

Project Ideas: Innovation DAGs

2025-26 UNIV-Evans-1

Overview

The aim of this project is to produce a numerical model that reproduces important features of both the innovation process and the pattern it leaves in documents (paper, patents, medical trials etc). This will then be used to test various approaches used to find the critical path of innovation. The project will also involve some network science (graph theory) and students have the option to download and analyse real data.

Innovation and Citation Networks

There is great debate about how to fund research, what type of funding is needed for blue skies research, what is the best way to maximise the transfer of proven ideas into actual commercial products. One way to study these questions quantitatively is to look at the patterns left by the innovation process in documents: patents, medical trials, academic papers etc. Each step forward is recorded in one of these documents and the bibliographies record earlier documents containing the key pieces needed to make the current advance. This data forms a citation network where nodes are documents connected by directed edges, from the newer document to the older documents contained in its bibliography.

Citation Networks and DAGS

Citation networks are examples of a very special type of network called a “Directed Acyclic Graph” or DAG (see PhD theses by Clough (2017) or Vasiliauskaite (2020) for an introduction or try my own notes). These are special because the edges only every point back in time. If you follow a path in the network, following the direction on the edges, you can only go backwards in time. This order (strictly a “partial order” mathematically), the constraint of causality, leads to some special properties for citation networks and that in turn requires us to adapt or find new ways to analyse such networks.

There are various tools from the field of bibliometrics (Fortunato et al 2018), such as “main path analysis” (see Liu et al 2019 for references) or my own suggestion (Ho et al. 2024), used to analyse these data looking for a critical path of innovation. That is we are looking for a path of successive papers/patents/trials that mark the most important steps in the development of a new product such as a new vaccine (Ho et al. 2024) or a quantum computer. I have been developing new ways to find these critical paths in citation networks. One aim for this project is to compare and contrast different methods for finding such paths in the network. This can be done on simple unrealistic models that give DAGs or on real data. It would be best if we could develop a realistic model of innovation that produces an artificial citation network to test our ideas.

Models of Innovation

I have found many models of innovation in the literature e.g. see Watts and Gilbert (2015). These are largely very simple but encode some key ideas. Likewise, I have seen many models for citation networks (see Goldberg et al 2025 for references). However, I have not seen the two combined. That is can you produce an artificial citation network that encodes an artificial innovation process. If you can, we will know which are the key papers that recorded steps forward in the innovation process but then we can see if our methods for finding this critical path in a citation network actually work, at least on this test data. Note that the focus of the project (at least at first) will be on simple numerical models with one or two parameters. We will not start from complicated economics theories with a lot of words and diagrams or simulations with thousands of parameters learnt from vast data sets..

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<https://d.docs.live.net/69a36eef8ef823aa/Documents/TEACHING/UG/PROJECTS/ProposalsAll/2025-26/InnovationDAG-MSciProject.docx>

JR.Clough 2017. "Causal Structure In Networks", PhD Thesis Imperial College London.
<https://doi.org/10.25560/50162>

TS.Evans, Dagology, private notes.

S.Fortunato et al. 2018. Science of science, *Science* **359** 1007.

S.R.Goldberg, H.Anthony, TS.Evans, 2015. Modelling Citation Networks, *Scientometrics* **105** 1577-1604.

M.Ho, et al, 2024. Dynamics of technology emergence in innovation networks, *Science Reports* 14 1411

JS.Liu, YY.Lu, Louis, MH.Ho 2019. A few notes on main path analysis, *Scientometrics* **119** 379-391.

V.Vasiliauskaite, 2020. "Paths and Directed Acyclic Graphs," PhD Thesis Imperial College London
<https://doi.org/10.25560/81811>

C.Watts, N.Gilbert, 2015. *Simulating Innovation: Computer-Based Tools for Rethinking Innovation*, Elgar Publishing Limited, ISBN 9781783472451.

Further Reading

Nigel **Gilbert**, Andreas Pyka and Petra **Ahrweiler** (2001). [Innovation Networks - A Simulation Approach](https://www.jasss.org/4/3/8.html), *Journal of Artificial Societies and Social Simulation* **4**, no. 3, <https://www.jasss.org/4/3/8.html>

Christopher Watts, 2014. [Simulation In Innovation: What models of innovation generation, diffusion and impact can teach us](https://signosis.eu/wp-content/uploads/2014/09/Watts_SimulationInInnovation.pdf), slides from talk
https://signosis.eu/wp-content/uploads/2014/09/Watts_SimulationInInnovation.pdf

You might also search for work by the authors in bold, for terms like "innovation model" perhaps with "review", "notes" or "lectures" added, using google scholar, any search engine or even LLMs like ChatGPT. Can you find existing code on GitHub?

Copilot

I asked Copilot about "Summarise models of innovation based on numerical simulations ..." and it returned the following. Not sure the key papers suggestions are much good! We are going to focus on simple numerical models with one or two parameters, not complicated economics theories with a lot of words and diagrams (and little real content?!).

Numerical simulations play a crucial role in understanding and modeling innovation processes. Here's a summary of some key models and insights:

Key Models of Innovation Based on Numerical Simulations

1. Agent-Based Models (ABMs):

- **Description:** ABMs simulate interactions of autonomous agents to assess their effects on the system. They are particularly useful for modeling complex systems with heterogeneous agents.
- **Applications:** Used to study innovation diffusion, collective learning, and technological evolution^[1].

2. System Dynamics Models:

- **Description:** These models use feedback loops and time delays to understand the behavior of complex systems over time.

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- **Applications:** Applied to study the dynamics of innovation implementation and the impact of various policies on innovation outcomes[2].

3. Percolation Models:

- **Description:** These models simulate the spread of innovation through a network, akin to the flow of liquid through porous material.
- **Applications:** Useful for understanding how innovations spread through social networks and the role of network structure in diffusion[1].

4. Hypercycle Models:

- **Description:** These models focus on the self-organization and evolution of cooperative cycles of innovation.
- **Applications:** Applied to study the co-evolution of technologies and the emergence of dominant designs[1].

Key Academic Papers

1. "Simulation In Innovation: What models of innovation generation, diffusion and impact can teach us" by Christopher Watts[1].
2. "A Simulation-Based Approach to Understanding the Dynamics of Innovation Implementation" by Nelson P. Repenning[2].
3. "Models Of Innovations: An overview of Perspectives and Expositions" by Bala Krishnamoorthy and Madhavi Damle[3].

General Notes on the Subject

- **Importance of Heterogeneity:** Models often emphasize the role of heterogeneous agents and their interactions in driving innovation.
- **Role of Networks:** Social networks and their structures significantly influence the diffusion and adoption of innovations.
- **Feedback Mechanisms:** Understanding feedback loops and dynamic interactions is crucial for modeling innovation processes.
- **Policy Implications:** Numerical simulations can help policymakers design better strategies to foster innovation by predicting potential outcomes of different interventions.

These models and insights provide a comprehensive framework for understanding the complex dynamics of innovation through numerical simulations. If you have any specific questions or need further details, feel free to ask!

References

- [1] [Simulation In Innovation: What models of innovation generation ...](#)
- [2] [Simulation-Based Approach to Understanding the Dynamics of Innovation ...](#)
- [3] [Models Of Innovations: An overview of Perspectives and Expositions](#)
- [4] [What Is Innovation? A Study of the Definitions, Academic Models and ...](#)
- [5] [Innovation Theory: A review of the literature - Imperial College London](#)
- [6] [Simulation and Modeling in Product Development and Innovation - Rescale](#)
- [7] <http://www.simian.ac.uk/resources/models/simulating-innovation>
- [8] <https://orcid.org/0000-0002-6188-2081>
- [9] <http://insight.cumbria.ac.uk/id/eprint/3475/>
- [10] <http://www.scirp.org/journal/jss>
- [11] <https://doi.org/10.4236/jss.2017.511010>
- [12] <http://creativecommons.org/licenses/by/4.0/>