From Secular Stagnation to Robocalypse? Implications of Demographic and Technological Changes

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*Opinions expressed in this presentation are those of the authors. They do not necessarily coincide with those of the Banco de España or the Eurosystem.

Broad Motivation

- Demographics changes are often mentioned as one of the headwinds affecting growth - (see Gordon (2012, 2014), Fernald and Jones (2014))
- Aksoy, Basso, Smith, and Grasl (2018), using a Panel of OECD economies find that changes in the demographic structure affect macroeconomic trends, showing that for all countries of the OECD demographics changes lead to lower growth. Trend output growth is expected to be reduced on average by 0.64 pp during the 2015-2025 decade. They argue that the link between demographics and innovation is important in explaining these findings.
- On the contrary, Acemoğlu and Restrepo (2017) argue that demographics gives incentive to automation, which would boost growth offsetting the secular stagnation implications of demography.

This Paper

Question

- How do demographic and technological changes interact when both innovation and automation occur?

Framework

- We build a model where both invention of new goods and automation of production processes of existing goods are endogenously determined.
- Model incorporates a tractable life-cycle structure to consider the effects of demographic changes.
- Production is organized into two sectors, one that is labour intensive and one that uses robots and does not employ labour (as in Acemoglu and Restrepo, 2017).

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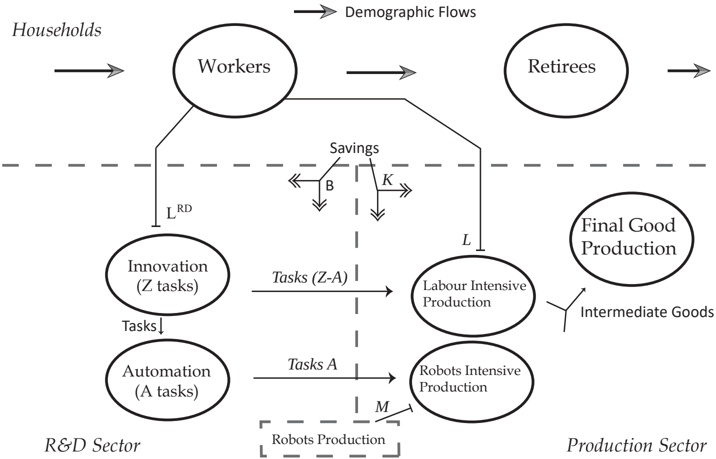
Key Findings

- In the long-run, after the economy converges to the new balanced growth path, growth rate per capita always decreases when population growth decreases.
- The projected demographic transition has stronger implications for Europe than the U.S. but in both cases per capita growth is affected negatively and degree of automation increases.
- The negative effect can be traced back to the trade-off in R&D. As automation incentives increase, resources are diverted from the creation of new varieties (product innovation), compromising growth.
- In a scenario where automation makes the production of robots cheaper, automation increases substantially but growth is severely affected.

The Model

- Five main structures:
  - Households: Life-cycle structure (fertility, retirement, mortality) à la Gertler (1999)
  - An innovation sector: Creation of new tasks/goods. Romer (1990) and Comin and Gertler (2006). The main source of endogenous growth.
  - Automation: Procedures invented so that robots can be used in the production of a task i. Robots more productive than labor thus, Automation $\Rightarrow$ growth.
  - A robot production sector: Transforms final goods into robots and sells them to intermediate producers.
  - A goods production sector: A final good producer aggregates tasks/goods and a continuum of intermediate good firms that employ a composite of goods from all firms (inputs), capital and either robots or labor to produce a good/task.

Economic Structure



Households

- There are a continuum of agents of mass N_t, divided amongst two age groups:
  - $\tilde{n}_{t,t+1} N_t^w$ individuals are **born** every period as workers. A fixed share Sw_{RD} are allocated to the R&D sector and the remaining to production. At every period a share $drop_{RD}$ of workers moves out of R&D sector.
  - Workers **retire** with a probability $1-\omega^w$, and retirees **die** and leave the economy with a probability $1-\omega^r_{t,t+1}$
- Population flows are:

$$
\begin{aligned}
N_{t+1}^w &= \tilde{n}_{t,t+1} N_t^w + \omega^w N_t^w, \\
N_{t+1}^r &= (1-\omega^w) N_t^w + \omega^r_{t,t+1} N_t^r. \\
N_{t+1}^{wRD} &= \omega^y_{t,t+1} N_t^w Sw_{RD} + (1-drop_{RD})\omega^w N_t^{wRD}, \\
N_{t+1}^{wL} &= \omega^y_{t,t+1} N_t^w (1-Sw_{RD}) + \omega^w N_t^{wL} + (drop_{RD})\omega^w N_t^{wRD}
\end{aligned}
$$

- Following Gertler (1999), we aggregate conditions within each age group. Age dependent marginal propensity to consume are a function of fertility and mortality. Age composition affects interest rate and aggregate demand.

Households Decisions

Production

- Final good production:

$$y_t = \left[\int_0^{Z_t} y_{i,t}^{\frac{\psi-1}{\psi}} di \right]^{\frac{\psi}{\psi-1}}$$

- Intermediate inputs: For tasks $i \in A_t$ robots are used. For the remaining tasks $i \in Z_t \setminus A_t$ labor is employed in the production process:

$$\begin{cases} y_{i,t} = ((K_{i,t})^{\alpha}(\theta_t M_{i,t})^{1-\alpha})^{1-\gamma_l} \Upsilon_{i,t}^{\gamma_l} \text{ for } i \in A_t \\ y_{i,t} = ((K_{i,t})^{\alpha}(L_{i,t})^{1-\alpha})^{1-\gamma_l} \Upsilon_{i,t}^{\gamma_l} \text{ for } i \in Z_t \setminus A_t \end{cases}$$

where $\theta_t > 1$ denotes the relative productivity of robots

- Robots replace labour, capital is complementary to labour $\Longrightarrow$ Automation reduces wages.

R&D Sector: Innovation and Automation

- Product Creation $\frac{Z_{t+1}}{Z_t} = \chi \left(\frac{S_t}{\tilde{\Psi}_t} \right)^{\rho} (L_{I,t}/N_t)^{\kappa_L} + \phi$

  S_t - Investment, $L_{I,t}$ - Labour in innovation - Demographic Structure influences innovation

- The value of an invented product J_t depends on $\Pi^L_{i,t}$, the profit of labour intensive firms

$$\Pi^L_{i,t} \downarrow \Rightarrow J_t \downarrow \Rightarrow S_t, L_{I,t} \downarrow \Rightarrow Z_t \downarrow$$

Innovation Decision

R&D Sector: Automation

- Automation $A^q_{t+1} = \lambda_t \phi (Z^q_t - A^q_t) + \phi A^q_t$

  Ξ_t - Investment, $L_{A,t}$ - Labour in Automation, - Demographic Structure influences automation
  λ_t - productivity - $f(\Xi_t, L^{\kappa_L}_{A,t})$

- The value of a product whose production process is automated V_t depends on $\Pi^M_{i,t}$ profit of robots intensive firms

$$\Pi^M_{i,t} \uparrow \text{relative to } \Pi^L_{i,t} \Rightarrow V_t \uparrow \text{relative to } J_t \Rightarrow \Xi_t \uparrow \Rightarrow A_t \uparrow$$

Automation decision

Closing the model

- Robots Production:

$$M_t = \varrho \Omega_t^{\eta}, \text{ Price of Robots: } q_t$$

- η - Parameter that ensures balance growth path exists.
- Clearing Conditions: Labour, Product, Capital and Robot Markets clear

Balanced Growth Path and Population

Proposition

After a reduction in population growth, in the long run, as the economy converges to a new balanced growth path, per capita growth decreases when $\eta < 1$.

- Under a balanced growth path, the ratio of the output shares of the automated and labour intensive sectors converge to a constant. As each sector's output is produced by capital, inputs and machines or labour, the last two must eventually grow at the same pace.
- The price of robots, q_t, changes ensuring the result $\Rightarrow$ the growth rate of output in each sector is a function of labour supply growth
- $\downarrow$ labour supply $\Rightarrow \downarrow$ incentive to innovate $\Rightarrow \downarrow$ output per capita growth in the new balanced growth path.
- In sum, and in the words of Aghion, Jones, and Jones (2017), "growth may be constrained not by what we are good at but rather by what is essential and yet hard to improve".

Demographics and Technological Change - Channels

Demographics to Economic Activity

- Labour Supply $\Rightarrow$ Wage $\Rightarrow$ Profits of Labour Intensive Sector
- Longevity/Ageing $\Rightarrow$ Savings $\Rightarrow$ Capital Accumulation and Innovation Investment
- Demographic Composition and Labour Supply $\Rightarrow$ Productivity of Innovation and Automation when Labour is needed in R&D

Economic Activity to R&D

- Production of new ideas/products
  Profits of Labour Intensive firms $\downarrow \Rightarrow$ Value of new tasks $(J_t) \downarrow \Rightarrow Z \downarrow$
- Automation: Investment of new procedures to produce a good with Robots
  Profits of Robots Intensive firms $\uparrow \Rightarrow$ Value of automates tasks $(V_t) \uparrow$
  As $V_t \uparrow$ relative to $J_t \Rightarrow A_t \uparrow$

Labour Supply Effect - Permanent Fall in Fertility

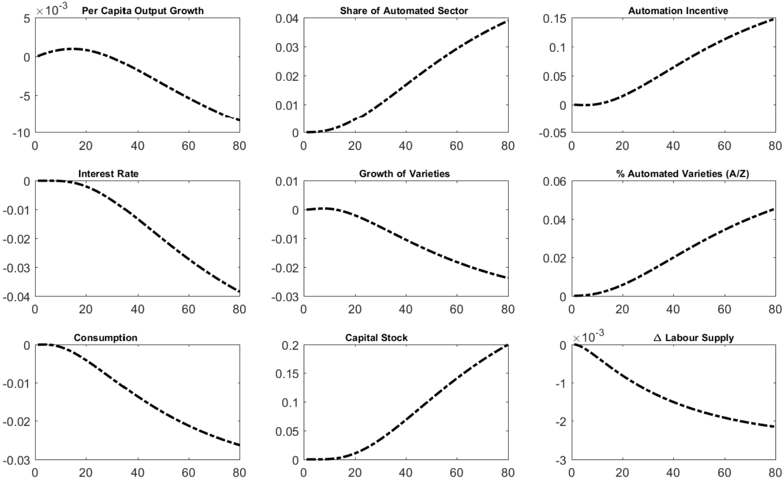


Figure: Fertility, Automation and Growth

Ageing and Demographic Composition - Permanent increase in Longevity -constant population growth-

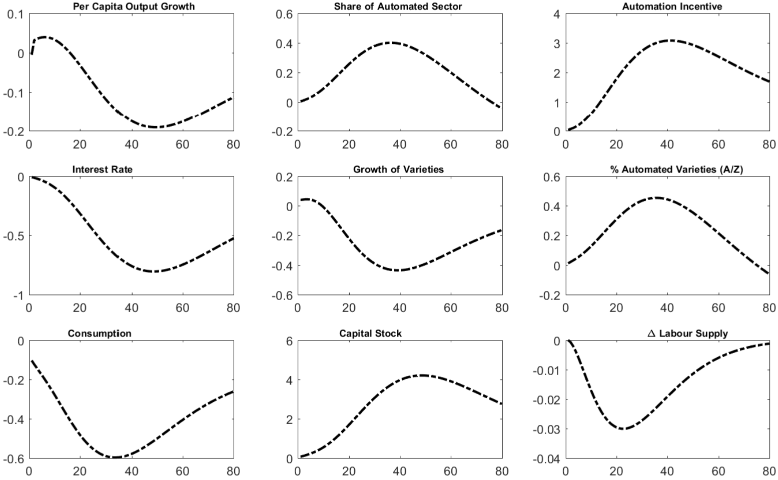


Figure: Mortality, Automation and Growth

Demographic Transition

- Most advanced economies are experiencing a sharp reduction in fertility, and a substantial increase in longevity, in most cases resulting in falling population growth.
- We use our theoretical model to analyse the consequences of demographic changes predicted for the U.S. and for Core Europe (defined as the sum of Germany, France, Italy and Spain) using the data from the UN World Population Prospects, 2015 Revision.
- We calculate population shares for workers (age 20-65) and the retirees (age above 65) in the year 1993 and the projected shares in 2055 for each country/region. We then simulate a transition path from population structure of 1993 to the structure in 2055
- Focus on the transition, discarding initial years to decrease influence of the initial steady state on the results. Simulation results from the year 2000 until 2040.

Demographic Transition - U.S. and Europe

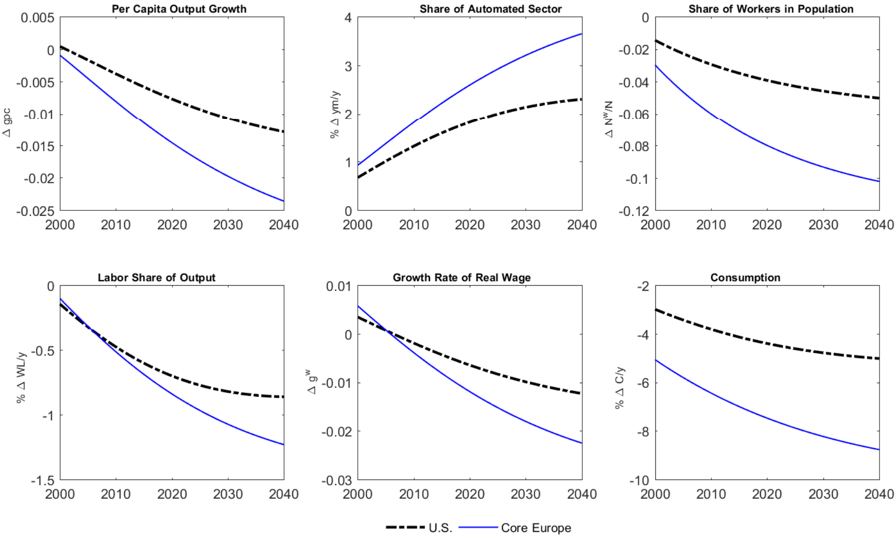


Figure: Demographic Transition: United States and Europe

Demographic Transition

- In both cases, lower fertility, impacting labour supply, leads to more automation. Moreover, as longevity increases, savings increase, providing cheaper resources that are allocated to innovation and automation, generating, initially, higher growth
- As the lower fertility becomes a main driver of the transition, the labour supply effect on innovation, reducing its productivity, is sufficiently strong to depress growth.
- As the growth of new varieties Z_t decreases, overall growth is reduced, hampering the pace of automation.

The Trade-off

- The key trade-off behind our results is that although automation increases and generates growth, technological change is diverted from product creation to automation. As the initial effect of high savings and lower interest rates wears off, the reduction in invention of new varieties outweighs the benefits of automation leading to lower growth.

- Using a cross-section data on patents and demographics, Acemoğlu and Restrepo (2018) confirms this opposing effect of demographics on automation and new product creation. They find that ageing leads to an increase in patents of classes related to Robots, while decreasing patents of classes related to computer, software, nanotechnology and pharmaceutics.

Patents and Demographics

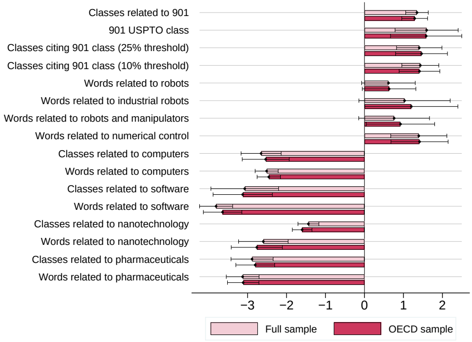


Figure: Demographic and Patents

Source: Acemoğlu and Restrepo (2018)

Extensions - Demographics and Innovation

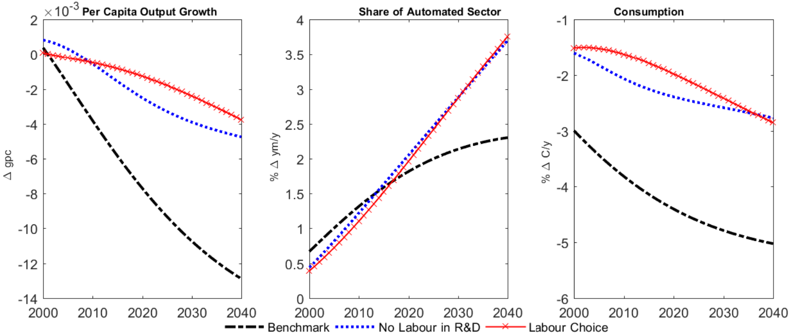


Figure: Demographic Transition: Labour in Innovation

Extensions - Robots, Productivity and Innovation

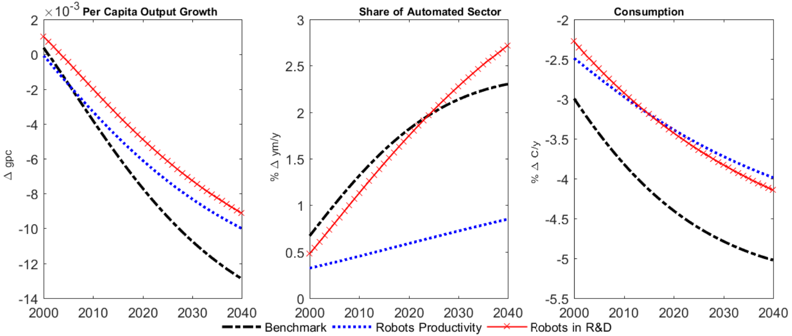


Figure: Demographic Transition: Robots vs Labour

Extensions - Increase in Longevity with Delaying Retirement Age

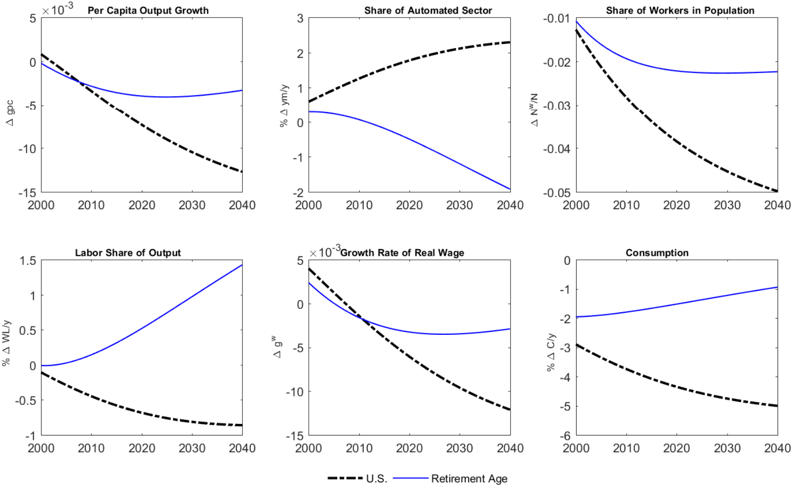


Figure: Increase in Longevity with Delaying Retirement Age

Divergence and Robocalypse

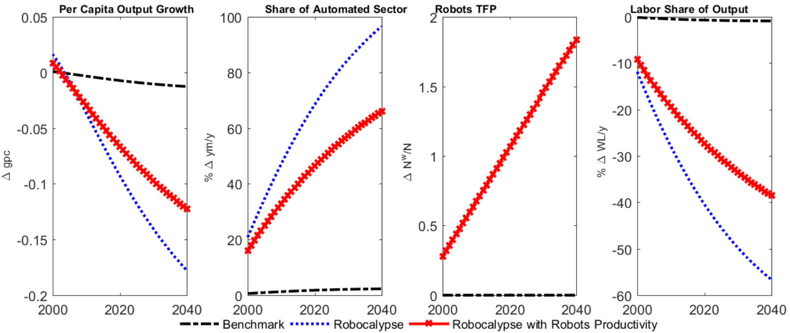


Figure: Demographic Transition: Robots vs Labour

Concluding Remarks

- Implications of demographic changes:
  - Demographics and Technological change interact but automation does not seem to offset the headwind
  - As more workers move away from production and towards R&D, effects are mitigate, but are ideas harder to get, are newcomers as productive?
  - How robots and productivity are related. How gains in automation offset decrease in product creation?

- Macro modelling of technological changes:
  - Too many uncertainties on both the production and the use of "robots".
  - We may need to substantially revise the current paradigm about the economic implications of technological change.

Concluding Remarks II

- Policy responses:
  - Given the impact of fertility changes delaying retirement age improves but is not very effective.
  - Developing skills that complement, rather than substitute, robotics and artificial intelligence
  - Redistribution
    - Through taxation and transfers
    - Ownership of capital. Richard Freeman (2015): "*Who owns the robots rules the world*"

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Households' Problem

- Agent j of age $z = \{w, r\}$ chooses consumption and financial assets

$$\max_{c^i_{z,t},\, FA^i_{z,t+1}} v^i_{z,t} = \left\{ \left(c^i_{z,t}\right)^\eta + \beta \mathbb{E}_t[v^i_{z',t+1} \mid z]^\eta \right\}^{1/\eta}$$

$$s.t. \quad c^i_{z,t} + FA^i_{z,t+1} = \frac{R_t}{1 - \mathbb{I}_{\{z=r\}}(1-\omega_r)} FA^i_{z,t} + \left[1 - \mathbb{I}_{\{z=r\}}\right] W_t l^i_{z,t} + d^i_{z,t}$$

- After aggregation, the key conditions are the consumption functions of workers and retirees

$$c_{w,t} = \varsigma_t [R_t FA_{w,t} + H_{w,t} + D_{w,t}] \quad \text{and} \tag{1}$$

$$c_{r,t} = \varepsilon_t \varsigma_t [R_t FA_{r,t} + D_{r,t}], \tag{2}$$

$H_{w,t}$ is the present value of labour gains, $D_{z,t}$ is the present value of dividends for $z = \{w, r\}$. ς_t is the marginal propensity of consumption of workers and $\varepsilon_t \varsigma_t$ the one for retirees. These are function of population dynamics, interest rates and preferences.

Go back

Detail - Innovation

Owning the rights of a variety/taks allows investors to charge a fraction ϑ of the profits of the intermediate good firm who produces that variety/task and thus the value of an invented variety J_t is given by

$$J_t = \vartheta \Pi_{i,t} + (R_{t+1})^{-1} \phi E_t J_{t+1}, \text{ for } i \in Z_t \setminus A_t \tag{3}$$

where $\Pi_{i,t}$ for $i \in Z_t \setminus A_t$ is the profit of the intermediate good firm producing the newly created variety.

The innovator p will then invest $IS_{p,t} = (S_{p,t})^{\kappa_{RD}} (L_{I,p,t})^{\kappa_L}$ until the marginal cost equates the expected gain. Defining $\tau_{S,t}$ as the shadow price of $IS_{p,t}$, we have that

$$\begin{aligned} \phi E[J_{t+1}] &= \frac{R_{t+1} \tau_{S,t}}{\varphi_t}, && (4) \\ S_{p,t} &= IS_{p,t} \tau_{S,t} \kappa_{RD} && (5) \\ L_{I,p,t} W_{RD,t} &= IS_{p,t} \tau_{S,t} \kappa_L && (6) \end{aligned}$$

Go back

Detail - Automation

The problem for the automation investors is

$$\max_{\Xi_{q,A,t},\Xi_{q,t},L_{A,q,t}} -\tau_{A,t}\Xi_{q,A,t} + (R_{t+1})^{-1}\phi E_t[\lambda_t V_{t+1} + (1-\lambda_t)J_{t+1}]. \qquad (7)$$

where, $\tau_{A,t}$ is the shadow price of $\Xi_{q,A,t}$.
Assuming the elasticity of λ_t to changes in its input is constant, thus $\epsilon_\lambda = \frac{\lambda'}{\lambda_t}\frac{(Z_t^q - A_t^q)^{\kappa_{RD}+\kappa_L}\Xi_{q,A,t}}{\tilde{\Psi}_t^{\kappa_{RD}} N_t^{\kappa_L}}$, then we obtain

$$\begin{aligned} \Xi_{q,t} &= \epsilon_\lambda \lambda_t R_t^{-1}\phi[V_{t+1} - J_{t+1}] && (8) \\ L_{A,q,t} W_{RD,t} &= \Xi_{q,t}\frac{\kappa_L}{\kappa_{RD}} && (9) \end{aligned}$$

Go back