

Distorted Innovation: Does the Market Get the Direction of Technology Right?

Daron Acemoglu

September 27, 2025

Motivation

- Common perspective among economists: the market is the best judge of how research efforts should be allocated: government should only provide basic support.
- Opposite view:
 - There are myriad distortions in the equilibrium innovation process.
 - The government can be as good as the private sector in innovation (Mazzucato, 2015).

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- Common perspective among economists: the market is the best judge of how research efforts should be allocated: government should only provide basic support.
- Opposite view:
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→ This paper: take an intermediate position - assume that the market (working through competition between corporations and scientists) is best placed to experiment with new methods and carry out innovations, but it is possible for systemic factors to distort the direction of technology.

This paper...

- Extends the directed technological change framework (Acemoglu, 2002), focusing on an economy in which the private sector spearheads innovation and can choose between imperfectly substitutable technologies.
→ links the direction of technology to relevant market sizes, the price of other inputs into the production process, markups and regulations.
- Highlights several factors that can lead to systematic misalignment between market incentives and social objectives:
 - Negative externalities (e.g. fossil fuel innovation)
 - Markups (e.g. curative vs preventative medicine technologies)
 - Social forces (e.g. modern digital technologies)
 - Distributional effects (e.g. skill-biased technical change)
 - Coordination failures (e.g. The QWERTY keyboard)

This paper...

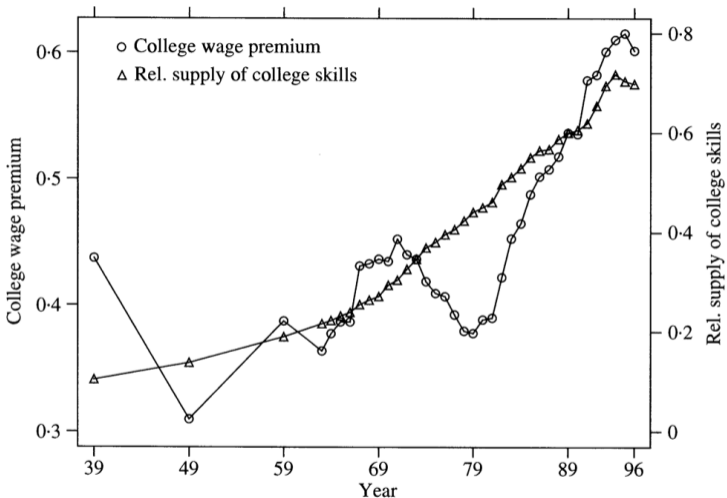
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Related Literature

- Directed Technical Change - both theoretical and empirical works: Acemoglu (1998), Acemoglu (2002), Acemoglu and Zilibotti (2001), Acemoglu and Linn (2004),...
- Inefficiency of equilibrium direction of technology: Acemoglu (2011), Acemoglu, Alp, Akcigit, Bloom and Kerr (2018), Akcigit, Hanley and Serrano-Velarde (2021),...

→ This paper builds on Acemoglu (2002) to perform comparative statics with respect to input prices, markups and externalities + assess efficiency of the direction of technology

Background knowledge: Directed Technical Change - Restud 2002



Relative Supply of College Skills and College Premium

Background knowledge: Directed Technical Change - Restud 2002

There are two competing forces determining the relative profitability of different types of innovation:

- The price effect, which creates incentives to develop technologies using more expensive factor.
- The market size effect, which encourages the development of technologies that have a larger market, more specifically, technologies that use the more abundant factor.
- The elasticity of substitution between the factors determines the relative strengths of these two effects. When the elasticity of substitution is low, scarce factors command higher prices, and the price effect is relatively more powerful.

Background knowledge: Directed Technical Change - Restud 2002

- "Weak induced-bias hypothesis": irrespective of the elasticity of substitution between factors (as long as it is not equal to 1), an increase in the relative abundance of a factor creates some amount of technical change biased towards that factor.
- "Strong induced-bias hypothesis": if the elasticity of substitution is sufficiently large, the induced bias in technology can overcome the usual substitution effect and increase the relative reward to the factor that has become more abundant.
→ directed technical change can make the long-run relative demand curve slope up

A Simple Static Model of Directed Technology

- The economy is static and inhabited by a representative household with preferences given by: $U = \ln C + \ln E$
- The unique final good is produced with the production function:

$$Y = [\gamma_1 Y_1^{\frac{\varepsilon-1}{\varepsilon}} + \gamma_2 Y_2^{\frac{\varepsilon-1}{\varepsilon}}]^{\frac{\varepsilon}{\varepsilon-1}}$$

- Intermediate good's production function:

$$Y_j = X_j^\alpha R_j^{1-\alpha}$$

- Variable input's production function:

$$X_j = \left(\int_0^{N_j} x_j(v)^{1-\beta} dv \right) \tilde{L}_j$$

where $[0, N_j]$ denotes the range of machines used in the production of j .

Innovation Possibilities Frontier

- Innovation possibilities frontier: specifies how new machine varieties are invented by scientists

$$N_j = \tilde{\eta}_j \phi(S_j) S_j$$

where $\phi(S_j) = S_j^{\frac{\delta}{1-\delta}}$ - when $\delta > 0$, the innovation possibilities frontier features increasing returns to scale at the sectoral level.

- In the dynamic model, these increasing returns will take the form of path dependence, meaning that past advances in the technology of a sector will make further advances in the same sector easier.
- Once invented, each machine can be produced at the fixed marginal cost $\psi > 0$ in terms of the final good.

Scientists

- Scientists that innovate and create varieties of machines become the owners of the technology monopolists that sell those varieties \rightarrow make profit π_j
- Adopt a simple market structure where each sector is subject to a fringe of competitive firms that can imitate and produce every machine, but do so less efficiently
 \rightarrow the market structure implies a limit price in each sector:

$$q_j = (1 + \mu_j)\psi$$

where $\mu_j = (0, \frac{\beta}{1-\beta}]$ is the markup term for each sector.

- Assume that the externality term takes a simple form:

$$E = e^{-\sum_j \bar{\tau}_j \ln N_j}$$

where $\bar{\tau}_j \geq 0$ represents a negative externality from technology j . Note that these externalities do not impact market prices and are ignored by scientists and firms.

Static Equilibrium

- Profit maximization of the intermediate good:

$$\max_{\{x_j(v), L_j, R_j\}} p_j \left[\int_0^{N_j} x_j(v)^{1-\beta} dv \cdot L_j^\beta \right]^\alpha R_j^{1-\alpha} - \int_0^{N_j} q_j(v) x_j(v) dv - w_j L_j - q_j^R R_j$$

→ we can derive cost-minimizing demands for machines x_j and resources R_j

- Technology monopolists' profits:

$$\pi_j(v) = \mu_j \psi x_j(v) = \mu_j \psi \left[p_j \left(\frac{(1-\beta)\alpha}{(1+\mu_j)\psi} \right)^\alpha \left(\frac{1-\alpha}{q_j^R} \right)^{1-\alpha} \right]^{\frac{1}{\alpha\beta}} L_j$$

- The cost-minimization condition for the final good sector implies:

$$p_j = \gamma_j \left(\frac{Y_j}{Y} \right)^{-\frac{1}{\epsilon}}$$

Static Equilibrium

- The *relative price* of a sector's product is:

$$p \equiv \frac{p_2}{p_1} = \left(\frac{\gamma_2}{\gamma_1} \right)^{\frac{\alpha\beta\epsilon}{\sigma}} \left(\frac{1 + \mu_2}{1 + \mu_1} \right)^{\frac{\alpha(1-\beta)}{\sigma}} \left(\frac{q_2^R}{q_1^R} \right)^{\frac{1-\alpha}{\sigma}} \left(\frac{N_2}{N_1} \right)^{-\frac{\alpha\beta}{\sigma}} \left(\frac{L_2}{L_1} \right)^{-\frac{\alpha\beta}{\sigma}}$$

where $\sigma = \alpha\beta\epsilon + 1 - \alpha\beta$ is the derived elasticity of substitution between the two types of labor

- Intuitively, the relative price is:
 - decreasing in the technology and labor supply to the sector, since these tend to expand its output.
 - increasing in resource prices and markups
- The *price level* is pinned down the normalization that the final good's price is set to 1 + final good expenditure minimization FOC.

Static Equilibrium

- The relative wage of the two types of labor can be derived as:

$$\frac{w_2}{w_1} = \left(\frac{\gamma_2}{\gamma_1}\right)^{\frac{\epsilon}{\sigma}} \left(\frac{1 + \mu_2}{1 + \mu_1}\right)^{-\frac{(1-\beta)(\sigma-1)}{\beta\sigma}} \left(\frac{q_2^R}{q_1^R}\right)^{-\frac{(1-\alpha)(\sigma-1)}{\alpha\beta\sigma}} \left(\frac{N_2}{N_1}\right)^{\frac{\sigma-1}{\sigma}} \left(\frac{L_2}{L_1}\right)^{-\frac{1}{\sigma}}$$

→ σ is indeed the elasticity of substitution between the two types of labor.

→ N_2/N_1 plays the role of relative factor-augmenting technological change

Static Equilibrium

- In an interior equilibrium in which research is directed to both technologies, scientists should make the same profits from improving the technology for either sector:
 → Indifference equation: $\eta_1 N_1^\delta \pi_1 = \eta_2 N_2^\delta \pi_2$
- The equilibrium relative level of technology in the two sectors:

$$n^{EQ} = \frac{N_2}{N_1} = \left[\frac{\eta_2}{\eta_1} \left(\frac{\gamma_2}{\gamma_1} \right)^{\frac{\epsilon}{\sigma}} \frac{\mu_2}{\mu_1} \left(\frac{1 + \mu_2}{1 + \mu_1} \right)^{-\frac{\sigma - (1 - \beta)}{\beta \sigma}} \left(\frac{q_2^R}{q_1^R} \right)^{-\frac{(\sigma - 1)(1 - \alpha)}{\alpha \beta \sigma}} \left(\frac{L_2}{L_1} \right)^{\frac{\sigma - 1}{\sigma}} \right]^{\frac{\sigma}{1 - \delta \sigma}}$$

- The equation links the equilibrium technology ratio between the two sectors to parameters of the final good production function, the innovation possibilities frontier, resource prices, markups, and the relative supplies of factors employed in the two sectors.

Some Properties of Equilibrium Technology Choices

- Relative supply effect: The direction of technology is determined by the relative supply of labor used with the two types of technologies L_1 and L_2
 - When $\sigma > 1$, the market size effect dominates the price effect, and n^{EQ} is increasing in L_2/L_1 .
 - When $\sigma < 1$, the price effect is more powerful and n^{EQ} is decreasing in L_2/L_1 .
- Weak bias of technology: regardless of the exact value of the elasticity of substitution between the two factors, technology always (weakly) moves in a direction that is favorable to the more abundant factor.
 - When $\sigma > 1$, $L_2/L_1 \uparrow \Rightarrow n^{EQ} \uparrow \Rightarrow w_2/w_1 \uparrow$.
 - When $\sigma < 1$, $L_2/L_1 \downarrow \Rightarrow n^{EQ} \uparrow \Rightarrow w_2/w_1 \uparrow$.

Some Properties of Equilibrium Technology Choices

- Strong bias of technology: we can obtain the long-run relationship between relative supplies and relative wages as:

$$\left(\frac{w_2}{w_1}\right)^{BGP} = \Gamma\left(\frac{L_2}{L_1}\right)^{\frac{\sigma-2+\delta}{1-\sigma\delta}}$$

→ The relationship between relative wages and relative supplies is upward-sloping when $\sigma > 2 - \delta$.

- Resource prices: when $\sigma > 1$, an increase in q_2^R decreases n^{EQ} .
- Effects of markups: An increase in μ_2 increases n^{EQ} .

Distorted Technology

- Consider the social planner's solution: Differently from equilibrium incentives, the social planner takes into account the externalities that the two intermediates generate.
- Focus on the case in which the social planner cannot directly control prices and allocations \rightarrow not able to correct for externalities and markups by introducing Pigovian taxes/subsidies \rightarrow the only choice of the social planner is the allocation of scientists between the two technologies.
- The planner's problem: maximizing household's utility by choosing S_1 and S_2 :

$$\max_{S_1, S_2 \geq 0: S_1 + S_2 \leq \bar{S}} \ln Y[N_1, N_2] + \ln E[N_1, N_2]$$

subject to the resource constraint, the market prices and the innovation possibilities frontier

Distorted Technology

- Taking the FOC + plug in the expression for the market price, we can derive the socially optimal relative level of technology n^{EQ} . The ratio of socially optimal and equilibrium technologies is:

$$\frac{n^{SP}}{n^{EQ}} = \left[\left(\frac{\mu_2}{\mu_1} \right)^{-1} \left(\frac{1 + \mu_2}{1 + \mu_1} \right) \left(\frac{1 - \tau_2}{1 - \tau_1} \right) \right]^{\frac{\sigma}{1 - \delta\sigma}}$$

- given τ_1 and τ_2 , a higher μ_2 always implies a lower $\frac{n^{SP}}{n^{EQ}}$.
- A higher τ_2 always implies a lower n^{SP} and $\frac{n^{SP}}{n^{EQ}}$ because of the negative externalities.
- The impact of these factors on the extent of technology distortion is amplified by $\sigma/(1 - \delta\sigma)$. Because a higher elasticity of substitution and a greater degree of increasing returns to scale in innovation makes n^{EQ} more responsive to markups and n^{SP} more sensitive to externalities.

Existing Empirical Evidence - Energy

- There is a large and growing literature that shows the responsiveness of both energy-generation and energy-use technologies to resource prices.
- Popp (2002) studies US patent and citations data from 1970 to 1994. He establishes a robust association between energy prices and energy-efficient innovations.
- Aghion et al. (2016) build a firm-level data set of automobile-related patents across 80 countries, and classify these innovations into dirty and clean technologies. They show that higher fuel prices induced by carbon taxes lead to more clean and less dirty innovations in the automobile industry.

Existing Empirical Evidence - Health and Medical Technologies

- The direction of health care and medical technologies appears to be highly responsive to market sizes, prices and regulations.
- Finkelstein's pioneering (2004) study focuses on several policy changes, expanding the market size for certain vaccines. Finkelstein estimates a 2.5-fold increase in the likelihood of clinical trials for the relevant vaccines following the policy-induced expansion of market size.
- Acemoglu and Linn (2004) focus more directly on the market size for new pharmaceuticals. They exploit variation originating from demographic change. Their baseline estimate suggests that a 1% increase in market size is associated with a 4% increase in new non-generic drugs.

Existing Empirical Evidence - Inappropriate Technologies

- Another implication of the framework: when a disproportionate share of innovative activity is concentrated in a few countries, and researchers in these countries target their own economies' factor endowments and prices, then the global technology will be inappropriate to the needs of remaining countries, especially when their conditions are very different from those of innovative economies.
- Moscona and Sastry (2023) establish that new crop varieties and seeds are developed to be resistant to pests and pathogens that are important in the US and Western nations, while the major pests and pathogens in the rest of the world, though closely related, are distinct.
- They estimate that global agricultural output could be increased by about 58%, if the direction of innovation were better targeted towards the agricultural conditions in less developed economies.

Discussions

- In the last section, the paper uses the model to arrive at some estimating equations for regression relating relative technology level to markups and externalities (he also explains how to measure them). The goal is to estimate σ and δ and thus $\frac{\eta^{SP}}{\eta^{EQ}}$ for different industries: healthcare and automation.
- Some potential objections to the papers that are also valid:
 - Even if the market does not get the direction of innovation completely right, governments and bureaucrats could be worse at it.
 - Distortions resulting from the direction of technology are secondary relative to underinvestment in overall innovation and/or they are small relative to other costs that government intervention in the innovation process.
 - Attempts to deal with distortions in the direction of innovation could lead to new and challenging political economy questions.
- Future work: It would be instructive to model and empirically investigate the extent to which other social factors can also create distortions in the direction of scientific and corporate research.