

The Inertia Problem of Technological Innovation: Tracing the Origins of “Path Dependency” and Principles for Breaking Free

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Abstract: *The path dependency of technology refers to the phenomenon where once a specific technological development path is chosen, a developmental inertia is formed. Future research and innovation are more likely to continue along this path rather than turn to other possible innovative routes, thereby affecting the sustainable progress of technology. The reasons behind the formation of technological path dependency can be traced back to complex factors such as developmental dilemmas, technological risks, technological alienation, and limitations of technological tool rationality. In addressing these root causes, principles such as technological progress, categorized and gradual implementation, non-mandatory reform, and collaborative efforts should be followed to escape the current technological path dependency predicament and achieve harmonious development between technology and human society, as well as technological innovation.*

Keywords: *Path dependency; Technological innovation; Origins of technological problems; Technological phenomena*

1. Introduction

In the realm of technological innovation, the phenomenon of path dependency emerges as a formidable barrier, ensnaring the strides of innovation within a cyclical trap of past choices and inertia. This entrenched mechanism of path dependency represents a core challenge in the evolution of technology, where the principal quandaries of technological advancement are rooted. Previous studies have seldom approached path dependency from a philosophical standpoint or delved into the essence of technology itself, leaving discussions on the fundamental causes behind the formation of technology-dependent paths scant and underexplored. This paper, through an in-depth analysis of historical contexts and the inherent characteristics of technological development, meticulously deconstructs the internal mechanisms that cultivate an environment of technological path dependency. These include the dilemmas of development, technological risks, the alienation intrinsic to technology, and the limitations imposed by the instrumental rationality of technological tools.

Furthermore, by proposing strategies such as ensuring continuous technological progress, implementing categorized and gradual approaches, advocating for non-mandatory reforms, and fostering principles of collaboration, this research aims to chart a novel trajectory for the future direction of technological innovation. Such a trajectory is envisioned to transcend historical inertia, thereby facilitating a harmonious progression between technology and human society. In doing so, the paper seeks not only to expand the scholarly conversation around technological path dependency but also to enrich the theoretical and practical understanding of overcoming such dependency. By situating the discussion within broader philosophical and essentialist frameworks, it offers a nuanced exploration of the complex interplay between technological innovation, societal needs, and the potential for transformative change. This introduction sets the stage for a comprehensive examination of path dependency, inviting readers to reconsider established paradigms of technological development in light of a forward-thinking, inclusive, and integrative approach.

2. Path Dependency as an Inertia Challenge in Technological Innovation

The origin of path dependency theory can be traced back to the realms of economics and sociology, first introduced by economists such as Paul David and Geoffrey Hodgson. The theory emphasizes the

significance of history and past choices, suggesting that once a specific path is chosen, it generates an inertia that makes the system more likely to continue along this path rather than exploring alternative innovative avenues. This inertia from past decisions and choices has a lasting impact on the current and future direction of development, thereby influencing the evolution of technology, institutions, and other social systems. Although initially proposed by economists, the challenge of path dependency is most prevalently observed in the field of science and technology today, rather than in economics and social domains.

A quintessential example of path dependency in technology is the dilemma of keyboard layouts. The QWERTY standard input keyboard layout we use today originates from the typewriter settings of the last century. Initially designed to mitigate the technical limitations of typewriters that often led to jamming during character input, researchers developed the QWERTY layout based on the frequency of character combinations in words. However, as time passed, despite the introduction of new input standards by scholars and technicians over a century, no new keyboard layout has been widely adopted. This stagnation is attributed to the comprehensive coverage and technological cost efficiency of existing keyboard input strategies, which have become highly optimized over the years. Recent proposals for technological innovation, although more scientific and effective, have not been embraced due to the established path dependency. Few enterprises and technology creators are willing to risk deviating from this path to advance and refine technology, with most users and producers preferring the development of mature, traditional technologies over new technological models. This inclination towards more stable and mature technologies for improvement, and the state of chaos in technological innovation, highlight a significant dilemma. On one hand, developers are aware that technology has become shackled by its past trajectory; on the other hand, various constraints impede the establishment of new developmental paths for technology, even when the prospects for technological development are broader and more aligned with contemporary needs.

It is evident that technological development has been consistently mired in a state of historical inertia, where reliance on existing paths significantly hinders innovative thinking in technology. Such inertia breeds skepticism at the inception of technological innovation, raising questions such as: Will the emergence of a new technology impact the profitability of existing foundational technologies? Can the development and operational costs of new technology be justified by its benefits? Or, can the ethical and risk concerns associated with new technology be swiftly addressed, making it worthwhile to invest substantial time and capital for improvement compared to existing technology? These and similar issues continuously arise on the path of technological innovation, with technological development being constrained by historical inertia not just in application but across the entire innovation process. The challenges faced by new technologies include potential impacts on existing technological gains, considerations of development and application costs, as well as ethical and risk concerns. Although these issues may gradually resolve during the promotion of new technologies, the presence of historical inertia marginalizes many innovative objectives. Path dependency has transcended its original confines of economics and sociology to become a pressing challenge in technology, persisting across both the application of technological innovation and theoretical advancement, with the root causes of technological path dependency remaining largely unexplored.^[1]

3. Tracing the Origins of Path Dependency

Exploring the underlying reasons for the dilemma of technological path dependency necessitates an analysis from the source, recognizing that while technological predicaments stem from inherent contradictions within technology itself, they are also significantly influenced by various social and cultural factors.

3.1. Technological Development Challenges

The challenge of technological development, as the term suggests, refers to the innovation difficulties encountered during the technological evolution process. Typically, these challenges are influenced by the externalization of technological contradictions, societal competitive pressures, and environmental changes. The formation of path dependency fundamentally arises from an overreliance on technology, as individuals facing ever-increasing material cultural demands frequently resort to technological means to fulfill their material needs. However, the limits of material needs are insurmountable, and aspects such as the safety, reliability, applicability, and efficiency of technology cannot undergo limitless growth and breakthroughs. This results in the externalization of technological

contradictions, where humanity's infinite pursuit of material culture inherently conflicts with the limitless development of technological content, leading to increasingly acute contradictions as technology progresses. Limited by physical laws and natural principles, if human needs and the pace of technological development fail to align, technology may swiftly fall into a self-reinforcing loop.

Furthermore, technological advancement must also contend with the challenges posed by societal competition and environmental changes. Within the process of societal development, technology does not assume a wholly neutral role but is influenced by societal dynamics. Faster and more efficient technologies become the objectives of technology developers, aiming to transform technology into an effective tool for political, military, and economic development. At this juncture, technological development has internalized into human conscious actions, with the direction of technological advancement not determined by its inherent innovative orientation but rather serving specific developmental paths dictated by certain objectives. In addition to societal constraints, technological development is also limited by environmental considerations. Technology is founded upon material bases, and the intrinsic motion of materials is not subject to human will. Pursuing efficiency while disregarding natural variations is untenable, ensuring that the challenges of technological development persist over the long term, intrinsically linked to human technological advancement.

3.2. Technological Risk Challenges

The manifestation of risk within technology indicates that technology is not entirely reliable and stable. Regardless of its maturity or obsolescence, the composition of technology consists of various complex, independent components, with technology becoming more prone to defects as it evolves. The most common obstacle in technological innovation arises from the continuous evolution of technology, leading to increasingly cumbersome and complex constituent units.^[2] A mature technology evolves from previously immature systems through continuous maintenance and updates, potentially composed of multiple older technologies stacked or improved upon. Original technology research or creation was limited by societal factors or historical development constraints at the time, resulting in a lack of homogeneity among technological components.

Due to the absence of complete homogeneity among technological systems and their components, different technological units may possess entirely distinct properties and compatibility systems. These systems interdependently achieve a state of incomprehensible yet stable operation. Should a single system component suffer damage or a single technological unit become obsolete, it can lead to the collapse of the entire technological system, reducing technological stability and necessitating the overhaul of existing technological foundations and specifications to rebuild new technological standards, in hopes of restoring a stable operational state for the technological system. These scenarios are unavoidable before technology creators establish technological standards and units, and no creator can guarantee the absolute stability of technology, leading to the persistent presence of technological risk challenges throughout the process of technological innovation.^[3]

3.3. Technological Alienation Dilemmas

Alienation, inherent in technology since its inception, is defined by Marx within the capitalist system as the process through which, as technology and productive forces improve, workers become increasingly estranged from their labor outcomes. Technology transforms into an external, adversarial force that, in turn, endangers humanity, marking an inevitable phase in technological development.^[4] However, in contemporary views on technology, alienation is not solely confined to capitalist societies but is attributed to human-induced technological issues. The creators, operators, and units of technology are the true sources of technological alienation. A characteristic feature of path dependency is the alienation of technology concerning its developmental path, fundamentally suggesting that while technological development should cater to human needs, post-alienation, the technological path demands human adaptation to achieve greater technological efficiency.

On the other hand, technological alienation is a specific manifestation of societal contradictions. Even identical technologies can exhibit both positive and negative effects when confronted by different human groups. The benefits derived from technology are boundless, leading some technology operators or creators to exploit loopholes in social systems for personal gain. As technology expands in pursuit of such objectives, barriers to technological alienation increasingly rise, ostensibly caused by technological advancement but essentially due to technology being alienated and influenced by humanity.

3.4. The Influence of Technological Instrumental Rationality

For an extended period, instrumental rationality, rooted in utilitarianism, has significantly influenced technological development throughout human history. The prevailing ideology of technological instrumental rationality posits the world as a tool, segregating factual situations from values, where technology deemed useful becomes the truth, irrespective of other factors, with the realization of objectives constituting the essence of technology. This perspective essentially represents the predominant inclination of modern technological thought, with its core being Weber's proposition that efficiency is paramount. Any technology not predicated on efficiency is artificially eliminated, directing the purpose of technological innovation towards a singular objective, with any deviation from this trajectory inherently rejected.

However, the mere presence of instrumental rationality does not constitute the primary barrier to technological innovation; rather, it is the synthesis of societal dynamics with instrumental rationality that results in a purely technocratic paradigm. Since the industrial age, there has been an explosive growth in productive forces, reaching a threshold where societal competition needs intensification, and instrumental rationality aligns perfectly with human needs of this era. As technology becomes a central competitive force, its integration with instrumental rationality provides immediate positive feedback for human competition, making technological instrumental rationality the sole preferred solution over time. Technology, as a means, becomes wholly subjugated by human objectives, leading to the inertia of developmental challenges. Existing technological means are incapable of defining goals; instead, means exist solely to pursue objectives, inevitably leading technology into a path-dependent quagmire.^[5]

4. Principles for Surpassing the Path Dependency Dilemma

To address the causes of technological path dependency, it's essential to establish principles from the root rather than merely addressing the superficial technological issues. Most existing solutions to path dependency focus on specific technical problems without elevating to a more macro-level resolution. Therefore, addressing technological path dependency should adhere to the following four principles:

4.1. Principle of Technological Progress

The most crucial and reliable principle in resolving path dependency issues is to ensure the stable progress of technology. This involves guaranteeing that technological innovation is characterized by significant advancement and cost-effective progress patterns while continuously maintaining the state of technological progress. Innovation and progression in existing technologies are inevitable, serving as the foundation for sustaining technology's vitality. Any technology that does not advance is in violation of the principles of technology.^[6]

4.2. Categorized and Gradual Principle

Escaping from the quagmire of path dependency requires a considerable duration, during which it is vital to establish a correct sense of problem categorization and adopt corresponding technological innovation strategies, clearly identifying the reasons behind the challenges faced by different technology units. When technology is transitioning away from dependency, it is imperative to establish phased goals, allowing for the stable and orderly replacement of old technology units without cessation. Dependency issues should be recognized as the core problem, and targeted adjustments should be made accordingly.

4.3. Non-Mandatory Reform Principle

When dealing with technologies that have been long used by society or the general public and cannot be swiftly abandoned, a non-mandatory principle should be applied. Due to the complex composition of society, including various strata, professions, and geographic environments, technological reform poses significant challenges. At this time, it is essential to intensify the promotion of new technologies while temporarily delaying changes to the core of technology, employing non-coercive guidance policies or desensitization to similar technologies to mitigate social contradictions in technological innovation, ultimately achieving the goal of technological reform.

4.4. Collaborative Principle

Reforming technology is not a task that can be accomplished by a single enterprise or group in a short period. Establishing a common social consensus is the first step, fully leveraging the strength of various social groups, broadly absorbing opinions on relevant technologies, and mobilizing reform efforts based on actual situations to provide favorable conditions for overcoming technological dependency.^[7]

5. Conclusion

The issue of technological path dependency is a long-standing and complex problem of historical inertia. It is evident that path dependency is not insurmountable; it is merely a deeply ingrained challenge within technology itself. The most effective approach to addressing this challenge is to establish a correct understanding of the problem and the principles for its resolution. Enhancing the technological awareness of both creators and users of technology can achieve the avoidance of such issues and the possibility of transcending dependency. This requires a concerted effort to recognize the roots of path dependency and to apply strategic principles that encourage innovation, flexibility, and collaboration in the face of technological development's inherent challenges. By doing so, we can ensure that technology continues to evolve in a manner that is both progressive and responsive to the changing needs of society.

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