Artificial Intelligence, Knowledge Spillovers, and Growth

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Abstract

Advances in artificial intelligence (AI) have demonstrated significant potential to reshape the global economy. This paper develops an endogenous growth model that distinguishes two key effects of AI on innovation: the **intensive margin**, where AI improves the processing and application of human-accessible knowledge, and the **extensive margin**, where AI acquires and processes knowledge beyond human capacity. Our findings suggest that in a social planner economy, AI accelerates economic growth through both margins, although it may reduce the fraction of labor allocated to research and development (R&D) due to the **extensive margin**. In a decentralized economy, however, AI could reduce the fraction of labor allocated to R&D because of the **extensive margin**, thus exacerbating market inefficiencies. We also examine how optimal tax policies can mitigate these inefficiencies.

Introduction

The human brain may face two main challenges
1) the human brain has limited capacity to process knowledge involving large amounts and complex content;
2) it often demands a substantial amount of time and effort for human brain to collect and process knowledge.

Differentiate knowledge into two parts
1) the portion that can be obtained by humans without AI ;
2) the portion that can only be acquired through the use of AI.

Two key effects of AI on innovation
1) the intensive margin, where AI improves the processing and application of human-accessible knowledge; (AI improves the innovation efficiency of R&D workers.)
2) the extensive margin, where AI acquires and processes knowledge beyond human capacity. (A prominent example is GNoME, which generated 2.2 million new materials---a task estimated to require approximately 800 years of human research.)

Mian work
Bulid an endogenous growth model to characterize the process by which AI collects and creates knowledge, and to study AI's impact and mechanisms on innovation and growth.

Methods and Materials

We incorporate AI into an endogenous growth framework, where our core model setup concerns **how AI reshapes the innovation possibilities frontier**.

$$\dot{N}(t) = \eta\{\Phi(Z(t))\alpha N(t)L_N(t) + [\Phi(\mathrm{Z(t)}) - 1](1-\alpha)N(t)\}$$

The contribution of AI to innovation, $\boldsymbol{\Phi(Z(t))}$
1) $Z(t)$ is the resources devoted to the adoption of AI technology from gross output.
2) We assume that $\Phi(Z(t))$ is increasing in $Z(t)$ with diminishing marginal returns and is bounded below by 1 and above by $\phi^* > 1$.

Partition existing knowledge into two parts
1) one accessible and analyzable by humans, $\alpha N(t)$, $0 < \alpha < 1$;
2) another barely accessible or interpretable by humans and thus reliant on AI, $(1-\alpha)N(t)$.

AI affects innovation through two distinct channels
1) **Intensive margin, $\boldsymbol{\Phi(Z(t))\alpha N(t)L_N(t)}$**
AI enhances the processing of knowledge within human cognitive limits by raising researchers' productivity. This use of AI requires allocating a fraction of labor, $L_N(t)$.
2) **Extensive margin, $\boldsymbol{[\Phi(Z(t)) - 1](1-\alpha)N(t)}$**
AI broadens the scope of knowledge collection and analysis, facilitating innovation beyond human capability. This activity requires (almost) no human input.

Results

Social planner economy

$$g^S = \underbrace{\frac{\alpha\eta L - \rho}{\gamma}}_{\text{without AI}} + \underbrace{\underbrace{\frac{(\phi^*-1)\alpha\eta L}{\gamma}}_{\text{AI's intensive margin}} + \underbrace{\frac{(\phi^*-1)(1-\alpha)\eta}{\gamma}}_{\text{AI's extensive margin}}}_{\text{AI's aggregate effect}}$$

$$l_N^S = \underbrace{\frac{\alpha\eta L - \rho}{\alpha\gamma\eta L}}_{\text{without AI}} + \underbrace{\underbrace{\frac{(\phi^*-1)\rho}{\phi^*\alpha\gamma\eta L}}_{\text{AI's intensive margin}} + \underbrace{\frac{(\phi^*-1)(1-\alpha)(1-\gamma)}{\phi^*\alpha\gamma L}}_{\text{AI's extensive margin}}}_{\text{AI's aggregate effect}}$$

AI accelerates economic growth through both margins, although it may reduce the fraction of labor allocated to R&D due to the extensive margin ($\phi^* > 1$, $0 < \alpha < 1$, $\eta > 0$, $\rho > 0$, $\gamma > 0$, $L > 1$).

Decentralized economy

$$g^D = \underbrace{\frac{\alpha\eta L(1-\beta) - \rho}{1+\gamma-\beta}}_{\text{without AI}} + \underbrace{\underbrace{\frac{(\phi^*-1)\alpha\eta L(1-\beta)}{1+\gamma-\beta}}_{\text{AI's intensive margin}} + \underbrace{\frac{(\phi^*-1)(1-\alpha)(1-\beta)\eta}{1+\gamma-\beta}}_{\text{AI's extensive margin}}}_{\text{AI's aggregate effect}}$$

$$l_N^D = \underbrace{\frac{\alpha\eta L(1-\beta) - \rho}{\alpha\eta L(1+\gamma-\beta)}}_{\text{without AI}} + \underbrace{\underbrace{\frac{(\phi^*-1)\rho}{\phi^*\alpha\eta L(1+\gamma-\beta)}}_{\text{AI's intensive margin}} + \underbrace{\frac{-\gamma(\phi^*-1)(1-\alpha)}{\phi^*\alpha L(1+\gamma-\beta)}}_{\text{AI's extensive margin}}}_{\text{AI's aggregate effect}}$$

AI could reduce the fraction of labor allocated to R&D because of the extensive margin, and exacerbating market inefficiencies ($0 < \beta < 1$).

Market failures

$$\Delta g = g^S - g^D = \underbrace{\frac{\alpha\eta L(1-\beta+\gamma\beta) - \rho(1-\beta)}{\gamma(1+\gamma-\beta)}}_{\text{without AI}} + \underbrace{\underbrace{\frac{(\phi^*-1)\alpha\eta L(1-\beta+\gamma\beta)}{\gamma(1+\gamma-\beta)}}_{\text{AI's intensive margin}} + \underbrace{\frac{(\phi^*-1)(1-\alpha)(1-\beta+\beta\gamma)\eta}{\gamma(1+\gamma-\beta)}}_{\text{AI's extensive margin}}}_{\text{AI's aggregate effect}}$$

$$\Delta l_N = l_N^S - l_N^D = \underbrace{\frac{\alpha\eta L(1-\beta+\gamma\beta) - \rho(1-\beta)}{\alpha\eta L\gamma(1+\gamma-\beta)}}_{\text{without AI}} + \underbrace{\underbrace{\frac{(\phi^*-1)\rho(1-\beta)}{\phi^*\alpha\eta L\gamma(1+\gamma-\beta)}}_{\text{AI's intensive margin}} + \underbrace{\frac{(\phi^*-1)(1-\alpha)(1-\beta+\beta\gamma)}{\phi^*\alpha L\gamma(1+\gamma-\beta)}}_{\text{AI's extensive margin}}}_{\text{AI's aggregate effect}}$$

Conclusions

Conclusions in a social planner economy
1) Economic growth
AI boosts the growth rate of per capita output by enhancing both intensive and extensive margins.
2) Labor allocated to R&D
While AI's intensive margin can can increase labor allocated to R&D, the impact of its extensive margin remains ambiguous, making AI's aggregate effect uncertain. This outcome stems from the degree of consumers' risk aversion (γ) and the purely AI-driven nature of the extensive margin.

Conclusions in a decentralized economy
1) Economic growth
The effect of AI on the economic growth is similar to in the social planner economy.
2) Labor allocated to R&D
AI's intensive margin of can raise labor allocated to R&D, whereas its extensive margin can reduce it. The effect of AI on the fraction of labor allocated to R&D varies depending on the dominant margin.

Conclusions in AI and market failures
1) Market failures
AI may exacerbate market failures.
Both channels of AI affecting innovation amplify knowledge spillovers, intensifying inefficiencies in the decentralized economy.
2) Mitigate market failure
Government policy interventions, such as subsidizing R&D firms, can mitigate these market inefficiencies.

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References

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