Uncertainty, Openness to Novelty and Economic Growth

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Motivation

" First, technology has to be invented or adopted. Human societies vary in lots of independent factors affecting their openness to innovation."

JARED DIAMOND, 2003

Motivation

- Technological progress through successful innovations = key driver of long-run economic growth
- Innovations $\rightarrow$ UNCERTAINTY (i.e. a lack of information)
- Growth literature has abstracted from uncertainty so far
- Decisions under uncertainty come with:
  - $\rightarrow$ subjective beliefs coloured by personality traits, past experience, narratives
  - $\hookrightarrow$ hypes, misallocation, disappointment, possibly paralysis

Motivation

- These are not just innocuous by-products but sometimes have significant feedback effects!

$\rightarrow$ Bubbles & crashes!

Image Sources: Seeking Alpha, Bloomberg, Focus Economics

Motivation

Openness to Novelty:

Entrepreneurs' intrinsic attitudes towards innovation

$\Rightarrow$ How does openness to novelty matter? Unclear!

- More openness:
  - Potential innovations are more likely to be tested, quicker adoption of technology
  - Lack of scepticism $\rightarrow$ ignorance of negative signs, exuberance, misallocation, possibly crisis-induced paralysis

Motivation

1. Which economy grows faster? One with more or less **average** openness?
2. What about **heterogeneity** of openness within one economy? Is it detrimental or beneficial?

Contribution

A first glance at the data:

→ Surprising but robust negative correlation between growth rate of GDP p.c. & a new measure of openness to novelty

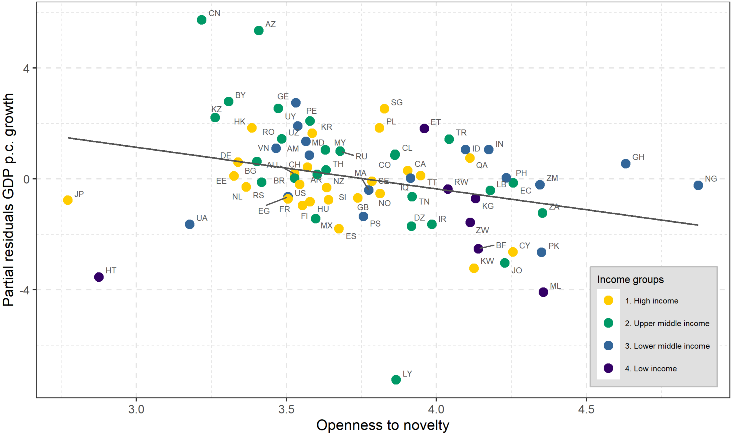
A formal model with simulations:

Describes + analyses positive & negative mechanisms that link openness to novelty to long-run growth

1. General openness: mechanisms' relative strength changes → hump-shaped relationship
2. Heterogeneity: clear positive impact on growth

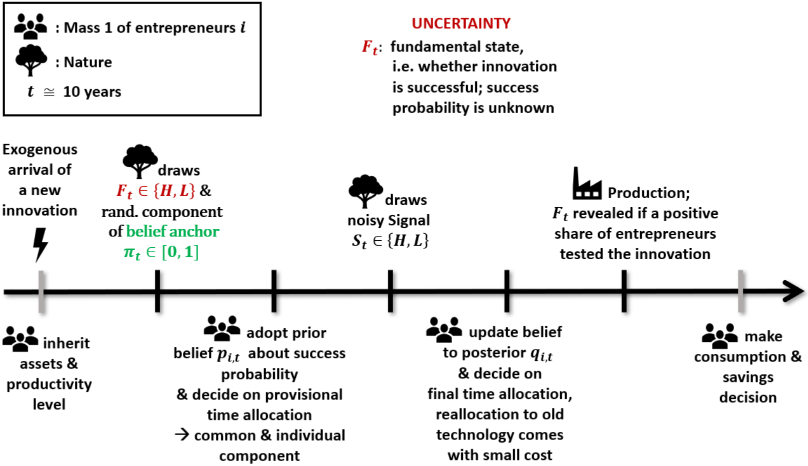
▸ Literature

Openness to Novelty and Economic Growth



▸ Details ▸ Robustness

Timeline of One Period/ Model Overview



Static Equilibrium

Time allocation via "backward approach"
⇒ categorisation of prior beliefs:

- **Pessimistic**: allocates entire time endowment to old method (no opportunity to reconsider)
- **Impartial**: provisionally allocates full time endowment to new method and then listens to the signal
- **Exuberant**: allocates full time endowment to new method and sticks to that decision even if $S_t = L$

⇒ thresholds change each period

Graph

Common Belief Anchor π_t Components

$$\pi_t = (\tilde{\pi}_t)^{1/\Psi} Q_t$$

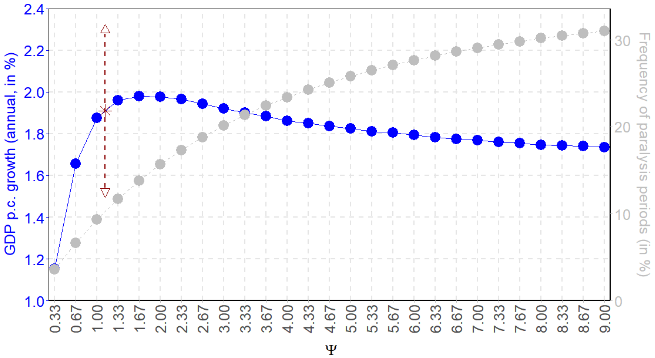
RANDOM FORCES	$\tilde{\pi}_t \sim iid\, U[0,1]$	E.g. (non-)appearance of a contagious narrative	*Shiller (2017,2019)*
GENERAL OPENNESS	$\Psi \in (0, \infty)$	Cultural component affecting economic decision making	*Guiso et al. (2006)*
SPILLOVERS of PAST EXUBERANCE	Q_t=**0** if in t-**1** positive share of exuberant entrepreneurs misallocates time	Negative experiences enhance downsides of experimenting with uncertain innovations & lead to temporarily more conservative priors	*Bordalo et al. (2012) & Dittmar and Duchin (2016); Malmendier (2021)*

Simulations

1. **General** openness to novelty and growth ($\delta = 0$)
2. **Heterogeneity** in openness to novelty and growth

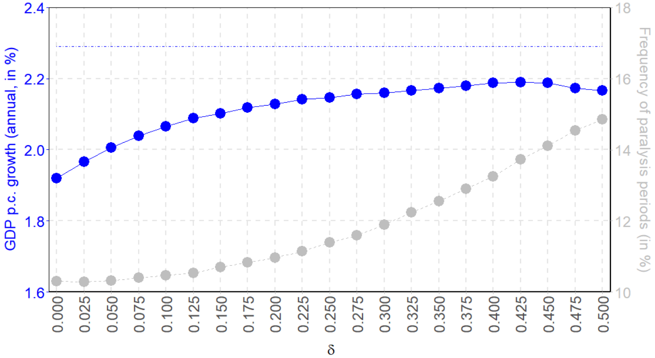
- $100,000$ simulations of a 20-period economy ($\widehat{=}$ 200 years)
- Focus on Western European Economies

General Openness to Novelty & Growth



⇒ Annual GDP p.c. growth falls by ~ 0.25 pp from the peak of Ψ to the upper bound

Heterogeneity in Openness to Novelty & Growth



⇒ Annual GDP p.c. growth increases by ∼ 0.36 pp from lower end of δ to max

Note: The horizontal dashed line indicates GDP p.c. growth in a simulated economy that is populated by entrepreneurs who stick to the principle of indifference.

Take-Aways

- **Uncertainty** about innovations offers room for **subjective beliefs** and **narratives** which can create booms, busts & potential paralysis on the macro level of an economy
- **General openness to novelty** has an ambiguous (hump-shaped) effect: at a low level, an increase is extremely beneficial (curiosity/experimentation) but relatively quickly the relationship becomes negative (exuberant beliefs) with a sizeable impact on long-term growth
- **Heterogeneity in openness to novelty** appears to have a non-negligible positive effect on long-term growth

Thank You!

Literature

- **Effect of culture on long-run economic development**: Doepke and Zilibotti (2008), Galor and Özak (2016), Gorodnichenko and Roland (2017), Sunde et al. (2022),...
- **Cultural influences on prior beliefs**: Guiso et al. (2006, 2008), Mokyr (2017)
- **Impact of experience effects on priors**: Malmendier and Tate (2011), Dittmar and Duchin (2016), Guiso et al. (2018), Malmendier (2021)
- **Relaxing the common prior assumption (heterogeneity)**: e.g. Gilboa et al. (2014) - welfare analysis
- **Diversity along various dimensions connected to long-run growth**: e.g. Ashraf and Galor (2013) - genetic diversity

◂ Contribution

Empirical Motivation - Details

- **Data**: 75 countries, 2005-2014, average annual GDP p.c. growth in const. 2011 int.$ (WDI data) & own openness to novelty measure (World Value Survey data)
- **Openness to Novelty Measure**: weighted avg. over individuals in each country of 2 items describing a person (subjective ranking)
  - ∗ Item 1: "Thinking up new ideas and being creative is important to her/him. She/he likes to do things in her/his own original way."
  - ∗ Item 2: "She/he looks for adventures and likes to take risks. She/he wants to have an exciting life."
- **Partial Residual Plot**: controls for 2005 level of log GDP p.c. (convergence growth), significant slope coefficient of -1.67
  - → One-standard-deviation increase in openness measure associated with 0.66 p.p. fall in growth

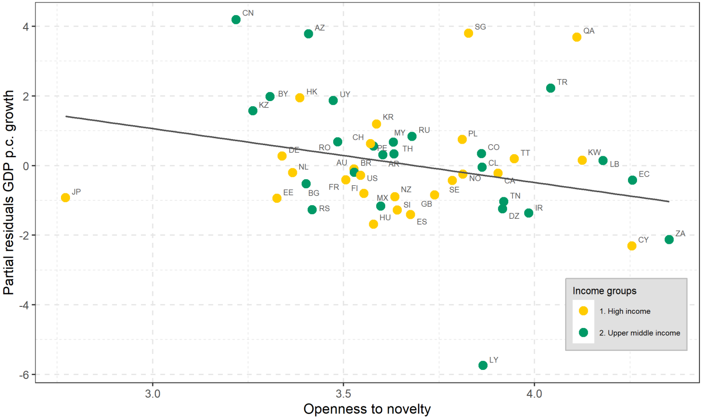
◂ Empirical Motivation

Robustness

- Removing outliers (5% in each dimension)
- Subgroups: without low income countries, without low and lower middle income countries
- Additional Controls: quality of institutions, human capital
- Each item separately

Empirical Motivation

Robustness



◂ Simulations

Table: Baseline and Subsets

	Dependent variable: Average annual GDP p.c. growth			
	(1) Baseline	(2) W/o outliers	(3) W/o low income	(4) W/o low & lower middle income
Openness to Novelty	−1.669***	−2.185***	−2.110***	−2.759***
	(0.601)	(0.570)	(0.595)	(0.806)
log(GDP2005)	−1.379***	−1.274***	−1.802***	−1.994***
	(0.214)	(0.168)	(0.242)	(0.367)
Constant	21.815***	22.829***	27.721***	32.133***
	(3.487)	(3.150)	(3.674)	(4.787)
Observations	75	67	68	51
R^2	0.370	0.477	0.470	0.457
Adjusted R^2	0.352	0.460	0.454	0.435
Residual Std. Error	1.869	1.324	1.713	1.790
F Statistic	21.118***	29.131***	28.832***	20.236***
Note:				*p<0.1; **p<0.05; ***p<0.01

Empirical Motivation

Table: Additional Controls

	Dependent variable: Average annual GDP p.c. growth			
	(1) Baseline	(2) Add. Controls	(3) W/o low income	(4) W/o low & lower middle income
Openness to Novelty	-1.669^{***}	-1.068^{*}	-1.785^{**}	-2.142^{**}
	(0.601)	(0.632)	(0.684)	(0.940)
log(GDP2005)	-1.379^{***}	-1.874^{***}	-2.214^{***}	-2.767^{***}
	(0.214)	(0.327)	(0.358)	(0.600)
Quality of Institutions		0.143	0.388	0.600
		(0.344)	(0.374)	(0.500)
Human Capital		0.263^{**}	0.105	0.107
		(0.109)	(0.128)	(0.180)
Constant	21.815^{***}	21.897^{***}	29.419^{***}	36.296^{***}
	(3.487)	(3.998)	(4.878)	(6.587)
Observations	75	75	68	51
R^2	0.370	0.424	0.493	0.489
Adjusted R^2	0.352	0.391	0.461	0.444
Residual Std. Error	1.869	1.812	1.701	1.775
F Statistic	21.118^{***}	12.894^{***}	15.329^{***}	10.983^{***}

Note: *p<0.1; **p<0.05; ***p<0.01

Table: Each Item Separately

	Dependent variable:		
	Average annual GDP p.c. growth		
	(1) Baseline	(2) Item 1	(3) Item 2
Openness to Novelty	-1.669^{***}		
	(0.601)		
Item 1		-1.300^{**}	
		(0.552)	
Item 2			-1.347^{**}
			(0.531)
log(GDP2005)	-1.379^{***}	-1.260^{***}	-1.422^{***}
	(0.214)	(0.208)	(0.224)
Constant	21.815^{***}	19.969^{***}	20.322^{***}
	(3.487)	(3.287)	(3.239)
Observations	75	75	75
R^2	0.370	0.352	0.359
Adjusted R^2	0.352	0.334	0.342
Residual Std. Error (df = 72)	1.869	1.895	1.884
F Statistic (df = 2; 72)	21.118^{***}	19.565^{***}	20.203^{***}
Note:			$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Final Good Sector

→ single final good Y produced from capital K and intermediate good X with CES aggregate PF:

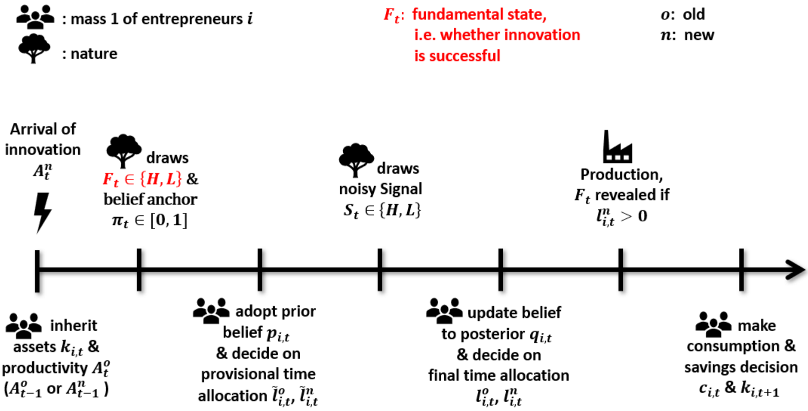
$$\boldsymbol{Y_t = Y(K_t, X_t) = (K_t)^{\alpha}(X_t)^{1-\alpha}}, \tag{1}$$

where $\alpha \in (0, 1)$

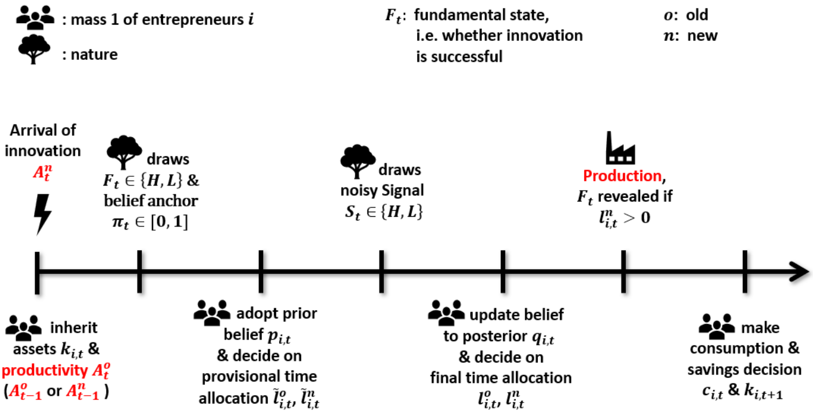
→ rental rate r of capital & technology good price m:

$$r_t = \alpha(K_t/X_t)^{\alpha-1} - \kappa \quad \text{and} \quad m_t = (1-\alpha)(K_t/X_t)^{\alpha} \tag{2}$$

Timeline of One Period/ Model Overview



Timeline of One Period/ Model Overview



Technologies

Final Good Sector:

- Single final good PF: $Y_t = (K_t)^{\alpha}(X_t)^{1-\alpha}$
- Factor prices, r_t and m_t, = marg. productivities (less depreciation for capital)

Intermediate Good Sector:

- X_t produced by continuum (mass 1) of independent entrepreneurs i who also own & supply K_t
- Each period access to two production methods: A_t^o & A_t^n
  PFs: $x_{it}^o = A_t^o \ell_{it}^o$ and $x_{it}^n = A_t^n \ell_{it}^n$,

  $\rightarrow \ell_{it}$: time of entrepreneur $i \in [0, 1]$, $\ell_{it}^o + \ell_{it}^n = 1$

Technologies

- Productivity of new method depends on fundamental F_t:

$$A_t^n = \begin{cases} \theta^H A_t^o & \text{if } F_t = H \\ \theta^L A_t^o & \text{if } F_t = L \end{cases}, \tag{3}$$

where $\theta^H > 1 > \theta^L$ (for simplicity $\theta^L = 1/\theta^H$)

- "Default technology" (F_t not always revealed)

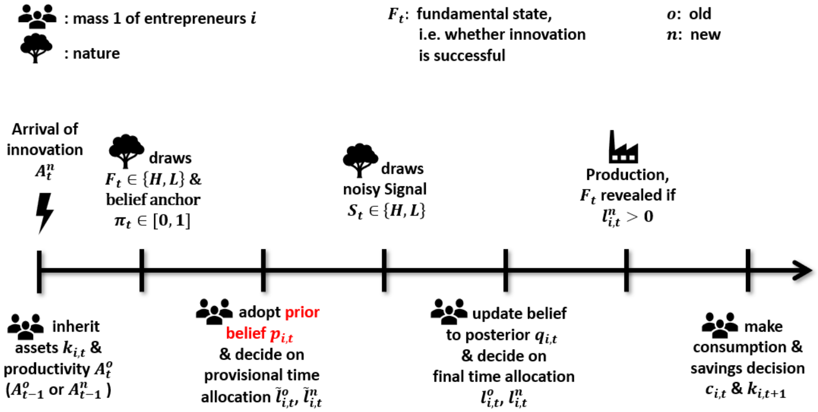
$$A_{t+1}^o = \begin{cases} A_t^n & \text{if } F_t \text{ revealed } \vee \; F_t = H \\ A_t^o & \text{otherwise} \end{cases} \tag{4}$$

Technologies

Entrepreneurs' **time allocation decision**:

1. Provisional choice $\tilde{\ell}_{it}^{k}$ without information on $Pr(F_t = H)$ based on subjective prior p_{it}
2. Potential to terminate use of new technology after updating belief according to Bayes' Rule based on receiving a signal $S_t \in \{H, L\}$ about F_t with signal quality $\sigma = \Pr(S_t = F_t) > 1/2$
   $\rightarrow$ Withdrawing from new technology comes with a small loss of time $(1 - \lambda)$

Timeline of One Period/ Model Overview



Prior Beliefs $p_{i,t}$

Uncertainty and Beliefs

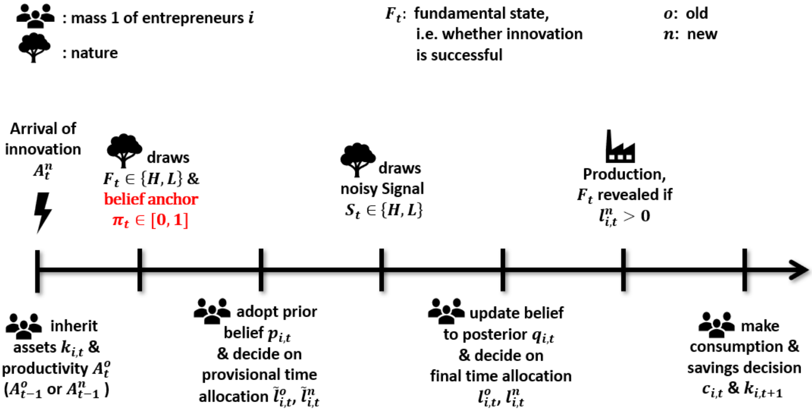
$\rightarrow$ Entrepreneurs adopt a subjective prior belief about $Pr(F_t = H)$:

$$\boldsymbol{p_{it} = \pi_t^{(1/\psi_i)-1}} \tag{5}$$

- $\pi_t \in (0,1)$: **belief anchor**
- ψ_i: entrepreneur-specific characteristic, i.e. individual openness to novelty
  $\rightarrow \psi_i \sim U[\frac{1}{2} - \delta, \frac{1}{2} + \delta]$, $\delta \in (0, \frac{1}{2})$: degree of belief heterogeneity

▸ Graph

Timeline of One Period/ Model Overview



Entrepreneurs: Prior Beliefs $p_{it}(\pi_t; \psi_i) = \pi_t^{(1/\psi_i)-1}$

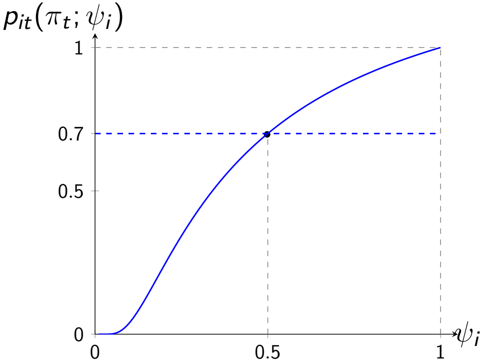


Figure: Distribution of p_{it} with max. heterogeneity & $\pi_t = 0.7$

◂ Prior Beliefs

Distribution of Openness to Novelty ψ_i

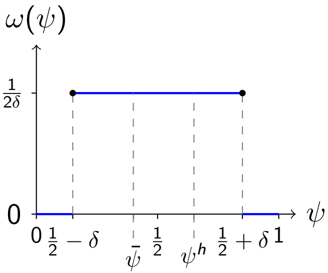


Figure: Distribution of ψ

→ density function ω:

$$\omega(\psi) = \begin{cases} 1/(2\delta) & \text{if } \psi \in [1/2-\delta, 1/2+\delta] \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

Belief Anchor π_t

In practice, **belief anchor** affected by

- Random forces, e.g. (non-)appearance of a contagious narrative (*Shiller, 2017,2019*)
- General openness: cultural component affecting economic decision making (*Guiso et al., 2006*)
- Spillovers of past exuberance: leads to lower anchor
  $\rightarrow$ captures that negative experiences enhance downsides of experimenting with uncertain innovations (*Bordalo et al., 2012*) & lead to temporarily more conservative priors (*Dittmar and Duchin, 2016; Malmendier, 2021*)

Belief Anchor π_t

→ Components of the **belief anchor**:

$$\pi_t = (\tilde{\pi}_t)^{1/\Psi} Q_t$$

- $\tilde{\pi}_t \sim$ *iid* $U[0,1]$: random forces (e.g. narratives)
- $\Psi \in (0, \infty)$: general level of openness (cultural component)
  → the larger Ψ, the larger the mean of $(\tilde{\pi}_t)^{1/\Psi}$
- Q_t: spillovers of past exuberance
  → chance of $Q_t = 0$ if in previous period a positive share of exuberant entrepreneurs (who ignored $S_t = L$) allocated time to a failed innovation

Entrepreneurs: Preferences & Aggregation

Consumption and Saving Decision

- Preferences over c_{it} & k_{it+1}: $U_{it} = \mathbb{E}_{it}\left\{(c_{it})^{1-\beta}(k_{it+1})^{\beta}\right\}$ $(\beta \in (0,1))$ s.t. i's flow budget constraint $k_{it+1} = (1+r_t)k_{it} + m_t x_{it} - c_{it}$
- Decision after resolution of uncertainty $\Rightarrow$ time allocation maximises $U_{it} = (1-\beta)^{1-\beta}\beta^{\beta}\ \mathbb{E}_{it}\left\{(1+r_t)k_{it} + m_t(x^o_{it} + x^n_{it})\right\}$

Aggregation over mass 1 of entrepreneurs

Timing

Within each period t, there is a maximum of seven stages. The sequence of events is as follows:

1. From the previous period, all entrepreneurs $i \in [0, 1]$ inherit their individual asset holdings, k_{it}, and the productivity level A^o_t (either A^o_{t-1} or A^n_{t-1}).
2. Nature draws the initially unobservable fundamental of the new production method, $F_t \in \{H, L\}$, as well as the belief anchor, $\pi_t \in [0, 1]$.
3. Observing π_t, all entrepreneurs adopt a subjective prior belief about $\Pr[F_t = H]$, p_{it}, and then decide on the provisional time allocation, $(\tilde{\ell}^o_{it}, \tilde{\ell}^n_{it})$.

Timing

If non of the entrepreneurs provisionally allocates time to the new production method, stages 4 and 5 are skipped. Otherwise, the sequence continues with stage 4:

4. Nature draws the informative but noisy signal about the fundamental, $S_t \in \{H, L\}$.
5. Observing S_t, all entrepreneurs with $\tilde{\ell}^n_{it} > 0$ form their posterior belief, q_{it}, and then decide on the final time allocation, $(\ell^o_{it}, \ell^n_{it})$.
6. Production takes place, incomes are incurred (and the z_{it}s observed), and - provided that $\ell^n_{it} > 0$ for some entrepreneurs - F_t is inferred.
7. All entrepreneurs divide z_{it} between current consumption, c_{it}, and future assets, k_{it+1}.

Time

Period Length:

- One period starts with arrival of new innovation and ends with (possible) resolution of uncertainty
- ▶ *Goldfarb and Kirsch (2019)*, tracing major innovations over past 180 years, suggest window of $\sim$ 15 years for major innovations
- ▶ *Dedehayir and Steinert (2016)*, dealing with hype cycles surrounding innovations: $\sim$ 2-20 years, "normal technologies" $\sim$ 5-8 years

$\Rightarrow$ Based on this we choose **10 years** for calibration

Static Equilibrium: Time Allocation Decision - **Backwards Approach**

(1) **Termination Decision**:
Entrepreneur i receives signal $S_t \in (L, H)$ with quality $\sigma = Pr(S = F) > \frac{1}{2}$ and updates prior $p_{it} = Pr_i(F_t = H)$ to posterior $q_{it} = Pr_i(F_t = H)$
$\Rightarrow$ decision whether to terminate if they had previously invested some time in new method ($\tilde{\ell}^n_{it} > 0$)

(2) **Time Allocation decision**:
Based on subjective prior $p_{it} = Pr_i(F_t = H)$
$\Rightarrow$ time allocation decision old and/or new method

Static Equilibrium: Time Allocation Decision

- Update prior p_{it} to posterior q_{it} with Bayes' rule:

$$q_{it}(S_t, p_{it}, \sigma) = \begin{cases} \left[1 + \frac{1-p_{it}}{p_{it}} \frac{1-\sigma}{\sigma}\right]^{-1} & : \quad S_t = H \\ \left[1 + \frac{1-p_{it}}{p_{it}} \frac{\sigma}{1-\sigma}\right]^{-1} & : \quad S_t = L \end{cases} . \tag{7}$$

- Condition to continue (assuming investment in new method):

$$q_{it}\theta^H A_t^o \tilde{\ell}_{it}^n + (1 - q_{it})\theta^L A_t^o \tilde{\ell}_{it}^n \geq \lambda A_t^o \tilde{\ell}_{it}^n \tag{8}$$

- Resulting threshold:

$$\bar{q} = \frac{\lambda - \theta^L}{\theta^H - \theta^L} \in (0, 1). \tag{9}$$

Static Equilibrium: **Termination Decision**

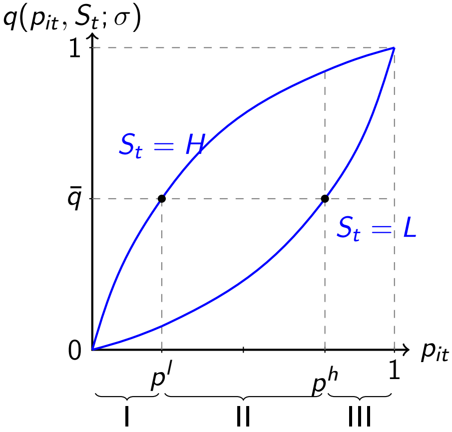


Figure: Posterior belief q_{it} as a function of p_{it} and S_t

Static Equilibrium: **Termination Decision**

- $q_{it}(H, p^l) = \bar{q}$:

$$p^l = \frac{(1-\sigma)(\lambda - \theta^L)}{\lambda - \theta^L + \sigma(\theta^H + \theta^L - 2\lambda)}. \tag{10}$$

- $q_{it}(L, p^h) = \bar{q}$:

$$p^h = \frac{\sigma(\lambda - \theta^L)}{\theta^H - \lambda + \sigma(2\lambda - \theta^L - \theta^H)}. \tag{11}$$

Static Equilibrium: **Provisional Time Allocation**

I)

$$\mathbb{E}_{p_{it\in \text{I}}}[x_{it}(0,1)] = \lambda A_t^o. \tag{12}$$

II) Signal is decisive

S_t=

F_t=		H	L
	H	$p_{it}\sigma$	$p_{it}(1-\sigma)$
	L	$(1-p_{it})(1-\sigma)$	$(1-p_{it})\sigma$

$$\mathbb{E}_{p_{it\in \text{II}}}[x_{it}(0,1)] = \left\{p_{it}\sigma\theta^H + (1-p_{it})(1-\sigma)\theta^L + [p_{it}(1-\sigma) + (1-p_{it})\sigma]\,\lambda\right\} A_t^o. \tag{13}$$

III)

$$\mathbb{E}_{p_{it\in \text{III}}}[x_{it}(0,1)] = \left[p_{it}\theta^H + (1-p_{it})\theta^L\right] A_t^o. \tag{14}$$

Static Equilibrium: **Provisional Time Allocation**

$$\mathbb{E}_{\bar{p}}[x_{it}(0,1)] = A_t^o \tag{15}$$

$\Rightarrow$ Invest time in new method for all $p_{it} > \bar{p}$:

$$\bar{p} = \frac{1 - \theta^L + \sigma(\theta^L - \lambda)}{\lambda - \theta^L + \sigma(\theta^H + \theta^L - 2\lambda)}. \tag{16}$$

Static Equilibrium: Provisional Time Allocation

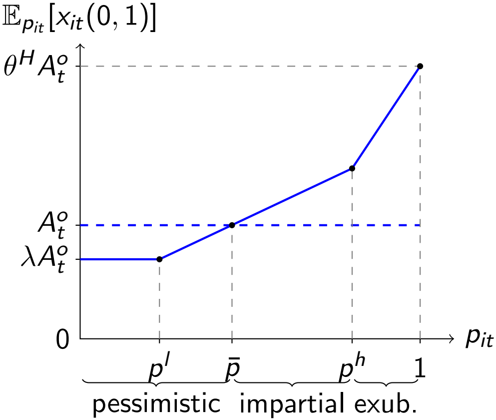
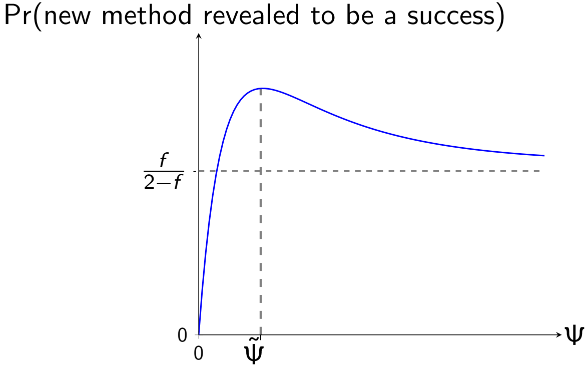


Figure: A priori exp output with full time endowment allocated to new method

Static EQ

Static Equilibrium: Analysis

Figure: Openness to novelty and the pace of innovation—theory



Parameter Values

Panel A			
Parameter	**Description**	**Determination**	**Value**
α	Reproducible capital's share	Literature	0.20
κ	Depreciation rate	Literature	0.79
θ^H	Innovation size	Literature	1.75
λ	Reallocation share	Literature	0.95
Ψ	Openness to Novelty	World Value Survey	1.13
β	Weight of future assets	Calibration	0.217
σ	Signal quality	Calibration	0.896
f	Obj. $\Pr(F_t{=}H)$ (unknown)	Calibration	0.450
Panel B			
	Avg. GDPp.c. Growth	**SD GDPp.c. Growth**	**Avg. Int. Rate**
Data	0.019	0.008	0.029
Model	0.019	0.007	0.029

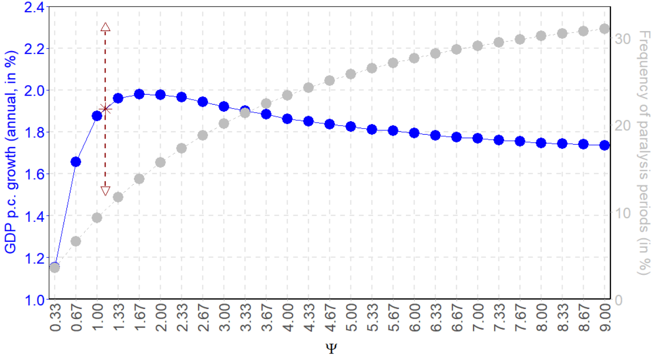
Table: Parametes and Moments Determination Details

Parameter Values

- α & κ: Caselli and Freyer (2007) for Western European countries, κ translated to 10 year frequency
- θ^H: Akcigit and Kerr (2018)
- Ψ: data from our empirical motivation (World Value Survey)
- β, σ & f: calibrated to match mean & std.dev. of 20 Western European GDP p.c. growth rate 1820-2018 (Maddison Project Database: Bolt and Van Zanden, 2020) as well as mean annual real interest rate 1820-2018 of 5 Western European countries (Schmelzing, 2020)

◂ Parameters

General Openness to Novelty & Growth



Notes. Each dot results from 100,000 simulations of a 20-period (200 years) economy. The vertical red structure indicates the empirical value for average Western European GDP p.c. growth (star), as well as the standard deviation in that sample (arrow).

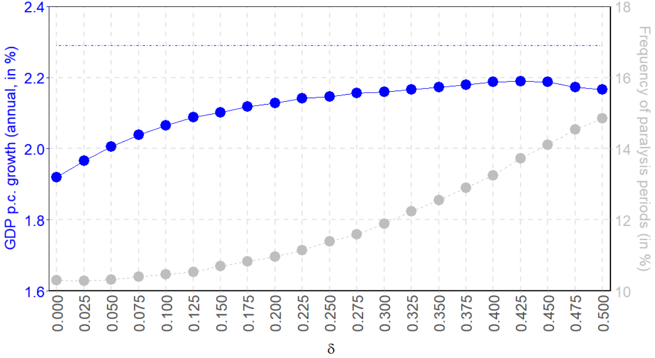
General Openness to Novelty & Growth

- Annual GDP p.c. growth rises by 0.84 pp (from 1.15% to 1.99%) from lower bound of Ψ to peak (1.67)
- It falls by $\sim$ 0.25 pp to 1.73% as Ψ approaches upper bound
- If two countries start with same GDP p.c., $\frac{1}{4}$ of a pp growth differential means: after 100 years, GDP p.c. in one country is just 78% of that in the other

▶ Consistency with empirical observation?!

Empirical Motivation

Heterogeneity in Openness to Novelty & Growth



Notes. Each dot results from 100,000 simulations of a 20-period (200 years) economy. The horizontal dashed line indicates GDP p.c. growth in a simulated economy that is populated by entrepreneurs who stick to the principle of indifference.

Heterogeneity in Openness to Novelty & Growth

- For most part of the range, growth rate monotonically increases in δ (from 1.91% p.a. to max of 2.27% p.a.)

$\rightarrow$ Difference of 0.36 pp in terms of annual growth = sizeable effect

▶ Mean-preserving increase in heterogeneity makes some entrepreneurs more open for experimentation & learning without giving a boost to the risk that a large number of entrepreneurs adopt an exuberant prior at the same time

Technology Good Sector: Aggregation

$\Rightarrow$ aggregate supply of X_t:

$$X_t = \int_0^1 (x_{it}^o + x_{it}^n)\ di = \int_0^1 (A_t^o \ell_{it}^o + A_t^n \ell_{it}^n)\ di. \tag{17}$$

Aggregation

⇒ aggregate level of capital:

$$K_{t+1} = \int_0^1 (k_{it})\, di = \int_0^1 (\beta[(1 + r_t)k_{it} + m_t x_{it}])\, di = \beta[(1 + r_t)K_t + m_t X_t] \tag{18}$$

⇒ aggregate level of consumption:

$$C_t = \int_0^1 (c_{it})\, di = \int_0^1 ((1-\beta)[(1+r_t)k_{it}+m_t x_{it}])\, di = (1-\beta)[(1+r_t)K_t+m_t X_t] \tag{19}$$

Aggregation: Technology Good

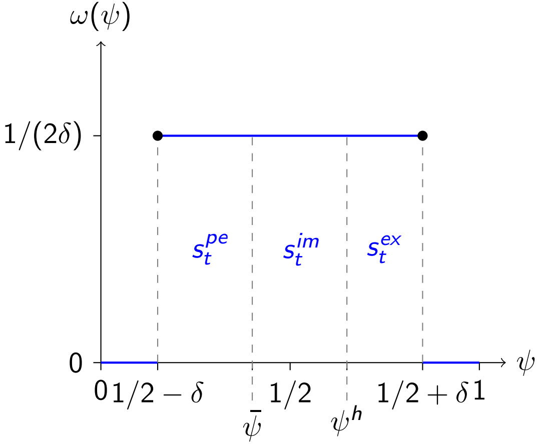


Figure: Distribution of ψ and categorisation

Aggregation: Technology Good

→ with:

$$\bar{\psi}(\pi_t) = [1 + \ln(\bar{p}) / \ln(\pi_t)]^{-1} \quad \text{and} \quad \psi^h(\pi_t) = \left[1 + \ln(p^h) / \ln(\pi_t)\right]^{-1}$$

→ which yields the shares:

$$s_t^{pe} = \int_0^{\bar{\psi}(\pi_t)} \omega(\psi)\ d\psi$$

$$s_t^{im} = \int_{\bar{\psi}(\pi_t)}^{\psi^h(\pi_t)} \omega(\psi)\ d\psi$$

$$s_t^{ex} = \int_{\psi^h(\pi_t)}^{1} \omega(\psi)\ d\psi$$

Aggregation: Technology Good

⇒ Aggregation:

$$\boldsymbol{X_t = s_t^{pe} A_t^o + s_t^{im} \left[\mathbf{1}_{S_t=H} \cdot A_t^n + \mathbf{1}_{S_t=L} \cdot A_t^o \lambda \right] + s_t^{ex} A_t^n}$$

→ with:

$$A_{t+1}^o = \begin{cases} A_t^n & \text{if } F_t = H \ \wedge \ (s_t^{im} \cdot \mathbf{1}_{S_t=H} > 0 \ \vee \ s_t^{ex} > 0) \\ A_t^o & \text{otherwise} \end{cases} \tag{6'}$$

General Openness to Novelty and Growth - Analytical Results

PROPOSITION 2

Suppose that $\bar{p} < p^h$ and $\psi_i = 1/2$ for all i (no heterogeneity in openness to novelty). Then, for any arbitrary period t,

$$\Pr[Q_t = 1] = \left\{1 + (1 - f)\left[1 - (p^h)^{\Psi}\right]\right\}^{-1},$$

where f is the time-invariant probability of $F_t = H$ (which is not known to the entrepreneurs).

General Openness to Novelty and Growth - Analytical Results

PROPOSITION 3

Suppose that $\bar{p} < p^h$ and $\psi_i = 1/2$ for all i (no heterogeneity in openness to novelty). Then, for any arbitrary period t

$$\Pr[\textit{new method in t revealed to be a success}] = f\,\frac{1-(1-\sigma)(p^h)^{\Psi}-\sigma(\bar{p})^{\Psi}}{1+(1-f)\left[1-(p^h)^{\Psi}\right]},$$

where f is the time-invariant probability of $F_t = H$ (which is not known to the entrepreneurs).

General Openness to Novelty and Growth - Analytical Results

PROPOSITION 4

Suppose that the signal's quality, $\sigma \in (1/2, 1]$, *is sufficiently large such that*

$$f < \frac{2\sigma - 1}{\sigma},$$

where f *is the time-invariant probability of* $F_t = H$ *(which is not known to the entrepreneurs). Then,* $\Pr[\textit{new method in } t \textit{ revealed to be a success}]$ *is a quasi-concave function of* $\Psi \in [0, \infty)$. *As* Ψ *rises from zero towards infinity, it monotonically increases from zero to some maximum level that is strictly greater than* $f/(2-f)$ *and then monotonically decreases towards* $f/(2-f)$.

General Openness to Novelty and Growth - Analytical Results

PROPOSITION 5

Suppose that $\bar{p} < p^h$ *and* $\psi_i = 1/2$ *for all* i *(no heterogeneity in openness to novelty). Then, for any two periods* t *and* $t+1$*, the expected growth rate of the "technology frontier" is given by*

$$\mathbb{E}_f \left\{ \frac{A^o_{t+1} - A^o_t}{A^o_t} \right\} = (\theta^H - 1) f \frac{1 - (1-\sigma)(p^h)^\Psi - \sigma(\bar{p})^\Psi}{1 + (1-f)\left[1 - (p^h)^\Psi\right]},$$

where the notation $\mathbb{E}_f\{\cdot\}$ *indicates that the expectation is based on the true chance of* $F_t = H$*.*

Future Research

- More extensive empirical analyses
- Investigating the origins of differences (both general & heterogeneity): through what mechanisms can such differences emerge/persist?
- Possible policy implications? Incentives to experiment/invest in uncertain innovations country-dependent?