Baseline Model for FRAME:
A Framework to Study the Macroeconomic Effects of Innovation Policies

Mid-term Conference

Diego Comin
CEPR

Mario Giarda
UPF

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Europe's expenditure in R&D (2016):

2% of GDP

Private: 1.32%; government: 0.22%; higher education: 0.46%.[1]

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H2020 Goal:

3% of GDP

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H2020 Goal:

3% of GDP

We propose a model to study:

- Policies to achieve this goal.
- Their impact on the economy.

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- We follow Anzoátegui et al. (2015) and Comin and Gertler (2006)

  ⋆ Neo-keynesian DSGE with endogenous growth in the form of **technology development** (R&D) and its **adoption** in the production process.

  ⋆ **Technology takes time** to diffuse into the economy. See Comin and Mestieri (2014).

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  ⋆ **Technology takes time** to diffuse into the economy. See Comin and Mestieri (2014).
- We include a **government** that is part of the technological process.
- In our model, policies can be **centralized** or **decentralized**.
- We find:
  - The government is able to stimulate R&D.
  - But is subject to two trade-offs: **time horizon** and **financing**.

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- New Keynesian DSGE model similar to Christiano et al. (2005) and Smets and Wouters (2007). We include:
  - Habit formation in consumption. Investment adjustment costs. Variable capital utilization.
  - “Calvo" price and wage rigidities. Monetary policy that obeys a Taylor rule.
  - Households provide skilled and unskilled labor.

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Sketch of The Model

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- In the Technology process, TFP depends on two endogenous variables:
  - The creation of new technologies via R&D, Z_t.
  - The diffusion of these new technologies, A_t.

    ⋆ Skilled labor L_{st} is used as input in technological activities.

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    - The diffusion of these new technologies, A_t.
        - ⋆ Skilled labor L_{st} is used as input in technological activities.

- We consider as Innovation Policies:
    - Subsidies/taxes on innovation, τ^s_{rt}.
    - Direct public investment in R&D, L_{purt}.
    - Direct public investment in Adoption, L_{puat}.

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Final GDP and Total productivity

- Aggregate output is a composite of a continuum mass one of final goods i:

$$Y_t = \left(\int_0^1 (Y_t^i)^{\frac{1}{\mu_t}} di \right)^{\mu_t}, \text{ where } Y_t^i = Y_{mt}^i \tag{1}$$

where $\mu_t > 1$ is given exogenously. Y_{mt}^i are units of intermediate goods composite.

$\star$ We assume each firm sets its nominal price P_t^i on a staggered basis with Calvo price adjustment.

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- The intermediate goods composite is the following CES aggregate of individual intermediate goods:

$$Y_{mt} = \left(\int_0^{A_t} (Y_{mt}^j)^{\frac{1}{\vartheta}} dj \right)^{\vartheta} \tag{2}$$

with $\vartheta > 1$.

$\star$ **Technological progress in production** is the expansion of the number of intermediates A_t the economy is able to absorb (Romer, 1990).

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Final GDP and Total productivity

- Each final good m is produced with

$$Y_{mt}^{j} = \theta_t \left(U_t^j K_t^j\right)^{\alpha} \left(L_t^j\right)^{1-\alpha} \tag{3}$$

$\star$ Up to a first order approximation and symmetry, we get $Y_t = Y_{mt}$.

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- Symmetric equilibrium in intermediates m implies

$$Y_t = \left[A_t^{\vartheta-1}\theta_t\right] \cdot \left(U_t K_t\right)^{\alpha} \left(L_t\right)^{1-\alpha} \tag{4}$$

⋆ Total productivity is composed by two elements:

θ_t: exogenous "conventional" technology shock.
$A_t^{\vartheta-1}$: endogenous technology component.

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- The number of new technologies follow

$$\varphi_t = \chi_t Z_t L_{srt}^{\rho_z - 1} L_{purt}^{\gamma_z}$$

$0 < \rho_z < 1$: private R&D elasticity.

$0 < \gamma_z < 1$: public R&D elasticity.

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$0 < \rho_z < 1$: private R&D elasticity.
$0 < \gamma_z < 1$: public R&D elasticity.

- There is a continuum of inventors $p \in [0, 1]$, that maximize the value of a patent:

$$\max_{L_{srt}^p} E_t\{\Lambda_{t,t+1} J_{t+1} \varphi_t L_{srt}^p\} - (1 - \tau_{rt}^s) w_{st} L_{srt}^p,$$

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- Free entry condition:

$$E_t\{\Lambda_{t,t+1} J_{t+1} \chi_t Z_t L_{srt}^{\rho_z - 1} L_{purt}^{\gamma_z}\} = (1 - \tau_{rt}^s) w_{st} \quad (5)$$

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We allow for obsolescence of technologies, ϕ is survival rate for any given technology.

The evolution of technologies is:

$$Z_{t+1} = \underbrace{\varphi_t L_{srt}}_{\text{Creation}} + \underbrace{\phi Z_t}_{\text{Survival}} \tag{6}$$

$$\frac{Z_{t+1}}{Z_t} = \chi_t L_{srt}^{\rho_z} L_{purt}^{\gamma_z} + \phi \tag{7}$$

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- There is a group of adopters that take technologies and convert them into ones that can be used in production.

  Probability of adopting a technology:

$$\lambda_t = \bar{\lambda}_0 * (Z_t L_{sat})^{\rho_a} * \left(1 + \bar{\lambda}_{pu} * (Z_t L_{puat})^{\gamma_a}\right) \quad (8)$$

  $0 < \rho_a < 1$: private Adoption elasticity.

  $0 < \gamma_a < 1$: public Adoption elasticity.

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- Let V_t be the price of the technology, that follows

$$V_t = \Pi_{mt} + \phi E_t\{\Lambda_{t,t+1} V_{t+1}\} \tag{9}$$

- Adopter's problem:

$$J_t = \max_{L_{sat}} E_t\{-w_{st} L_{sat} + \phi \Lambda_{t,t+1}[\lambda_t V_{t+1} + (1 - \lambda_t) J_{t+1}]\}$$

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- The first order condition for L_{sat} is

$$Z_t \lambda' \phi E_t \{ \Lambda_{t,t+1} [V_{t+1} - J_{t+1}] \} = w_{st} \tag{10}$$

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$\star$ $V_t - J_t$ is pro-cyclical. This plus the stickiness in w_{st} and $\lambda' < 0$, implies that L_{sat} varies pro-cyclically.

Then λ_t varies pro-cyclically.

Making A_t to be pro-cyclical too.

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Making A_t to be pro-cyclical too.

- Aggregating the adopters we get the aggregate law of motion of difussion:

$$A_{t+1} = \underbrace{\lambda_t \phi [Z_t - A_t]}_{\text{New adoption}} + \underbrace{\phi A_t}_{\text{Survival}} \tag{11}$$

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Parameter	Description	Value
α	Capital share	$1/3$
δ	Capital depreciation	0.02
β	Discount factor	0.995
φ	Inv. Frisch elasticity	3.381
$\frac{G}{Y}$	SS govt. consumption/output	0.2
γ_y	SS output growth	1.87%
μ	SS final goods mark-up	1.1
μ_w	SS wage mark-up	1.87%
ϑ	Intermediate goods mark-up	1.35
$1-\phi$	Obsolescence rate	0.08/4
$\bar{\lambda}$	SS adoption lag	0.15/4
ρ_λ	Private adoption elasticity	0.95
ρ_z	Private R&D elasticity	0.39
ρ	Taylor rule smoothing	0.805
ϕ_π	Taylor rule inflation	1.571
ϕ_y	Taylor rule labor	0.47
f''	Investment adj. cost	1.386
$\frac{\delta'(U)}{\delta}$	Capital utiliz. Elast.	3.868
ξ_p	Calvo prices	0.927
ξ_w	Calvo wages	0.87
ι_p	Price indexation	0.276
ι_w	Wage indexation	0.338
b	Consumption habit	0.389

Table 1 : Calibration.

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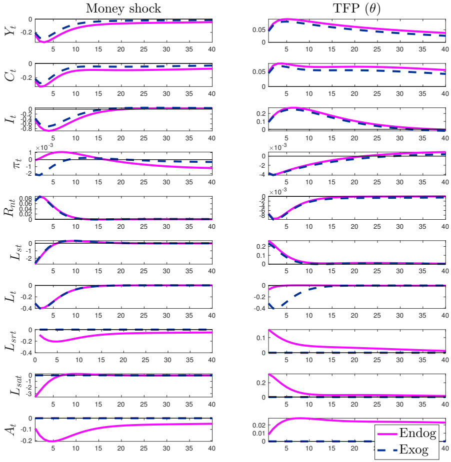
Monetary policy and exogenous TFP (θ_t) shocks



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We consider two ways by which government finances its policies:

- Lump-sum taxes T_t:

$$G_t + w_{st}(L_{purt} + L_{puat}) + w_{st}(\tau^s_{rt} L_{srt} + \tau^s_{at} L_{sat}) = T_t \tag{12}$$

- Distortionary taxes:

$$G_t + w_{st}(L_{purt} + L_{puat}) + w_{st}(\tau^s_{rt} L_{srt} + \tau^s_{at} L_{sat}) = \tau^l_t (w_t L_t + w_{st} L_{st}) \tag{13}$$

Policies $\mathcal{X}_t \in \{G_t, L_{purt}, L_{puat}, \tau^s_{rt}, \tau^s_{at}\}$ follow:

$$\log(\mathcal{X}_t/(1+\gamma_y)^t) = (1-\rho_{\mathcal{X}})\bar{\mathcal{X}} + \rho_{\mathcal{X}} \log(\mathcal{X}_{t-1}/(1+\gamma_y)^{t-1}) + \epsilon^{\mathcal{X}}_t \tag{14}$$

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Calibration

Parameter	Description	Value
$\overline{\lambda}_{pu}$	SS public adoption lag	0.2
$\rho_{\lambda_{pu}}$	Public adoption elasticity	0.7
γ	Public R&D elasticity	0.3
ρ_{lr}	Persistence in Pub Inv in Adoption	0.9
ρ_{la}	Persistence in Pub Inv in R&D	0.9
ρ_{κ_r}	Persistence Pub subsidies in Adoption	0.9
ρ_{κ_a}	Persistence Pub subsidies in R&D	0.9
σ_{lr}	Pub Inv in Adoption	0.01
σ_{la}	Pub Inv in R&D	0.01
σ_{κ_r}	Pub subsidies in Adoption	0.01
σ_{κ_a}	Pub subsidies in R&D	0.01
$G/Earnings$	SS gov spending share	0.8
$L_{spua}/Earnings$	SS adoption inv share	0.05
$L_{spur}/Earnings$	SS R&D inv share	0.05
$\kappa_a/Earnings$	SS adoption subsidy share	0.05
$\kappa_r/Earnings$	SS R&D subsidy share	0.05

Table 2 : Calibration of government parameters.

Calibration 2

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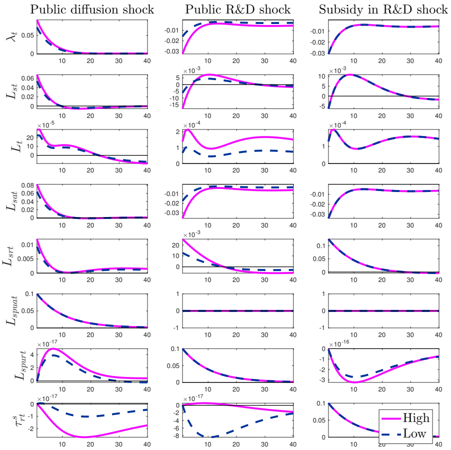
The effect of innovation policies: lump-sum taxes (1/2)



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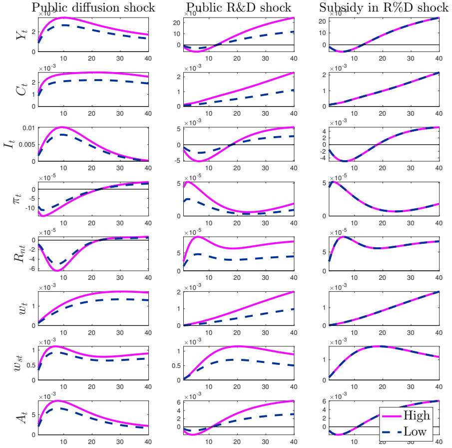
The effect of innovation policies: lump-sum taxes (2/2)



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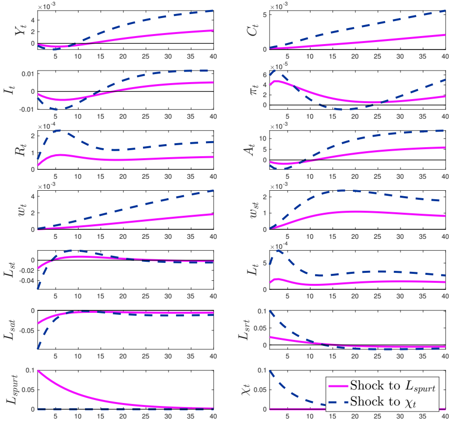
Shock χ_t



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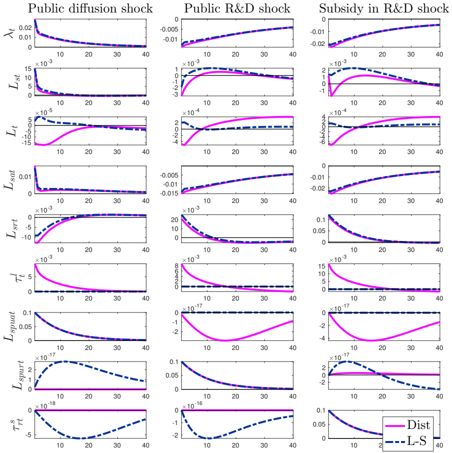
The effect of innovation policies: distortionary taxes & low rigidities (1/2)



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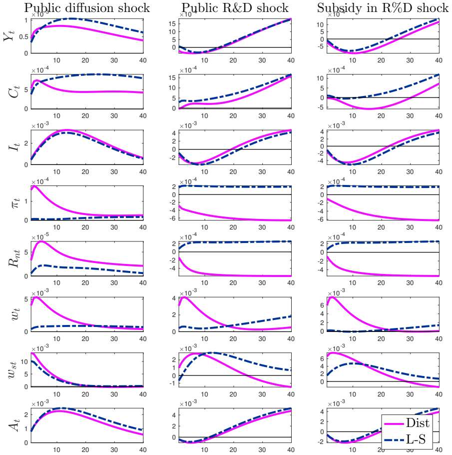
The effect of innovation policies: distortionary taxes & low rigidities (2/2)



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Extension: a model with Endogenous Human Capital Accumulation

- We include endogenous human capital accumulation, h_t and education e_t in a model without nominal rigidities.
- The representative household now solves also

$$\max_{L_t, e_t, h_{t+1}} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left\{ \frac{\upsilon_s (1 - L_{t+\tau} - e_{t+\tau})^{1-\kappa}}{1-\kappa} \right\} \tag{15}$$

subject to

$$0 = (1 - \tau_t^l) w_t L_t h_t - \frac{P_t^e}{P_t} (1 - \tau_t^e) e_{st} \tag{16}$$

and

$$h_t = \Lambda_{t-1} e_{t-1} + (1 - \delta_h(Z_t)) h_{t-1}. \tag{17}$$

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Extension: a model with Endogenous Human Capital Accumulation

- We include endogenous human capital accumulation, h_t and education e_t in a model without nominal rigidities.
- That gives rise to

$$h_{t+1}: \quad \gamma_t = (1-\tau_t^l)w_t L_t + E_t\left(M_{t,t+1}\gamma_{t+1}(1-\delta_h(Z_{t+1}))\right), \tag{18}$$

$$e_t: \quad \frac{\nu(1-L_t-e_t)^{-\kappa}}{\mu_t} + p_t^e(1-\tau_t^e) = E_t\left(M_{t,t+1}\gamma_{t+1}\Lambda_t\right), \tag{19}$$

$$L_t: \quad \nu(1-L_t-e_t)^{-\kappa} = \mu_t(1-\tau_t^l)w_t h_t, \tag{20}$$

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$$L_t: \quad \nu(1-L_t-e_t)^{-\kappa} = \mu_t (1-\tau_t^l) w_t h_t, \tag{20}$$

- Also, given that $H_t = h_t L_t$:

$$H_t = (Z_t - A_t)(H_{at} + H_{puat}) + H_{rt} + H_{purt} + H_{yt} \tag{21}$$

$$\begin{aligned} Y_t &= \left[A_t^{\vartheta-1} \theta_t \right] (U_t K_t)^{\alpha} H_{yt}^{1-\alpha} \\ &= \left[A_t^{\vartheta-1} h_t^{1-\alpha} \theta_t \right] (U_t K_t)^{\alpha} L_{yt}^{1-\alpha} \end{aligned} \tag{22}$$

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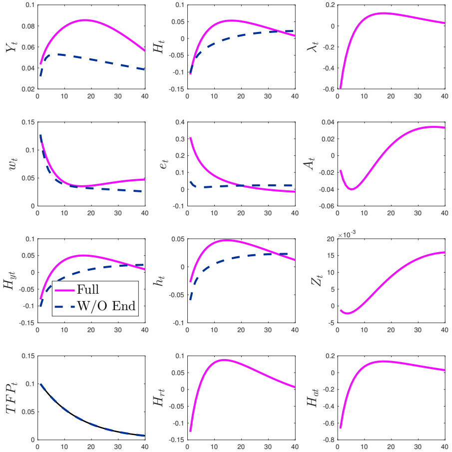
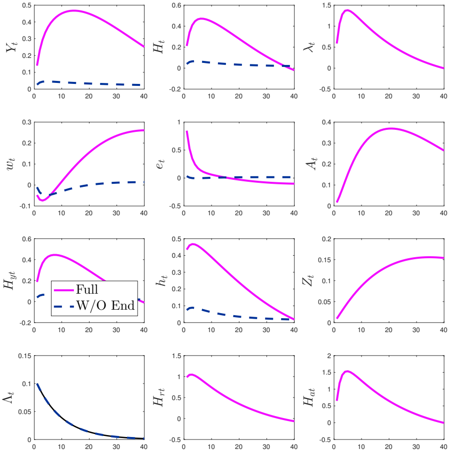
Endogenous human capital: TFP shock



Endogenous human capital: a Λ_t shock



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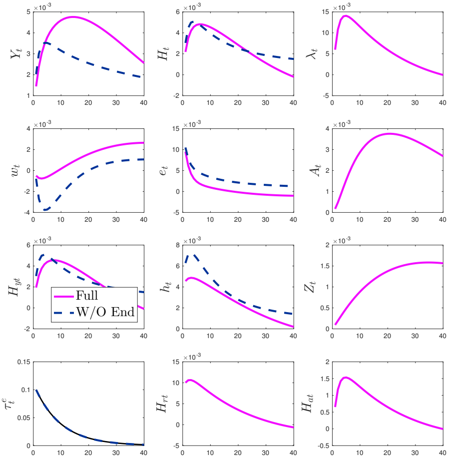
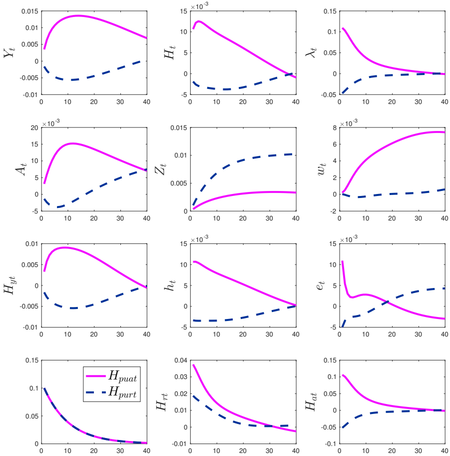
Endogenous human capital: a τ_t^e shock



Endogenous human capital: public investment shocks



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Conclusion

- We follow Anzoátegui et al. (2015) and Comin and Gertler (2006) by including an active role of government policies in the process of R&D and adoption of technologies.
- We include direct public innovation investment, and innovation subsidies.
- And analyze their effects along with the way they are financed in order to get an intuition of their impact in general equilibrium as well.

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- We include direct public innovation investment, and innovation subsidies.
- And analyze their effects along with the way they are financed in order to get an intuition of their impact in general equilibrium as well.
- We find:
  - Public innovation expands the economy in the medium term. Can work as a substitute to private innovation.
  - Its effects on the economy depend crucially on some parameters, in particular those related with labor markets.
  - For instance, a great degree of wage rigidities hides the aggregate trade-offs generated by labor tax raises.

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Conclusion: human capital extension

- We follow Anzoátegui et al. (2015) and Comin and Gertler (2006) by including an active role of government policies in the process of R&D and adoption of technologies.
- We include education and human capital accumulation decision. Adding subsidies to education and policies that improve educational quality.
- Also, direct public innovation investment, and innovation subsidies.

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- We include education and human capital accumulation decision. Adding subsidies to education and policies that improve educational quality.
- Also, direct public innovation investment, and innovation subsidies.
- We find:
  - Human capital accumulation interact with endogenous growth. Amplification effect.
  - In this setup policies to enhance human capital improve technology as well.

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Calibration

Parameter	Description	Value
ρ_θ	TFP	0.91
ρ_{pk}	Investment	0.87
ρ_ϱ	Liquidity demand	0.91
ρ_{mp}	Monetary	0.57
ρ_μ	Mark-up	0.38
ρ_g	Govt. expenditures	0.99
ρ_{μ_w}	Wage mark-up	0.26
ρ_χ	R&D	0.84
σ_θ	TFP	0.51
σ_{pk}	Investment	0.74
σ_ϱ	Liquidity demand	0.23
σ_{mp}	Monetary	0.1
σ_μ	Mark-up	0.1
σ_g	Govt. expenditures	2.87
σ_{μ_w}	Wage mark-up	0.3
σ_χ	R&D	2.13

Table 3 : Calibration of stochastic processes.

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