time on balanced growth path (τ on and off the BGP)

$$\tau_{ss} = -\frac{\log z}{g_A + \delta_I} > 0 \tag{4}$$

Result: Innovation on the BGP

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$$\tau_{ss} = -\frac{\log z}{g_A + \delta_I} > 0 \tag{4}$$

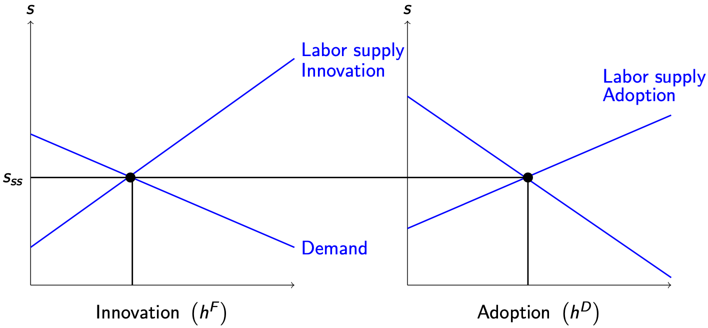
- Now can solve for V_I as simple function of z (V_I on and off the BGP)

$$V_I = \underbrace{\frac{1}{\tilde{\rho} + g_F + \delta_I}\left(\frac{\alpha L_P w}{A_F}\right)}_{\text{Romer/Jones}} \underbrace{z^{\frac{\tilde{\rho}}{g_A+\delta_I}}}_{\text{Adoption Gap}}$$

- Complementary: $\frac{\partial \log A_F}{\partial \log z} > 0$ (From V_I to H_F to A_F)

Market Clearing for Skilled Labor

- **Rivalry** on factor market for skilled labor in general equilibrium
  - Small letter notation for normalized variables $h_D := \frac{H_D}{L}$
  - Constant share of skilled labor devoted to innovation vs. adoption
  - $h_F + h_D = h_{tot}$ (h_{tot} fixed but could make function of s)
  - Closing the Model – Neoclassical Backbone



Aggregate Features of the BGP

- Semi-endogenous growth so population growth pins down tech change

$$g_F = \frac{g_L}{1-\phi}$$

- Nests Solow (56), Romer/Jones (95)

$$Y = K^{\alpha}\left(zA_F L^P\right)^{1-\alpha}$$

- Twist on sources of growth: technology frontier A_F, technology adoption z
    - *Jointly* pin down productivity: $TFP := z\,A_F$
    - Cross country inequality: $w_c \propto z_c A_F$
    - Within country inequality: $w_{Hc} = s_c w_c$

Welfare Non-Trivial – Over or Underinvestment in Research?

- Autarky planner solution in Germany

$$\frac{h_D}{h_F} = \frac{\beta}{1-\theta}(1-\phi)$$

- De-central solution for case $\tilde{\rho} \approx 0$

$$\frac{h_D}{h_F} = \frac{\beta}{1-\theta}\frac{1}{\alpha}\left(\frac{1}{1+\frac{\delta_{ex}+g_M}{(1-\theta)(g_F+\delta_I)}}\right)$$

  - Knowledge spillover missing $\phi \Rightarrow$ too much innovation
  - Markup $\frac{1}{\alpha} \Rightarrow$ too little innovation
  - Churn in production sector $+$ balanced growth $\Rightarrow$ knowledge spillover at entry

- No reason adoption efficieint, so interesting **innovation-adoption tradeoff**

Simple open economy model

- Consider two-country setting: GER and Eastern Europe
    - Denote foreign variables using $*$ and world aggregates with W
    - Friction-less trade in ideas and undifferentiated final output
    - Capital goods are produced locally & balanced trade
    - Trade in idea usage (royalty)
    - No migration and no intermediate goods trade
    - **Same preferences & same adoption technology & same production sector**
    - **Country differences**:
        - Skill intensity: $h_{tot} > h^*_{tot}$
        - Research productivity: $\frac{1}{f_R} \geq \frac{1}{f^*_R}$

Eastern Europe Before and After Fall of Iron Curtain

- Specify Pre 1990 foreign economy somehow
- Integration means market access to Western technology & market reforms
  - Fast technology adoption
  - Skill premium s^* goes up
  - Cross country convergence driven by adoption in East
- Adoption in East **ought to interact** with innovation in GER
  - Global Convergence ($z^* \uparrow$)
  - Local Divergence ($A_F \uparrow$, $s \uparrow$)
  - Aggregate growth ambiguous ($A_F \uparrow) \cdot (z \downarrow$)

PDV Innovation

Sufficient Statistic of Trade Impact

- Callibrate version in the paper: $\phi = -1$
- Asymmetric integration: -10% GDP growth, $+$30% skill premium growth
- Symmetric integration: $+$41% GDP growth, $+$0% skill premium growth (like Jones)
- Only emerging market **that adopts but does not develop ideas** creates bias!
- Let $\chi := \frac{A_F}{\sum_c A_{F,c}} > 0$ be share of ideas of home economy, then ACR-type formula

$$\frac{w^{open}}{w^{closed}} = \underbrace{\left(\frac{h_F^{open}}{h_F^{closed}}\right)^{\frac{1}{1-\phi}} \left(\frac{1}{\chi}\right)^{\frac{1}{1-\phi}}}_{\text{Gains from frontier innovation}} \underbrace{\left(\frac{s^{open}}{s^{closed}}\right)^{-\frac{\beta}{1-\theta}}}_{\text{Loss from missing adoption}}$$

Empirics

Rising Innovative Effort and Slow Growth

- Innovation takes off in the 90s, while per capita growth is stalling
- This model can reconcile different trends, others don't
  - Regress population growth on initial specialization in innovation Cross-sectional regression
  - Rising skill premium/Gini from 1995 – 2015 Skill Premium in Klems data

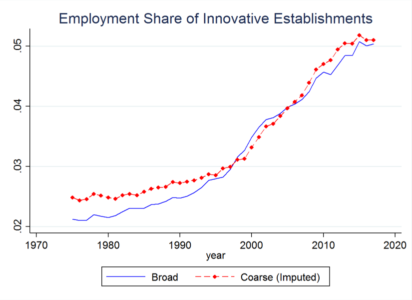


Figure 1: IAB

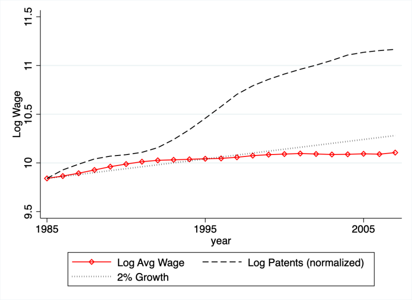


Figure 2: KLEMS & PATSTAT

Missing Adoption & Changing Spatial Convergence Dynamics

- Adoption hard to measure w/out detailed technology measures on firm level
  - But take account of Imbert et al. (2022) or Beaudry et al. (2010)
- Try to get at that indirectly through regional wage and skill growth patterns

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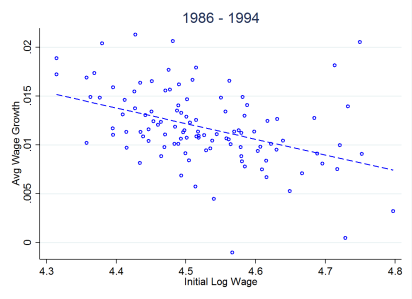

Figure 3: 1986 - 1994

Figure 4: 1994 - 2006

Conclusion

Conclusion

- Develop a simple theory of innovation and adoption that explains jointly
  - Declining cross-country inequality
  - Rising within-country inequality
  - And the overall rate of growth in West and East
- Asymetric integration gives rise to domestic innovation-adoption trade-off
- Suggests much follow-up work
  - Effect of foreign adoption on domestic returns to innovation
    - More econometric and quantitative work to draw out channel
    - Rising skill premium retards domestic tech. adoption
  - Theory & Empirics with Spatial, Firm, and Worker heterogeneity

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May more things but I have to conclude...

- Scale Effects Puzzle, immigration, more general entry cost, pick parameters, dynamics
- Empirics
  - Diverngece between innovation & GDP/TFP & unskilled wage growth
  - Uneven growth across regions and sectors unfolding in West Germany after 1995 (Poland joins WTO)
  - Stagnation in hinterlands cannot undo fast growth of frontier regions
  - Skill accumulation unveven across sectors and regions, in contrast to pre 1995
- Follow up work
  - Spatial growth model where brain drain has bite
  - Any way to think of a causal research design to test the ideas
    - Effect of skill (premium) on adoption
    - Lewis (2011) and Imbert et al. (2022)

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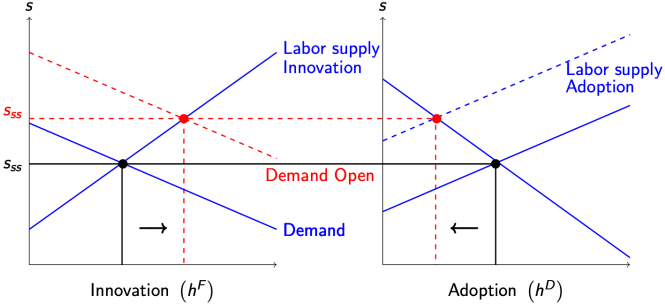
Backup Slides

Global Idea Demand Shock Matches Qualitative Patterns

- PDV

$$V_I = \frac{1}{\tilde{\rho} + g_F + \delta_I} \left(\frac{\alpha L_P w}{A_F} \right) z^{\frac{\tilde{\rho}}{g_A + \delta_I}} \left\{ 1 + \underbrace{\frac{L_P^*}{L_P} \left(\frac{z^*}{z} \right)^{\frac{\tilde{\rho}}{g_A + \delta_I} + 1}}_{\text{Pull from Abroad}} \right\}. \quad (5)$$

- Econ 101 plot



Back

Quantitative Results & Empirics

- Quantification of model (level effects)
    - Fast growth in **East** +114%
    - Uneven and sluggish growth in Germany
        - Wage growth of **production labor** -17%
        - Wage growth of **skilled labor** +11%
    - Contrast to Romer/Jones model: -10% vs. +41% in Germany
- Paper really about scale effects in open economies
    - Adoption margin useful for realistic theory of **global growth**
    - Still same sizeable scale effects for symmetric integration (+41%)

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  - Adoption margin useful for realistic theory of **global growth**
  - Still same sizeable scale effects for symmetric integration (+41%)
- Empirical evidence using regional variation within Germany & Fall of Iron Curtain
  - Aggregate: Decoupling from innovation and GDP/wage growth
  - Cross-Sectional: Distribution of skilled labor shifts across sectors and space
    - Wage and population growth in innovative regions, stagnation elsewhere

Contribution to the (selected) Literature

Endogenous Growth & Globalization: Romer (91, 94), Sampson (16, 22), Acemoglu/Gancia/Zilibotti (15), Benhabib/Perla/Tonetti/Waugh (14, 21), Buera/Oberfield (20), Zilibotti et al (16, 22)

- Generalize Jones (95) to study novel interaction of innovation and adoption
  - **Endogenous adoption margin** explains growth patterns previously out of reach
    - **Inequality** within and across countries
    - **Rate of growth** in advanced and emerging markets

Growth Slowdown: De Ridder (21), Peters/Walsh (22), Andrews/Criscuolo/Gal (15, 16),

- But: innovation takes off and slowdown hides large heterogeneity underneath

Skill-Biased Tech Change & Trade: Katz/Murphy (92), Acemoglu/Autor (11), Burstein/Vogel (17)

- Adoption margin allows for **new role of skill premium** in speed of tech adoption
- Adoption and Innovation explain **rising inequality everywhere**

Complementarity between Innovation and Adoption

- Derive demand for skilled labor H_F in research (resource constraint & free entry)
  - Downward sloping function of skill premium ($V_I \propto w$ & $f_R \propto w_H$)
  - Adoption matters for innovation

$$H_F = \frac{1}{s} \underbrace{(z)^{\frac{\tilde{\rho}}{\delta_I + g_A}}}_{\text{Adoption Gap}} \left(\frac{g_F + \delta_I}{\tilde{\rho} + g_F + \delta_I} \right) \alpha L_P$$

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- **Complementarity** on the market for ideas between innovation and adoption

$$\frac{\partial \log A_F}{\partial \log z} = \underbrace{\frac{1}{1-\phi}}_{\frac{\partial \log A_F}{\partial \log H_F}} \underbrace{\frac{\tilde{\rho}}{g_A + \delta_I}}_{\frac{\partial \log H_F}{\partial \log z}} > 0$$

Back

Closing the model to solve for a BGP

- I am skipping some steps...
  - Neoclassical household problem (log c) with capital accumulation Household
  - Markup on capital goods $p_x = \frac{r+\delta_k}{\alpha}$ Ownership Structure
  - Total capital goods equal physical capital $X = K$
  - Labor supplied inelastically but trade-off between sectors emerges
    - $H_D + H_F = H$ (market clearing of skilled labor in adoption and research)
    - $L_E + L_P = L$ (market clearing of production labor in entry and production)
    - $g_L = g_H > 0$ so $\frac{H}{L}$ constant
  - Equilibrium Concept Definition
  - Define skill premium $s := \frac{w_H}{w}$; g_A, g_F, g_L denote growth rates, $P_Y := 1$
- Take out scale effect in production sector for convenience: $A_t^Y = L_t^{-\frac{1}{\sigma-1}}$

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Transition Dynamics Technology

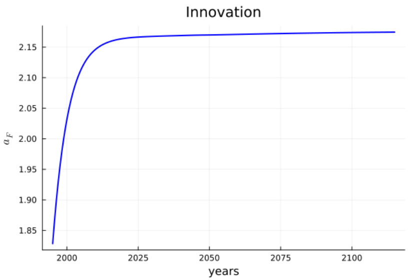

Figure 5: Normalized Frontier

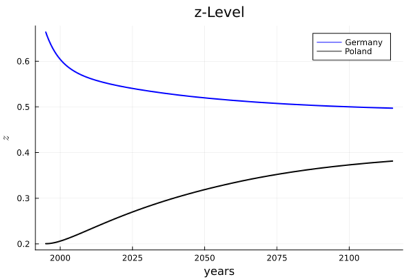

Figure 6: Fraction Adopted

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Frictionless trade leads to simple theory of cross-country inequality

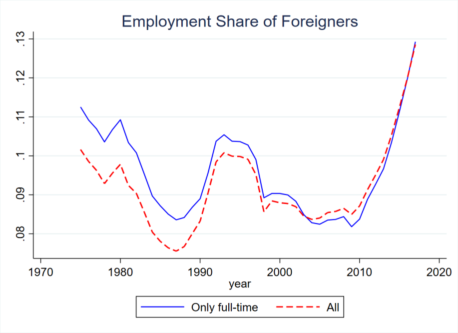
- Frontier global: A_F^W
- Adoption pins down global productivity distribution $\{z_c\} \propto \{h_c^{\frac{\beta}{1-\theta}}\}$

$$\frac{A^*}{A} = \frac{z^*}{z} = \left(\frac{h^*}{h}\right)^{\frac{\beta}{1-\theta}}$$

- Key: IRS innovation (Global) + CRS Adoption (National)
  - India not richer than Luxembourg
  - Doubling world population
    - increases A_F^W
    - but $\{z_c\}$ constant
- Focus on two-country case only for transition dynamics Back

Immigration

- Immigration has very different implications for domestic innovation in theory
  - $h_{tot} \downarrow \Rightarrow \frac{h_F}{h_D} \downarrow$, i.e. innovation takes a hit
- Large micro literature finding no negative avg wage effects (Dustmann et al., 2016)



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Missing Adoption

- In principal just as consistent with urban bias of tech change (Giannone (17))
- Important difference: Adoption raises everyones' wages, innovation may not
  - Note persistent correlation between skilled labor growth and income growth
  - But direction is changing & correlation with low-skilled wages

Table 1: Wage Growth & Total High Skill Employment Growth

		$g_H^{1986-1994}$		$g_H^{1994-2006}$		obs
		Coeff.	R^2	Coeff.	R^2	
1.	regional average wage growth	0.1326	**0.3177**	0.1665	**0.3733**	109
2.	regional average wage growth (low skill)	0.1043	**0.1644**	0.0621	**0.0312**	109

Back

Divergent Skill Ratio Across Sectors

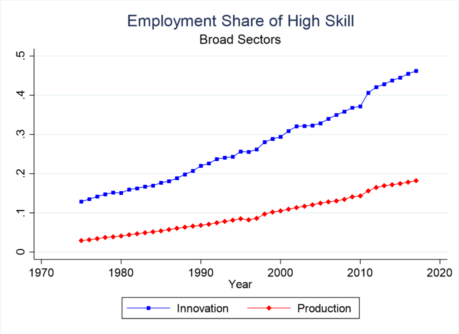


Figure 7: College Share across Income Deciles

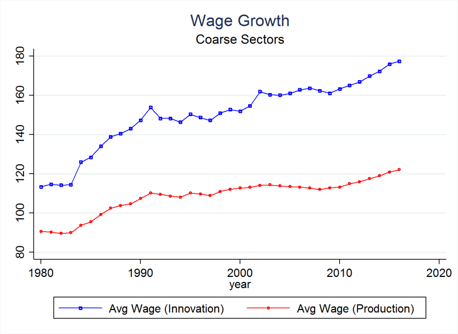


Figure 8: Share Innovative Employment

Back

Cross Sectional Evidence across Counties

- Cross Sectional Predictions
  - Innovation-driven growth
  - Related to market access in the "East" (post 1995)
- What can be measured in micro data?
  - Slowdown and skill premium **aggregate general equilibrium effects**
  - **Regional heterogeneity** in specialization in innovation vs. production
    - Autor et al. (2013), Nakamura and Steinsson (2014), Mian and Sufi (2014)
  - Perfect mobility $\Rightarrow$ rel. faster skilled labor growth in innovative regions after 1995

Cross Sectional Evidence using Population Growth across Counties

- County level data on
  - Population in 1986, 1996, 2011 (Roesel (22))
  - Patents from 1980 to 2014 (PATSTAT, Coffano/Tarasconi (14))
  - Scatter plot population and patents Scatter Plot

Spezialiation in Innovation

- One region more specialized in innovation than another
  - $\frac{Pat_i}{Pop_i} > \frac{Pat_j}{Pop_j}$
- Predictions
  - 1987-1996 pop growth unrelated to specialization in innovation (BGP)
  - 1996-2011 pop growth positively related to specialization in innovation (new BGP)
- Implicit assumption
  - Initial distribution of patents reflects persistent comparative advantage in innovation
  - Controling for **population per square kilometer** nets out confounding factors

$$g\_pop_{it} = \alpha + \underbrace{x'_{it}\gamma}_{Controls} + (\beta + \underbrace{\delta_{t>=1996})}_{>0} Pat_{it} \tag{6}$$

Predictions Borne out in Simple Regression Model

- No effect on population growth pre-marekt integration ($\beta \approx 0$)
- But powerful predictive power from 1996 to 2011 ($\delta > 0$)

	Population Growth
patents (β)	-0.000151
	(-1.56)
(1996-2011) $\times$ patents (δ)	0.000745***
	(5.99)
Time FE	Yes
Pop per Sq KM	Yes
Observations	613
R^2	0.676

Clustered standard errors at county level. T stats in parantheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back

Data consistent with Rising-Returns-to-Innovation Interpretation

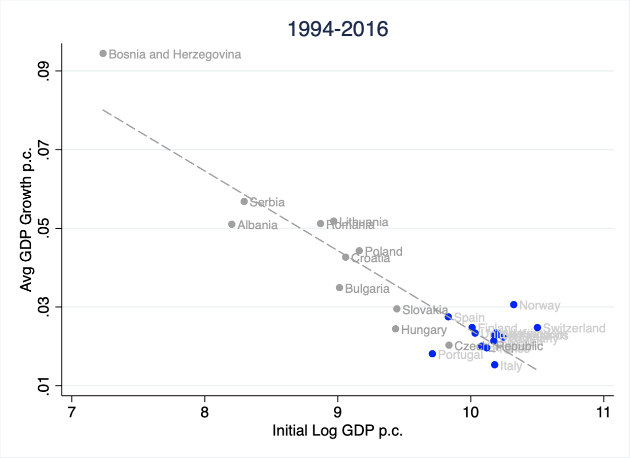
- Evidence in favor of rising importance of innovation in Germany after 1996
- Through the lens of the model
  - Integration and Adoption in East raises returns to innovation
- Key channel in general equilibrium: **missing adoption**
  - Hard to measure directly
  - Suggestive evidence from changing regional growth
  - Only adoption channel opens up **real wage losses**
- WIP: use occupational composition to get at (stagnant) tech change

German Unification and Skill Biased Tech Change

- What about German Unification?
  - East-West convergence before 1995 (Bachman et al (21), Findeisen et al (21))
  - Leaves 1995 – 2015 open for alternative explanation
- What about skill-biased tech change
  - Definitely, but note how the skill-bias played out very different in the past
  - Mississippi fastest GDP growth and fastest skilled labor growth 1950-1980
  - Mentioned before: supply shock not that helpful

Back | Changing Convergence Growth Patterns GER | Convergence Growth East

Convergence in Europe



- Catch-up Growth **did not disappear** but shifted from the West to the East in mid 90s

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Regional Divergence in Skill & Innovation

- Skill growth and innovative employment growth biased

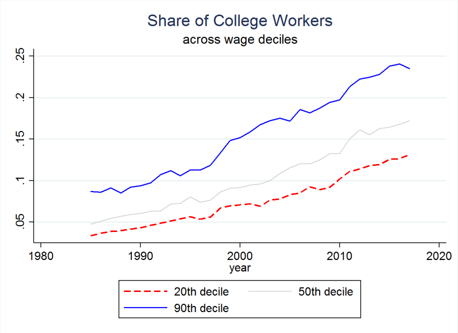


Figure 9: College Share across Income Deciles

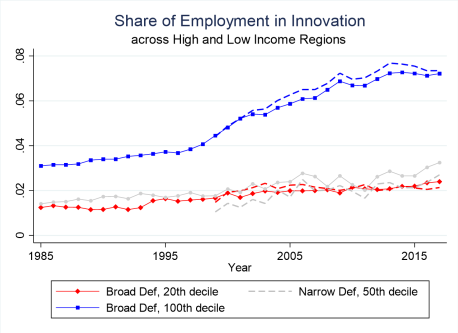


Figure 10: Share Innovative Employment

Correlation Skill Growth and Wage Growth | Diverging Skill-Ratio between Research and Production Sector | Back

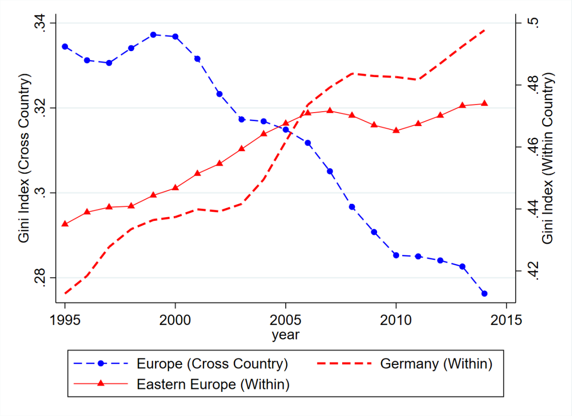
Population and Patents

Figure 11: PATSTAt & Population

- Patenting unevenly distributed across counties (200K people on avg)
- Note similar population level sustains very different number of patents

Back

Global Growth Patterns



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Sluggish Growth & Integration in West Germany

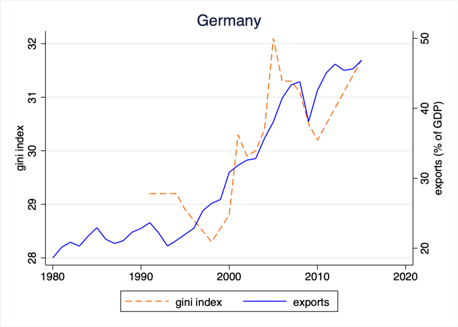

Figure 12: Openness

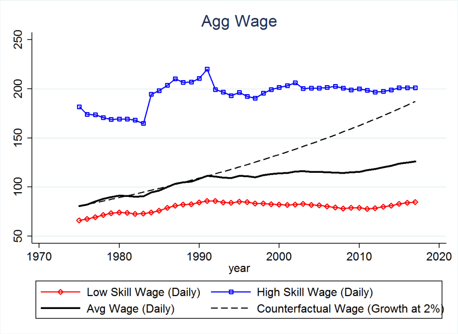

Figure 13: Wage Growth

- Relative robust wage growth prior to 1994, stagnant from 1994 to 2010
- GDP p.c. growth also weak ($g_{Y/L} = 1\%, g_{TFP} = 0.3\%$, Van Ark et al. (2008))

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Catch-up Regression & Correlates of Growth

Table 2: Barro Coefficient with controls

	Controls in base period	$\hat{\beta}^{1986-1994}_{Barro}$		$\hat{\beta}^{1994-2006}_{Barro}$		obs
		Coeff.	SE	Coeff.	SE	
1.	-	**-0.0133**	.00275	**0.0159**	.00212	324
2.	10 digit industry employment shares	**-0.0125**	.00437	**0.0128**	.00403	324
3.	avg. establishment size	**-0.0136**	.00295	**0.0138**	.00259	324
4.	college share	**-0.0263**	.00334	**0.0143**	.00494	324
5.	manufacturing share	**-0.0133**	.00275	**0.0163**	.00213	324
6.	share of professional occupations	**-0.0144**	.00275	**0.0176**	.00278	324
7.	share of engineers and scientists	**-0.0229**	.00292	**0.0201**	.00354	324
8.	import exposure (shift share)	**NA**	NA	**.0154**	.00312	109
9.	export exposure (shift share)	**NA**	NA	**.0120**	.00386	109
10.	total full-time employment	**-0.0139**	.00381	**0.0172**	.00268	324
11.	total high skill employment	**-0.0166**	.00325	**0.0161**	.00276	324
12.	total wage bill of full time employees	**-0.0143**	.00379	**0.0170**	.00275	324
13.	total number of establishment	**-0.0132**	.00348	**0.0175**	.00248	324
14.	total number of high skill establishments	**-0.0148**	.00359	**0.0166**	.00260	324
15.	total number of firms with scientists	**-0.0152**	.00389	**0.0174**	.00272	324
16.	log patents p.c.	**-.02152**	.00507	**.01331**	.00569	109
17.	log patents quality adjusted p.c.	**-.02145**	.00509	**.01286**	.00556	109

This table reports the catch-up coefficient after controlling for a number of factors. Standard errors are clustered at the regional level. High skilled establishments are defined as establishments with more than 30% of skilled labor. Firms with scientists are defined as the ones with strictly more than one engineer or natural scientist. The share of professional occupations includes the following occupation codes in the IAB: az_bf_tec, az_bf_semi, az_bf_ing, az_bf_prof, az_bf_man (technical, semi professional, engineers, professional, managers). See the IAB codebook for additional details (http://doku.iab.de/fdz/reporte/2016/DR_03-16_EN.pdf).

Figure 14: Barro Regression with Controls

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Catch-up Regression & Correlates of Growth

Table 3: Correlates of Growth

	regional geometric average wage growth	$g_w^{1986-1994}$		$g_w^{1994-2005}$		obs
		Coeff.	R_sq	Coeff.	R_sq	
1.	total employment growth	0.0945	**.1044**	0.1379	**.1365**	324
2.	high-skill employment growth	0.1023	**.3103**	0.1283	**.2997**	324
3.	share high-skill employment growth	0.1159	**.2294**	0.1512	**.2016**	324
4.	patent growth	0.0083	**.0243**	0.0079	**.0089**	324
5.	per capita patent growth	0.0089	**.0225**	0.0008	**.0001**	324
6.	quality adjusted patent growth	0.0090	**.0302**	0.0069	**.0071**	324
7.	quality adjusted per capita patent growth	0.0061	**.0136**	0.0002	**.0000**	324

Patents here concern 3 year moving averages due to data confidentiality concerns. Quality adjusted patents add a count of one for every cite that a patent receives from another patent.. The patent data is based on the same data as 8. The rest of the data is based on the BHP establishment panel.

Figure 15: Correlates of Growth

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Convergence and Divergence by Skill Group

- Convergence and Divergence Dynamics by Skill Group
- Convergence broadly based, divergence about composition

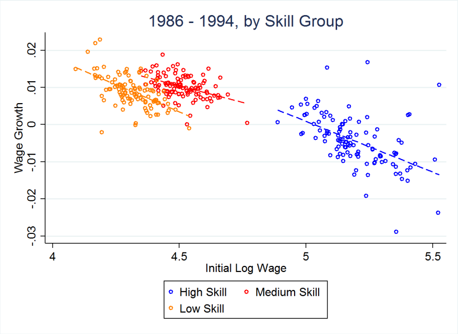

Figure 16: 1986 - 1994

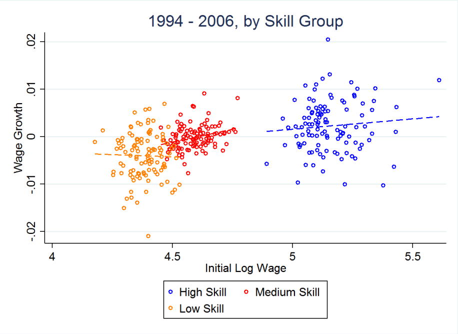

Figure 17: 1994 - 2006

Back

Aggregate Patterns

- Evolution of the skill premium consistent although Germany a little tricky

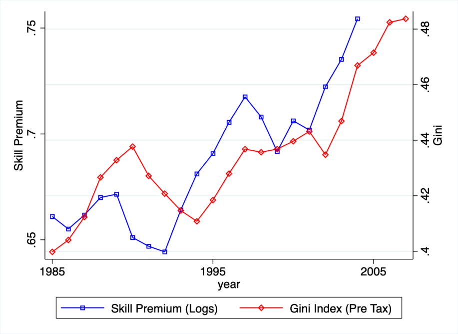

Figure 18: KLEMS & WID, Own Calculation

- Recall Card et al. (2013)

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Convergence and Growth Slowdown in Germany

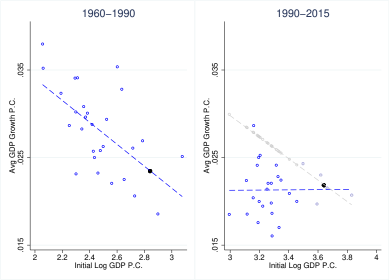


Figure 19: West-German Regions.

- Changing convergence dynamics "account" for sluggish aggregate growth
- "accounts" for 80% of the slowdown
- Note $\lim_{t\to\infty} \beta_{t,k}^{BB} > 0$ through lens of Solow model, i.e. catch-up doesn't disappear

Calibrating θ

- Use cross-country convergence dynamics to match θ
  - Barro's Iron Law of 2% convergence, conditional on h
  - Linearize around steady state

$$\frac{\dot{z}}{z} \approx \underbrace{(1-\theta)(\delta_I + g_F)}_{\hat{\beta}_{BB}} (\log z_{ss} - \log z_t) + \beta(\delta_I + g_F)(\log \log h_{ss} - h_t)$$

- $\hat{\beta}_{BB} \approx .02$ (Barro-Baumol)
  - Suppose capital good on average in market for 25 years ($25 = \frac{1}{0.04}$)

$$2\% = (1-\theta) * \underbrace{(\delta_I + g_F)}_{5\%} \Rightarrow \theta = .6$$

Calibrating β

- Use cross-country inequality, given $\{h_c\}_{c \in C}$; θ
  - $z_c \propto h_c^{\frac{\beta}{1-\theta}}$
- Note difference to development accounting

$$\log z_{ct} = \alpha + \delta_t + \underbrace{\gamma}_{\frac{\beta}{1-\theta}} \log h_{ct} + u_{ct}$$

- Approximate
  - $z_c \approx Y_c / L_c$
  - $h_c \propto$ Share College Complete
  - Ignores bias due to innovation and skill premium
- $\hat{\gamma} = .9 \Rightarrow \beta = .35$

Back Scatter Plot & Fit

Scatter Plot & Fit

- Causal theory but consistent with development accounting
  - $R^2 = .65$
  - Check Congo, Brazil & Germany

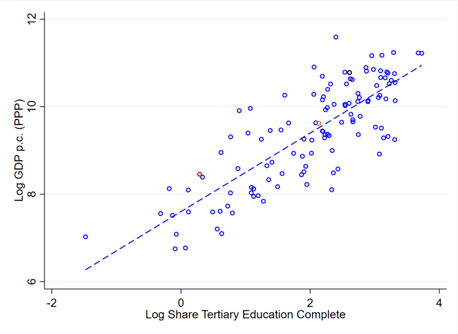
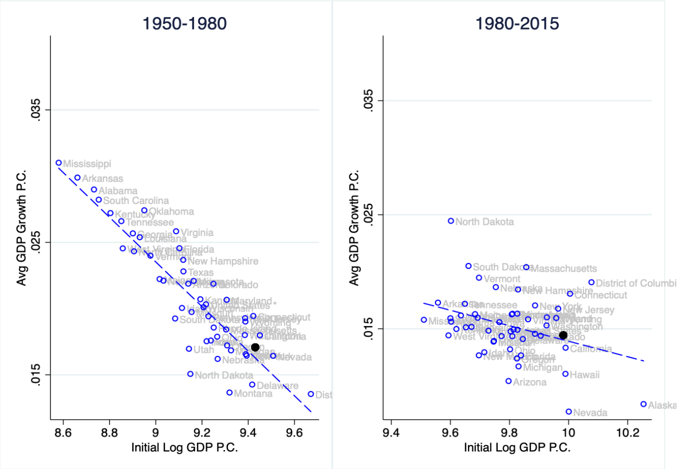


Figure 20: PWT & Barro and Lee (2013), Own Calculation for 2015

Back

Changing Regional Convergence Patterns in USA



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Changing Convergence Dynamics in the US

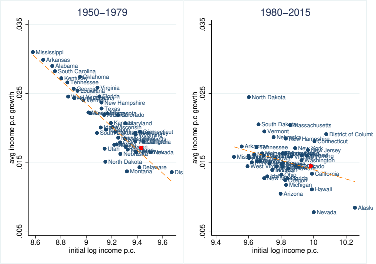

Figure 21: State GDP data from `https://www.bea.gov/data/gdp`.

- Are ideas harder to find? (Bloom et al., 2020; Gordon, 2000)
- New Angle: Mississippi was probably not finding many new ideas in 1950...?
- Seems useful to think of adoption and innovation jointly, even in developed economies!

Cross-Sectional Motivation: From Catch-up to Frontier Growth

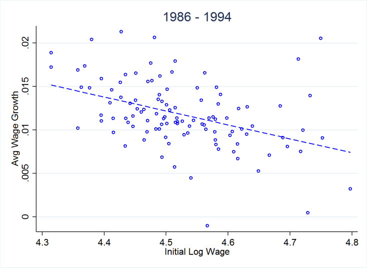

Figure 22: 1986 - 1994

Figure 23: 1994 - 2006

- This is true across advanced Europe Europe and USA USA
- Convergence within skill-group, divergence across (compositional) By skill group
- Both periods, skilled labor growth strongest correlate of growth $R^2 \approx .3$

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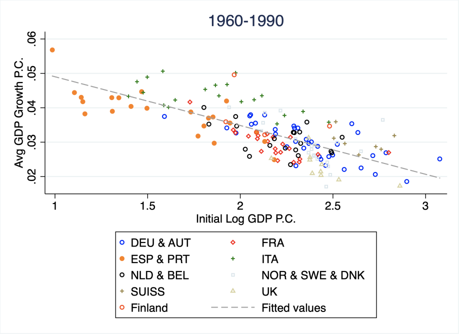
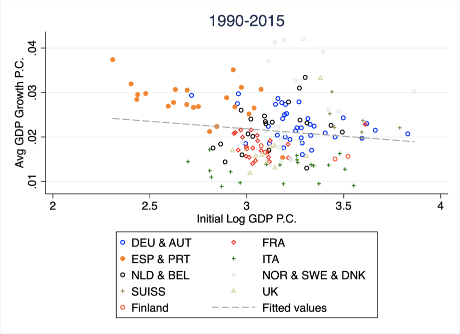
Changing Regional Convergence Patterns in Europe





- Data from Rosés and Wolf (2018)
- Fractal pattern shows disappearance of catch-up growth on several levels

Back

Environment: Innovation & Profits

- Standard monopoly pricing of innovator leads to

$$p_x = \frac{\epsilon}{\epsilon - 1}(r + \delta_k), \quad \frac{\epsilon}{\epsilon - 1} = \frac{1}{\alpha} \tag{7}$$

- Intermediate good firm's capital elasticity α in here where instantaneous profits read $\alpha L^P w \left(\frac{1}{A}\right)$

Back

Environment: Households

- Dynastic households solve consumption-saving problem

$$\max_{\{c,B\}} \int_0^\infty e^{-(\rho-g_L)t} \log c \, dt \tag{8}$$

$$\text{subject to: } \dot{B} = rB + wL + w_H H - C \tag{9}$$

- $B_t = K_t + V_t * M_t + \int_0^{A_F} V_{I,t}(y)\, dy$

$$\frac{\dot{c}}{c} = r_t - \rho \tag{10}$$

Back

Equilibrium Concept Definition

A balanced growth path equilibrium with constant population growth $g_L = g_H$ and $\phi < 1$ consist of a sequence of prices $\{L_t^P, L_t^{fe}, H_F Ft^D, H_F Ft^F, K_t, M_t, A_t, A_{F,t}, C_t\}_{t \in R}$ that grow at a constant rate over time (possibly zero), and a constant adoption gap $\Gamma = -\log z$, where

- Final goods producer maximizes profit subject to constraints, households maximize utility
- Intermediate goods produces solve static and dynamic problem
- Free entry into R & D and intermediate goods sector hold
- plus market clearing and initial conditions

Back

Generalize Entry Cost inito Production

- Suppose $V = f_e w^{\mu} w_H^{1-\mu}$

$$\frac{\partial \log z}{\partial \log s} = -\frac{\mu\beta}{1-\theta}$$

- Effects of skill premium on z weaker
- But novel margin on equilibrium measure of firms $\frac{\partial \log M}{\partial \log s} < 0$
    - Not pursuing in this paper but interesting given lit on declining business dynamics
    - See also Salgado (2020)
    - Note how profits rise even though there is no difference in competitive evironment

Back

Skill-Biased Tech Change

- Katz and Murphy (1992) not helpful to understand wage stagnation
- Better: Autor et al (03) and Acemoglu/Restrepo (18)'s changing task content
  - Changing task content like negative labor supply shock ($h_{tot} \downarrow$)
  - Note $\frac{H_F}{H_D} \propto (z)^{\frac{\tilde{\rho}}{\delta_I + g_A}}$
  - Adoption and innovation hurt by rising skill price, but innovation gets hit twice
- Once you combine endogenous adoption with changing task-content, skill-biased tech change can have negative growth effects

Back

A Simple Solow Model?

$$\frac{\log y_{t+j} - \log y_t}{j} = -(1-\alpha)(n+\delta+g)(\log y_t - \log y_*)$$

$$\hat{\beta} = -(1-\alpha)(n+\delta+g)\frac{Cov(\alpha(\log k_t - \log k_*), \alpha \log k_t)}{Var(\alpha \log k_t)}$$

$$\hat{\beta} = -(1-\alpha)(n+\delta+g)$$

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Aggregate Growth and Convergence

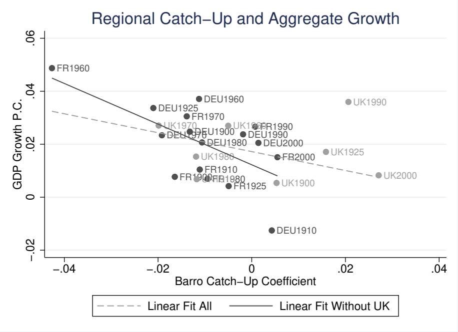

Figure 24: Regional GDP data from Rosés and Wolf (2018).

- How serious should we take this correlation – larger coefficient for more laggard places even in Solow Model – useful to focus on "Frontier Economies"

Complementarity between Innovation and Adoption in Closed Economy

- Recall $\frac{\partial \log A_F}{\partial \log z} > 0$
- Complementarity matters in general equilibrium, too
  - Suppose biased tech change favoring research ($f_R \downarrow$)
    - Allocation $\frac{h_D}{h_F}$ unchanged, $A_F \uparrow$, z constant
  - Suppose adoption improves ($\zeta \uparrow$)
    - z and A_F improve
  - Suppose negative skilled labor supply shock ($h_{tot} \downarrow$)
    - $z \downarrow$ and $A_F \downarrow$ decline, but A_F declines more
- Very hard to construct a shock where "innovation runs away" from production

Back

Innovation on the BGP

- General solution for value function

$$V_I = \underbrace{\frac{\pi_{I,t+\tau}}{r_t + \delta_I - g_{w_H} + \phi g_F}}_{\text{Romer/Jones}} \underbrace{\exp\left(-\int_t^{t+\tau} [r_x + \delta_I]\, dx\right)\left(1 + \frac{\partial \tau}{\partial t}\right)}_{\text{Adoption Gap implicit in } \tau} \tag{11}$$

$$V_I = \underbrace{\frac{1}{\tilde{\rho} + g_F + \delta_I}\left(\frac{\alpha L_P w}{A_F}\right)}_{\text{Romer/Jones}} \underbrace{z^{\frac{\tilde{\rho}}{g_A + \delta_I}}}_{\text{Adoption Gap}}$$

- PDV of innovation proportional to
  - Market size ($L^P w \propto Y$) & competition (A_F)
  - Adoption gap & discounting: $z^{\frac{\tilde{\rho}}{g_A+\delta_I}}$

Back

Waiting time τ

- τ implicitly defined

$$\tau = -\frac{\log z_t}{\left[\frac{\int_t^{t+\tau} g_A(x)dx}{\tau}\right] + \delta_I} \tag{12}$$

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BGP: Existence and Uniqueness

Proposition 1

Suppose

$$\frac{\rho + \delta_{ex}}{g_F + \delta_I} + (1 - \theta) > \beta (\sigma - 1) (1 - \alpha)$$

holds, then a unique saddle-path stable steady state equilibrium obtains.

- Adoption problem needs to be "well-behaved"
- No free entry equilibrium in production sector can survive if
  - Elasticity of substitution too high (σ large)
  - Adoption too easy (β large)
  - Adopt too much, cannot recover fixed entry cost

Back

Solve for BGP: Adoption

- Convenient to solve normalized adoption problem
  - Normalized technology level $z = \frac{A}{A_F}$
  - Normalized value function $v = \frac{V}{w}$
  - Relative price of skill $s = \frac{w_H}{w}$
- Leads to dynamic investment equation (really like q-theory):

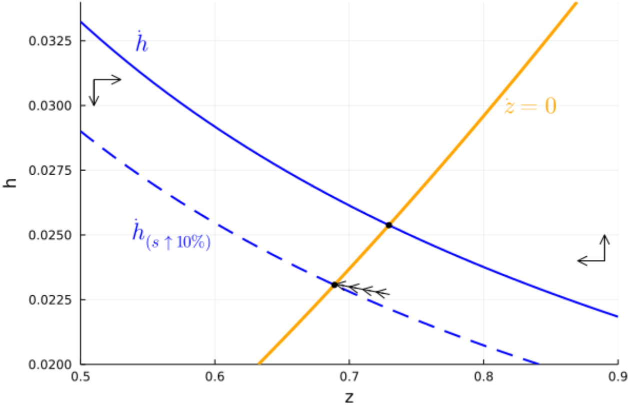
$$\frac{\dot{h}}{h} = \frac{1}{1-\beta}\left\{\underbrace{(\rho + \delta_{ex} + (1-\theta)(g_F + \delta_I))}_{\text{effective discounting}} - \underbrace{\left\{\frac{\beta z^{\theta}\zeta h^{\beta-1}}{s}\left[\frac{\pi_t}{w}\frac{(1-\alpha)(\sigma-1)}{z}\right] + \frac{\dot{s}}{s}\right\}}_{\text{marginal benefit of extra unit of human capital}}\right\}. \tag{13}$$

- q-theory like transitions dynamics Phase Diagram Skill Price Shock

Back

Solve for BGP: Adoption – Phase Diagram

Permanent increase in the price of skill of 10%



Back | Back to main slides

Ownership Structure

- Production firms rent capital goods like in neoclassical model
- Capital good = capital + idea
- Innovator gets royality, households get risk-free rate, the two are connected through a markup $p_x = \frac{1}{\alpha}(r + \delta_k)$
- A_i not only measure of capital goods but a state variable reflecting "know-how" $A_{iK} = A_i$

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Matching Model to Data

parameter	baseline value
capital share	$\alpha = .5$
discounting	$\rho = .04$
Poisson death firm	$\delta_{ex} = .04$
Poisson death idea	$\delta_{I} = .04$
Entry cost production	$f_e = 1$
Entry cost research	$f_R = 1$
Diminishing returns in Diff.	$\beta = 0.35$
Elas. Substitution	$\sigma = 3$
Pop Growth	$g_L = .02$
Knowledge Spillover	$\phi = -1$
Add parameter	$\zeta = .23$
Skill to Production Labor	$\frac{H}{L} = .15$

Back

Environment: Innovation & Profits

- Standard monopoly pricing of innovator leads to

$$p_x = \frac{\epsilon}{\epsilon - 1} r, \quad \frac{\epsilon}{\epsilon - 1} = \frac{1}{\alpha} \tag{14}$$

- Intermediate good firm's capital elasticity α in here where instantaneous profits read $\alpha L_P w \left(\frac{1}{A}\right)$

Back

Environment: Households

- Dynastic households solve consumption-saving problem

$$\max_{\{c,B\}} \int_0^\infty e^{-(\rho - g_L)t} \frac{c^{1-\gamma}}{1-\gamma} dt \tag{15}$$

$$\text{subject to: } \dot{B} = rB + wL + w_H H - C \tag{16}$$

- $B_t = K_t + V_t * M_t + \int_0^{A_F} V_{I,t}(y)\, dy$

- note $\delta_K = 0$ and $p_K = 1$

- Supply high and low skilled labor H, L inelastically

- Define relative price of skill $s := \frac{w_H}{w}$

Equilibrium Concept

Definition 1

A balanced growth path equilibrium with constant population growth $g_L = g_H$ and $\phi < 1$ consist of a sequence of prices $\{L_t^P, L_t^{fe}, H_F Ft^D, H_F t^F, K_t, M_t, A_t, A_{F,t}, C_t\}_{t \in R}$ that grow at a constant rate over time (possibly zero), and a constant adoption gap $\Gamma = -\log z$, where

- Final goods producer maximizes profit subject to constraints, households maximize utility
- Intermediate goods produces solve static and dynamic problem
- Free entry into R & D and intermediate goods sector
- plus market clearing and initial conditions

Solve for BGP: Profits, Firm Measure, and Production Labor

- profits equal

$$f_e \rho \kappa_1 = \frac{\pi}{w} \tag{18}$$

- where

$$\kappa_1 = \frac{\kappa_2}{\kappa_2 - 1} \text{ and } \kappa_2 = \frac{\beta (1-\alpha)(\sigma-1)(g_F + \delta_I)}{\rho + \delta_{ex} + (1-\theta)(g_F + \delta_I)}$$

- L^P and M read

$$M = \frac{L}{f_e \rho \kappa_1 (\sigma - 1)(1-\alpha) + g_L + \delta_{ex}}$$

$$L^P = L - M(g_L + \delta_{ex})$$

Profit of an Innovator

$$\pi^I_{t+\tau} = \frac{\alpha L^P_{t+\tau} w_{t+\tau}}{A_{F,t+\tau} z_{t+\tau}} \tag{19}$$

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Firm Entry

- Innovation obvious
- Production sector characterized by following free entry condition $f_e = \frac{\frac{\pi}{w} - sh}{r_t + \delta_{ex} - g_w}$

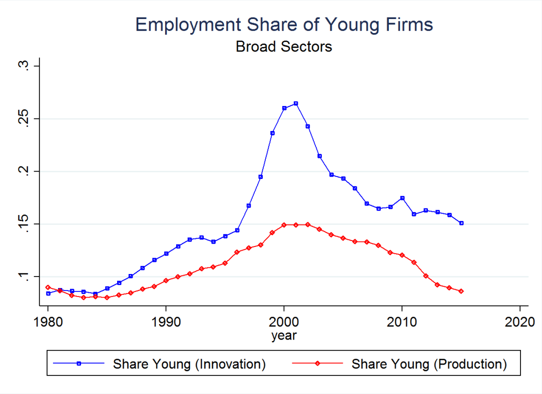

Figure 25: IAB BHP Data