The role of finance in environmental innovation diffusion: an evolutionary modeling approach

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OeNB Summer School 2020
The Economics of Climate Change: a Central Bank Perspective

Introduction

P. D'Orazio and M. Valente, (2019) ***The role of finance in environmental innovation diffusion: An evolutionary modeling approach***, *Journal of Economic Behavior and Organization*, pp. 417-439, vol. 162 (Link)

Aim of the research

- Address the issue of financial constraints as a relevant barrier to eco-innovation diffusion
- Address the *green finance gap* and understand how it is related to (environmental) technological progress
- Study the role of public-private partnership through the action of a state investment bank (subsidiarity principle)

Contributions

- Literature on environmental innovation-(green)finance nexus
- Several evolutionary models that study the role of demand for market dynamics;
  - Few ABM studies take into account the interaction among the demand side, the supply side and its innovation dynamics, and the **financial side** (See, e.g., Vitali et al., 2013; Caiani et al., 2014; Fagiolo et al., 2017; Lauretta, 2018);
  - Existing literature lacks models that address the importance of **climate finance** aimed at fostering green technologies for a sustainable economic transition.
- Policy applications of ABMs: Implementation and analyses of green finance in ABM

Environmental concerns and policies

COP21 goals

strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2°C

What should be done to achieve the goals?

According to COP21 agreement:

- *Gather appropriate financial flows* (Art. 2, point c)
- Set up a new technology framework
- Develop an enhanced capacity building at global level

Barriers to eco-innovation diffusion

- The implementation of ***adaptation and mitigation policies*** is based on the development of **green technologies** whose diffusion is constrained by a number of "**barriers**", i.e., costs, markets, knowledge, finance (D'Este et al., 2012)
- **Green innovation** is inherently different from other types of innovation processes: ***double-externality feature*** (Rennings, 2000).

Factors affecting financial barriers

Features of the post-crisis financial framework:

- *Low willingness by banks to lend, especially long-term (green)*
  → ***short-termism*** (Haldane, 2011)
  → The availability of ***financial capital for green investments*** is relevant especially for Europe, whose economy is significantly more dependent on bank intermediation than other economies (see Beck and Demirguc-Kunt, 2006; Ayyagari et al., 2007; Hernández-Cánovas and Martínez-Solano, 2010; Namara et al., 2017, among others).
- *Financial instability*
  → affects investments' dynamics especially at the level of **small and medium firms**

The green finance gap

The resulting ***"green finance gap"***, i.e. *the lack of sufficient financial resources to be directed towards green investments*, is particularly relevant for the transition towards a low-carbon economy

Methodology

Our ABM model study

ABM approach allows us to:

- study the complex patterns emerging from the interaction of **consumer preferences** and firms' **technology**;
- incorporate heterogeneity and **bounded rationality** of interacting individual decision-makers;
- incorporate different **institutional settings** and conduct scenario analyses;
- include interactions in the **financial market**;
- study **complex technology adoption and diffusion dynamics**.

Definition

An agent-based model is a computerized simulation of a number of decision-makers (agents) and institutions, which interact through prescribed rules.
The agents can be as diverse as needed - from consumers to policy-makers and Wall Street professionals - and the institutional structure can include everything from banks to the government.
Such models do not rely on the assumption that the economy will move towards a predetermined equilibrium state, as other models do.
Instead, at any given time, each agent acts according to its current situation, the state of the world around it and the rules governing its behaviour.
(Farmer and Foley, 2009, p.685)

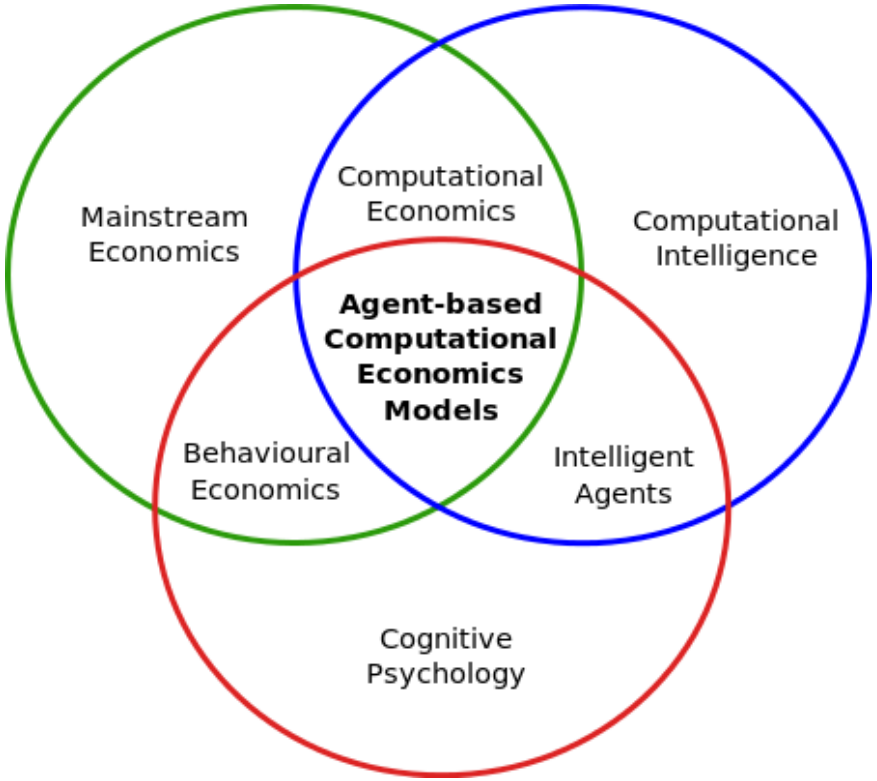
The economy as a complex system

- several stationary states ("***multi-stability***"), and the resulting outcome may depend on the previous history (such as the size of occurring perturbations, the initial state , etc., and such history-dependencies are often called hysteresis effect)
- "***out of equilibrium***" and behave in non-stationary ways.
- "***self-organization***": periodic or non-periodic oscillations, "chaotic" or "turbulent" behavior
- new, "***emergent***" properties, which cannot be understood from the properties of their system elements ("*the system is more than the sum of its parts*")
- many of the above features are results of strong interactions which can often lead to counter-intuitive (vs deterministic) behaviors.

Comparison of methodologies

	Equilibrium approach	**Agent-based approach**
Agents	1,2 or ∞ fully rational optimizing no history	N large but finite simple entities sophisticated learning adaptive behaviors
Interactions	frictions	local interactions path dependency
Time	Timeless	Timely
Heterogeneity	Homogeneous Possibly heterogeneous, but diversity does not matter	Persistently heterogeneous: diversity matters
System behavior	Optimizing: only equilibrium states count	Adaptive equilibria possibly irrelevant emergent (self-organized) properties

Cross-Fertilisation of approaches



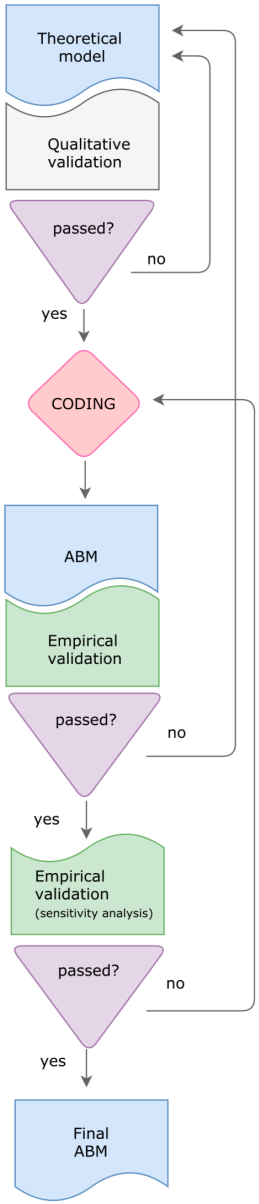


Figure: Source: D'Orazio (2017)

Critiques and ways out

Main critiques

1. ABMs are "black boxes"
2. Too many degrees of freedom: ad-hoc assumptions regarding behavioral rules
3. Validation: poor link with data

Ways out

1. Use of ODD protocols (Overview, Design concepts and details); promote reproducibility; use of UML (Unified Modeling Language); counterfactual analysis and sensitivity analysis; use of "modeling principles" (see Tesfatsion, 2017)
2. Use empirical and experimental evidence (strong link with behavioral economics), important potential link with big data (D'Orazio, 2017)
3. Recent research developments: simulated minimum distance methods, machine learning techniques, data-driven identification in VAR models (see Fagiolo et al., 2007, 2019, for a comprehensive review)

Features of the ABM

The model

- The **production sector** is populated by heterogeneous firms that compete in the market and receive **goods' demand** from the consumption sector S1
- Firms have the same cost structures, the mark-up is fixed and offer goods that are differentiated along three dimensions (**qualities**)
  - *user quality*: positively evaluated by consumers and represents the performance of the product as used by consumers;
  - *efficiency*: preference of consumers for cheaper products and is computed as a negative function of the price;
  - *environmental quality*: positively evaluated by consumers, and negatively related to the environmental impact caused by the product; S2
- **Product innovation** is the only process that allows firms to improve their competitive position;

- The technological landscape is **constrained**: innovation is used to improve one of the 3 products' characteristics S3B
- Each firm determines its innovation strategy in terms of **probabilities** to engage in specific R&D projects: the probabilities are the **strategic profile** of a company, determining which innovation pattern they are built to follow (Randomly set when the firm enters the market and does not change during its lifetime);
- Once the type of innovation project has been chosen, the firm tries to get a loan to **finance** it;
- *Assumption*: firms (SMEs) resort always to **external credit** in order to finance their innovation strategies; we thus rule out any possibility to resort to other forms of financing or to use a detailed capital structure;

- **Innovation and financing mechanism**
  We account for different behaviors of financial actors:

  a) the *standard commercial bank* lending is pro-cyclical (see Borio et al., 2001; Jim nez et al., 2012, among others);
  The ***provision of loans for innovation purposes*** depends on
  (1) the "*financial soundness*"of the firm proxied by the wealth/revenues ratio: the lower the wealth, the lower the probability to get the loan;
  (2) the *phase of the business cycle*: lower credit in times of economic distress S3A.
  b) the *public investment bank* (SIB) lending is counter-cyclical (Bertay et al., 2015; Micco and Panizza, 2006);
  c) ***subsidiarity principle***: collaborative private-public financial sector: *"contribution" to the commercial bank's "willingness to lend" to green innovation projects*, Pr_l^g;

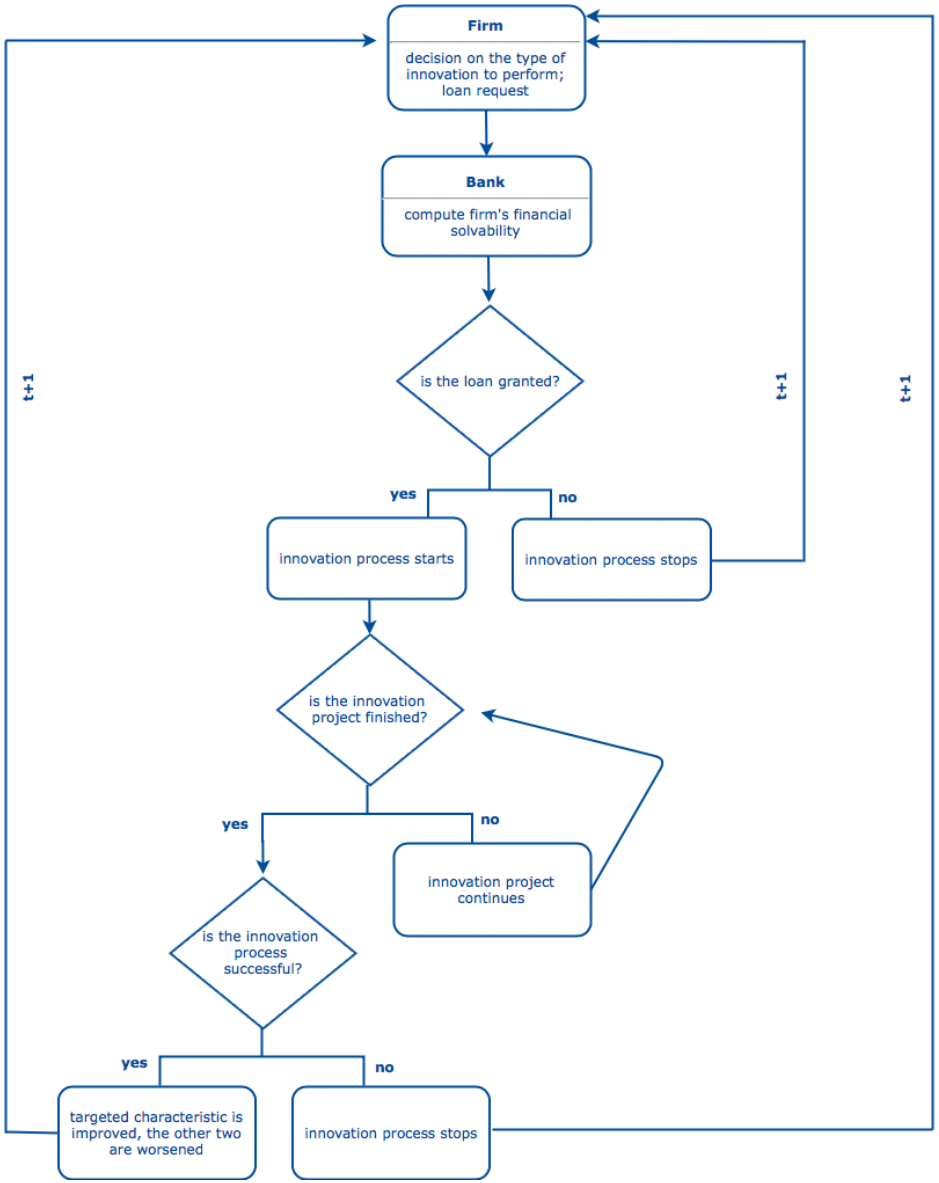


Figure: The financing process

- **Aggregate income levels** depend on the types of innovation performed by firms and by the "type" of finance available in the economy
- Growth rate

$$G^T(t) = [\omega_g \Theta_g(t) + \omega_b \Theta_b(t) - \omega_c \Theta_c(t)] \frac{(G_{max} - G_{min})}{2} + G_{min} \quad (1)$$

  - *environmental innovation* (ω_g +)
  - *product innovation*, i.e., user quality innov (ω_b +)
  - *process innovation*, i.e., efficiency/cost reduction innov (ω_c -)

Validation

Procyclical R&D investments

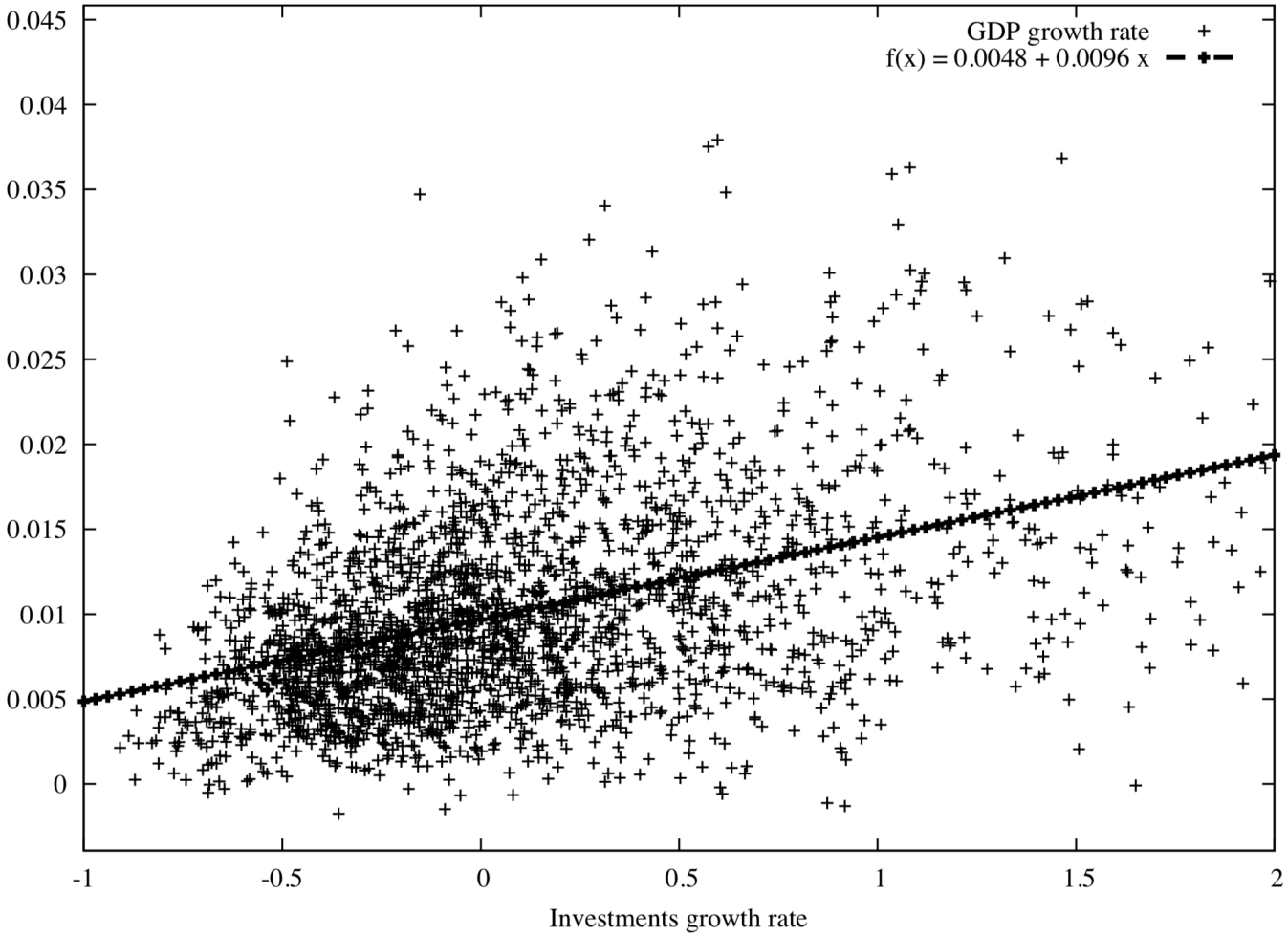


Figure: Total research investments. (Wälde and Woitek, 2004; Aghion and Howitt, 2008)

Firms' size distribution: right skewed

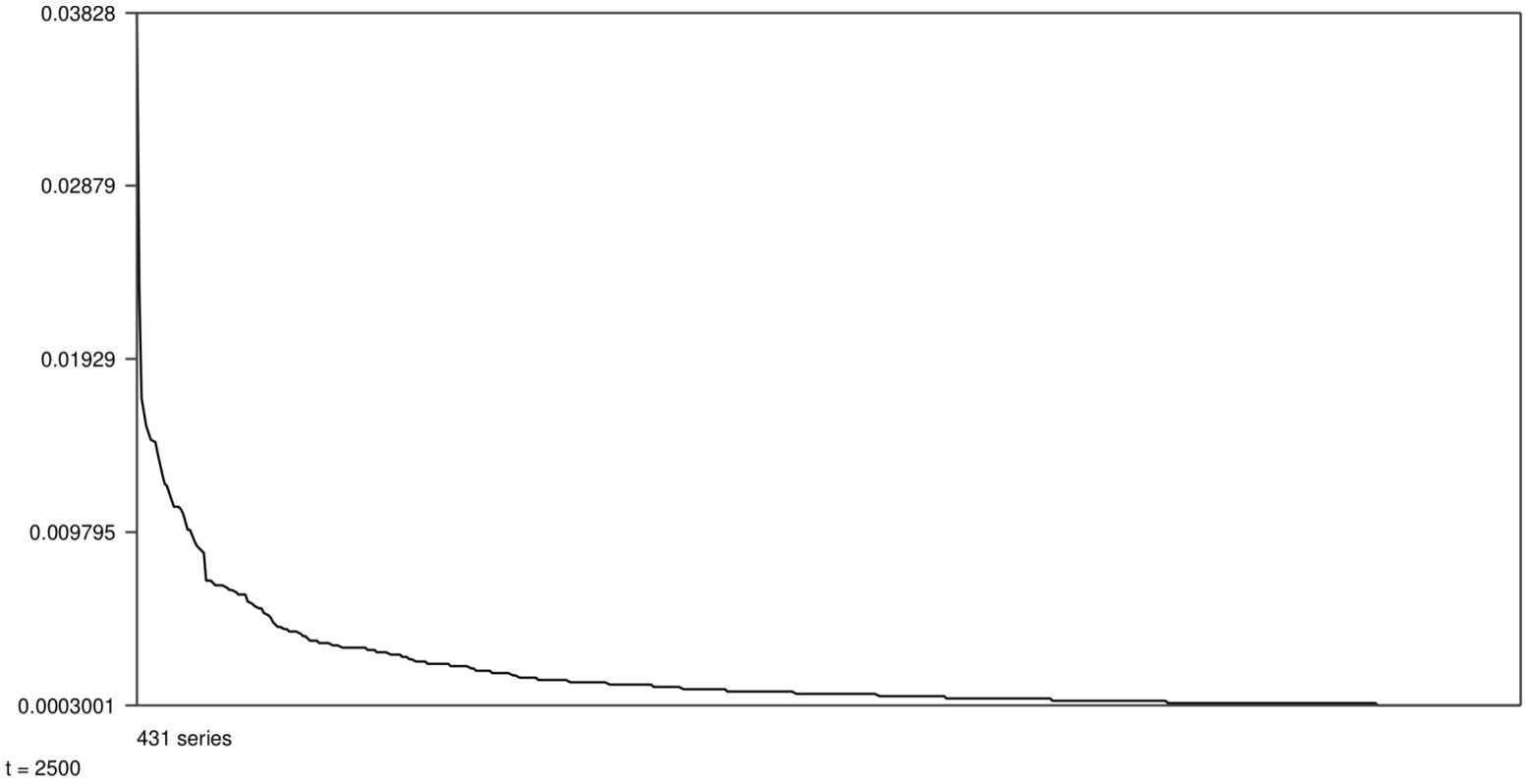


Figure: Market shares distribution measured at the end of a simulation run and limited to firms with a sales above a minimal threshold, comprising roughly 25% of all firms existing at that time. (Kwasnicki, 1998; Axtell, 2001; Gaffeo et al., 2003)

GDP growth rate distribution: fat-tailed

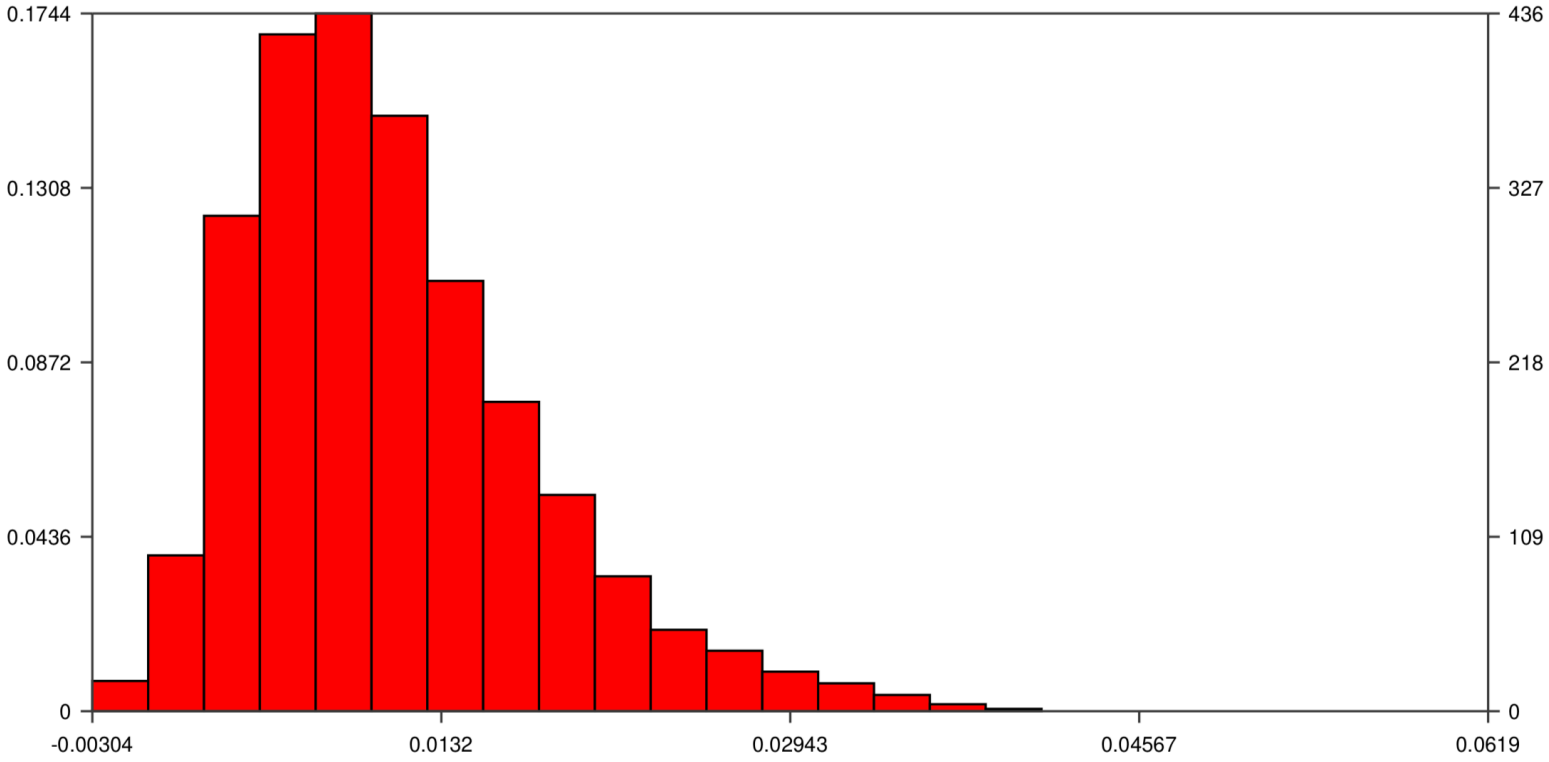


Figure: Frequencies of one-period GDP growth rates. (Fagiolo et al., 2008; Franke, 2015; Williams et al., 2017)

Simulation

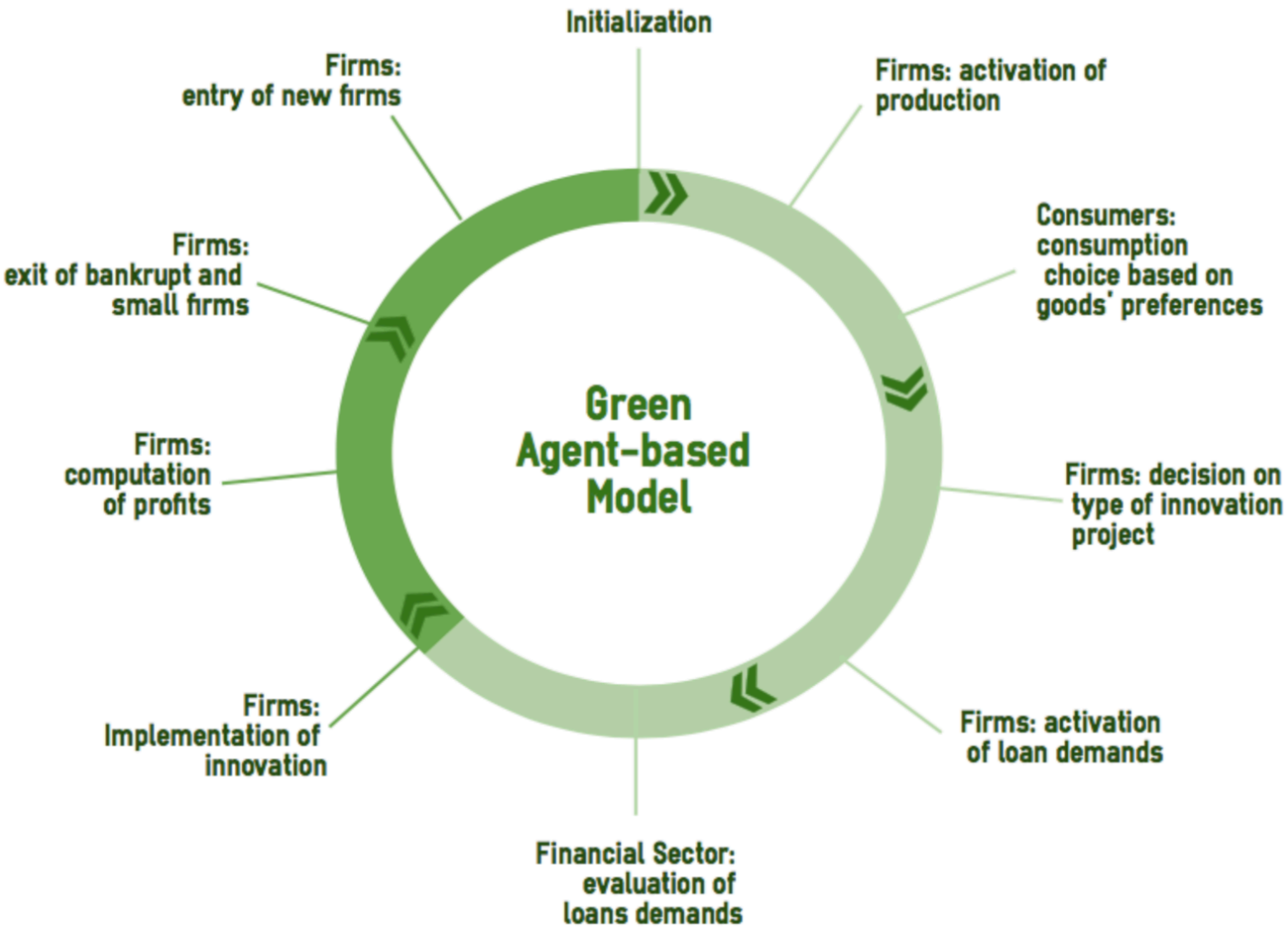


Figure: Sequence of events. Discrete time is represented as a circular flow over which the agents' actions are executed at each time t of the simulation. The initialization is executed only at $t = 0$.

Results

Scenarios

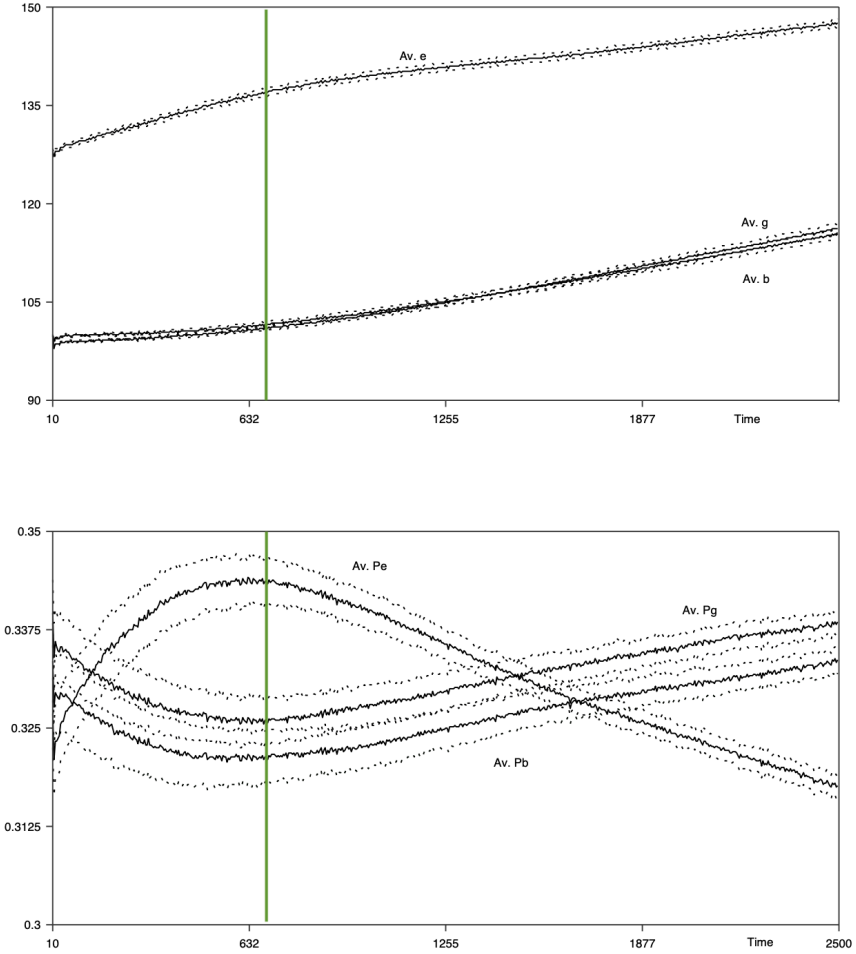
		Scenario	Parametrization	Financial sector	
				Private Bank	SIB
1		***Constant supply***	No entry/exit		
	a.	only user quality	$\lambda_b = 1, \lambda_e = 0, \lambda_g = 0$	✓	
	b.	only green quality	$\lambda_b = 0, \lambda_e = 0, \lambda_g = 1$	✓	
	c.	green & user quality	$\lambda_b = 0.5, \lambda_e = 0, \lambda_g = 0.5$	✓	
2		***Even Preferences***	$\lambda_b = 0.\overline{3}, \lambda_e = 0.\overline{3}, \lambda_g = 0.\overline{3}$		
	a.	Standard financing		✓	
	b.	Extra green financing	$\sigma = 0.2$	✓	✓
3		***Low green preferences***	$\lambda_b = 0.4, \lambda_e = 0.4, \lambda_g = 0.2$		
	a.	Standard financing		✓	
	b.	Extra green financing	$\sigma = 0.2$	✓	✓
4		***Hampered green innovation***	$Pr_l^g = 40\%$		
	a.	Standard financing		✓	
	b.	Extra green financing	$\sigma = 0.2$	✓	✓

Table: Overview of the sensitivity analysis and policy scenarios

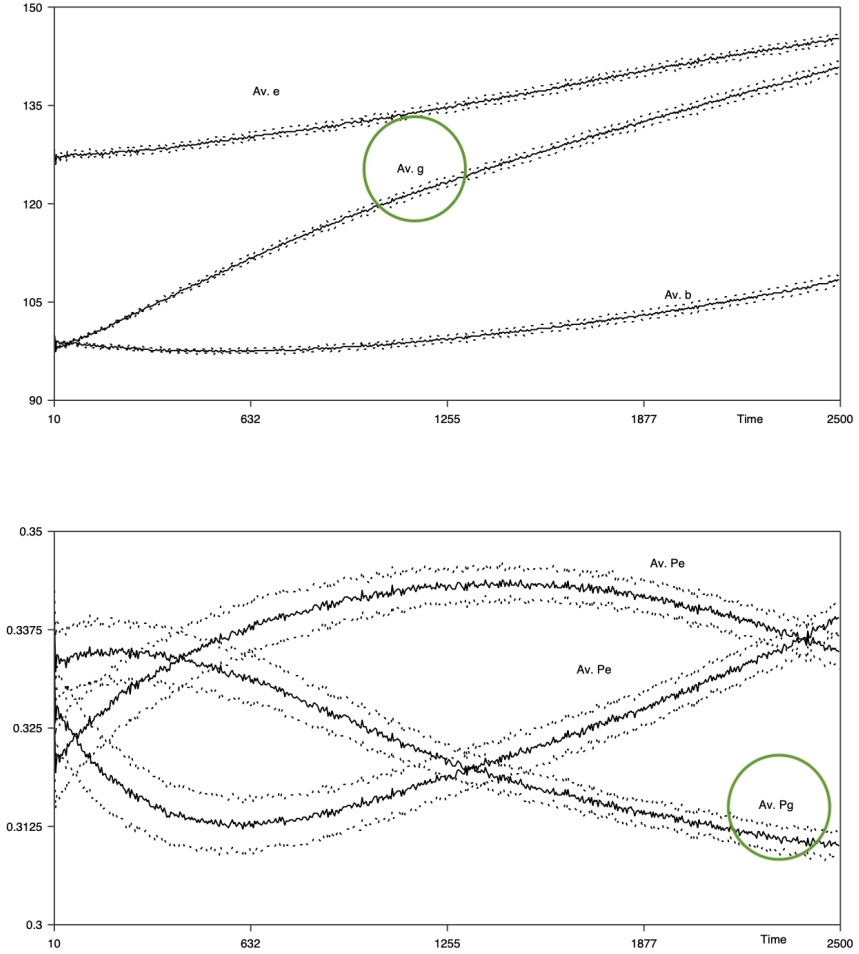
Baseline scenario

- Innovation drives the success of the firm: different demand landscapes reward a different type of firm in each of the 3 preferences cases
- To be successful, a firm has to innovate the product quality most appropriate to the type of consumers in the market

Private bank only



State Investment Bank



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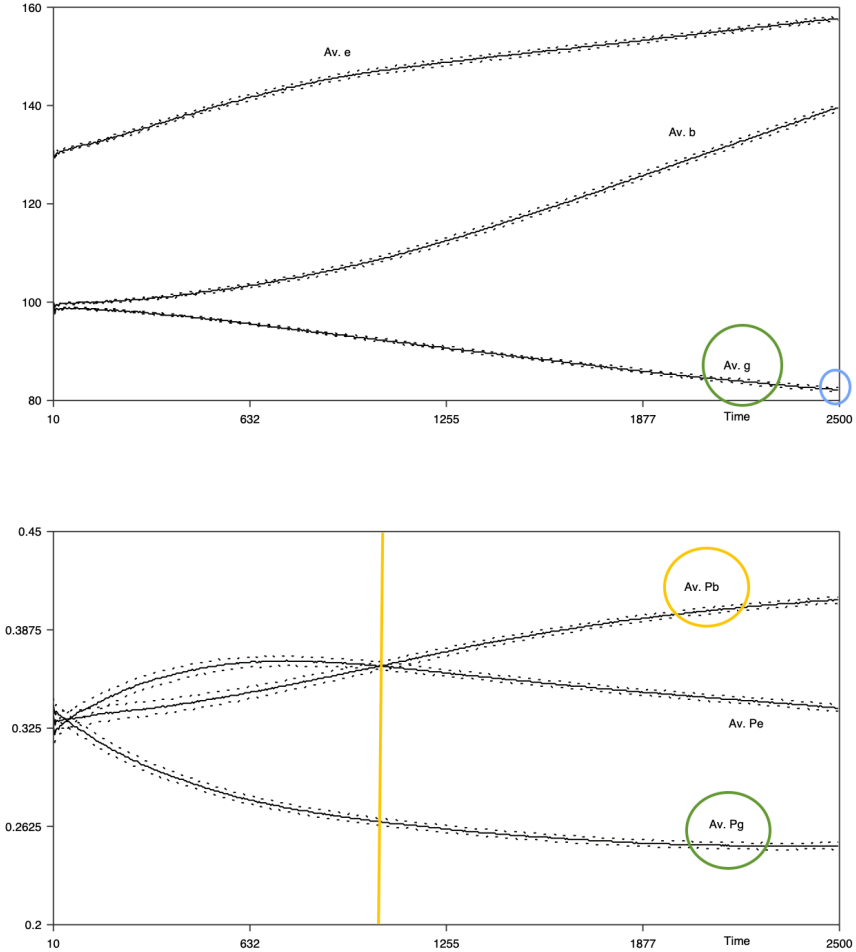

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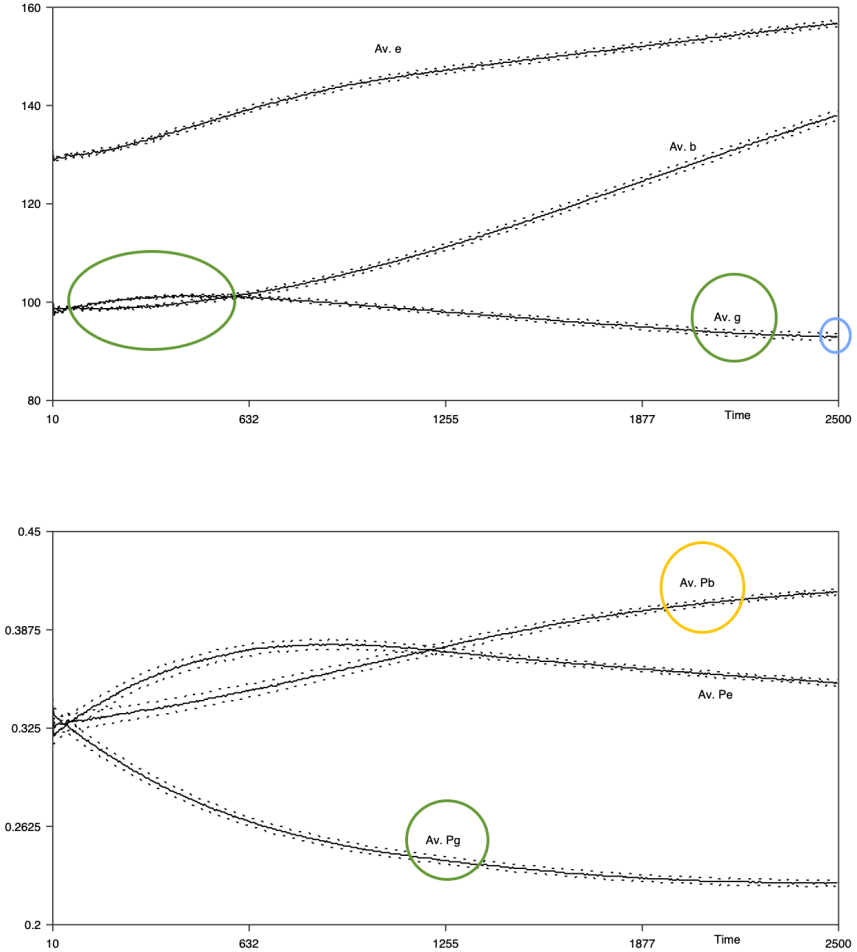

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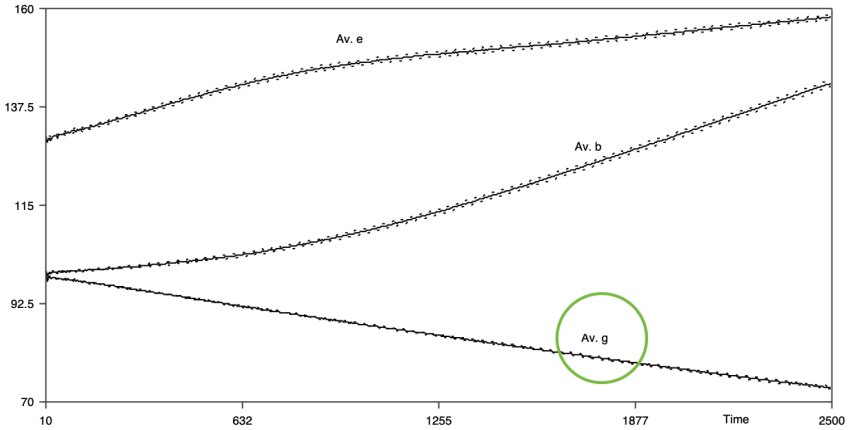
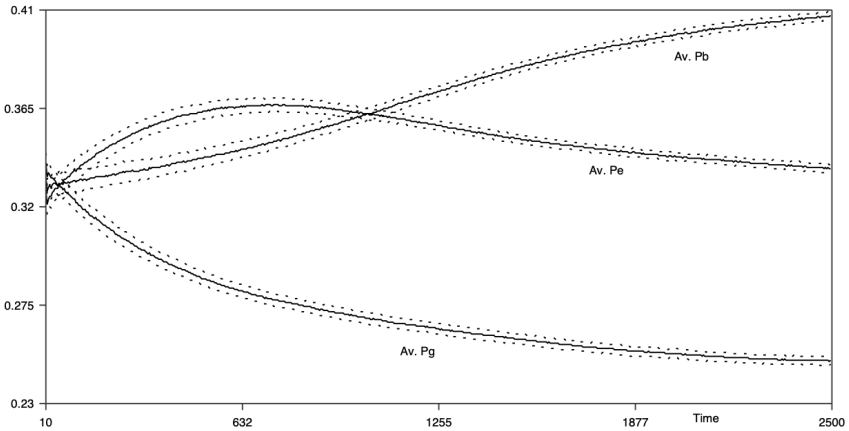
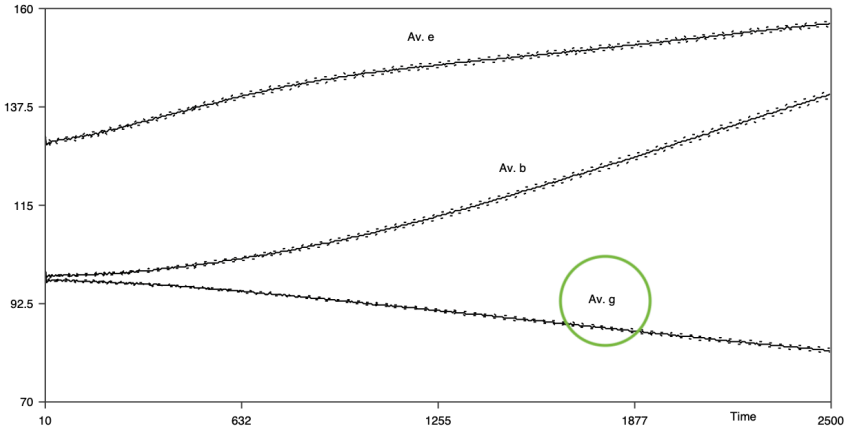
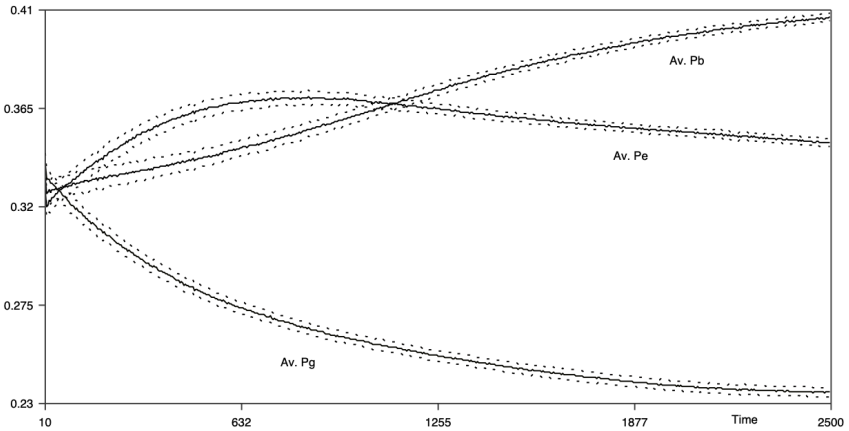




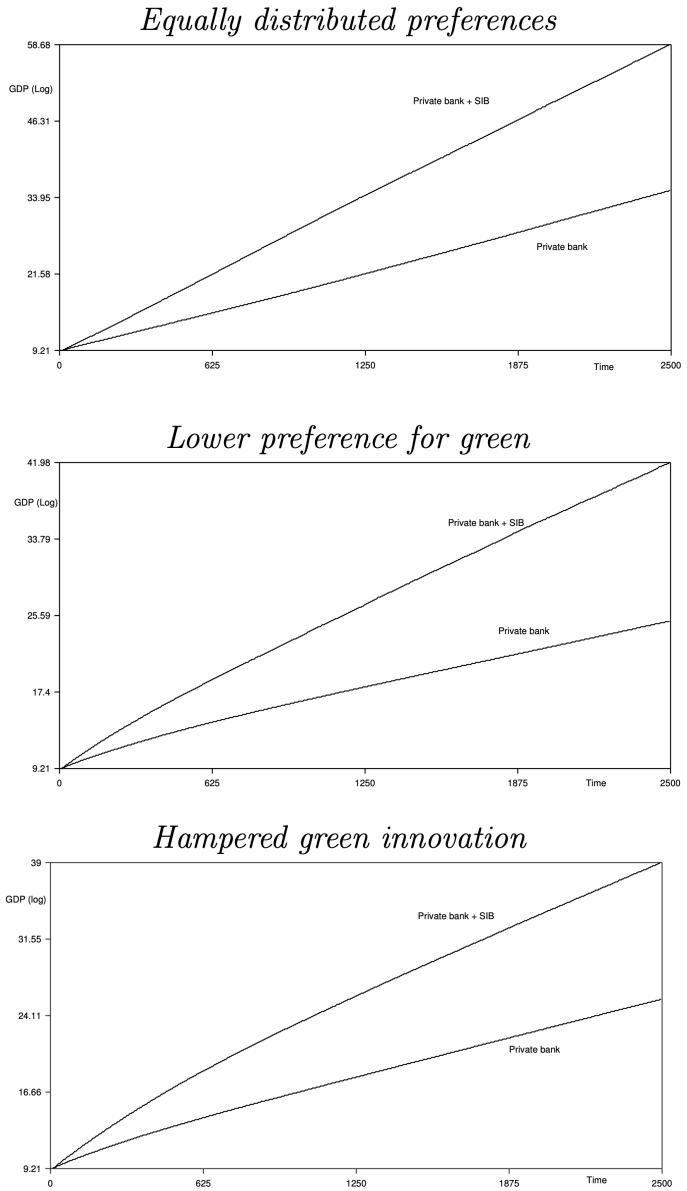
State Investment Bank





Average logGDP values for different scenarios

- **Role of the SIB**: the GDP grows faster, and shows higher levels when the SIB is taken into account.
- **Role of consumers' preferences**: when consumers attach the same preferences to the three product's characteristics, the GDP is higher and grows at a faster pace, while in the case of a lower preference for the green quality (mid panel) and hampered green innovation (bottom panel), the GDP is characterized by a lower growth rate.



Final remarks
&
policy implications

Final remarks

- Positive aggregate effect of the *subsidiarity principle*: the level of aggregate **green quality** and firms' **green propensity to innovate** are **higher** in presence of a public investment bank that explicitly supports the standard commercial bank "attitude" towards environmental projects;
- The **highest levels of green quality** are achieved when the presence of the SIB is *combined* with strong consumers' preferences oriented towards the environmental quality;

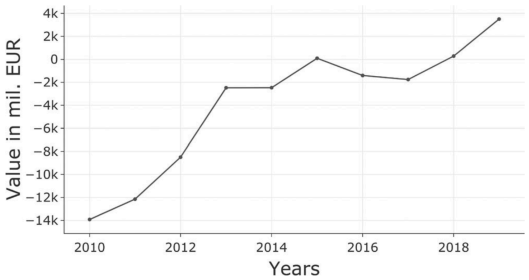
Policy implications I

- At the moment, the so-called "***Paris effect***" on climate finance is difficult to be detected ⇒ potential **crucial role for public investments banks** in improving the functioning of the financial system and sustain economic resilience by filling the so-called green financial gap
- **Successful case studies of active SIB**: **Brazilian BNDES** (Banco Nacional de Desenvolvimento Economico e Social) and the **German KfW** (Kreditanstalt für Wiederaufbau);

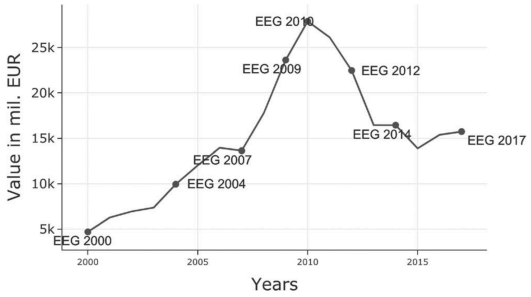
Policy implications II

- Case of *green investment banks* in Germany

Investment gap



Main energy policies and tot. investm.



Total GHG emissions

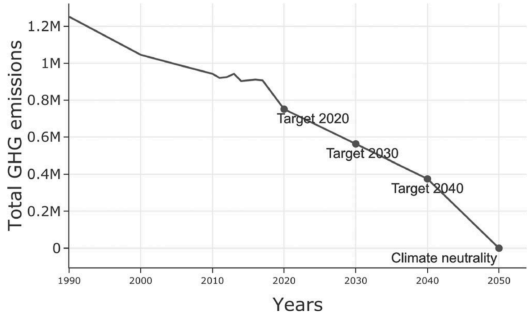


Figure: Source: D'Orazio and Löwenstein (2020)

Despite the rapid growth of renewable energy investments in the past decades and the progressive reduction of GHG emissions, the country is facing difficulties in meeting the desired targets.

Policy implications III

- A more significant commitment to "greening" the financial sector and scale-up green finance is needed also from the private financial sector → to generate considerable financial resources for mitigation measures, thus amplifying the action of the public investors, keeping in mind the concerns for climate-related financial instability (D'Orazio and Popoyan, 2019)

Thank you for your attention!

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Demand-Supply interaction

Each firm is assigned an index:

$$I_f = e_f^{\lambda_e} \times b_f^{\lambda_b} \times g_f^{\lambda_g} \tag{2}$$

where λ_b and λ_g are the parameters that describe consumers' preference for the user quality and green quality respectively, while $\lambda_e = 1 - \lambda_b - \lambda_g$. The index I_f is then used to compute individual firms' market shares

$$ms_f(t) = \left(\frac{I_f(t)}{\sum_{j=1}^{F} I_j(t)} \right)^{\alpha} \tag{3}$$

Efficiency quality:

$$e_f(t) = \frac{M_e}{1 + exp^{\gamma_e(p(t) - \hat{p})}} \tag{4}$$

Revenues:

$$r_f(t) = ms_f(t) \times GDP(t-1) \tag{5}$$

Back to main.

Prices, profits, dividends and wealth dynamics of firms

Price:

$$p_f(t) = c_f(t)\,(1+\mu) \tag{6}$$

Fixed costs:

$$fc_f(t) = \psi fc_f(t-1) + (1-\psi)\Phi \times r_f(t) \tag{7}$$

Profits:

$$\pi_f(t) = (p_f(t) - c_f(t))\frac{r_f(t)}{p_f(t)} - fc_f(t) \tag{8}$$

Wealth:

$$s_f(t) = (1-\delta)s_f(t-1) + \pi_f(t) \tag{9}$$

Back to main.

Innovation outcomes: effects on the qualities

Cost-reducing innovation	**User quality innovation**	**Environmental quality innovation**
$c_f(t) = c_f(t-1) - K$	$c_f(t) = c_f(t-1) + k$	$c_f(t) = c_f(t-1) + k$
$b_f(t) = b_f(t-1) - k$	$b_f(t) = b_f(t-1) + K$	$b_f(t) = b_f(t-1) - k$
$g_f(t) = g_f(t-1) - k$	$g_f(t) = g_f(t-1) - k$	$g_f(t) = g_f(t-1) + K$

Table: Implications of a successful innovation project on the three product's characteristics. The improvement obtained on the targeted characteristic is K while the reduction on the two other characteristics is $k < K/2$.

Back to main.