Article

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Abstract: Predatory research field in science is when an emerging scientific topic destroys current topics and characterizes a main scientific change. Predatory research field can be a basic driver of scientific and technological change that generates a 'creative destruction' in science and society in contexts of knowledge-based competition and rapid changes. The prediction of proposed theory of predatory research fields is that it destroys with a fast growth other research fields. The theoretical approach is tested here in research fields of large language models (LLM) by analyzing the transformers (a deep learning architecture based on the multi-head attention mechanism) proposed in 2017 and from November 2022 started main applications in generative artificial intelligence with innovations of BERT, ChatGPT, Microsoft Copilot (launched on February 7, 2023) and other natural language processing tools driven by AI technology for engaging conversations, gain insights, automate tasks, etc., etc. Statistical evidence suggests that growth rate of transformer technologies is 80.58%, a high level compared to all other research fields in machine learning (having a growth rate of 13.83%). Moreover, predatory research field of transformers has a destructive power such that all other domains in LLM from 2021 to 2023 have a general reduction of scientific growth. The impact of transformers is much more drastic of previous radical technologies such as CNN having a temporal growth rate of 0.16%, lower than 0.38% by transformers, ceteris paribus. These analysis reveals that transformers have characteristics to generate a radical scientific and technological change in a not-too-distant future. Overall, then, the study suggests that predatory research field on emerging topics and technologies can generate path-breaking innovations and the examination here can clarify the essential elements of the science dynamics for a better theory of scientific and technological change, providing also main implications for knowledge policy to support promising research fields and technologies to guide economic and social change.

Keywords: Predatory research field; Science evolution; Science of Science; Social dynamics of science; Transformers; ChatGPT; BERT; Microsoft Copilot:; Large Language Model; Emerging technology; Radical Technology; Natural Language Processing Tool; AI Technology; Deep Learning Architecture; Multi-Head Attention Mechanism.

JEL: O30; O31; O32; O33

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1. Introduction and Investigation Goal

One of the fundamental problems in science is how a scientific field and related technology emerge and sustain scientific and technological change (Kuhn, 1962; Lakatos et al., 1980; Price, 1986; Scharnhorst et al., 2012). This study confronts the problem here by developing the concept of predatory research field, which endeavors to explain one of the sources of scientific and technological change. Proposed concept is especially relevant in a world of knowledge-based competition and 'creative destruction' in existing competences both in science, technology and society (Teece et al., 1997). The goal here is both extending a theory of scientific change that clarifies some new dynamics of emerging scientific fields that generate technology change and designing science policy for supporting new fields and technologies having a potential impact in almost every sphere of human activity. This study is based on increasing availability of digital data about documents and recorded knowledge that offers unparalleled opportunities to explore new aspects in the structure and evolution of science and technology (Fortunato et al., 2018; Scopus, 2023). Efforts of scholars to describe, explain and predict different aspects of science and technology have intensified in recent years with a wide range of theoretical, mathematical, statistical and computational approaches (Scharnhorst et al., 2012). In particular, the investigation of the evolution of emerging research fields and technologies is basic for planning the allocation with effectiveness of resources towards positive scientific and societal impact (Coccia, 2018, 2020). For example, the emergence of new fields in bioinformatics, nanophysics, quantum computing, and data science generates conditions for ''converging technologies'' with high potential of growth that influences our lives in society (Roco and Bainbridge, 2002).

Although the vast literature in these topics, quantitative works on behaviour related to the emergence and effects of new disciplines and technologies on other related research fields are lacking to date. This study suggest the concept of *predatory research field* and is analyzed in practical contexts of large language models (LLM) to show evolutionary behaviour to design appropriate research policy implications directed to scientific and technological development.

2. Critique of Current Literature

The development of this study flows from a recognition that research scientists have performed less well in the understanding of how and why certain scientific fields and technologies emerge in regimes of rapid change and generate radical impacts on other research fields and technologies (Coccia, 2018, 2020; Sun et al., 2013). Many theories of scientific development have been inspired by theory of Kuhn (1962) with the notion of paradigm shifts and Lakatos (1980) with the management of research program. Some theory of science development explains the evolution of fields with branching mechanisms, caused by evolutionary growth with new discoveries or technologies (Coccia, 2020, 2022a; Dalle Lucca Tosi and dos Reis, 2022; Mulkay, 1975; Small and Garfield, 1985), specialization or merging of different research fields (Coccia, 2018; Coccia et al., 2022; Coccia et al., 2024). Other models focus on the synthesis of elements of preexisting disciplines (Noyons and van Raan, 1998). All of these models point to the self-organizing development of science exhibiting growth and interaction between inter-related research fields measured with co-citations in publications (van Raan, 1990). Studies also shows that the evolution of research fields is guided by the social interactions among scientists with an invisible college (Crane, 1972; Sun et al., 2013; Wagner, 2008; cf. also, Dalle Lucca Tosi and dos Reis, 2022). Regardless the sources or specific dynamics leading to the birth and evolution of a new discipline and technology, such an event is critical to clarify scientific and technological development and impact in science and society (Bettencourt et al., 2009).

Although the vast literature, quantitative works on how emerging research fields and technologies impact on other research fields and technologies are lacking to date. In particular, how an emerging research fields can affect patterns of growth of other research fields and related technologies is a topic hardly known in science. This paper endeavors to analyze the dynamics of a new research field and how can affect inter-related pathways of growth of other research fields in a context of knowledge-based competition and 'creative destruction' in existing competences both in science, technology and society (Teece et al., 1997). The study is based on a large dataset of publications for bibliometric and scientometric analyses to show how a new research field evolves and destroys established research fields and technologies to clarify the evolutionary behaviour that can explain scientific and technological change (Cozzens et al., 2010).

3. Research Philosophy

Proposed theoretical framework to explain here predatory behaviour in scientific fields is developed with an evolutionary perspective of technological change guided by generalized or universal Darwinism (Dawkins, 1983; Nelson, 2006; Levit et al., 2011). Hodgson (2002, p. 260) maintains that: "Darwinism involves a general theory of all open, complex systems". In this context, Hodgson and Knudsen (2006) suggest a generalization of the Darwinian concepts of selection, variation and retention to explain how a complex system evolves (cf., Hodgson, 2002; Stoelhorst, 2008). In the economics of technical change, and in Science of Science (Sun et al., 2013) the

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generalization of Darwinian principles ("Generalized Darwinism") can assist in explaining the multidisciplinary nature of scientific and innovation processes (cf., Hodgson and Knudsen, 2006; Levit et al., 2011; Nelson, 2006; Schubert, 2014; Wagner and Rosen, 2014). In fact, the heuristic principles of "Generalized Darwinism" can explain aspects of scientific and technological development considering analogies between evolution in the biological dynamics and similar-looking processes in science and technology (Oppenheimer, 1955). Arthur (2009) argues that Darwinism can explain technology and science development as it has been done for the development of species (cf., Schuster, 2016, p. 7). In general, technological and scientific evolution, as biological evolution, displays radiations, stasis, extinctions, and novelty (Kauffman and Macready, 1995; Kauffman, 1996; Solé et al., 2013). Kauffman and Macready (1995, p. 26) state that: "Technological evolution, like biological evolution, can be considered a search across a space of possibilities on complex, multipeaked 'fitness,' 'efficiency,' or 'cost' landscapes". Schuster (2016, p. 8) shows the similarity between technological and biological evolution, for instance, technologies have finite lifetimes like biological organisms and similar dynamics. The evolution and diffusion of a new research field and technology are associated with the nature of some comparable research field or technology in use (remark: this study uses the concept of research field or technology interchangeably, when research field is associated with a technology, such as quantum sensing, quantum optics, deep learning, etc…). When comparable research fields and technologies do exist, each research field or technology tends to affect the behavior of others (Coccia, 2018). In fact, the evolution of a research field and/or technology is a process of substitution of a new for the established one. Pistorius and Utterback (1997) argue that emerging technologies often substitute for established one in a context of competition between new and established technology. As a matter of fact, Pistorius and Utterback (1997, p. 72) claim: "Pure competition, where an emerging technology has a negative influence on the growth of a mature technology, and the mature technology has a negative influence on the growth of the emerging technology." Overall, then, a competition is often embodied in substitutes, and Porter (1980) considers substitutes as one of the forces in his model of industrial competition for competitive advantage of firms and nations (cf. Calabrese et al., 2005; Coccia 2005a, 2015b, 2017b, 2018c, 2018d, 2019d; Coccia and Wang 2015). The model of Fisher and Pry (1971, p. 75) argues that technological evolution consists of substituting a new technology for the established one. Fisher and Pry (1971, p. 88) state that: "The speed with which a substitution takes place is not a simple measure of the pace of technical advance . . .. It is, rather a measure of the unbalance in these factors between the competitive elements of the substitution." Competition between research fields and technologies can be also analyzed with a perspective of Predator-Prey Approach. Farrell (1993a, b) used a model of Lotka-Volterra to examine pure competition between various technologies. In particular, the predator-prey relation is when one technology enhances the growth rate of the other, but the second inhibits the growth rate of the first (Pistorius and Utterback 1997, p. 74). In fact, a predator-prey relationship can exist between an emerging and established research field or technology, where emerging research field or technology enters in a niche domain or market. In this case, emerging research field or technology can benefit from the presence of established technology. At the same time, emerging research field or technology may reduce the share of established research field or technology in a specific domain or market. In this philosophical stance, the study here introduces the concept of predatory research field.

3.1. Theory of Predatory Fields in Science

- Postulates
  - Let A the space or domain in which scientific fields and technologies evolve
  - Let α_1, α_2, …, α_j, …, α_n scientific fields or technologies that birth, evolve and decline in A over time

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- Let τ a new scientific field or technology that emerges suddenly in A

- Prediction

Predatory research field or technology is a new technology/research field τ having an accelerated grow rate that destroys or inhibits the growth of other alternative established technologies/research fields (α_1, α_2, …, α_j, …, α_n), by reducing their share in domain or market to become a dominant research field or technology that generates major scientific and technological change in human society.

3.2. Research Design

- Case study to test the prediction of predatory research field or technology: research fields and technologies of transformers and Convolutional Neural Network (CNN)

The crux of the test of just mentioned prediction is rooted in the transformer architecture (a new technology in information science) and since this concept is uncommon in the social sciences some brief backgrounds is useful to understand and clarify the test of the proposed theory. A large language model (LLM) is a language model that has the ability to achieve general-purpose language generation and understanding (Pinaya et al., 2023). LLMs are trained on massive amounts of text data and as a consequence can generate coherent and fluent text for specific tasks (such as language translation, text summarization, conversational agents, etc., Tojin et al., 2023). The transformer architecture is a deep learning architecture and a basic building block of all LLMs and was introduced in the paper "Attention is all you need," published in December 2017 by Vaswani et al. (2017). A critical advantage of transformer architecture is the ability to process input faster than a *Recurrent Neural Network* (*RNN*) for many Natural Language Processing (NLP) tasks (Dell, 2023). One of the main radical innovations in transformer models is the development of large-scale, pretrained language models, referred to as generative pretraining transformers (GPTs) that are a Large Language Model based on human-like processes (Menon, 2023). Main examples are: OpenAI's GPT series, from GPT-1 in 2018 to ChatGPT-4 in 2023 capable of generating human-like content (OpenAI, 2015, 2022), Google's Bidirectional Encoder Representations from Transformers (BERT) model (Devlin et al., 2018), Microsoft Copilot a chatbot developed by Microsoft and launched on February 7, 2023 (Mehdi et al., 2023). These pretrained models can be used for specific NLP tasks with relatively little additional training data, making them highly effective for a wide range of NLP applications (cf., Assael et al., 2022; Kariampuzha et al., 2023).

We assume that Transformers is a predatory research field and to generalize the scientific concept with a backward induction. We also analyze a previous technology/research field, having similar purposes for a comparative analysis, Convolutional Neural Networks (CNNs, a Deep Learning algorithm that can take in an input image, assign importance -learnable weights and biases- to various aspects/objects in the image, and be able to differentiate one from the other, Saha, 2018) to assess its behaviour as predatory research field compared to transformer architecture. A comparative analysis of these main research fields and technologies in the field of Depp Learning can clarify general characteristics and properties of predatory research fields that can be a main driver of scientific and technological change.

- Measures and sources of data

This study uses number of scientific documents concerning research topics and technologies under study. Data are from Scopus (2023), downloaded on 9 November 2023.

- Logic structure of search

In order to detect with accuracy the research fields and technologies under study in the database Scopus (2023), a definition of General Domain D for queries is introduced to detect scientific documents for A) transformers and B) CNN

A) Search strategy for Transformers

D= ("machine learning" OR "data science" OR "artificial intelligence").

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After that we refine the Domain for two technologies under study to analyze predatory research fields.

- Transformers, period under study 2017-2023

Domain Restricted for Transformers is called DTR

DTR= ("machine learning" OR "data science" OR "artificial intelligence")

AND

("large language models" OR "LLM" OR "Natural Language Processing" OR "Natural Languages" OR "Sentiment Analysis" OR "Text Mining" OR "Question Answering Systems" OR "Semantic Web" OR "Chatbot" OR "Knowledge Representation" OR "Natural Language Understanding" OR "Text-mining" OR "Opinion Mining" OR "Topic Modeling" OR "Word Embedding")

Or

DTR= (D) AND ("large language models" OR "LLM" OR "Natural Language Processing" OR "Natural Languages" OR "Sentiment Analysis" OR "Text Mining" OR "Question Answering Systems" OR "Semantic Web" OR "Chatbot" OR "Knowledge Representation" OR "Natural Language Understanding" OR "Text-mining" OR "Opinion Mining" OR "Topic Modeling" OR "Word Embedding")

In order to detect the impact of Transformers (TRF) in science that is also used with other terms, the query is given by:

TRF= (DTR) AND ("bert" OR "chatgpt" OR "transformer" OR "attention mechanism"). This set TFR includes the technology with predatory behaviour.

The complement of set TRF is TRF^C:

TRF^C = (DTR) AND NOT ("bert" OR "chatgpt" OR "transformer" OR "attention mechanism").

This set included the technologies that have been predated by TRF.

Of course, TRF+ TRF^C=DTR

B) Search strategy for CNN

- Convolutional Neural networks, in short CNN, period under study before 2017, year of the emergence of Transformers

The general domain is D, as defined above, but in order to detect the science dynamics of CNN, we refine the search with a restriction considering the field in which CNN operates. The keywords are stopped when the restricted set has a marginal increase of scientific documents.

Domain Restricted for CNN is called DCNN

DCNN= ("machine learning" OR "data science" OR "artificial intelligence")

AND

("computer vision" OR "image recognition" OR "Image Processing" OR "Object Detection" OR "Image Segmentation" OR "Image Enhancement" OR "Object Recognition" OR "Image Analysis" OR "Image Classification" OR "Images Classification" OR "Face Recognition" OR "Machine Vision" OR "Image Interpretation" OR "Gesture Recognition" OR "Machine-vision" OR "Augmented Reality")

Or

DCNN= (D) AND ("computer vision" OR "image recognition" OR "Image Processing" OR "Object Detection" OR "Image Segmentation" OR "Image Enhancement" OR "Object Recognition" OR "Image Analysis" OR "Image Classification" OR "Images Classification" OR "Face Recognition" OR "Machine Vision" OR "Image Interpretation" OR "Gesture Recognition" OR "Machine-vision" OR "Augmented Reality")

In order to detect the impact of CNN, the query is given by:

CNN=(DCNN) AND ("convolutional neural network" OR "CNN"). This set CNN includes the technology with predatory behaviour.

The complement of set CNN is CNN^C is

CNN^C = (DCNN) AND NOT ("convolutional neural network" OR "CNN"). This set included the technologies that have been predated by CNN.

Moreover, CNN+CNN^C=DCNN

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- Samples

In particular, the study considers the following sample of data, detected using the previous logic structure of search:

- Set of Transformers TRF: 4,322 scientific documents (all data available from 1961 to 2023).
- Complement of set TRF, TRF^C: 55,120 scientific documents (all data available from 1972 to 2023).
- Set of CNN: 21,967 scientific documents (all data available from 1997 to 2023).
- Complement set of CNN, CNN^C: 91,056 scientific documents (all data available from 1965 to 2023).

- Data and information analysis procedures

Let P(TRF) =number of publication of Transformers, having predatory behaviour.

Let $P(TRF^C)$ =number of publication of technologies predated by Transformers.

Let DTRF = P(TRF) +$P(TRF^C)$, total number of publication in the domain of technologies of Large Language Models

$\alpha = \frac{P(TFR)}{DTFR}$; $\beta = \frac{P(TFR^C)}{DTFR}$ such that $\alpha + \beta = 1$

Let P(CNN) =number of publication of CNN, having predatory behaviour.

Let $P(CNN^C)$ =number of publication of technologies predated by CNN.

Let DCNN = P(CNN) +$P(CNN^C)$, total number of publication in the domain of technologies of Large Language Models

$$\delta = \frac{P(CNN)}{DCNN} \; ; \quad \varepsilon = \frac{P(CNN^C)}{DDCNN} \quad \text{such that} \quad \delta + \varepsilon = 1$$

These shares of the growth of predatory research fields in the related domain are calculated over time and visualized graphically.

After that, the temporal growth of these technologies is analyzed with a rate of growth compound continuously: *r*. In this case, the function of publication development is exponential:

$$P_t = P_0 e^{rT}$$

Hence, $\frac{P_t}{P_0} = e^{rT}$ where e is the base of natural logarithm (2.71828…)

$$Log\frac{P_t}{P_0} = rT$$

$$r = \frac{Log\frac{P_t}{P_0}}{T}$$

Where P_0 is the population to the time 0, P_t is the population to time t.

$$T = t - 0$$

r= rate of exponential growth of technology from 0 to t period.

Finally, trends of predatory research field/technology *i* at *t* are analyzed with the following model:

$$Log_{10}\, y_{i,t} = a + b\; time + u_{i,t} \qquad [1]$$

$y_{i,t}$ is scientific products in predatory research fields/technology *i* over time *t*

t=time

$u_{i,t}$ = error term

(a = constant; b=coefficient of regression)

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4. Analysis of Data and Test of the Prediction

4.1. Pattens of Temporal Change

Table 1 shows that growth rate of transformers is 80.58%, a high level compared to all other research fields/technologies in machine learning (having a growth rate of 13.83%. Predatory research field of transformers seems to have a destructive power over time, such that all other domains in LLM from 2021 to 2023 have a general reduction of scientific growth.

Table 1. Exponential rate of growth in Large Language Models of predator (transformer=TFT) and CNN compared to prey in their domain (i.e., all other alternative models).

	Transformers	Domain excluded Transformers, representing all Preys
Publications	*Rate%*	*Rate %*
r^{TRF} = Exponential growth 2016-2023	80.58	13.83
r'^{TRF} = Exponential growth 2021-2023	32.51	−1.00
	CNN	Domain excluded CNN with all Preys
Publications	Rate%	Rate %
r^{CNN}= Exponential growth 1997-2015	23.52	13.27
r'^{CNN} = Exponential growth 2015-2023	47.05	26.79
r''^{CNN} = Exponential growth 1997-2023	32.51	15.27

Table 2 shows a preliminary analysis of regression of estimated relationship. The impact of transformers is much more drastic of previous radical technology of CNN in the domain of deep learning having a growth rate of 0.16% (p-value 0.001, R^2 =.95), lower than 0.38% (p-value 0.001, R^2 =.83) by transformers. R^2 is remarkably high, showing a high goodness of fit of models, and F-test of robustness of the model (the ratio of the variance explained by the model to the unexplained variance) is significant at 0.001. These aspects reveal that transformers have characteristics to generate a radical scientific and technological change higher than CCN in a not-too-distant future. Figure 1 and Figure 2 confirm previous results with a visual representation of estimated relationships.

Table 2. Parametric estimates of the relationships based on publications.

Dependent variable Publications	Constant α	Coefficient β	R^2	*F*	Period
Log10 Pubs Transformers	0.45***	0.38*** (0.034)	0.95 (0.222)	125.47***	2016-2023
Log10 Pubs not transformers	3.29***	0.08*** (0.011)	0.89 (0.068)	50.45***	

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Log10 Pubs CNN	–0.81***	0.16*** (0.015)	0.83 (0.584)	113.40***	1997-2023
Log10 Pubs not CNN	2.24***	0.07*** (0.004)	0.91 (0.177)	247.00***	

Note: *** p<0.001; Explanatory variable: time; period is from starting year of the publications on technology to 2023 (last year available); In round parentheses the Standard Error.

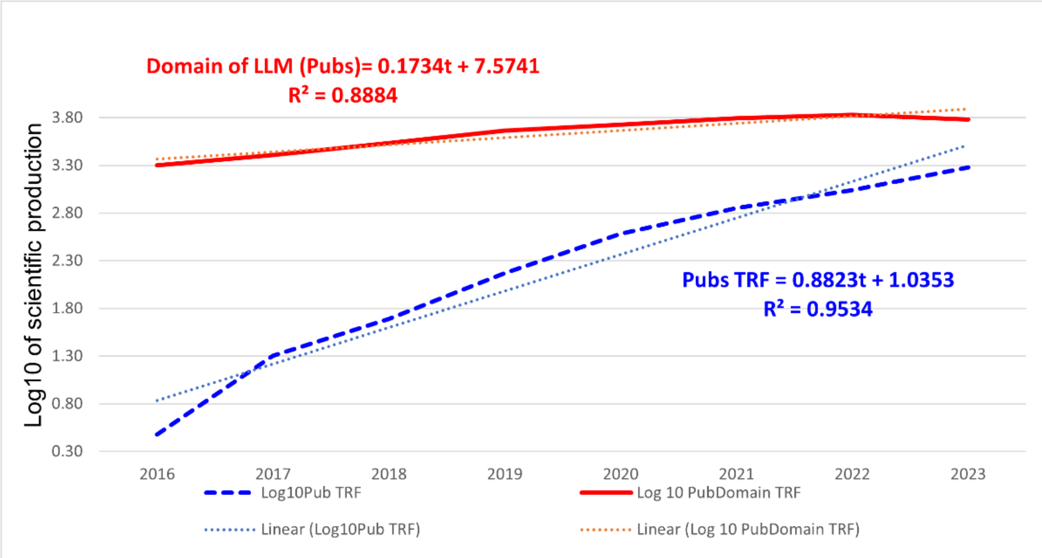

Figure 1. Estimated relationships for temporal evolution of Transformers (TFR, blue dotted line) compared to overall domain of Large Language Models, LLM (red continuous line) -Publications.

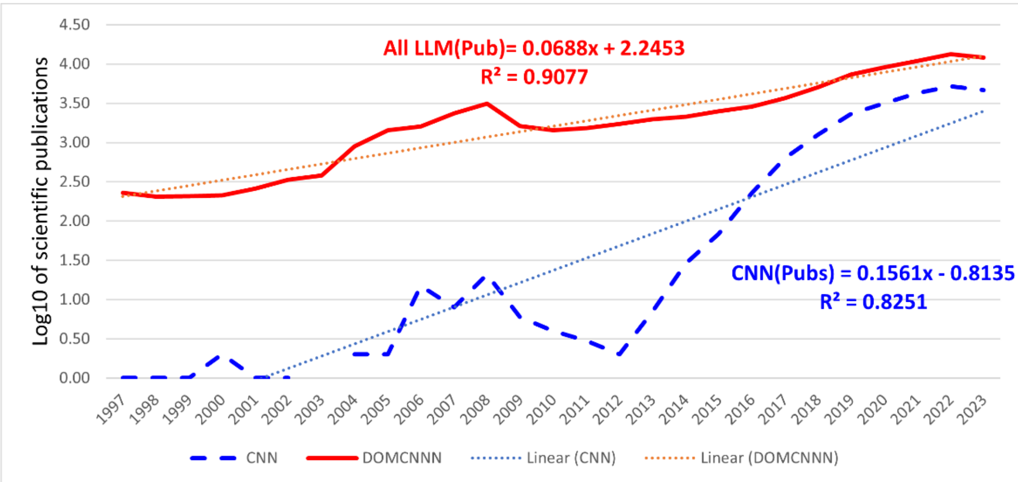

Figure 2. Estimated relationships for temporal evolution of CNN (blue dotted line) compared to overall domain of Large Language Models (red continuous line)- Publications.

4.2. Patterns of Morphological Change of Transformers and CNN in the Domain of LLM

Figure 3 and 4 show a visual representation of how the emerging research field/technology of transformers and CNN is growing with a predatory behaviour, in a short period of time, increasing its share in the related domain occupying the space of alternative technologies/research fields and laying the foundation to be a dominant research field/technology for supporting a scientific and technological change.

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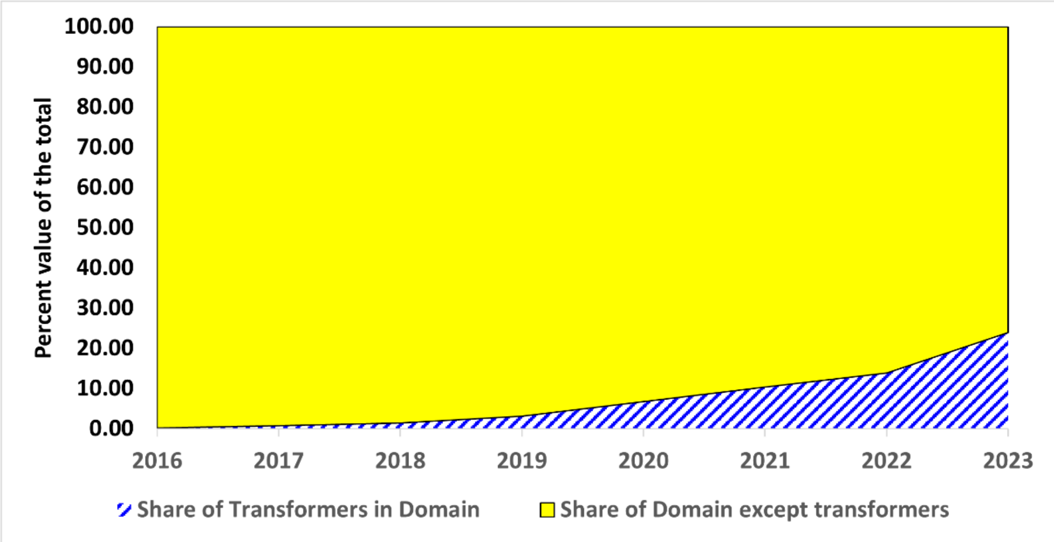

Figure 3. Patterns of morphological change in domain of large language models (LLMs) generated by emerging technology of transformers (publications).

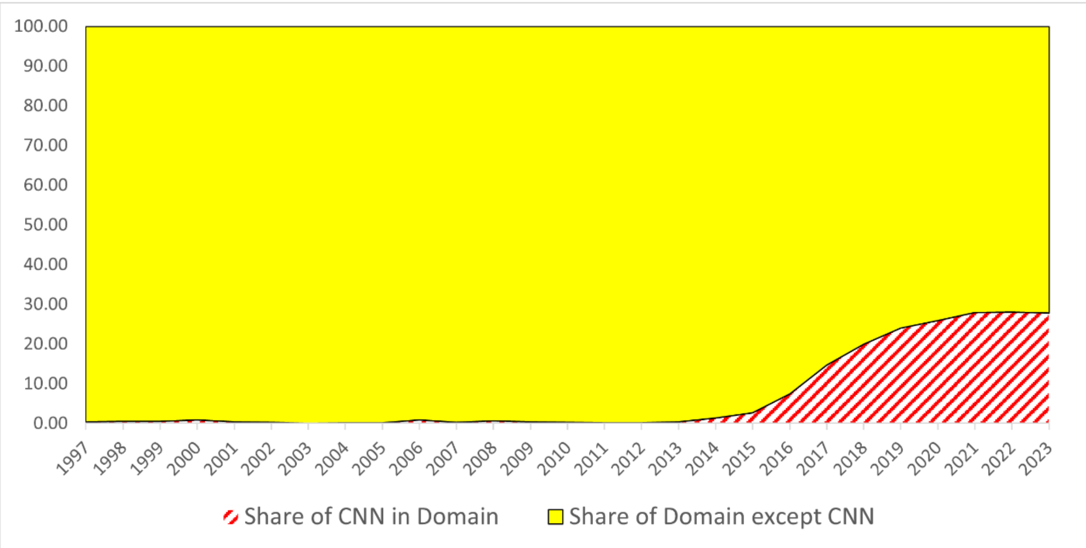

Figure 3. Patterns of morphological change in domain of large language models (LLM) generated by CNN (publications).

5. Discussions

5.1. Explanations of Results

The prediction of the proposed theory of predatory research fields/technologies, verified with empirical evidence in the context of LLL, can be explained with the approach of destructive technology that lay the foundations for radical scientific and technological change, based on new products and/or processes, that have high technical and/or economic performance directed to reduce market share or destroy the usage value of established technologies/products/processes previously used in markets, generating technological and social change (Coccia, 2020). Adner (2002, pp. 668-669) claims that: “Disruptive technologies . . . introduce a different performance package from mainstream technologies” (cf., Calvano, 2007; Coccia, 2019).

Abernathy and Clark (1985, pp. 4*ff* and pp. 12-13, original emphasis) claim that:

An innovation is . . . . derived from advances in science, ... that disrupts and renders established technical and production competence obsolete, yet is applied to existing

> markets and customers, is … labelled 'Revolutionary'. It thus seems clear that the power of an innovation to unleash Schumpeter's 'creative destruction' must be gauged by the extent to which it alters the parameters of competition, as well as by the shifts it causes in required technical competence. An innovation of the most unique and unduplicative sort will only have great significance for competition and the evolution of industry when effectively linked to market needs.

Christensen (1997) argues that disruptive technology has specific characteristics: a) higher technological performance; b) provide products/processes that satisfy needs and are demanded by mainstream market. Christensen et al. (2015) claim that disruptive technologies or innovations can be generated by small firms with fewer resources that successfully challenge established incumbent businesses (e.g., the case of OpenAI for ChatGPT). Innovative firms, generating disruptive innovations, grow more rapidly than other ones (Abernathy and Clark, 1985; Tushman and Anderson, 1986, p. 439). Christensen's (1997) approach also shows that disruptive technologies generate significant shifts in markets (cf., Henderson, 2006). In general, technological and market shifts embody competence-destroying and competence-enhancing because some firms can either destroy or enhance the competence and technologies existing in a specific industry (cf., Hill and Rothaermel, 2003; Tushman and Anderson, 1986). Predatory research fields and technologies are disruptive technologies that undermine the competences and complementary assets of existing producers, and change markets and habits of consumers in society (Christensen and Raynor, 2003; Garud et al., 2015; Markides, 2006; cf., Coccia, 2005). The diffusion and growth rate of predatory research fields, guided by emerging firms, support disruptive innovations that are important drivers to create and sustain competitive advantage of firms amidst rapidly changing business environments (Kessler and Chakrabarti, 1996, p. 1143). Calvano (2007) argues that it is the role of destruction rather than creation in driving innovative activity, such as predatory research field of transformers that is supporting, more and more, applications of Artificial Intelligence in practical contexts (cf., Nonaka and Nishiguchi, 2001; Nonaka and Toyama, 2003).

Predatory research fields, as disruptive technology, affect the behavior of other technologies and research fields, generating a process of actual substitution of a new technique or research topic for the established one and, as a consequence, fostering technical, industrial and corporate change. What this study adds is that predatory research field explain a modern dynamics of the scientific and technological evolution in LLM that has the potential to be a disruptive technology that generates cluster of radical innovations in generative artificial intelligence in a short period of time fostering a wide technological, economic and social change.

5.2. Deduction for General Properties of Predatory Research Field

a) Let PTi a research field i having predatory behaviour

Let Prj research fields that are preys in the inter-related domain D of i; j=1, 2, …, m

(PTi, Prj)$\subseteq$D

t=year of emergence of PTi

σi=growth rate of predator PTi

τj =growth rate of pray Pr j

A predatory behaviour of PTi in the domain D is when at $t+n$

$\sigma i>0$, and $\sigma i > 2\tau j$, $\forall j=1, 2, \dots, m$

b) Predatory research fields is always associated with some comparable established research fields/technologies (pray) in markets.

c) The long-run behavior and evolution of any predatory technology is not independent of from the behavior of other comparable technologies.

d) In the short run, predatory research fields/technologies destroy with a rapid growth alternative technologies and lay the foundations for radical shifts driven by clusters of radical innovations.

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e) A predatory behaviour, in a short period of time, increases its share in the related domain occupying the space of alternative technologies/research fields and laying the foundation to be a dominant research field/technology for supporting a major scientific and technological change.

f) In the long run, predatory research field/technology has a series of technological advances of its own resulting from various major and minor innovations that pave the technological direction to be a dominant technology over other established technologies/research field in markets.

6. Conclusions

This study shows, for the first time, the basic role of predatory research fields in driving scientific and technological change. The theoretical framework is verified in the case study of transformer architecture technology that has an unparalleled growth at expense of other established technologies and research fields, occupying space, destroying them, and creating basic conditions to generate a drastic scientific change in LLM with consequential radical technological change driven by generative artificial intelligence having main effects on economic and social change. Driving force of Transformers and related applications such as ChatGPT by Open AI launched in November 2022, Microsoft copilot emerged in February 2023, etc. is the improvement of performance in LLM such as it is able to enter into the mainstream of research field and technological domain. In particular, transformer architecture outperforms in terms of performance other technologies such as Recurrent Neural networks (RNNs) because of the "attention mechanism" concept that focuses on different parts of the input sequence when making each output token. This science dynamics affects and attracts community of scholars in this new scientific fields to develop various major and minor innovations that pave the technological direction by ''expanding the adjacent possible'' (Kauffman, 1996; Monechi at al., 201; Tria et al., 2014; Iacopini et al., 2018) to be a dominant technology over other established technologies in markets (Crane, 1972; Guimera et al., 2005; Wagner, 2008).

5.1. Theoretical Implications

Predatory research fields of transformer architecture, as disruptive topics and/or technologies, introduce a different performance package from mainstream technologies. Scientific and technological development raises the disruptive technology's performance on the focal mainstream attributes to a level sufficient to satisfy mainstream customers (Adner, 2002; Adner and Zemsky. 2005). The underlying force is the learning via diffusion and diffusion by learning that support the development and adoption of the predatory research field with disruptive technology in turbulent (complex and fast changing) markets.

5.2. Managerial and Policy Implications

In fact, this study shows main properties of the evolution of technologies, which can guide R&D investments towards fruitful scientific and technological domains for a positive socioeconomic impact (Coccia, 2022). Hence, policymakers and R&D managers can use the findings here for making efficient decisions regarding the sponsoring of specific trajectories in LLM to foster technology transfer with fruitful effects for generating radical innovations and boosting up next technological change. In the presence of these findings, organizations can apply an ambidexterity strategy of innovation management by balancing exploration and exploitation approaches in LLM, which allow the organization to be adaptable to turbulent environments and achieve and sustain competitive advantage (Duncan, 1976; March, 1991; Raisch and Birkinshaw, 2008). In particular, organization can apply an innovation strategy of exploration based on search, risk taking, experimentation, selection, discoveries and flexibility between different scientific technological pathways. Firms that focus only on exploration have to consider facing the risk of wasting resources on some research topics and emerging technologies that may fail and never be developed (Coccia, 2023). The innovation management implications is that financial resources on vital fields of research can be an accelerator factor of progress and diffusion of science and technology (Mosleh et al., 2022; Roshani et

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al., 2021, 2022). Policymakers and R&D managers can apply results of this study for an effective allocation of resources towards new research fields and converging technologies to foster the development of new knowledge, scientific research and innovations for a positive impact in science and society.

5.3. Limitations and Ideas for Future Research

This study shows for the first time, to our knowledge, evolutionary dynamics of predatory research fields that is verified with emerging technologies of transformers in LLM to explain some properties of evolutionary pathways. These findings here can encourage further theoretical exploration in the *terra incognita* of the predatory behaviour in science and technology to clarify basic properties of scientific and technological evolution. These conclusions are, of course, tentative. This study provides some interesting but preliminary results in these complex fields of research related to technological analysis of emerging technologies. Some limitations are that: 1) scientific outputs and research topics can only detect certain aspects of the ongoing dynamics of predatory research fields and next study should apply complementary analysis; 2) confounding factors (e.g., level of public and private R&D investments, international collaboration in specific technologies, etc.) affect the evolution of technologies having a predatory behaviour and these aspects have to be considered in future studies to improve data gathering for technological analyses.

In short, there is need for much more detailed research into the investigation of the predatory behaviour to clarify evolutionary patterns of technologies and support implications for innovation management and technological forecasting. Despite these limitations, the results here clearly illustrate that a predatory research field can clarify basic characteristics of scientific and technological change in environments with rapid changes. These aspects are basic for improving the prediction of evolutionary pathways of emerging technologies and supporting R&D investments towards technologies and innovations having a high potential of growth and of impact on socioeconomic system. To conclude, the proposed theoretical framework may lay the foundation for development of more sophisticated concepts and theoretical frameworks in economics of technical change to explain and forecast technological evolution. However, a comprehensive explanation of the predatory behaviour in the evolution of technology is a difficult topic for manifold complex and inter-related factors in the presence of changing and turbulent environment (Ziman, 2000), such that Wright (1997, p. 1562) properly claims that: "In the world of technological change, bounded rationality is the rule."

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