Faculté des sciences économiques et de gestion
Université de Strasbourg

UNIVERSITÉ DE STRASBOURG

UE ÉCONOMIE NUMÉRIQUE

Research file - Literature review

Strategic Human Capital Investment: An Agent-Based Modeling Approach to Differentiating Growth Trajectories

---

Salmane LOUALI
Khalid NASER
Chafi KHERMOUCHE
Hakim NESSAH

Under the supervision of André Lorentz, Professor of Economics and researcher at BETA (Bureau d'Economie Théorique et Appliqué), University of Strasbourg.

Year 2023-2024

CONTENTS

I.	***Introduction***	***2***
II.	***Education and human capital as an extension***	***4***
III.	***Presentation of the model***	***7***
IV.	***The simulation results***	***10***
V.	***Conclusion***	***12***
VI.	***References***	***13***

I) *Introduction*

In this paper, we build upon the foundational framework established by the seminal work of Llerena, P., & Lorentz, A. (2004) in "Cumulative Causation and Evolutionary Micro-Founded Technical Change: On the Determinants of Growth Rate Differences." This original investigation embarked on a comprehensive journey, employing a sophisticated theoretical model that interweaves evolutionary economics with the Kaldorian tradition. At its core, the study introduced a groundbreaking approach by incorporating micro-founded processes of technical change within a cumulative causation framework, taking inspiration from both evolutionary and Neo-Austrian theories to dissect economic growth as a disequilibrium process.

The exploration of the "Kaldor-Verdoorn law" through a micro-level lens was a key feature of the original research, aiming to demystify the industrial dynamics influencing macroeconomic growth patterns. By examining critical factors such as income elasticities, technological opportunities, absorptive capacity, price elasticity, and wage adjustment mechanisms, the study delved deep into the complexities of how demand structure, technological evolution, and selection mechanisms collectively shape growth rate dynamics across various economies.

The findings from the original study's simulations were particularly revealing, delineating three distinct regimes of growth rate divergence: sustained, transitory, and destructive. These regimes highlighted the importance of heterogeneity in income elasticities and technological opportunities, as well as the crucial role of wage dynamics in managing the impact of technological shocks. The study poignantly underscored the destructive potential of inadequate wage adjustments, which could culminate in the dominance of a few technologically advanced firms or economies, ultimately leading to the marginalization of less advanced counterparts.

Moreover, the study advanced our comprehension of the interplay between macroeconomic and technological parameters in shaping economic growth. It not only validated the insights offered by Kaldorian theories on growth rate disparities but also enriched the dialogue by uncovering more intricate patterns of divergence, setting the stage for further exploration into the underlying causes and mechanisms at play.

Building upon these insightful findings, our paper seeks to extend the theoretical and empirical analysis of growth rate differences among economies by introducing education and human capital into the agent-based model (ABM) initially described in the Lorenz (2009) model. Recognizing the pivotal role of human capital in fostering innovation, productivity, and, by extension, economic growth, this extension aims to offer a more rounded understanding of the determinants of firm success and economic development. By incorporating this additional dimension, our study not only enriches the existing literature but also provides a robust platform for policy simulation and analysis, thereby offering new avenues for both policy-making and theoretical advancement in the dynamic field of economic growth and development.

Our paper is structured to seamlessly navigate through the intricacies of incorporating education and human capital into an existing economic model. Initially, we delve into the rationale behind this extension, outlining the theoretical motivations and empirical justifications. Subsequently, we present the modified model, detailing the integration of human capital and its expected impact on economic dynamics. The core of our analysis unfolds as we discuss the main results from the model's simulations, closely examining the implications of our findings on growth rate disparities among economies. This discussion is enriched with interpretations that link our results to broader economic theories. Finally, the paper culminates in a conclusion that succinctly summarizes our key discoveries, reflects on the study's contributions to the field of economic growth, and proposes directions for future research.

II) *Education and human capital as an extension*

In the field of human capital economics, Gary Becker and Theodore Schultz have made seminal contributions that have significantly shaped our understanding of the importance of human capital in economic development. Gary Becker, in his landmark 1964 book "Human Capital," defined human capital as the sum of productive capabilities that an individual acquires through the accumulation of general or specific knowledge, skills, and other attributes. This perspective broadens the traditional neoclassical view of labor, which was primarily quantified, by incorporating the quality and efficacy of the labor factor as critical determinants of production. Becker highlighted this by referencing the Cobb-Douglas production function, where labor and capital factors have a unitary substitution elasticity, emphasizing that the impact of increasing the labor factor on production inherently depends on the level of human capital of workers. Conversely, in 1961, Theodore Schultz, in his article "Investment in Human Capital" published in the American Economic Review, critiqued the prevailing economic growth models of the time, such as those by Harrod-Domar and Solow, which linked economic growth rates primarily to the accumulation of physical capital. Schultz compellingly argued that investments enhancing human capacities play a crucial role in differentiating economic growth rates and in enhancing consumption satisfaction, highlighting the often-overlooked significance of human capital in economic growth analysis. Becker further conceptualized human capital not just as a set of skills and knowledge but also as an asset or wealth that can generate income, thereby positioning it as a vital subset within the broader concept of capital. This perspective underscores the strategic nature of investing in human capital, seen through the lens of economic agents' optimization, who must consider the opportunity cost associated with accumulating human capital. These pioneering works by Becker and Schultz have thus established a robust theoretical framework underscoring the critical importance

of investing in human capital, not only for enhancing productivity and economic growth but also for enriching human potential and advancing societal progress.

Incorporating education and human capital into the existing agent-based model (ABM) described by Lorentz (2009) represents a significant enhancement that bridges the model more closely with central tenets of economic growth theories, particularly the endogenous growth theory. This theory underscores the pivotal role of human capital in steering the direction and pace of technological progress and, by extension, economic growth. The extension thus enriches the model's capacity to simulate complex dynamics of economic development, providing a more holistic understanding of how investments in education and skill development contribute to innovation, productivity, and competitive advantage across firms and economies.

The rationale for this integration stems from a multifaceted understanding of human capital's role in economic dynamics. Human capital, encompassing the skills, knowledge, and experience of individuals, is recognized as a cornerstone for fostering innovation and enhancing productivity. By embedding this element into the ABM, the research ventures beyond traditional analyses of firm dynamics, innovation, and market competition, offering a comprehensive view that encapsulates the determinants of firm success and broader economic growth patterns. This approach enables the exploration of how disparities in human capital levels among firms and regions can lead to divergent economic outcomes, shedding light on the mechanisms through which education and skill development act as catalysts for economic prosperity.

The extended model adeptly captures the feedback loop between economic growth and education, wherein economic prosperity fuels further investments in education, leading to the cultivation of a more skilled workforce, which, in turn, propels economic growth. This dynamic is crucial for understanding long-term economic trends and the potential for sustained growth driven by continuous improvements in human capital. Furthermore, the model serves as a potent tool for policy analysis, allowing for the simulation of educational policies' impacts on the economy. Such

simulations offer invaluable insights for policymakers, enabling the assessment of long-term effects of various educational strategies on economic performance.

By accounting for education and human capital, the model also enhances its portrayal of labor market dynamics, including wage determination, skill premiums, and labor allocation across firms. This expanded framework allows for a more nuanced understanding of labor market responses to technological changes, shifts in economic structure, and variations in demand for skills. Additionally, the model sheds light on the intricate relationship between human capital and R&D activities, elucidating how investments in education enhance firms' innovative capacities and contribute to technological advancements.

The introduction of human capital into the ABM adds a layer of complexity by incorporating additional dimensions of firm heterogeneity, related not only to productivity and innovation but also to firms' strategies in attracting and retaining skilled workers. This aspect offers a richer analysis of the competitive landscape, emphasizing human capital's role in firm success. Moreover, the model's ability to simulate sectoral shifts and structural changes in the economy—often moving from manufacturing to services, which are more human capital-intensive—provides insights into the economic transformations accompanying development processes.

Lastly, the model's enriched framework facilitates comparative dynamics analysis, enabling an examination of different economies or sectors based on their human capital investment levels. This comparative approach helps explain growth trajectory disparities, offering lessons on the strategic importance of human capital development. In summary, the extension of the ABM to include education and human capital significantly broadens the analytical scope of the model, allowing for a deeper exploration of the nuanced interplay between human capital, innovation, and economic growth. This comprehensive approach not only advances theoretical understanding but also offers practical insights for policymaking, highlighting the strategic value of human capital investment in fostering sustainable economic development.

III) Presentation of the model

In integrating education and human capital within the agent-based model (ABM) delineated in the Lorentz (2009) model, we are proposing a comprehensive extension that encapsulates several new dynamics which are fundamental to the understanding of growth within economies. The addition of human capital factors allows for a richer simulation environment, capturing the nuanced interactions between firm-level decision-making and macroeconomic growth trajectories.

Human Capital Dynamics :

The equation below represents the dynamics of human capital within a firm over time, incorporating both depreciation and investment effects:

$$H_{i,t} = (1 - \delta).H_{i,t-1} + \gamma.Ed_{i,t} \quad (1)$$

where $H_{i,t}$ Human capital of firm i at time t, $\delta \in [0; 1]$ the depreciation rate of human capital, reflecting the idea that skills and knowledge can become outdated or forgotten over time if not updated or used, the closer this rate approaches 1, the more pronounced the depreciation becomes, $H_{i,t-1}$ Human capital of the firm i at the previous time period $(t - 1)$, showing that this period's human capital is influenced by the past level of human capital, $\gamma \in [0; 1]$ The efficiency of education investments, indicating how effectively investments in education $Ed_{i,t}$ translate into human capital, A value of 0 would mean that education investments have no effect, while a value of 1 would mean that they directly and fully translate into human capital, $Ed_{i,t}$ investment in education or training by firm i at time t.

Education Investment Decision :

$$Ed_{i,t} = \tau_i . \Pi_{i,t} \quad (2)$$

where $\tau_i \in [0; 1]$ is the fraction of profits $\Pi_{i,t}$ that firm i invests in education at time.

This strategic decision is a reflection of the firm's commitment to growth and its recognition of the value of a skilled workforce. The firm's investment in education is an investment in its future, with the potential to enhance its productivity and competitive edge.

Human Capital Impact on Productivity :

$$A_{i,t} = \left(\frac{I_{i,t}.a_{i,t-1} + \sum_{t=1}^{t-1} I_{i,t}.A_{i.t}}{\sum_{t=1}^{t} I_{i,t}} \right) . \left(1 + \theta . H_{i,t}\right) \quad (3)$$

Equation (3) modifies the original productivity update by including a term $\theta . H_{i,t}$ to account for the positive impact of human capital $H_{i,t}$ on productivity $A_{i,t}$, with $\theta \in [0; 1]$ as the strength of this effect, the closer it tends to 1, the stronger the effect becomes. This relationship acknowledges that human capital is not static; it actively shapes the firm's productive capacity and ability to innovate.

Impact of Human Capital on Firm's Profit :

$$\Pi_{i,t} = \mu . \frac{W}{A_{i,t-1}.H_{i,t-1}} . Y_{i,t} \quad (4)$$

Equation (4) measures how human capital $H_{i,t-1}$ affects the firm's profit, reflecting the idea that more educated workers can potentially contribute to higher efficiency and lower production costs.

Human Capital Effect on R&D Success Probability :

$$Success\ Probability\ =\ f(R_{i,t}, H_{i,t}) \qquad (5)$$

The success of R&D investments could be modeled as a function f of both the R&D investment $R_{i,t}$ and the level of human capital $H_{i,t}$ indicating that a more educated workforce increases the likelihood of R&D breakthroughs.

Firm's Growth Dynamics with Human Capital :

$$z_{i,t}\ = z_{i,t-1}\,.\left(1\ +\ \phi\,.\left(\frac{E_{i,t}(H)-\overline{E}_t}{\overline{E}_t}\right)\right) \qquad (6)$$

Where $E_{i,t}(H)$ is the firm's competitiveness adjusted for human capital. The replicator equation is modified to incorporate human capital as follows:

$$E(H)\ =\ E_0\ +\ \psi.H_{i,t-1}$$

Where E_0 is the base competitiveness without the human capital effect, and $\psi \in [0; 1]$ is the parameter that represents the contribution of human capital to the firm's competitiveness, a small value (e.g., 0.1) represents a modest impact of human capital on firm growth, a high value (e.g., 0.9) suggesting that firms with higher human capital may grow faster due to enhanced capabilities.

Each of these equations[1] is crucial in extending the ABM to more realistically simulate the multifaceted role of human capital in the economy. By capturing the essence of how education and experience translate into economic outcomes, these

[1] Please note that the equations presented here are specifically the modified components introduced to incorporate education and human capital into the model. All other existing equations(except for those related to exports and imports) of the model remain unaltered and continue to function as originally formulated in the Lorentz (2009) framework.

equations enable the ABM to generate insights into the long-term dynamics of economic growth, firm development, and the evolution of industries.

IV) The simulation results

- The growth path of human capital over time and its depreciation rate

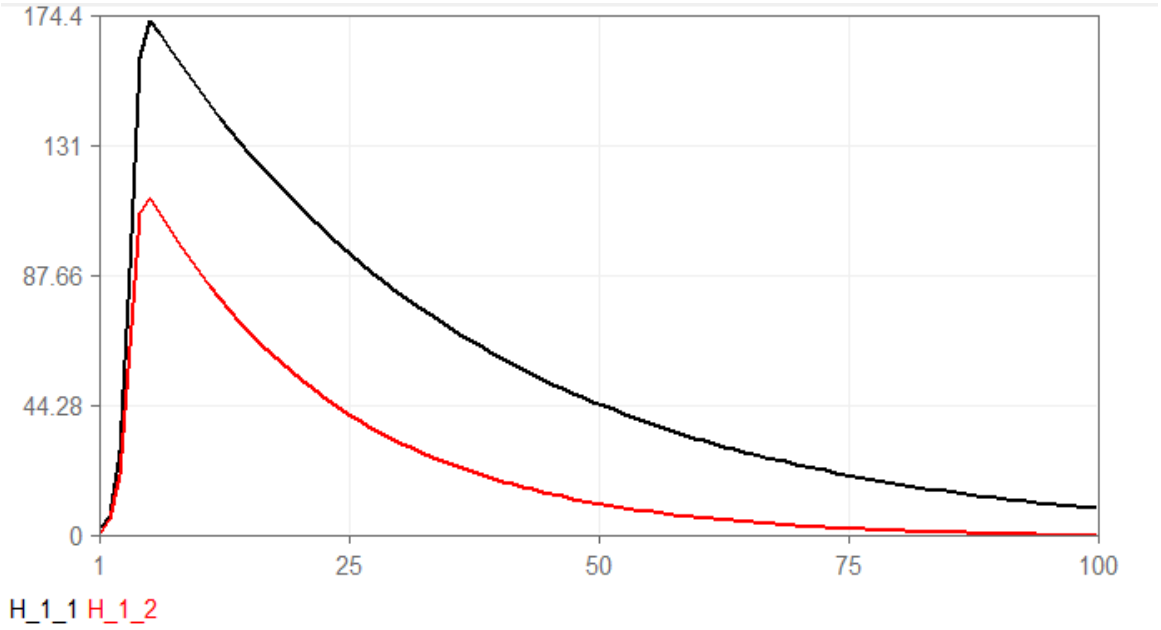

Figure 1. *The evolution of human capital over time*

The graph illustrates the evolution of human capital for two distinct types of firms: an innovator (H_1_1, black curve) and an imitator (H_1_2, red curve), over a given time frame. Initially, both firms exhibit a rapid accumulation of human capital, indicative of significant investment in education and skill development. However, the innovator firm demonstrates a steeper decline in human capital over time, which could be attributed to a higher depreciation rate (δ). This suggests that without sustained investment in human capital, even the most innovative firms may experience a sharp decline in their knowledge base. In contrast, the imitator firm shows a more gradual depreciation, potentially indicating a more consistent approach to human capital investment or a lower depreciation rate. The divergence

of paths between the two firms underscores the long-term impact of human capital strategies on firm growth and competitiveness.

- The relationship between education investment and human capital

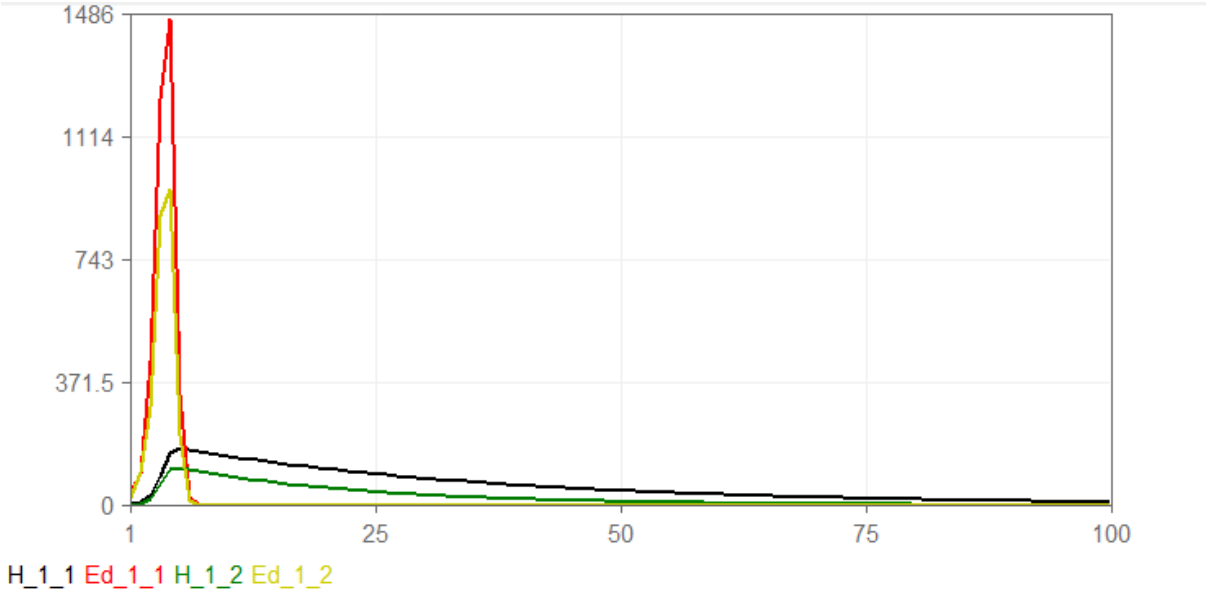

Figure 2. *The evolution of education investment and human capital over time*

The graph contrasts the dynamics of education investment and its effect on human capital between an innovator firm (_1_1) and an imitator firm (_1_2). The innovator firm, indicated by the black and red curves, shows an initial peak in education investment that leads to a rapid accumulation of human capital. This suggests an aggressive strategy to bolster capabilities for innovation. The subsequent sharp decline may indicate a reduction in education investment or a saturation point in human capital utility. Meanwhile, the imitator firm, represented by the yellow and green curves, displays a more moderate and consistent investment in education, resulting in a gradual build-up of human capital. This approach points to a strategy of steady progress and sustained investment in workforce skills, contrasting with the high-intensity approach of the innovator firm that seeks immediate gains in human capital, potentially risking longer-term sustainability.

- The effect of human capital on firm competitiveness and market dynamics

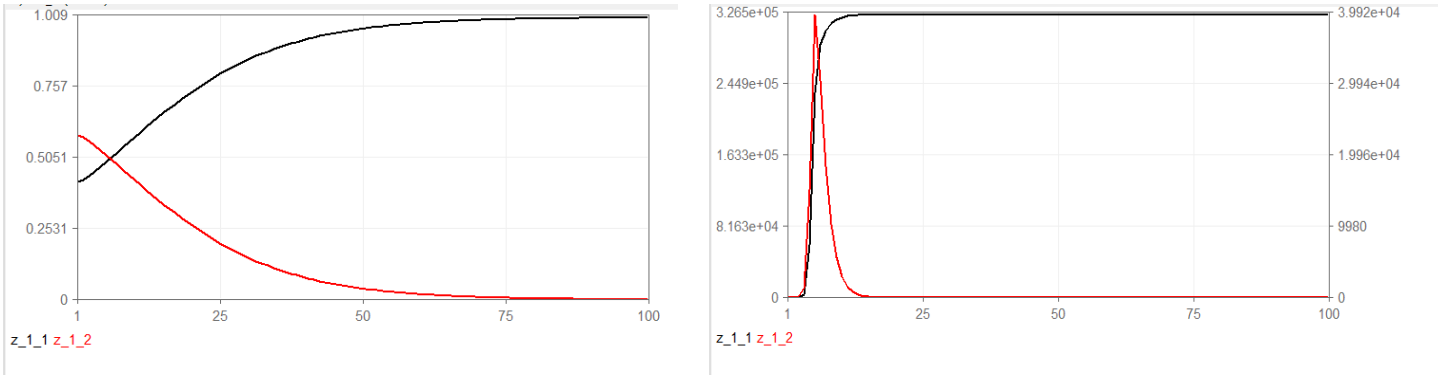

Figure 3. *The effect of human capital on the market share*

Analyzing the market share evolution for both an innovative firm (z_1_1) and an imitator firm (z_1_2) across two scenarios—one without human capital (the graph on the left) and the other with it (the graph on the right) —reveals the profound impact of human capital on market dynamics. In the absence of human capital, the market share trajectories suggest that both firms operate on a more level playing field. However, when human capital is factored in, the innovative firm (z_1_1) shows a pronounced advantage, rapidly gaining and sustaining a higher market share. The imitator firm (z_1_2), while initially experiencing a boost, does not sustain growth and its market share plateaus. This dichotomy suggests that human capital significantly amplifies the innovative firm's competitive edge, leading to greater market dominance, while the imitator firm, despite initial gains from human capital, fails to translate this into long-term market share growth.

V) Conclusion

In conclusion, our extended agent-based model (ABM), incorporating education and human capital, has provided critical insights into the dynamics of economic growth and firm performance. The inclusion of human capital significantly differentiates the trajectories of innovative and imitator firms. Our simulations have demonstrated that

innovative firms accrue and sustain higher levels of human capital over time, which translates into a more robust market share and competitive advantage. This is in stark contrast to imitator firms, which, despite an initial boost from investments in human capital, do not experience the same growth in market share.

The simulations further reveal that the aggressive investment in human capital by innovative firms leads to a rapid accumulation of this asset, suggesting a strategy of front-loading investment to gain a competitive edge. However, this comes with the risk of human capital depreciation without continued investment. Imitator firms, while benefiting from a more consistent approach to human capital investment, fail to leverage it to the same extent for market share growth.

Overall, the analysis underscores the importance of strategic investment in human capital as a key driver of divergence in economic performance between firms. Innovative firms show a clear pattern of leveraging human capital for growth, suggesting that policies promoting education and skill development can be potent tools for fostering innovation-led economic expansion. As we look to the future, it is evident that the sustained development and strategic deployment of human capital will be pivotal in shaping the competitive landscape of industries and the growth trajectories of economies.

REFERENCES

Llerena, P., & Lorentz, A. (2004). *Cumulative Causation and Evolutionary Micro-Founded Technical Change: On the Determinants of Growth Rate Differences. Revue économique*, 55(6), 1191-1214. DOI: 10.3917/reco.556.1191

Becker, G. S. (1964). *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*. The University of Chicago Press.

Schultz, T. W. (1961). Investment in Human Capital. *The American Economic Review*, 51(1), 1-17.

Appendix

Agents	Micro-variables	Micro-parameters	Macro-parameters	Decision Rules	Interactions	Aggregate variables
$Firms$	$Y_{i,t}$ $A_{i,t}$ $P_{i,t}$ $\Pi_{i,t}$ $z_{i,t}$,$a_{i,t}$ $\sigma_{i,t}$ $E_{i,t}$, $R_{i,t}$ $\epsilon_{i,t}$, $I_{i,t}$ $H_{i,t}$, $Ed_{i,t}$	ι_i ρ_i μ Inn Im τ_i	$\underline{\phi}$ $\underline{z}$ σ χ δ W γ θ Ψ $Total\ Demand$	ι_i ρ_i $I_{i,t}$ $R_{i,t}$ $P_{i,t}$ τ_i	$Replicator\ dynamic$ $Imitation$	$\overline{E_t}$ $\overline{a_i}$