Beyond the Linear Model: A Holistic Approach to Funding Equitable and Sustainable Innovation

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Introduction

Linear model of innovation is a framework that describes the sequential process where basic scientific research leads to applied research, technological development, and economic growth. This paper analyzes the dual-edged nature of this model, which has facilitated significant industrial advancements while also causing long-term societal and environmental challenges. It seeks to answer the research question: how does this dual-edged nature inform the debate on the funding of scientific research? To do so, the paper first outlines the theoretical critiques of the model's simplicity and market-driven priorities, drawing on Godin (2005) and Mirowski (2011). It then supports these critiques with empirical case studies of innovations like tetraethyl lead (TEL), chlorofluorocarbons (CFCs), and asbestos. Building on this analysis, I argue that the linear model should be replaced by a more holistic framework that integrates sustainability and equity. A key implication of this shift is that government funding of scientific research is preferable to reliance on the private sector. Governments, as the entities ultimately responsible for mitigating negative externalities, are more inclined to prioritize long-term public welfare in funding, advertising, and distributing scientific innovations.

The Linear Model of Innovation: Historical Origins and Critiques

In this section, the historical origins and fundamental flaws of the linear model will be identified through the work of two key critics. First, Benoît Godin's historical analysis reveals the model's oversimplification of the innovation process. Second, Philip Mirowski's critique highlights its instrumentalization for geopolitical and market-driven ends, often at the expense of societal good. Together, their work exposes the model's inherent inability to address complex global challenges. By tracing the historical evolution of the linear model, this analysis underscores its limitations in addressing the broader impacts of innovation.

For starters, Benoît Godin's historical construction of the linear model, in *The Linear Model of Innovation: The Historical Construction of an Analytical Framework* (2005),

highlights its origins and development as an analytical framework for understanding innovation. He argues that the linear model oversimplifies the innovation process by presenting it as a straightforward progression from basic research to applied research and ultimately to marketable products or outcomes. According to Godin, this narrative fails to account for the iterative, dynamic, and non-linear nature of innovation, where feedback loops and interactions between different stages often play a critical role.

The model's adoption as a dominant framework emerged partly because of its utility in policy-making and resource allocation, particularly in promoting basic research as the foundation for technological advancements. However, Godin underscores that this framework overlooks the complexities of societal needs, institutional dynamics, and the multifaceted relationships between research and application. By focusing exclusively on causality and economic benefits, the linear model neglects the broader societal and ethical dimensions of innovation.

Philip Mirowski (2011) builds on this critique by tying the linear model to Cold War-era science policy, as discussed in his book *Science-Mart: Privatizing American Science*. Mirowski argues that the institutionalization of the linear model during the Cold War was driven by geopolitical imperatives, particularly the race for industrial and technological dominance between the United States and the Soviet Union. Governments and institutions embraced the model as a justification for public investments in scientific research, emphasizing its potential to produce tangible outcomes that could strengthen national security and economic competitiveness.

Mirowski critiques this approach for its instrumental focus on innovation as a tool for power and profit, often at the expense of broader societal implications. The prioritization of research with immediate industrial or military applications marginalized other fields of inquiry and neglected the ethical, social, and environmental consequences of technological advancements. This critique exposes the inherent bias in the linear model towards market-driven outcomes, which can perpetuate inequalities and fail to address the root causes of societal challenges.

Both Godin and Mirowski highlight the linear model's failure to integrate societal and ethical considerations into the innovation process, with Godin focusing on its structural oversimplifications and Mirowski emphasizing its instrumental role in market-oriented research. The model's reductionist view of innovation fails to consider the iterative, collaborative, and interdisciplinary processes that are often essential for solving global issues like climate change, health crises, and social inequality. Furthermore, the focus on causality and economic benefit may lead to the

exclusion of marginalized voices and alternative approaches to innovation. While Godin underscores the model's lack of complexity and Mirowski highlights its market-driven priorities. Building on the critiques of Godin and Mirowski, which the following section will empirically substantiate, I argue for a holistic perspective on science funding, advocating for government-led research initiatives.

The Dual-Edged Nature of Innovation: Case Studies

The theoretical critiques raised by Godin and Mirowski are starkly illustrated by historical examples of innovations developed under the linear model paradigm. While this model spurred industrial growth through groundbreaking innovations, it often neglected broader societal and environmental considerations. By examining government policies, funding patterns, and the outcomes of specific innovations, this paper will eventually posit that the linear model incentivized short-term economic gains at the expense of long-term sustainability.

The linear model of innovation has driven significant industrial growth through groundbreaking technologies like tetraethyl lead (TEL), chlorofluorocarbons (CFCs), and asbestos. These innovations, funded and commercialized largely by private entities, provided substantial economic benefits and revolutionized industries such as automotive, refrigeration, and construction. However, the long-term societal and environmental costs of these innovations have been severe. TEL contributed to widespread lead pollution, harming public health, particularly of children. Similarly, CFCs, while initially celebrated for their role in refrigeration, caused significant ozone depletion, leading to increased risks of skin cancer and environmental damage (Edelmann, 2015). Lastly, Asbestos, widely used for its fire-resistant properties, resulted in devastating health crises, including lung cancer and mesothelioma (Paluch, 2025).

These cases reveal a recurring pattern: the linear model of innovation often fails to integrate precautionary measures, assess risks, or consider the broader implications of technological advancements. Governments, as the entities ultimately responsible for addressing these negative externalities, bear the financial and societal burden of cleanup, healthcare, and regulation. This responsibility provides governments with a strong incentive to prioritize sustainability when funding and overseeing scientific research. The presumption that innovation inherently benefits society overlooks critical factors, such as health crises, environmental degradation, and the economic costs of remediation. The model's narrow focus on economic gains has historically led to unintended consequences that outweigh the initial benefits.

To address these issues, future innovation frameworks must adopt a systems approach that integrates sustainability into every stage of research and development. Policymakers and funders should emphasize long-term goals and align incentives with societal and environmental well-being, moving beyond the limited scope of the linear model. By learning from the unintended consequences of TEL, CFCs, and asbestos, we can refine innovation frameworks to balance economic growth with the public good, ensuring a more responsible approach to technological progress.

A Holistic Approach to Science Funding

As demonstrated above, the theoretical limitations and empirical failures of the linear model necessitate a shift toward a more holistic framework for innovation. This framework would integrate sustainability, equity, and ethical considerations at every stage of research and development, thus, moving beyond a narrow focus on market-driven outcomes. A primary implication of adopting this holistic approach is the reaffirmation of government's central role in funding and guiding scientific research.

Government funding for initial research in developing new technologies is essential due to the public good nature of such research. Early-stage research often exhibits characteristics of public goods—it is non-excludable and non-rivalrous, meaning that the benefits cannot be confined to those who invest in it. As a result, private firms are often unwilling to allocate sufficient resources to foundational research because they cannot fully capture its benefits and may face free-rider problems. By providing funding, governments ensure that critical research is conducted, enabling the development of foundational innovations that private firms can later build upon and commercialize.

Moreover, technological innovations, while valuable, frequently come with negative externalities, such as environmental degradation, societal disruption, or health risks. For example, industrial innovations might lead to pollution, or new technologies like artificial intelligence might create privacy concerns (Clark, 2003). Governments, as regulators, are already equipped to address these externalities through policies and enforcement mechanisms. By being involved in the research and development stages, governments can proactively design regulations and safeguards to minimize risks. This ensures that emerging technologies are developed responsibly and align with societal values, thereby reducing the likelihood of harmful consequences (Douglass, 1999).

Empirical analyses support this view. Carlos Henrique de Brito Cruz (2024) examines research funding organizations and their alignment with the UN Sustainable

Development Goals (SDGs). He demonstrates how public funding mechanisms can effectively prioritize research that promotes equitable and sustainable development. For instance, government initiatives often emphasize capacity building, inclusivity, and interdisciplinary approaches, which are critical for addressing complex global challenges like poverty, education, and clean energy.

Similarly, the South African Department of Science and Innovation's (2021/22) report on government funding highlights the strategic benefits of public investment in research. The report showcases how government-led frameworks have supported technological advancements and societal progress by prioritizing research areas with high social impact, such as renewable energy and public health. These efforts mitigate the negative externalities often associated with market-driven innovation, such as environmental exploitation and socioeconomic inequality.

The high-risk, long-term nature of developing new technologies further necessitates government involvement. The private sector often avoids investing in areas where profitability is uncertain or where the timeline to returns is lengthy (Clark, 2003). Government funding helps absorb some of this risk, enabling innovation in fields that might otherwise remain unexplored. By sharing the financial burden of early-stage research, governments encourage private sector participation in subsequent stages, thus, facilitating the commercialization of socially beneficial technologies that might not otherwise attract investment.

Governments also play a critical role in creating the infrastructure needed for the commercialization of new technologies. Beyond funding research, they can establish ecosystems that foster innovation by building infrastructure, offering tax incentives, and supporting early adopters of new technologies. This comprehensive involvement bridges the gap between research and market readiness, ensuring that innovations transition smoothly from laboratories to real-world applications. Without such support, the commercialization process may become fragmented, limiting the societal impact of technological advancements.

Lastly, a holistic approach recognizes that government funding aligns technological progress with long-term societal benefits. Governments can prioritize funding for research that addresses pressing global challenges, such as climate change, clean energy, and healthcare. By steering innovation toward these critical areas, governments ensure that new technologies contribute meaningfully to societal well-being while mitigating potential risks. This strategic involvement ensures that

technological advancements are not just economically beneficial but also serve the public good, addressing both current and future societal needs.

It is important to note that this argument presents a normative view of government's role based on its unique responsibility for public welfare. Governments *should* fund this research because they *are* the entities ultimately tasked with managing its consequences. While not all governments consistently prioritize sustainability, the institutional mandate and accountability mechanisms inherent in democratic governance make it the most suitable entity to fund research within a holistic framework.

Conclusion

In conclusion, by tracing the limitations of the linear model through theory and case studies, this paper has argued for its replacement with a more holistic framework. This framework integrates sustainability and societal equity at every stage of the research and development process. A critical component of this shift is a reaffirmation of government's role in funding science, as its responsibility for the public good aligns with the long-term, risk-aware perspective that holistic innovation requires. Therefore, a vital question for future research and policy is: *How can innovation frameworks be concretely designed to operationalize sustainability and equity?* Addressing this question will ensure that technological advancement truly serves the public good and mitigates the unintended consequences of past advancements.

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