JOIV : Int. J. Inform. Visualization, 8(3-2): IT for Global Goals: Building a Sustainable Tomorrow - November 2024 1791-1801

INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

Determinants Generating General Purpose Technologies in Economic Systems: A New Method of Analysis and Economic Implications

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***Abstract*— This research proposes using the fishbone diagram, a visualization tool for constructing a comprehensive theoretical framework to analyze the sources of innovation. Traditionally employed to identify causes of specific events, the fishbone diagram is applied innovatively to explore the root causes driving the emergence and evolution of General Purpose Technologies (GPTs). The study identifies critical driving forces such as increased democratization, population growth, demographic shifts, significant investments in research and development (R&D), global leadership aspirations among major powers, competitive socioeconomic environments, and potential threats from adversarial actors. By visually representing these drivers, the fishbone diagram offers insights crucial for technological analysis and foresight, illuminating groundbreaking innovations that drive technological and economic progress. Illustrated through examples from historical GPTs like the steam engine and contemporary technologies such as Information and Communication Technologies (ICTs), this study establishes a foundational framework for developing precise hypotheses about the specific causes and socio-economic impacts of GPTs. The fishbone diagram emerges as a versatile tool adept at systematically analyzing the complex root causes associated with GPTs, facilitating foresight and strategic management of these transformative innovations within society.**

***Keywords*— General Purpose Technology (GPT); technological evolution; economic systems and implications; fishbone diagram.**

Manuscript received 23 Mar. 2024; revised 19 Jun. 2024; accepted 28 Jul. 2024. Date of publication 30 Nov. 2024.

I. INTRODUCTION

This study aims to propose the use of the fishbone diagram. This new visual representation method will enable in-depth analysis of the root causes affecting the emergence and development of General Purpose Technologies (GATs). Identifying the main driving forces driving the emergence of GATs and systematically visualizing the complex interactions of these factors can offer a valuable perspective for technological analysis and forecasting. The effectiveness of the fishbone diagram will be demonstrated by applying it to such technologies in the past (e.g., the steam engine) and today's examples, such as Communication and Information Technologies, thereby creating a framework for understanding the long-term effects of GATs on socio-economic systems. This research aims to highlight the importance of the fishbone diagram as a visual tool that can be used in the management of GATs and the strategic management of these transformative innovations. This research underscores the importance of technological advancement in driving sustained economic growth, a notion extensively corroborated by numerous scholars in the field [1]–[10]. General Purpose Technologies (GPTs) emerge as a pivotal element within this dynamic progress landscape. These transformative technologies can render prior knowledge obsolete, acting as a catalyst for far-reaching industrial and economic transformation across interconnected nations [11]–[13]. Significantly, GPTs function as advancements in themselves and as enabling technologies, fostering widespread adoption across many sectors and acting as a springboard for developing novel products, processes, and even new industries [1].

Furthermore, the emergence of GPTs often triggers paradigm shifts within the technological landscape, impacting virtually every facet of the economic sphere, from production and consumption patterns to labor markets and international trade [14]. The technological revolution has been a continuous driver of economic growth throughout human history [1], [15], [16]. Ruttan [17] further emphasizes the critical role that GPTs play in sustaining productivity and economic growth over extended periods, arguing that their impact goes far beyond simple one-time improvements [17]. It is crucial to recognize that the forces driving GPTs differ significantly from those that propel less impactful innovations [1], [6], [16], [18]–[20]. While scholars have proposed various methodologies to understand the source of technological change [1], [21]–[29], a universally accepted visualization technique for systematically analyzing the potential root causes of GPTs remains elusive. In recognition of this gap, the present study addresses this challenge by employing the fishbone diagram. This method is a powerful tool for effectively representing and dissecting the complex interplay of factors that determine the emergence and development of GPTs. The primary objective of this research is, therefore, to introduce a novel visual representation that facilitates a deeper exploration of the potential root causes behind General Purpose Technologies, ultimately contributing to a more comprehensive understanding of long-term economic change within society and paving the way for more strategic approaches to cultivating these transformative technologies.

Technological advancement has long been recognized as a cornerstone of sustained economic growth, a concept robustly supported by extensive scholarly research. General Purpose Technologies (GPTs) stand out in this context due to their exceptional transformative potential. Unlike incremental technological improvements, GPTs catalyze widespread industrial and economic changes, rendering previous knowledge and practices obsolete. Their influence extends across multiple sectors, prompting the development of new products, processes, and even industries. The dynamic nature of GPTs enables them to foster substantial shifts in production, consumption, labor markets, and international trade, thereby perpetuating technological revolutions that drive long-term economic growth.

The profound impact of GPTs on economic productivity and growth has been a focal point for scholars who argue that these technologies do more than provide one-time advancements. They are critical drivers of sustained productivity improvements over extended periods. Despite the significant role of GPTs, understanding the intricate factors that lead to their emergence and development remains a complex challenge. Various methodologies have been proposed to trace the sources of technological change, yet a universally accepted framework for visualizing these root causes still needs to be developed. This research addresses this gap by introducing the fishbone diagram as a novel tool to systematically analyze and represent the multifaceted factors influencing the development of GPTs. Doing so aims to enhance our comprehension of the mechanisms behind these transformative technologies, contributing to more strategic efforts in fostering their growth and ensuring continuous economic advancement.

II. Materials and Method

A. Conceptual Grounding

General Purpose Technologies (GPTs) represents a seismic shift from existing technological norms and established development paths [12], [30]. These groundbreaking innovations are not merely incremental improvements but rather transformative forces that usher in a period of "destructive creation" [30]. This process renders previously dominant products, processes, and knowledge obsolete, paving the way for entirely new paradigms. Lipsey et al. [31] offer a succinct definition of GPTs: technologies with significant potential for continuous improvement, achieving widespread adoption across many users. Furthermore, these technologies act as catalysts, fostering the development of numerous complementary technologies – both Hicksian (related to both demand and supply) and technological advancements.

The impact of GPTs extends far beyond individual companies or industries. These enabling technologies exert a pervasive influence, ultimately permeating the entire economic structure [7], [32]. The diffusion of GPTs creates cascading effects that dismantle barriers within and between socioeconomic systems. Imagine a domino effect, where the toppling of one domino triggers the fall of others in rapid succession. Similarly, GPTs trigger significant techno-economic transformations within society, fundamentally altering how we produce, consume, and interact with the world around us. Coccia [19] classifies GPTs on the scale of innovation intensity, reserving the highest designation for those with the most profound socioeconomic impact. In particular, Coccia [19] claims, referring to revolutionary innovations like GPTs, that:

> *"The means of human communication are radically changed and a new means of communication, which heavily affects all the economic subjects and objects, is born, forcing all those who use it to change their habits. A new technoeconomic paradigm is born ... The propulsive capacity for development offered by seventh-degree innovation is so high that it hauls the entire economy. Thanks to the new methods of communication, there is also greater territorial, social, and human integration. Another characteristic of seventh-degree innovations is the ease of their spread. The mobility of people, goods, capital, and information increases and the time taken to travel and communicate is reduced".*

Bresnahan and Trajtenberg [15] depict GPTs as having a tree-like structure, with the core new technology acting as the trunk and numerous derived technologies branching out into various sectors of the economy. This analogy aptly captures the essence of GPTs. They are foundational processes, components, or infrastructure for diverse products and process families across various industries. These families are built in distinctly different ways, highlighting the remarkable versatility of GPTs. Over time, pursuing profit, temporary monopolies, or long-term competitive advantages in various sectors and industries drives firms. This relentless pursuit of advantage motivates them to explore the diverse applications of GPTs continuously, identifying new ways to leverage these powerful technologies [19].

Several vital characteristics define GPTs:

1) Pervasiveness: They spread and influence most economic sectors, fostering technological advancements and productivity growth in many industries [33]. Imagine a rising tide that lifts all boats. Similarly, GPTs have the potential to trigger widespread growth across the economic landscape.

2) Continuous Improvement: They undergo ongoing advancements, leading to sustained cost reductions for their users across various sectors [33]. As GPTs mature, they become more efficient and affordable, opening doors to new applications and user bases.

3) *Innovation Spawning:* They facilitate developing and producing novel products and processes [33]. GPTs act as catalysts, sparking creativity and innovation across different industries.

Lipsey et al. [16] add other defining features:

1) *Scope for Improvement:* They possess significant potential for further development throughout their technological lifecycle. GPTs are not static inventions; they can be continuously refined and improved, leading to even greater capabilities over time.

2) *Wide Range of Uses:* Throughout their evolution, GPTs have offered a diverse array of applications. A single GPT can have countless potential uses, depending on the ingenuity of developers and the specific needs of different industries.

3) *Strong Complementarities:* They are compatible with existing and emerging technologies [35], [36]. GPTs act as building blocks, seamlessly integrating with other technologies to create even more powerful and versatile systems.

Another distinguishing characteristic is the often-lengthy period between a GPT's initial invention and its widespread commercialization in new products and processes [16], [31]. Rosegger [36] estimated this timeframe to be around 50 years for various technologies, such as electric motors, electric arc lights, and synthetic resins. This lag time highlights the complexity of GPTs, and the significant research, development, and adaptation efforts required before they can be fully harnessed for commercial applications. In summary, GPTs are complex technologies encompassing both general platforms (e.g., satellites) and fundamental components (e.g., semiconductors). They drive product and process innovations across various sectors, leading to transformative changes on corporate, industrial, economic, and social levels [37]–[42]. Electricity and information and communication technologies (ICT) are considered prime examples of GPTs [33], [19].

B. Study Design

This research aims to develop a visualization technique specifically tailored to analyze and represent the sources and potential effects of General Purpose Technologies (GPTs). To achieve this ambitious goal, the study first establishes a firm foundation by providing a general overview gleaned from the rich tapestry of socio-economic literature. This initial phase involves meticulously identifying and describing the key drivers that act as the lifeblood of GPTs.

Secondly, the study strategically leverages the power of the fishbone diagram, also known by its aliases – the Ishikawa diagram or cause-and-effect diagram – to systematically organize the complex network of these drivers. This visual representation is a powerful tool, aiding in elucidating the interconnected factors that contribute to the emergence of GPTs. Fishbone diagrams, aptly named for their resemblance to a fish skeleton, are a mainstay in management science, particularly valuable for cause-and-effect analysis. This established technique allows for meticulously identifying the intricate interplay between various causes contributing to a specific problem or event. (Fig. 1).

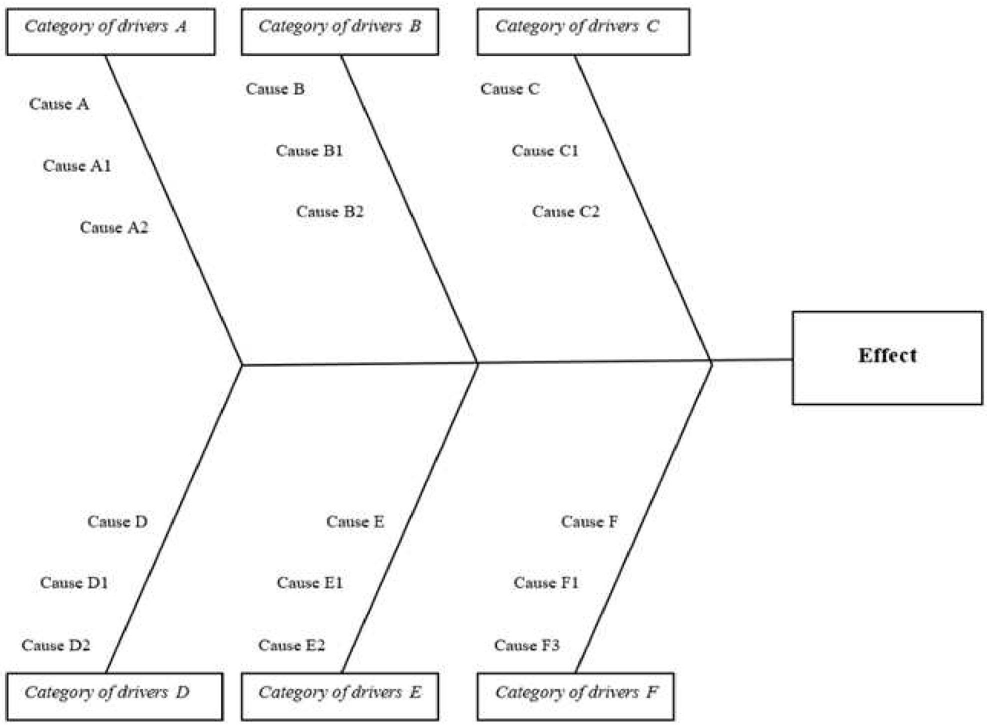

Fig. 1 A Fishbone Diagram

This research strategically leverages the power of the fishbone diagram, also known by its alternate name – the Ishikawa diagram – to systematically analyze and visually represent the intricate network of factors driving the emergence of General Purpose Technologies (GPTs). This technique boasts a rich history, initially developed by Kaoru Ishikawa [43] for quality control in product manufacturing. Over time, it has transcended its initial purpose, evolving into a valuable tool across various disciplines. In the context of GPTs, the fishbone diagram allows us to meticulously identify and categorize the potential causes that contribute to their development. Each cause on the diagram represents a variation influencing the trajectory of GPTs. By grouping these causes into major categories, we can begin to uncover the overarching themes and factors that lead to the emergence of these transformative technologies (Fig. 1). This visual representation serves as a powerful key to unlocking a deeper understanding of the complex interplay between various elements.

The versatility of the fishbone diagram makes it particularly well-suited for investigating phenomena with intricate cause-and-effect relationships, perfectly mirroring the complex interplay of factors driving the development of GPTs [44]–[46]. In fact, Ramakrishna and Brightman [47] conducted a study comparing the effectiveness of the fishbone diagram against other methods like Fact-Net-Model and Kepner-Tregoe for analyzing cause-and-effect relationships. Their findings underscore the fishbone diagram's strengths in this domain.

Overall, the fishbone diagram's exceptional ability to visually represent the interconnected drivers of complex technologies makes it an ideal tool for analyzing the factors that influence the emergence of GPTs. (Fig. 1, if applicable, can be referenced here to illustrate the concept). By leveraging this tool, we can gain a deeper understanding of the intricate dance between various elements that ultimately lead to the development of these groundbreaking technologies.

III. Results and Discussion

The emergence of General Purpose Technologies (GPTs) is driven by a multitude of complex factors that evolve and vary over time and across different regions [6]–[9], [12], [17], [48]–[50]. This section will explore some of these key drivers:

A. Geographical Factors: Natural Resources and a Moderate Climate

Geographical considerations and the natural environment are deeply knit into the fabric of technological innovation, primarily human enterprise [35]. The distribution of people is influenced by specific geographic elements such as mountain ranges, coasts, and bodies of water. Population concentrations like this consequently led to innovation centers, inventive activity, and technical improvement [51]. One specialized area of research, dubbed "the new geography of innovation," carefully looks at many spatial variables associated with the emergence and dissemination of technological innovation. These include resource clustering in particular regions and the physical proximity of economic organizations, such as firms and research institutions [52]–[54]. Specifically, the idea of "new economic geography" highlights how all forms of production are inextricably linked to and dependent on the environment [55]. The world's resources—material and human—are not dispersed equally.

Feldman and Kogler [56] contend that particular places' climate and resource endowments can spark economic growth and innovation [57]. Interestingly, Lichtenberg [58] argued that spatial considerations are more complex than being close to markets or raw resources. They impact knowledge generation and how different innovations build upon one another. This idea is further reinforced by Audretsch and Feldman [59], who point out that the clustering of businesses and creative endeavors is associated with benefits provided by the natural environment, like easily accessible resources and other physical geographic features.

Natural and human resources typically concentrate in particular geographic areas, such as huge cities. It has long been acknowledged that these urban areas are society's main sources of innovation and development [60]. Another important geographic component that affects both natural resources and human activity is climate. As early as 1748, Montesquieu [61] contended that the climate shapes human conduct, culture, and societal knowledge. According to recent economic research, warm, temperate climates provide a natural setting ideal for human habitation. Such conditions encourage the creation of complex civilizations, effective institutions, and communication networks through an evolutionary process of adaptation and learning. This socio-economic platform, developed within and across cities in temperate-zone nations, makes it easier to use resources and human capital effectively. In the end, this results in an increased frequency of inventions and innovations and their dispersion throughout space and time [19].

B. Religious and Cultural Aspects

Successful explanations of economic performance must venture beyond purely economic factors and delve into the complex interplay of political and social forces, recognizing that a nation's economic prosperity is not solely determined by financial metrics but also by an intricate web of social and cultural influences [62]. Modern economic literature increasingly sheds light on the social drivers of economic development, including the influence of culture, which encompasses a society's values, beliefs, norms, and behaviors [63]–[64]. These cultural factors can significantly shape economic outcomes by influencing work ethic, risk-taking propensity, and social trust [65-66].

Max Weber, in his seminal work The Protestant Ethic and the Spirit of Capitalism, explored how Protestant religious culture, with its emphasis on hard work, thrift, and worldly achievement, historically fostered economic behavior conducive to entrepreneurship within capitalist systems [67]. This notion has sparked a wave of contemporary socio-economic analyses that highlight religion and culture as fundamental drivers of economic growth and innovation, with studies exploring how cultural values like individualism, delayed gratification, and openness to new ideas can influence a society's propensity for innovation and economic dynamism [37], [68]–[70]. His exploration of how Protestant ethics such as hard work and thrift catalyzed entrepreneurial activity aligns with the concept of General Purpose Technologies (GPTs), which similarly act as catalysts for broad economic transformations. Weber's emphasis on cultural values shaping economic dynamism resonates with the role of GPTs in fostering innovation by enabling new products, processes, and industries. This perspective highlights the interconnectedness between cultural factors, like the Protestant work ethic, and transformative technological advancements that drive long-term economic growth.

The Intertwined Threads of Religion, Culture, and Economic Growth: Guiso et al. [63] meticulously examine the intricate interplay between religious beliefs and societal attitudes that promote economic growth. These attitudes include cooperation, trust, thriftiness, and the establishment of efficient governance structures. Their findings suggest a positive correlation between religious beliefs, higher per capita income, and economic growth [63]. Interestingly, Christian religions appear more strongly associated with these growth-conducive attitudes [71].

Religion is a powerful force that shapes people's values, educational attainment, and countries' broader cultural and institutional landscape. Consequently, it likely serves as a significant socio-cultural determinant of technological innovation patterns [23]–[34, [39], [40]. Studies reveal that societies dominated by Protestant, Jewish, and Eastern religions exhibit higher technological performance than those with other prevalent religious cultures [23-24]. This phenomenon is likely attributed to the complex interplay between specific religions, cultural values, and educational systems. These factors working in concert can foster a high-skilled workforce, effective institutions, and sound economic governance – all essential ingredients for a thriving innovation ecosystem.

Furthermore, within developed societies, a higher degree of religious and ethnic diversity, holding other factors constant, positively affects technological outputs. This correlation seems particularly strong in wealthier and more democratic nations, primarily in European and North American regions [24]. It's important to note that these findings are preliminary, and further research is needed to fully untangle the intricate relationships between religion, culture, and national innovation patterns.

C. Democratization

Democracy, characterized by a well-defined set of practices and principles that safeguard and institutionalize fundamental freedoms [72], [73], exhibits a complex and fascinating interplay with economic development. While the causal relationship may seem straightforward, it is far more nuanced. An economist, Barro [66], suggests that rising living standards predict a gradual increase in democratic practices. However, the relationship is flexible. Acemoglu et al. [74] delve deeper into this intricate dance, arguing that political and economic development paths are intricately linked, fostering a mutually reinforcing cycle.

Coccia [37] proposes a thought-provoking hypothesis: democratization may precede and even catalyze technological and economic change. Notably, democratization appears to be a key driver of technological advancements rather than simply a consequence. Countries with higher levels of freedom, as measured by established indices for liberal, participatory, and constitutional democracy, tend to exhibit greater technological output than less free and more autocratic nations.

This correlation can likely be attributed to the positive influence of democratic institutions on several key factors. A robust democratic framework fosters a richer flow of information and ideas, encouraging open discourse and knowledge sharing. This intellectual climate and strong higher education systems contribute to developing a highly skilled workforce. Ultimately, this fertile ground of freedom, education, and experienced talent leads to fruitful technological innovation patterns, improving citizens' well-being and long-term national prosperity [37]–[40].

D. High rates of Demographic and Population Change

Population growth significantly influences technological innovation patterns, wielding advantages and potential drawbacks [37]. Economist Simon Kuznets [75] proposed a compelling argument: larger populations naturally lead to more potential inventors. As cited by Kremer [76], Kuznets reasoned that population growth "produces a larger number of geniuses, talented men, and generally gifted contributors to new knowledge whose native ability would be permitted to mature to effective levels when they join the labor force" [75]. A larger population increases the odds of producing groundbreaking ideas simply by having more individuals who could be the next Isaac Newton [77]. Like Kuznets [75], Simon [50] echoed this notion, proposing that larger populations inherently have a higher probability of producing inventors due to the sheer number of individuals with the potential to spark revolutionary ideas.

Beyond numbers, the demand side of innovation, a large population can create significant demand for new inventions and innovations. This increased demand acts as a powerful driver, incentivizing the development of solutions to pressing problems and unmet needs. Consequently, population growth and dynamic demographic shifts can be crucial in supporting technological innovation within advanced national innovation systems [37, 78].

The Importance of Finding the Sweet Spot: However, research suggests that maximizing technological performance in developed nations may require an optimal population growth rate, potentially falling below 1% annually. Both negative and very high growth rates can have a detrimental effect on innovation due to a "quadratic effect," which can be visualized as an inverted-U-shaped curve. This suggests a tipping point, where populations either too small or growing too rapidly may hinder innovative output [37]. These findings align with Strulik's observation [79] that long-term economic growth can coexist with a stable population. There is a sweet spot regarding population size that fosters the ideal environment for sustained innovation.

E. Relevant Problem in Society

The text introduces the idea that General Purpose Technologies (GPTs) are inherently problem-solving-oriented, tackling significant challenges faced by society [32] or organizations [65]. To understand how GPTs emerge, it's helpful to consider the theoretical framework of Gestalt psychology, particularly Usher's [80] theory of cumulative synthesis [81]. This theory proposes four key stages that drive the evolution of new technologies:

1) Problem Perception: Recognizing an incomplete situation or unresolved challenge necessitating a solution.

2) Setting the Stage: Gathering and analyzing data related to the identified problem.

3) The Eureka Moment: A flash of insight that leads to a potential solution.

4) Critical Revision: Evaluating and refining the solution, potentially generating further insights and improvements.

Usher's theory emphasizes the role of "acts of insight" as fundamental drivers of problem-solving and groundbreaking innovation. This aligns with the argument that the psychological aspects of invention, fueled by the need to address critical problems, are central to developing new technologies that ultimately lead to cumulative societal change [81]. Building on this idea, Coccia's [37] inductive study in the medical field reveals those significant problems that act as catalysts for the evolution of radical and incremental innovations. This is exemplified by the various advancements in targeted cancer therapies [38]. In essence, GPTs are driven by a problem-solving imperative emerging in response to critical challenges society or organizations face. This aligns with Usher's concept of "acts of insight" and Coccia's observation that consequential problems fuel innovation.

F. Major Wars and Environmental Threats

Beyond the previously discussed drivers, Vernon Ruttan [9] proposes that war, or the threat of significant conflict, can also contribute to the emergence of GPTs. During major wars, the large-scale mobilization of scientific, technical, and financial resources can create fertile ground for the development of GPTs [9]. More specifically, Ruttan argues that significant wars, or the imminent threat of such conflicts, can act as a catalyst, prompting powerful nations to commit substantial resources to research and development (R&D) efforts. These resources are directed toward generating or sustaining the development of groundbreaking new technologies that address strategic problems and provide a competitive edge in potentially hostile environments [9]. In essence, Ruttan suggests that war and the threat of war can act as drivers for developing GPTs, leading to clusters of commercially viable innovations that fuel economic growth [9].

G. Purpose of Global Leadership in Contestable Environments

Building upon the concept of war as a driver of GPTs, Mario Coccia [37] proposes a broader theory of global leadership-driven innovation. This theory suggests that the primary source of GPTs lies not in war itself but in the purposeful actions of leading countries aiming to achieve or maintain global leadership. According to Coccia, these nations leverage their high economic potential and purposeful institutions to tackle critical environmental threats and capitalize on significant environmental opportunities.

This framework can be seen as an extension of Ruttan's [9] argument, emphasizing the strategic intent of leading powers in driving GPT development. Coccia argues that the ambition for global leadership is a stronger impetus than war alone, prompting nations to invest heavily in solving strategic and relevant problems through technological advancements.

Critical aspects of Coccia's theory include:

1) The purpose of global leadership as the main driver for developing GPTs.

2) Leading countries' strategic use of new technologies during military and political tension periods. This includes historical examples like the competition for technological and scientific supremacy between the US and the Soviet Union during the 1960s, which led to significant advancements in Information and Communication Technologies (ICTs) and satellite technology.

3) The emergence of GPTs like the US Navy's Mobile User Objective System (MUOS), a satellite constellation with the potential to fuel various future product and process innovations, ultimately contributing to maintaining US global leadership in contested environments.

In essence, Coccia's theory highlights the strategic motivations of leading powers in driving the development of GPTs, emphasizing their use as tools to address critical challenges and secure global influence. This framework complements Ruttan's perspective by placing the purpose of global leadership at the forefront of the narrative surrounding the emergence of GPTs.

H. National Innovation System, Public Research Labs, and Research Policy

Governments in developed nations prioritize significant increases in research and development (R&D) investments to catalyze technological advancements and propel economic productivity growth [4]–[5]. R&D funding encompasses expenditures by various sectors, including industry, government, higher education institutions (HEIs), and private non-profit organizations. This funding plays a critical role in supporting and fostering technological innovation across entire economies, with studies demonstrating a positive return on investment (ROI) for R&D spending [35], [37], [82].

Beyond just funding, efficient public research labs and their effective technology transfer mechanisms within economic systems are also recognized as essential drivers of innovation [38]. These labs are hubs for scientific exploration and discovery, attracting top researchers and fostering cutting-edge advancements. Effective technology transfer mechanisms ensure that these advancements reach businesses and industries, where they can be translated into practical applications, leading to the commercialization of new products, processes, and services. This knowledge transfer process can be facilitated through various mechanisms, including collaborative research projects between universities and industry, licensing agreements, and creating science parks that foster close physical proximity between researchers and businesses [83-84].

Studies by Griffith et al. [85] provide compelling evidence of a direct and positive correlation between R&D investments and Total Factor Productivity (TFP) growth across various OECD countries. However, Mamuneas and Nadiri [86] emphasize the importance of identifying the optimal mix of R&D incentives, such as tax credits and immediate deductions, to achieve balanced growth in output and productivity within the manufacturing sector (p.57). Striking this balance is crucial, as the wrong mix of incentives could lead to inefficiencies or a focus on short-term gains over long-term strategic investments in areas like basic research and high-risk ventures. Similarly, Zachariadis [86] observes a positive relationship between TFP and R&D investment. This reinforces the notion that R&D spending is a key driver of productivity gains, allowing companies to produce more output with the same input.

Furthermore, Coccia's research [32] suggests that when R&D spending by the business sector surpasses that of the government sector, this configuration tends to lead to higher labor productivity and more robust GDP growth, assuming other factors remain constant [34]. This highlights the importance of a strong private sector investment in R&D alongside continued government support. Additionally, Coccia's research [4], [6], [24] suggests that an R&D investment range of 2.3% to 2.6% of GDP may optimize long-term productivity growth in developed countries. This finding points towards a potential "political economy of R&D" that fosters sustained productivity, scientific and technical knowledge accumulation, and technological advancements within the industries of these nations. By strategically prioritizing and optimizing R&D investments across all sectors, governments can create an environment that cultivates a culture of innovation and propels economic growth, ultimately enhancing the living standards of their citizens.

This study highlights the fishbone diagram's effectiveness as a visualization tool for systematically analyzing and understanding the drivers of GPTs. Although not explicitly shown here due to limitations, this comprehensive theoretical framework helps to represent and explore the various factors contributing to the emergence of GPTs.

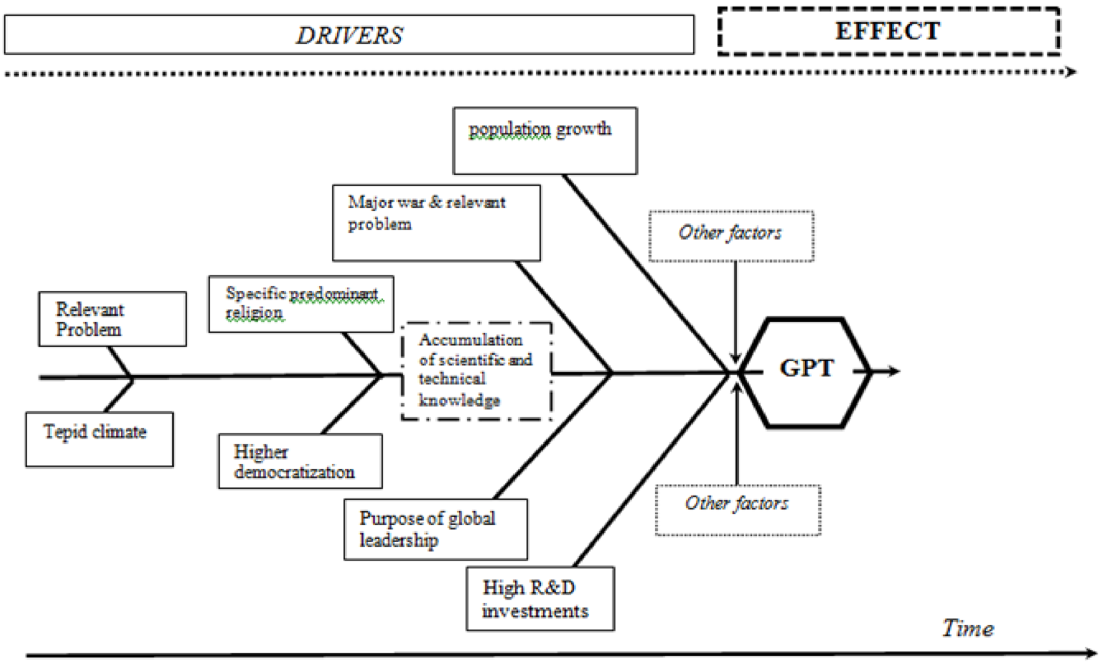

Fig. 2 Fishbone Diagram showing the factors influencing GPTs in developed countries.
Note: GPT = General Purpose Technology.

The study utilizes a fishbone diagram, a visualization tool, to explore the complex interplay of factors contributing to the emergence of GPTs (Figure 2, not shown here due to limitations).

1) Natural and human resources: Societies with temperate climates and abundant resources provide a foundation for GPT development. However, this is only a starting point.

2) Democratization and specific religions: Strong democratic institutions and the prevalence of certain religions, like Protestantism, can positively influence education systems and cultural factors, fostering environments conducive to GPTs.

3) Global leadership aspirations: Great powers striving to achieve or maintain global leadership often invest in technological advancements to address environmental challenges and secure competitive advantages in contested environments (e.g., during conflicts, military competition, or struggles for scientific and technological supremacy).

4) Efficient national innovation systems: Strong national innovation systems that invest in human and economic resources to solve critical problems through technological innovation are crucial.

5) Strategic competitive advantages: These factors ultimately contribute to strategic advantages in contested environments and support long-term economic growth.

6) Population growth: High population growth rates can also drive demand-driven innovation mechanisms within a society [4], [6], [24].

A. Long-Term Implications

The study suggests that some of the critical drivers of GPTs, as depicted in the fishbone diagram, may represent enduring and inherent characteristics of human societies throughout history rather than being solely influenced by isolated events [21]. This implies that the forces driving the emergence of GPTs might exhibit a degree of regularity in their historical development, particularly within the context of contested environments where advanced nations compete for global leadership or geo-economic dominance. In essence, the fishbone diagram serves as a valuable tool for visualizing and understanding the complex interplay of factors that influence the emergence and long-term impact of GPTs on human development.

B. Fishbone Diagram Benefits for Technology Analysis

The fishbone diagram is a powerful tool for undertaking a thorough technological examination of breakthroughs. Its strength lies in its ability to display every potential source of complex phenomena in a single, easy-to-understand diagram. This is particularly helpful for predicting the emergence of GPTs and other innovations. Fishbone diagrams illustrate rationally and clearly the underlying relationships between various factors. The fishbone diagram becomes an invaluable tool by visually representing the links and relationships between the possible causes and long-term effects of probable GPTs. It fosters a comprehensive technological study and evaluation that delves deeply into these ground-breaking technological advancements' potential causes and impacts.

This diagram offers a distinct advantage in understanding the cause and influencing variables of breakdowns within a particular technological process. By breaking down complicated phenomena like emerging GPTs into their constituent parts, the fishbone d diagram sheds light on the intricate web of factors at play. Furthermore, it goes beyond mere understanding by highlighting important elements that can be leveraged in favor of suitable technology policies designed to support the development of GPTs. In this way, the fishbone diagram becomes an active player in shaping the future of technological advancements.

The use of fishbone diagrams in technology management offers another layer of benefit. They can be instrumental in organizing and stimulating brainstorming sessions around the causes of particular GPT impacts. By providing a structured framework, the fishbone diagram ensures that brainstorming sessions are focused and productive, leading to a deeper exploration of the potential causes and effects.

In conclusion, visualizing the causes of GPTs and investigating their underlying causes through a fishbone diagram can be a powerful tool for predicting potential outcomes. This, in turn, can aid in developing technological policies to boost national income. Ultimately, the fishbone diagram serves as a springboard for technical analysis of GPTs by thoroughly representing all the causes and effects involved in technological processes. This comprehensive view allows for exploring secondary hypotheses depending on particular elements, paving the way for a more nuanced understanding of these emerging technologies.

The following is a representation of the sources of some GPTs throughout technological history, as shown by the Fishbone diagram. The English Steam Engine GPT (Fig. 3). Information and communications technologies (ICTs) are the source of the GPT in the United States of America (Fig. 4).

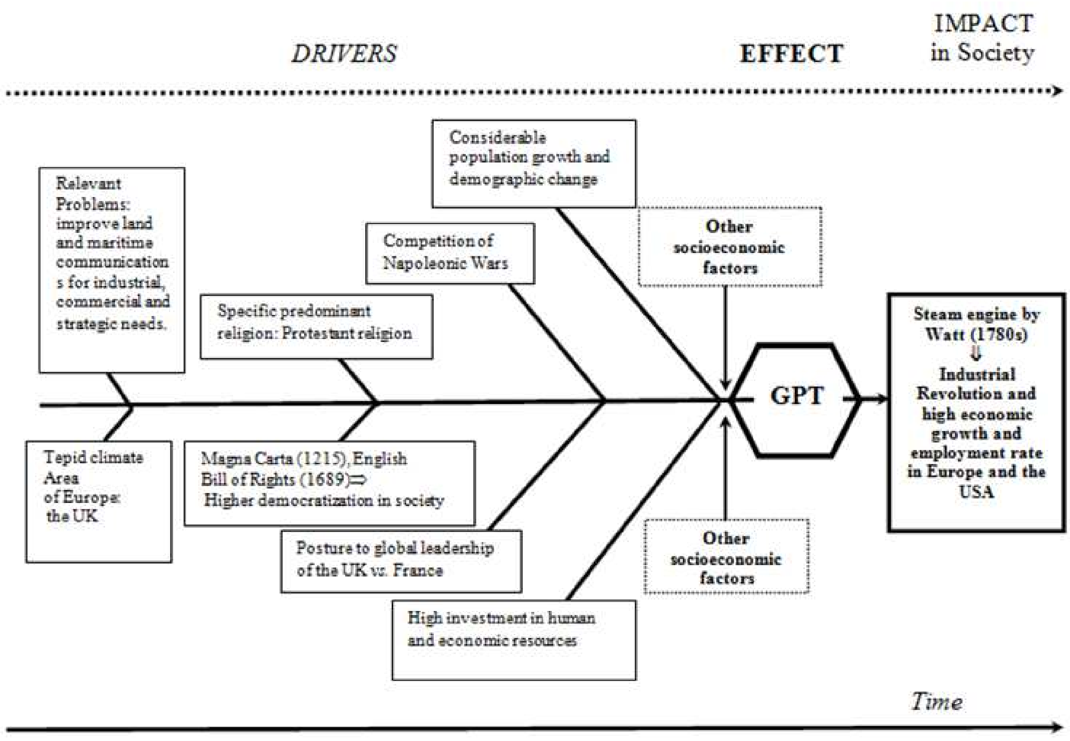

Fig. 3 A fishbone diagram from the 1700s that shows the factors that determined the performance of a steam engine

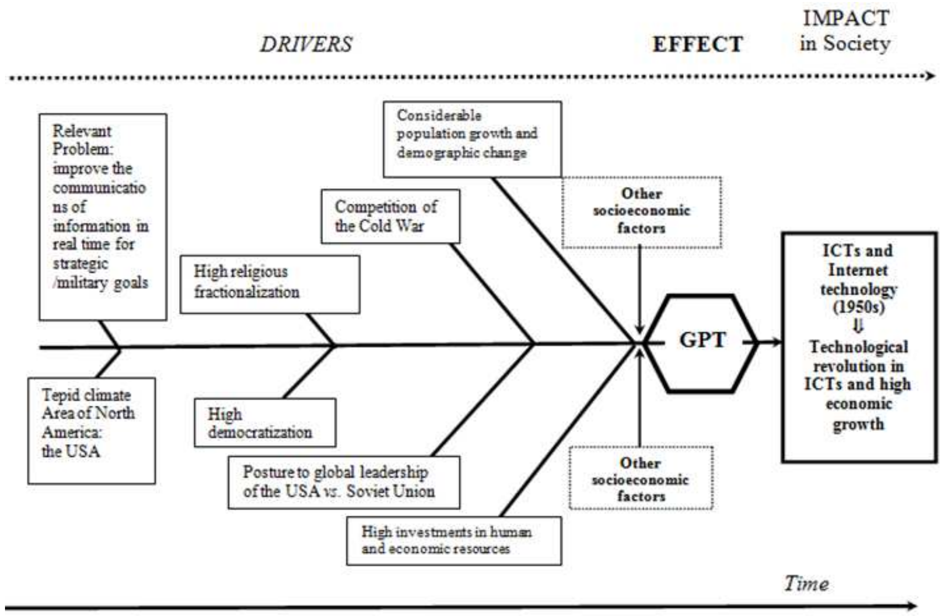

Fig. 4 The fishbone diagram offers a visual depiction of the 1950s ICT origins

IV. Conclusion

The historical evolution of GPTs demonstrates their pivotal role in driving economic and social transformation across industries [79]. Visual representations, such as fishbone diagrams, are essential for organizing and analyzing the origins of GPTs over time. This study emphasizes the effectiveness of fishbone diagrams in depicting the complex drivers of GPTs, offering clear insights into their development across various contexts.

Fishbone diagrams concisely overview the sequential determinants shaping GPT emergence throughout history and geographical locations. They facilitate a holistic understanding of the interconnected factors driving GPT development, enabling the identification of recurring patterns and contextual explanations for their flourishing in specific geo-economic regions.

Key findings highlight three main contributions of fishbone diagrams:

1. Comprehensive Visualization: They depict intricate cause-and-effect relationships driving GPTs, aiding in a deeper understanding of their developmental complexities.

2. Pattern Identification: Fishbone diagrams reveal familiar drivers across GPTs and historical periods, providing insights into the universal factors that foster their emergence.

3. Geo-Economic Insight: Visually mapping factors influencing GPTs, these diagrams elucidate why and how they thrive in particular regions and times, crucial for targeted policy and strategy formulation.

This theoretical framework aligns with the principles of simplicity and analogy, offering a coherent method for comprehending GPT dynamics and enhancing decision-making in technological advancements and socio-economic policies.

Further research directions include:

1) Contextual Factors: Exploring external and internal influences that shape GPT development across contexts.

2) Evolution Quantification: Applying phylogenetic methods to quantify GPT evolution and technological trajectories.

3) Generality Measurement: Developing metrics to assess the pervasiveness and impact of GPTs across diverse economic sectors.

In conclusion, fishbone diagrams provide a robust framework for visually understanding the intricate forces driving GPTs and related technological advancements. Continued research is necessary to refine this approach and deepen our understanding of the multifaceted predictors of GPT development, considering their context-dependent nature [21]. Therefore, further research is necessary to refine this strategy and gain a deeper understanding of the complex factors that predict the development of GPTs. We can gain a more nuanced perspective on these transformative technologies by exploring the influence of context-dependent factors, quantifying their evolution, and measuring their pervasiveness.

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