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# Introduction: innovation, knowledge dynamics, and the economics of science – A memorial issue in honor of Paul A. David

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## ABSTRACT

This is the introduction to a memorial issue in honour of one of the journal's founders, Professor Paul A. David. It contains a series of papers on topics in which he made seminal contributions: the economics of science, the dynamics of knowledge and path dependence in the direction of innovation and technological diffusion.

## ARTICLE HISTORY

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Economics of science; knowledge dynamics; path dependence; technological change; innovation

This special issue of *Economics of Innovation and New Technology* honors the intellectual legacy of Paul A. David (1935–2023), whose pioneering contributions shaped our understanding of technological change, innovation systems, technology diffusion, and the economics of science. Paul's work exemplified the power of combining historical perspective with economic analysis. As many of us experienced firsthand, his influence extended far beyond his published work through countless conversations, workshops, and collaborations that influenced numerous younger workers in the growing field of innovation economics. Among his other contributions was the founding of this journal jointly with Paul Stoneman and Peter Swann.

Paul David's scholarly career was multidisciplinary, spanning economic history, the economics of technological change, innovation studies, science policy, and intellectual property. Yet perhaps no theme was more central to his later work than his concern for the organization and funding of scientific research. As one of the architects of the 'new economics of science' – alongside his collaborator Partha Dasgupta – Paul brought economic reasoning to bear on questions about how science functions as a social institution, how knowledge is created and diffused, and what institutional arrangements best support scientific progress.

Paul David's scholarship was characterized by several distinctive features: a deep commitment to understanding the mechanisms underlying economic phenomena, careful

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historical analysis that went hand-in-hand with his emphasis on path dependence as important in explaining many economic phenomena, and a willingness to challenge conventional wisdom. For example, his studies of the QWERTY keyboard and other technology diffusion cases demonstrated how ‘small events’ and initial conditions could have lasting consequences through self-reinforcing mechanisms. His analysis of general purpose technologies (GPTs) provided essential frameworks for understanding how transformative innovations like electricity and computers completely reshape production systems and why their impacts can be seen only slowly for much the same reason.

Paul David was particularly attentive to the functioning of science, viewing it as a complex system characterized by what he called, following Merton, the ‘Republic of Science’ with its distinctive norms of communalism, universalism, disinterestedness, originality, and skepticism (CUDOS). He emphasized that open science represented a fragile system that grew out of the historical enlightenment movement but could easily revert to a closed, secretive system – an ‘occasional ghetto of national rivalries.’ These concerns about preserving the openness and collaborative nature of science, while ensuring adequate support for genuinely innovative research, animate several of the papers in this volume.

## The papers in this issue

Six papers in this special issue are concerned with issues in the conduct and performance of scientific research, while the remaining six focus on the firm-led innovation system and its performance. We discuss each of these papers and their connection to Paul’s work briefly in what follows.

The first paper in this special issue is an unpublished memorandum by **Paul David** entitled ‘Research Universities’ Futures in the Networked World: Technological Challenges and Opportunities for Institutional Responses, which has been lightly edited by us. This memorandum examines the evolving role of the research university within an increasingly networked global environment, focusing on the tension between the traditional ‘open science’ model and the rising pressures of proprietary R&D. The author explores how the integration of market-oriented intellectual property goals can perturb the ‘fragile equilibrium’ of the university’s core missions – namely, knowledge dissemination, fundamental research, and advanced training. David highlights several critical institutional challenges, including the complexities of university-industry-government interactions, the potential for institutional conflicts of interest, and the impact of digital technologies on the creation of open repositories for data and teaching materials. He questions whether universities can successfully blend these incompatible reward systems without degrading their capacity to serve as independent havens of expertise and primary drivers of long-term economic well-being.

**Souza, Geuna, and Lawson** examine the emergence and evolution of the Economics of Science as a field, using network analysis of co-authorship patterns to study the community of scholars working on this topic from 1994 to 2023. They define economists of science as authors who cited two seminal papers – Dasgupta and David (1994) and Stephan (1996) – and find that while the field has grown exponentially, it remains highly fragmented. Souza et al. also examine the role of the Workshop on the Organisation, Economics and Policy of Scientific Research (WOEPS) in the development of the field,

finding that WOEPS presenters have more economists of science as coauthors and occupy more central positions in the network. Paul David was a founding member of WOEPS's scientific committee and regular participant, and this analysis documents his role in building the intellectual community he helped create.

Among other applications of David's key contributions in the theory of path dependence as a determinant of economic outcomes was his emphasis on the role of reputation and cumulative advantage in the productivity of scientific researchers (David 1994). **Hall and Mairesse** investigate the importance of path dependence in scientific careers when researchers also differ in intrinsic productivity empirically, using a large dataset of approximately 1,500 physicists employed by France's CNRS. While they find only weak support for the stylized facts predicted by cumulative advantage theory, regressions with fixed effects provide evidence that cumulative advantage matters for future productivity. They show that while a large amount of the variation in productivity is accounted for by permanent differences in individual productivity, a small but significant additional amount is explained by lagged productivity. This work speaks directly to Paul's interest in how individual trajectories in science are shaped by early career experiences and institutional contexts.

**Veugelers, Wang, and Stephan** investigate whether funding agencies effectively support pioneering research, examining selection and treatment effects at the European Research Council (ERC), which was established in 2007 with an explicit mission to support 'high-risk/high-gain pioneering' research. Using measures of novelty in publication records, they find that applicants with a history of highly novel research are actually less likely to be selected for funding than those without such a history, especially for early career applicants in non-top host environments. They find positive treatment effects only for early career grantees, and this is partially due to unsuccessful applicants cutting back on highly novel research – which they interpret as a 'lesson learned' that novelty is not rewarded.

**Cowan and Jonard** take up one of Paul's recurring concerns: the tension between specialization and diversity in knowledge production. In their simulation model of academic research collaboration both within and across disciplines, they analyze knowledge production when demand for multi-disciplinarity varies, examining how scientists interact to produce papers. Their findings suggest that increasing demands for multi-disciplinarity generally decreases knowledge production, though intermediate levels can generate sustained innovation under specific conditions. They also find that such demands may lead to an even more skewed distribution of knowledge productivity across departments, with many falling behind and a few moving ahead. This echoes Paul's warning that institutional changes, even those driven by noble motives like addressing society's pressing problems, are unlikely to succeed without comprehensive changes to the broader system. As they note in their conclusion, individuals' research decisions are embedded in a larger structure, and 'the science system has many parts which interact with each other ... there is considerable path dependence and lock-in.'

**Huang and Soete** address the contemporary tension between open science and technological sovereignty, examining how these seemingly contradictory goals might be reconciled in European and Chinese science policy. They argue that despite geopolitical tensions, open science remains crucial for addressing global challenges like climate change, while also recognizing legitimate concerns about strategic technological

capabilities. The paper draws explicitly on Paul's historical and institutional analysis of open science, noting how he warned that the open science system represents a particularly fragile system, one which grew out of a historical enlightenment movement, but which can easily be reversed into a closed, secrecy system (David 2014). Their analysis of how both Europe and China have navigated these tensions provides valuable lessons for science policy in an era of renewed geopolitical competition.

**Ayoubi and Foray** analyze the integration of machine learning (ML) technologies into healthcare, treating these technologies as general-purpose (GPT). Their analysis draws directly from lessons learned in David's analysis of the diffusion of earlier GPTs (David 1990). They examine how ML exhibits the key GPT characteristics of pervasiveness, improvement over time, and complementary innovation, but also displays distinctive features in its diffusion pattern. Most notably, they identify access to data as a novel appropriability mechanism and document how technology firms are transforming from suppliers into active service providers within healthcare – a pattern they term 'co-invention with thyself.' They highlight that this pattern of GPT diffusion differs somewhat from those that were studied in the past by David, such as electricity and computers.

**Camuffo, Gambardella, and Kazemi** develop a theory-based analysis of path dependence, explicitly building on David's seminal work on QWERTY and path-dependent processes (David 1985). They examine how decision makers' theories – understood as causal-logical frameworks with associated beliefs and contemplated actions – shape the 'internal initial conditions' that influence path-dependent trajectories. The paper distinguishes four scenarios: ignoring path dependence entirely; anticipating path dependence with a fixed theory; maintaining a single evolving theory open to unknown contingencies; and entertaining multiple theories simultaneously. Using the QWERTY keyboard case as an illustration, they show how different approaches to theory formation affect the likelihood of lock-in to suboptimal paths. The framework clarifies how 'small causes can have large effects' not merely through random accidents but through the ways in which economic actors frame decisions, form priors, and contemplate which actions are feasible – providing micro-foundations for David's insight that initial conditions in path-dependent processes reflect deliberate (if uncertain) choices by economic actors. This work enhances David's historical and theoretical insights with contemporary developments in decision theory and strategic management.

**Dalle** offers an analysis of Gothic cathedrals as early 'moonshots' – ambitious ventures undertaken under significant uncertainty that emerged from decentralized, sequential experiments with knowledge spillovers. Drawing on Paul David's work on the economics of science along with discussions with Paul himself, Dalle argues that Early Gothic cathedrals exemplify 'collective venturing': multiple principals (bishops, abbeys, cities) financing uncertain architectural experiments with an intermediate disclosure regime (visible construction, circulating masons, architectural 'citations'). He extends this lens to contemporary venture-backed deep-tech moonshots, suggesting that similar mechanisms – multiple principals, staged financing, spillovers through syndication and due diligence – characterize both medieval cathedral building and modern entrepreneurship under uncertainty. The paper proposes that hybrid policy instruments leveraging venture-backed collective venturing could help direct innovation toward mission-oriented goals, contributing to the literature on innovation policy while honoring

David's insight that understanding historical processes can illuminate contemporary challenges.

**Arora, Cohen, and Cunningham** examine the ways in which a firm's capacity for invention affects their division of innovative labor. They use data from a US manufacturing survey that they have conducted to explore how firms' abilities to generate knowledge internally shape their use of external knowledge sources. They first develop a theoretical framework that links inventive capability to decisions about whether to generate innovations internally or source them externally. Empirically, using a finite mixture model approach to measure latent capabilities, they find that high-capability firms benefit more from external 'raw' knowledge (which complements their internal R&D), while low-capability firms rely more on externally-generated inventions as substitutes for internal invention. The paper is noteworthy also methodologically, as it treats inventive capability as an unobservable latent characteristic in the estimation strategy, rather than relying on observable characteristics such as R&D or patenting propensity.

**Antonelli, Orsatti, and Piali** revisit and empirically test the analytical framework developed by Paul David, Moses Abramovitz, and others concerning the direction of technological change (Abramovitz and David 1996). Using the newly assembled EUKLEMS & INTANProd database covering European countries from 2009–2019, they examine whether technological change has been capital-saving, intangible-intensive, and skill-intensive, as David and Abramovitz argued for the US economy. Their findings provide robust support for the same structure in the European context, documenting that technological change has been strongly directed – favoring the substitution of tangible capital with intangible assets and skilled labor. This work extends one of David's central insights about the non-neutral character of technological change and its relationship to factor endowments and technological congruence.

**Battisti, Stoneman, and Yuan** present a new output-oriented measure of firm innovativeness defined as 'the successful exploitation of new ideas'. Using longitudinal data on over 100,000 firm-year observations across 34 countries and 20 industries from 1995–2022, they calculate innovativeness as the contribution of innovative activity to profit growth, which they proxy as a residual from a growth regression that accounts explicitly for exogenous wage and demand changes. They find substantial variation in innovativeness across firms, countries, sectors, and time, with innovation contributing an average of 9 percentage points annually to profit growth. Using this approach, they find that the most innovative firms are not necessarily in countries at technological frontiers or in traditionally 'high-tech' sectors, which may reflect the fact that innovation includes catching up, organizational change, and 'soft innovation' alongside technological advances. However, it is worth keeping in mind that sources of profit growth beyond innovation may also be present, such as changes in access to natural resources as well as increases in concentration and therefore monopoly rents.

## Common themes and Paul's legacy

Several themes connect these papers and reflect Paul's enduring influence. First is the recognition that science is a complex adaptive system where individual behaviors, institutional arrangements, and outcomes co-evolve in ways that often produce unintended consequences. Whether examining multi-disciplinary mandates, career

trajectories, geopolitical pressures, or funding decisions, the papers demonstrate that well-intentioned interventions can fail or backfire if they do not account for systemic interactions.

Second is the importance of path dependence in the evolution of science, economies, and technologies. This focus is a natural outcome of Paul's training and early work as a historian working in economic research. His work consistently emphasized that institutional arrangements matter profoundly for innovation outcomes, and that historical contingencies shape which arrangements emerge and persist. In short, 'History matters,' the title of a 2004 Festschrift for Paul containing 17 papers by his students and colleagues (Guinnane, Sundstrom, and Whatley 2004).

Third is the tension between openness and closure in knowledge systems. Paul David was deeply committed to open science as both a normative ideal and a practical necessity for scientific progress. Yet he also recognized the political and economic pressures that threaten openness. The paper by Huang and Soete document how these tensions play out in contemporary science policy, with implications for the future trajectory of scientific research.

Finally, these papers exemplify the methodological pluralism that characterized Paul's own work. They employ simulation modeling, large-scale bibliometric analysis, network methods, historical case studies, and econometric approaches, including difference-in-difference designs. This diversity reflects Paul's belief that understanding complex phenomena requires multiple analytical perspectives and careful attention to measurement and identification challenges.

Paul David's intellectual legacy extends far beyond his published work. He was a generous mentor, thoughtful critic, and engaged participant in countless academic conversations. As Souza, Geuna, and Lawson note, Paul 'joined the WOEPS scientific committee in 2014 until 2020' after being 'a co-organizer in 2009 and a participant in 2010 and 2013.' This pattern of sustained engagement with emerging scholars and ideas was characteristic of his entire career. The papers in this special issue honor Paul's memory by continuing the conversations he valued and advancing the research agenda he helped establish. It is noteworthy that several papers even mention that they grew out of extensive discussions with Paul that had not yet born fruit in the form of a publication.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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