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Will Scientific Research Drive Technology to be a Hit? A Comparison between Emerging Technological Fields and Traditional Technological Fields

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Abstract

Translating scientific knowledge into viable technologies demands specialized efforts. The Linear Model, an early conceptual framework for understanding this process, is widely used in science-intensive sectors. Patent citations to scientific literature often measure the reliance of technology on science, but most studies focus on document-level analysis. However, they may fail to capture the full scope of the development and interconnections of technologies. This study identified the take-off times of technology trajectories and distinguished emerging technological fields (ETFs) from traditional technological fields (TTFs). We measured the distance of each field from the "paper-patent boundary" and conducted a comparative analysis between ETFs and TTFs. Additionally, we defined and calculated scientific connectivity within these fields to evaluate their integration of technology and science. Our findings show that ETFs experience more significant fluctuations in their distance to the paper-patent boundary over time and consistently exhibit higher scientific connectivity despite the divergence from the academic frontier. This study advances the understanding of knowledge transfer from science to technology, offering valuable insights in how scientific research fosters innovation.

Introduction

Scientific research forms the cornerstone of novel inventions, generating a wealth of valuable ideas that drive technological progress (Fleming & Sorenson, 2004; Chen, Mao, & Li, 2024). Since Narin and Olivastro's (1992) seminal work, growing evidence has shown that patent citations to scientific literature indicate knowledge transfer from science to technology. Most studies analyze this transfer at the document level, focusing on how discoveries from scientific publications lead to new inventions in specific fields. However, technologies rarely rely on a single invention; instead, they evolve through a developmental process, producing successive inventions that refine or expand their applications (Arthur, 2007). This progression allows technologies to increase their impact over time. Evolutionary economists have framed this structured development as progress along established trajectories (Dosi, 1982). To fully understand how scientific research drives technological progress, it is essential to examine its role in shaping technology trajectories rather than focusing solely on individual inventions.

The Linear Model outlines a progression from basic research to applied research, followed by development, production, and, finally, diffusion (Balconi et al., 2010; Bush, 2021). Although this model has faced criticism for implying that basic research is not always directly linked to technological progress, Balconi et al. (2010) highlight the critical role of knowledge supply in fostering industry development in science-

intensive sectors. Nonetheless, it remains unclear whether emerging technological fields maintain a closer relationship with scientific research compared to traditional technological fields.
In this study, we identified the Take-off time of technology trajectories and accordingly distinguished ETFs from TTFs. We subsequently measured the distance of each technological field to the "paper-patent boundary" and conducted a field-level comparison between ETFs and TTFs. This distance quantifies the proximity of a technological field to scientific research (Ahmadpoor & Jones, 2017). It essentially captures the translation path from scientific discoveries to technological innovations. Then we defined the scientific connectivity, which assesses the overall integration of technology with science within a given field. It reflects how much patents within a field operate in independent or overlapping fields relative to scientific work. Lastly, we examined the relationship between the distance and the scientific connectivity.
This ongoing study aims to reveal whether scientific research can drive technology to take off, or, in other words, be a hit. It highlights how ETFs and TTFs evolve in their reliance on scientific research along their technology trajectories.

Method

Data

This study collected utility patents from the USPTO and analyzed them at the patent family level to account for similar technical subject matter across different inventions. To account for the time lag between filing and granting, we limited the filing year to 2014. The final sample includes 3,105,854 patents filed between 1976 and 2014, belonging to 2,469,053 patent families.
Scientific references in patents are obtained from Reliance on Science (Marx and Fuegi, 2020a, 2020b), which contains 40,393,301 citations to papers from patents. We collected 2,728,680 paper-patent citations in 474,633 patent families between 1976 and 2014 using citations with a confidence score of 10. Each patent family cites an average of 5.75 scientific references.

Identification of emerging technological fields

We mapped the trends of technological fields by tracking the cumulative number of patent families filed and granted per year, using 4-digit IPC codes. To differentiate ETFs from TTFs, we identified the trajectory's *Take-off time* and *Technological impact* based on Pezzoni et al. (2022)'s method. *Technological impact* is measured by the cumulative number of patents a technology accumulates over 20 years. A technology reaches "takeoff" when it attains a specific percentage of its maximum technological impact (Griliches, 1957; Pezzoni et al., 2022). *Take-off time* refers to the number of years that pass from the appearance of a technological field until its contribution to the *Technological impact* reaches 10% (Pezzoni et al., 2022).
To mitigate the risk of underestimating the maximum technological impact of the technologies with a late takeoff, we fitted a trend function using the observed cumulated distribution of subsequent patent families.

$$Num_t = \frac{Ceiling}{1+e^{(\frac{t-Midpoint}{\alpha})}} \text{ (Pezzoni et al., 2022)} \quad (1)$$

where Num_t is the cumulative number of patent families predicted at year t; t is the number of years that pass from the appearance of a technological field; the parameter *Ceiling* is defined as the upper asymptote of the S-curve; *Midpoint* is the required time to reach 50% of the ceiling; α is the inverse of the curve slope at the *Midpoint*. The estimated take-off time can be determined by linearly combining the predicted trajectory's *Midpoint* and α parameters: *Take off* = *Midpoint*-2.2*α.

Identification of reliance on science

Distance to the "paper-patent boundary"

To assess the extent to which technological fields depend on science, we used the concepts of the "paper-patent boundary" and "distance to the boundary" (Ahmadpoor & Jones, 2017). The "paper-patent boundary" represents direct patent citations to academic papers within an integrated citation network. We then calculated the minimum citation distance of all other patents from this boundary. This approach maps the interface between scientific research and technological innovation, illustrating how discoveries transition into applications.

The distance to the "paper-patent boundary" was denoted as D_i for each patent i. When a patent directly cites a paper, $D_i = 1$, representing the patent is at the "paper-patent boundary". For the other patents, a patent i with $D_i = n+1$ is one that cites a patent j with $D_j = n$ and does not cite any patent k with $D_k < n$. Patents that are incapable of being linked at any distance to the "paper-patent boundary" are characterized as "unconnected." The process is shown in Figure 1(A). Subsequently, the distance to the "paper-patent boundary" was quantified by averaging the values of D_i within a patent family, thereby assessing its reliance on papers. Figure 1(B) illustrates that about 78% patents can be traced to scientific research.

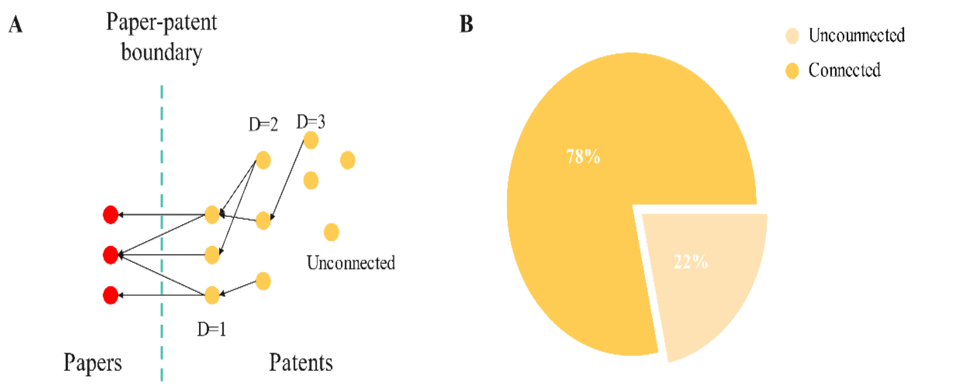

Figure 1. (A) The integrated citation network from patents to papers and the distance to the "paper-patent boundary". (B) The proportion of patents with backward links to a paper.

Scientific connectivity

Scientific connectivity reflects the extent to which patents exist in independent spheres, serving as a measure of the overall integration of technology with scientific research. It is:

$$SC = \frac{PT'}{PT} \quad (2)$$

where SC is scientific connectivity of a technological field; PT represents the number of patent families in a field; PT' is the number of patent families can be traced to papers.

Results

Distance to the "paper-patent boundary"

In this section, we evaluated the extent to which ETFs and TTFs rely on scientific research by comparing their distance to the "paper-patent boundary."

First, we categorized technological fields as either emerging or traditional. As shown in Figure 2(A), technological fields that took off after 2004 were labelled as ETFs and there are 191 ETFs and 455 TTFs. Figure 2(B) illustrates the mean distance to the paper-patent boundary for all patent families in a technological field. The plot shows that figures for both TTFs and ETFs range from 2.3 to 3.4.

Figure 3 shows the distribution of the mean distance to the paper-patent boundary of a technological field according to the take-off time. ETFs primarily concentrate their take-off time within the ranges of 1–12 years and 25–35 years. ETFs with different take-off times demonstrate a higher degree of fluctuation in their distance to the paper-patent boundary. In comparison, regardless of the take-off time, TTFs exhibit relatively stable distance to the paper-patent boundary. The interquartile ranges across the box plots generally remain consistent, indicating less variability in how they connect with scientific research.

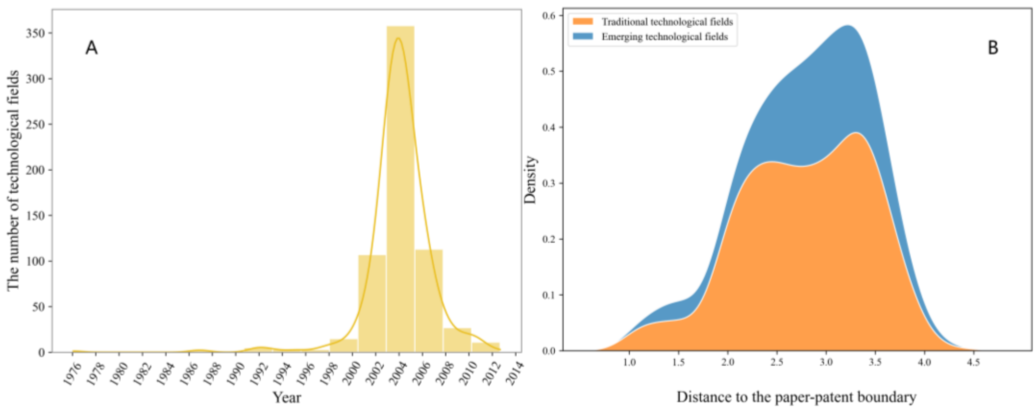

Figure 2. (A) The distribution of take-off times across all technological fields. (B) The distribution of the mean distance to the paper-patent boundary in a technological field.

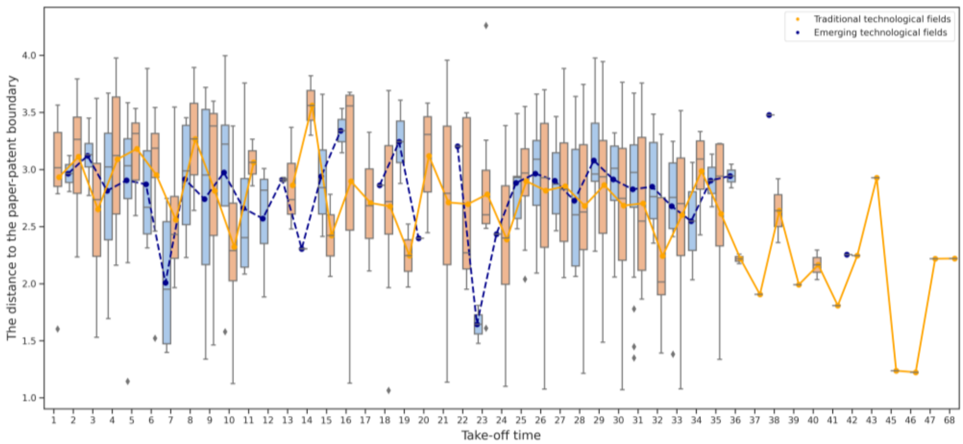

Figure 3. The distribution of the mean distance to the paper-patent boundary of a technological field according to the take-off time.

Figure 4 illustrates how the mean distance to the paper-patent boundary changes with takeoff status. ETFs consistently maintain a greater mean distance than TTFs. Before takeoff, both have a low mean distance, indicating strong ties to scientific research. After takeoff, the mean distance increases for both, but ETFs diverge more rapidly, suggesting a quicker shift toward practical applications. TTFs increase their distance more gradually. In later stages, TTFs slightly decrease their distance, indicating realignment with academic research, while ETFs also exhibit a gradual reduction, suggesting a renewed connection to science over time.

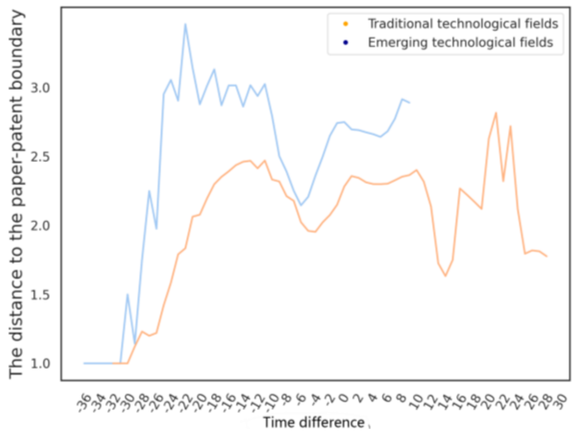

Figure 4. The mean distance to the paper-patent boundary of TTFs and ETFs. The x-axis represents a time difference metric, where the value is obtained by subtracting the natural year from the take-off year. Negative values indicate years before the technology reached its 10% impact threshold (i.e., pre-takeoff), while positive values indicate years after the technology achieved its takeoff.

Scientific connectivity

This section examines the relationship between the proximity of a technological field to scientific research and its integration with science by analysing scientific connectivity in TTFs and ETFs at varying distances from the paper-patent boundary. Figure 5(A) shows that ETFs exhibit decreasing scientific connectivity as they move away from the boundary, with high connectivity and low variability at the closest distance (D=1). In contrast, TTFs show increasing scientific connectivity with distance, starting lower than ETFs at D=1 but becoming more connected over time. This suggests that ETFs tend to cite patents derived from academic papers. Despite distance, ETFs consistently maintain higher scientific connectivity than TTFs. Figure 5(B) illustrates the mean scientific connectivity of TTFs and ETFs across different takeoff states. Both exhibit similar trends over time, with fluctuations before takeoff and convergence toward stability in the post-takeoff period.

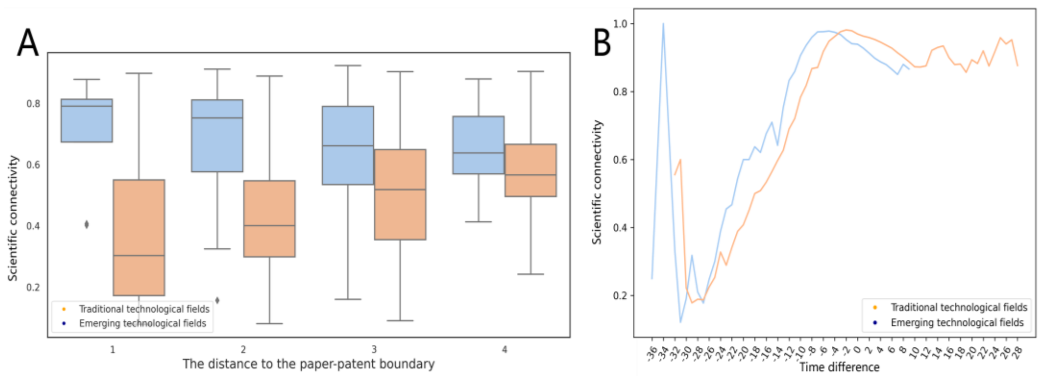

Figure 5. (A)The distribution of scientific connectivity at different distances to the paper-patent boundary. (B)The mean scientific connectivity of TTFs and ETFs.

Discussion and conclusion

This study investigates whether scientific research can serve as a catalyst for the takeoff of technologies by examining how ETFs and TTFs evolve in their reliance on it. The results show:

First, ETFs experience greater fluctuations in their distance from the paper-patent boundary over time, while TTFs follow a more stable trajectory after taking off. This suggests that emerging technologies, initially driven by scientific research, rapidly shift toward practical applications, temporarily diverging from academia (Stahl et al., 2017). However, as these fields mature, they realign with scientific research, possibly due to the convergence of academic advancements with practical needs or new research emerging in response to industry demands.

Second, the declining scientific connectivity in ETFs as they move away from the paper-patent boundary indicates that these fields start with strong academic foundations but gradually transition toward commercialization (Islam et al., 2018). In contrast, the increasing connectivity in TTFs suggests a cyclical relationship with research—initially shifting away from academia to refine and apply existing knowledge but later returning to academic research to address new challenges and drive further innovation.

Additionally, the consistently higher scientific connectivity in ETFs, even as they move away from the academic frontier, highlights the critical role of scientific research in emerging technologies. This underscores the need for ongoing collaboration between academia and industry to sustain innovation.

This study enhances the understanding of knowledge transfer from science to technology, offering insights into how scientific research shapes technological trajectories. It also clarifies when and how fields transition from research-driven innovation to application-focused development.

A key limitation of this study is the reliance on patent citations as a measure of the science-technology relationship. While useful, this metric may not fully capture the complexity of knowledge transfer. Future research should explore alternative indicators to provide a more comprehensive view of how science influences technological advancement.

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