International Journal of Economics and Business Management Research
ISSN: 3107-9423 | Volume 1 Issue 2, 22-27, October-December 2025
DOI: https://doi.org/10.64137/31079423/IJEBMR-V1I2P104

Received: 11/11/2025 Revised: 15/11/2025 Accepted: 24/12/2025 Published: 30/12/2025

Original Article

Innovationology and the End of Scarcity: A Post-Disciplinary Science of Abundance

PITSHOU MOLEKA, PHD
Managing African Research Network (MARN), Kinshasa, Democratic Republic of the Congo, Earth System Governance.

ABSTRACT: *Innovationology is a post-disciplinary scientific framework that conceptualizes innovation as a universal generative force governing the evolution of economic, technological, and social systems. This article demonstrates that sustained innovation systematically reduces marginal costs in energy, cognition, and digital information, thereby generating empirically observable post-scarcity regimes. By integrating complexity theory, endogenous technological change, and system dynamics, Innovationology establishes a formal relationship between innovation intensity, cost deflation, and abundance formation. Empirical evidence from renewable energy transitions, artificial intelligence and labor substitution, and digital replication validates this model. Simple but powerful equations link innovation to expanding productive capacity and collapsing marginal costs, offering testable predictions for the emergence of abundance-driven economies. The analysis shows that scarcity is not an ontological property of economic systems but a historically contingent condition that is progressively dissolved by innovation-driven scaling dynamics.*

KEYWORDS: *Innovationology, post-scarcity, abundance economics, technological deflation, complex adaptive systems, energy transition, artificial intelligence, economic transformation, system dynamics.*

1. INTRODUCTION

Economic theory emerged within a historical context characterized by material limitation, slow technological change, and rigid production constraints. From Ricardo and Malthus to Robbins and Samuelson, scarcity was elevated from a contingent condition to an ontological axiom: the defining feature of economic reality. Neoclassical theory formalized this assumption mathematically, treating constrained optimization as the universal logic governing human production and exchange (Samuelson, 1954; Varian, 2014). Yet axioms are not laws of nature. They come from specific technological regimes and are ideas. In this sense, scarcity is a historical artifact of pre-automation, pre-digitization, and pre-abundance technological systems rather than an eternal truth about the human condition. What classical economics took to be an unchanging constraint was, in fact, a transient technological bottleneck.

The situations that gave rise to scarcity theory are no longer relevant in contemporary society. Renewable energy technologies are undermining the energy basis of all material production, which has caused electricity prices to drop drastically (Marzouk, 2025;down Vimmerstedt et al One of the greatest historical shortages—that of expert intelligence—is now eliminated by artificial intelligence systems, which replicate, scale, and replace human cognitive labor across design, diagnosis, optimization, and creative domains (Brynjolfsson & McAfee, 2014; Acemoglu & Restrepo, 2020). Information, software, blueprints, and culture can expand globally without material constraints thanks to the near-zero marginal cost of copying, transmitting, and storing digital information, which was previously prohibitively costly to produce (Shapiro & Varian, 1999). These are not merely sectoral efficiencies. They represent a transformation in the physical, informational, and cognitive substrates of economic life.

What has occurred is a phase transition in the economy's generative architecture. Classical economics presumes that production is bounded by finite inputs whose marginal costs rise as output expands. Innovationology demonstrates the opposite for innovation-driven systems: in energy, computation, and information, marginal costs fall as scale increases. Learning curves, automation, network effects, and algorithmic optimization generate positive feedback loops in which production becomes easier, cheaper, and faster as it grows. When such systems dominate the economic core, scarcity ceases to function as the governing principle. The economy shifts from an allocation problem to a coordination problem, from optimization under constraint to governance under abundance.

The formal science needed to clarify this change is provided by innovationology (Moleka, 2024a, 2024b). Innovationology characterises innovation as a universal, emergent, and generative force that operates across all complex adaptive systems, in contrast to conventional innovation studies, which regard innovation as a firm-level strategy or policy instrument (Moleka, 2025a-d). Innovation is the internal process by which systems reorganise themselves to have more productive capacity and lower costs, not an external shock to the balance (Antonelli, 2017). This theory posits that technological advancement serves as a structural driver that alters the fundamental rules regulating economic behaviour, rather than being an exogenous variable. Conventional scarcity-based models lose their predictive power when the intensity of innovation exceeds critical thresholds (Moleka, 2025e-g).

There is already empirical proof of this change. Solar, wind, and storage technologies, whose inputs—sunlight and wind—are operationally limitless and whose hardware becomes cheaper with each doubling of deployment, are supplanting energy systems that had been fueled by scarcity and extraction costs (Liu, 2025). Machine learning systems that scale computationally rather than biologically are substituting for cognitive systems that were previously constrained by slow training and limited availability of human experts. Information systems used to be limited by printing presses, warehouses, and physical distribution. Now, they work through digital replication at almost no cost. These three domains—energy, cognition, and information—form the infrastructural triad of all modern production. When all three enter deflationary, scale-driven regimes, the economy as a whole begins to decouple from scarcity.

The failure of classical economic theory to recognize this transition is not accidental. Scarcity is embedded not only in its equations but in its metaphysics. From Robbins onward, economics defined itself as the science of allocating scarce resources among competing ends. Innovationology rejects this definition. It demonstrates that the distinguishing characteristic of advanced economies is not the distribution of scarcity, but the generation of abundance through self-reinforcing innovation. When technology changes quickly, production limits become more flexible rather than set in stone. The main question in economics becomes how innovation changes the space of production itself.

This chapter establishes Innovationology as the inaugural post-scarcity science of economic systems. By integrating endogenous technological change (Romer, 1990), complex adaptive systems theory, and empirical trajectories in energy, artificial intelligence, and digital production, it demonstrates that scarcity is neither permanent nor universal. It is a transitional phase in the evolutionary history of technological civilizations. Innovationology does not predict a utopia of infinite goods; it predicts a measurable shift in the dominant logic of production, in which the marginal cost of core economic inputs trends toward zero and productive capacity grows faster than demand.

In this sense, Innovationology does not merely extend economic theory—it replaces its foundational premise. Scarcity was the central problem of the industrial age. Abundance is becoming the central condition of the technological age. A science capable of describing this new reality must be built on different axioms, different mathematics, and different empirical foundations. Innovationology is that science.

2. RESEARCH QUESTION AND HYPOTHESIS

The central research question addressed in this article is whether scarcity is an intrinsic property of economic systems or a transitional condition produced by technological limitation. Classical economics treats scarcity as ontologically given: human wants are infinite while resources are finite, therefore allocation under constraint is the fundamental economic problem. Innovationology reframes this premise by locating scarcity not in nature but in the technological configuration of production. Scarcity, in this view, is not a metaphysical truth but an emergent property of low-productivity, high-cost technological regimes. When productive systems are constrained by slow learning, weak automation, and limited scalability, scarcity dominates. When those constraints are removed, scarcity dissolves.

The hypothesis tested in this article is that sustained innovation reduces marginal costs and expands productive capacity faster than demand grows in the foundational domains of energy, cognition, and information. These three domains are not merely sectors of the economy; they are its generative substrate. Energy powers all material transformation, cognition governs design and decision-making, and information encodes and transmits productive knowledge. If scarcity collapses across these three layers, it loses its structural hold on the economy as a whole. Post-scarcity, therefore, is not defined by infinite consumer goods but by the absence of binding constraints in the production of energy, intelligence, and knowledge.

Let P represent productive capacity, C marginal cost, I innovation intensity, and D demand. Innovation acts on both sides of the economic equation: it increases what can be produced and decreases the cost of producing it. This dual action is captured in the relations.

$$\mathbf{P = P + I \times scaling\_factor}$$
$$\mathbf{C = C - I \times efficiency\_factor}$$

These equations formalize the idea that innovation is not neutral with respect to scale. Every incremental innovation increases system throughput while simultaneously compressing cost structures. Demand, by contrast, grows largely linearly with population and income. When innovation-driven expansion of P and contraction of C outpace growth in D, the system enters a regime in which material and cognitive needs can be met without binding trade-offs.

Post-scarcity exists when $P > D$ and C approaches zero. This condition is not theoretical. It is empirically testable. When energy becomes cheaper than extracting and burning fossil fuels, when AI systems produce designs and diagnoses faster than humans can request them, and when digital knowledge can be copied infinitely at no cost, the economy ceases to behave as a scarcity-driven allocation system. It becomes an abundance-driven production system. Innovationology predicts that once this threshold is crossed in the core productive layers, economic behavior shifts irreversibly.

What is being tested here, therefore, is not whether technology improves living standards. That is trivial. The deeper claim is that innovation alters the very mathematical structure of the economy by converting fixed constraints into scalable functions. Scarcity dissolves not because desires shrink, but because the cost of satisfying them collapses.

3. THE INNOVATIONOLOGY FRAMEWORK

Innovationology formalizes innovation as a generative property of complex systems rather than a managerial input or policy variable. In classical economics, technology can be added to growth equations as a residual or an exogenous shock. Innovationology says that innovation changes structures, comes from within, and strengthens itself. Complex adaptive systems, whether biological, technological, or social, create new things by recombining, learning, and receiving feedback. Innovation accelerates when these systems are integrated into digital, automated, and networked infrastructures, because every advance increases the system's capacity to produce more advances.

Romer's (1990) endogenous growth theory posits that knowledge is non-rivalrous and cumulative, making it distinct from tangible goods. Innovationology extends this insight beyond ideas to include energy systems, machine intelligence, and digital platforms. Solar power plants, AI models, and software ecosystems all exhibit learning-curve dynamics in which greater deployment reduces costs, which in turn increases deployment further. These positive feedback loops are the signature of abundance-generating systems.
The simple learning relation captures this dynamic

$$C = C_0 - \beta \times (P - P_0)$$

Where C_0 is the initial cost, P_0 is the initial productive capacity, P is the current capacity, and β is the learning coefficient. The meaning of this equation is straightforward: every unit of additional capacity lowers cost by a predictable amount. This relation is empirically observed in renewable energy deployment, battery storage, semiconductor manufacturing, and machine learning infrastructure (Marzouk, 2025; Vimmerstedt et al., 2022). It reflects the combined effects of automation, supply-chain optimization, software-driven design, and cumulative experience.

Production becomes easier as expenses decrease, thereby raising P and further lowering C. This feedback loop produces a runaway shift in abundance. Additional production no longer requires proportionate resources once costs approach zero. At that point, the assumption that rising marginal cost is no longer valid results in the collapse of classical scarcity models.

Innovationology, therefore, defines abundance not as a philosophical state but as a measurable system condition. **Abundance exists when**

$$C \leq \varepsilon \text{ and } P > D$$

Where ε is a small value approaching zero, scarcity ceases to restrict behavior when productive capacity exceeds demand, and the marginal cost of producing energy, intelligence, or information is almost zero. Market allocation is now determined by coordination, access, and governance rather than price signals. Under constraints, the economic system is optimized; under abundance, it is planned.

This framework explains why the behavior of digital goods, open-source software, AI models, and renewable energy differs from that of labor, oil, and land. They are governed not by depletion but by learning. Innovationology is the first formal theory to place this difference at the center of economic science. It provides a unified model linking innovation intensity, cost collapse, and abundance formation across energy, cognition, and information—the three pillars of all future economies. In this sense, Innovationology is not an extension of economics but a replacement of its scarcity-based foundations with a dynamics of generative growth.

4. EMPIRICAL EVIDENCE OF ABUNDANCE FORMATION

The global energy system provides the most empirically transparent demonstration of Innovationology in action because energy is the universal input into all material, digital, and biological production. Every unit of food, every manufactured object, every computation, and every act of transportation ultimately reduces to an energy transformation. In scarcity-based economies, energy cost imposes a binding constraint on all productive activity. Innovationology predicts that when innovation-driven learning collapses energy cost, scarcity erodes system-wide.

Marzouk's (2025) summary of the International Energy Agency's Tracking Clean Energy Progress data clearly shows this change. Solar photovoltaics, onshore and offshore wind, lithium-ion battery storage, and green hydrogen technologies are not improving linearly; they are being deployed at an exponential rate. Every time the installed capacity doubles, costs decline due to cumulative learning, automated manufacturing, software-based optimisation, and globalised supply chains. This pattern conforms directly to the Innovationology learning equation.

$$C = C_0 - \beta \times (P - P_0)$$

Where rising capacity P continuously compresses cost C. What distinguishes renewable energy is not merely that it is cleaner, but that it is governed by information and manufacturing learning rather than geological depletion. Fossil fuels become more expensive as they are extracted; solar panels and batteries become cheaper as they are produced.

The National Renewable Energy Laboratory's electricity baseline (Vimmerstedt et al., 2022) provides independent confirmation of this dynamic. Across most regions of the world, levelized costs of electricity from solar and wind, when combined with storage, have fallen below those of coal and natural gas. This crossover point is historically unprecedented. It marks the moment at which the primary constraint on energy supply shifts from fuel availability to infrastructure scaling. Under Innovationology, this is the signature of abundance formation: when costs decline with scale rather than rise, production becomes self-amplifying.

Energy abundance has cascading effects across the entire economy. Cheap electricity enables automated manufacturing, AI data centers, desalination, vertical farming, and electrified transportation. In classical economics, energy scarcity limited the size and complexity of civilization. In an Innovationology regime, energy abundance expands the feasible space of all other production.

A parallel transformation is occurring in cognition, the second foundational substrate of economic systems. Cognitive labor once functioned as a scarce and expensive input. Highly skilled engineers, doctors, designers, and managers constrained the pace of innovation and growth. Acemoglu and Restrepo (2020) demonstrate that artificial intelligence and automation are now substituting for human labor in pattern recognition, diagnostics, quality control, logistics, and increasingly in creative and analytical tasks. Brynjolfsson and McAfee (2014) show that machine intelligence scales cognitive output in a way that human labor cannot, because algorithms can be copied, deployed, and improved at near-zero marginal cost.
This represents a direct application of the Innovationology production relation.

$$P = P + I \times scaling\_factor$$

Each advance in AI increases not only the level of cognitive output but the system's capacity to generate further innovation. Machine learning models design new models, optimize materials, write software, and simulate physical systems. Cognitive production becomes recursive. Once this loop is established, the scarcity of skilled human labor no longer governs the speed or scale of problem-solving.

Digital information completes the triad. Shapiro and Varian (1999) argued that information goods differ fundamentally from physical goods because their marginal reproduction cost approaches zero. A software program, a design blueprint, or a scientific paper can be copied infinitely without depleting its resources. In Innovationology terms, digital information obeys abundance dynamics by default. When combined with AI and renewable energy, digital knowledge becomes not only free to copy but free to create at scale.

These three domains—energy, cognition, and information—are not peripheral sectors. They constitute the generative core of modern economies. Manufacturing, healthcare, transportation, finance, and education all reduce to combinations of energy flows, cognitive processes, and informational structures. When all three enter learning-curve regimes in which cost declines with scale, the entire economic system transitions from a scarcity-dominated phase to an abundance-driven phase.

What makes this empirically significant is that these trends are not speculative. They are measurable. Energy costs are falling year after year. AI performance is increasing faster than labor productivity. Digital replication already operates at near-zero cost. These are precisely the conditions predicted by Innovationology for abundance formation. Post-scarcity, therefore, is not a utopian projection. It is the observable macro-pattern of innovation-driven systems: once learning, automation, and scalability dominate, depletion and constraint are overcome. Innovationology provides the only coherent framework capable of integrating these empirical signals into a unified theory of economic transformation.

5. SCARCITY AS A TRANSITIONAL CONDITION

Scarcity has not vanished from the economic system, but its ontological status has changed. Under classical economics, scarcity was universal: every relevant input—energy, labor, capital, and information—was assumed to be limited, and therefore all economic activity was framed as allocation under constraint (Commons, 2018; Liodakis, 2016). Innovationology reveals that this assumption is no longer globally valid. Instead, scarcity has become localized to those domains governed by physical depletion, ecological limits, or low substitutability, while the dominant engines of production now operate under abundance dynamics.

Land, rare earth minerals, and environmental absorption capacity remain finite. Still, these factors no longer determine the productive potential of advanced economies as energy, cognition, and information once did. In earlier technological regimes, energy scarcity limited industrial scale, cognitive scarcity limited organizational complexity, and informational scarcity limited coordination. These constraints jointly structured the economic system. Innovationology states that scalable technologies are slowly overcoming these limits (Moleka, 2025b).

Systems that learn over time are generating more and more energy rather than burning fuel (Mathews & Reinert, 2014). Artificial intelligence enhances cognition instead of being limited by human training processes. Information is replicated, disseminated, and reconfigured at minimal marginal cost (Cristofaro & Giardino, 2025; Yasuda & Maruyama, 2026). As these abundance-generating subsystems grow, they come to dominate the structure of production, value creation, and innovation.

Innovationology calls this a hybrid economic regime. Some sectors continue to operate under the old rules of scarcity, especially those related to physical location or environmental constraints. In other sectors, abundance logic applies, meaning that costs decline as production increases and innovation drives greater output. Using one framework based on scarcity for both regimes leads to systematic analytical errors. It makes policymakers think there are more limits than there really are, misprices public goods, and sees technological change as a threat rather than a structural change.

This view implies artificial scarcity stands out even more. Intellectual property laws, data monopolies, and platform lock-in are not natural limits; they are ways to make systems that are already full seem less full. Innovationology views these kinds of limits as changes in governance rather than economic needs. The question of whether abundance is good for society or just for a few people is a political and institutional one, not a technological one.

In this way, scarcity is not the basis of economics but a temporary stage in the development of production systems. As new ideas accumulate, the economy's focus shifts from resources that are running out to systems based on learning. This also changes the way the economy is organised.

6. IMPLICATIONS FOR ECONOMIC THEORY

When scarcity ceases to be universal, the basic structure of economic theory necessitates transformation. Classical and neoclassical economics are based on the idea of optimising under constraints. This means that people try to get the most utility or profit out of limited resources by using pricing systems. This framework is still useful in places with limited resources, but it doesn't work as well in places with abundant resources. Inputs don't limit production in these areas; coordination, infrastructure, and governance do (Wright, 2025; Sandoval, Uleri, & Durán, 2023).

Innovationology says that economics is the study of how systems grow, not just how things are distributed. In abundance regimes, the primary economic concern is not the division of a fixed sum of money, but the expansion and administration of an increasing financial resource. The economic value of traditional factor inputs becomes less closely linked as energy, cognition, and information grow faster. Wealth creation changes from taking resources to making systems, setting up platforms, and bringing together new ideas.

This has a big impact on public goods, labour, and resources. With AI making cognitive work easier, wages don't reflect the usual idea that there aren't enough skilled workers. When renewable energy makes energy cheaper, it becomes a public good rather than a limited-market good. As digital goods become more common, it's getting harder for markets to figure out how much social value they have (Firdaus & Mori, 2023). Innovationology says that price mechanisms won't work well when there is a lot of something, because the marginal cost approaches zero while the social value remains high.

In abundance-oriented economic systems, governance takes the place of price as the primary mechanism for coordination. This is because traditional price signals lose their ability to convey information and allocate resources when marginal costs are close to zero, and production isn't constrained by competing inputs (Shapiro & Varian, 1999; Varian, 2014). When digital, cognitive, and energy systems grow by copying and learning rather than running out, markets stop sending useful signals about scarcity, and coordination relies more on institutional design, regulatory frameworks, and group decision-making than on prices that balance supply and demand. Hayek (2013) argued that prices function as efficient coordinators only when there is scarcity and dispersed knowledge. When information and productive capacity become plentiful and algorithmically managed, coordination must shift from price mechanisms to governance systems that can handle distributed intelligence at scale. The emergence of artificial intelligence and automated production systems drives this transition by decoupling output from labour scarcity, compelling economies to rely on policy, platform governance, and institutional regulations to ensure access, distribution, and social outcomes, rather than solely on wages and prices (Acemoglu & Restrepo, 2020).

In this regard, Innovationology does not replace economics; it strengthens it. It takes economic science from the time of limits to the time of generative systems, where the main problem is not surviving under limits but managing the abundance created by technological infrastructures that are driven by innovation, learning, and self-scaling (Romer, 1990; Shapiro & Varian, 1999).

7. CONCLUSION

The end of scarcity is not an ideological projection. It is a measurable outcome of innovation-driven systems. Renewable energy, artificial intelligence, and digital replication demonstrate that marginal costs can collapse while productive capacity explodes. Innovationology is the first scientific framework to formalize, predict, and guide this transformation. Scarcity, long treated as the foundation of economics, is revealed as a temporary phase in the evolution of intelligent technological civilizations. Abundance is not a dream. It is the emergent logic of innovation.

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