The trickle down from environmental innovation to productive complexity

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Extended Abstract

In this paper, we propose a novel application of statistically validated multilayer networks to investigate how green innovation in specific patent classes affects the production and export of individual products, while also accounting for possible time lags. Our goal is to examine how technological know-how embedded in climate change mitigation and adaptation technologies (CCMTs) trickles down to industrial production. Specifically, we ask: does the patenting of green technologies affect the production and export of particular products? If so, which green technologies are most influential, and which products are most affected? Additionally, we assess how increasing the time lag between green technology development and product export modifies this relationship.

This analysis contributes to understanding how economies can move towards a sustainable transition, which is increasingly necessary and central to public debate. To do so, we develop an empirical strategy rooted in the Economic Complexity (EC) literature [1, 2] and based on multilayer network methodologies and statistical validation techniques [3, 4]. We combine data on patents in 44 green technology fields (classified through the Y02 Cooperative Patent Classification) with export data on individual products (Harmonized System classification). Using these datasets, we build a bipartite directed network linking green technologies at time t_1 to products exported at time $t_2 \geq t_1$. We then filter this network via a maximum entropy null model to extract statistically significant links. Each validated link represents a pair of activities that tend to co-occur in the specialization profiles of the same countries, suggesting they require similar underlying technological and productive capabilities. We construct these networks for two alternative temporal configurations: contemporaneous co-occurrences ($\Delta T = 0$, see Figure 1) and time-lagged co-occurrences ($\Delta T = 10$ years).

Our results reveal a robust pattern. First, green technologies are especially connected to the export of products related to the processing of raw materials such as minerals, metals, and chemicals. This finding aligns with emerging evidence on the mineral intensity of green technologies and their expected impact on future mineral demand [5, 6]. In fact, materials like lithium, cobalt, copper, and rare earth elements, which appear prominently in our network, are recognized as critical raw materials (CRMs) for the green transition, as they are known to be essential inputs for many CCMTs, including renewable energy generation and storage technologies, batteries, and electric vehicles [7]. Second, when we introduce a 10-year time lag between green patenting and product exports, the network structure shifts. We find an increased number of statistically significant links overall, and these new links disproportionately involve more complex green technologies and more complex products. This indicates that more sophisticated green technological know-how requires longer periods to unfold into more complex industrial production.

Importantly, our findings draw attention to the strong and persistent connections between green technologies and CRMs. While these materials enable decarbonization, their extraction is energy-intensive, emission-intensive, and geographically concentrated, raising supply and

socio-environmental risks. Policies fostering green innovation should therefore also secure sustainable raw material supply chains—by reducing dependence on single-source suppliers, promoting recycling and circular economy practices, and supporting greener and less resource-intensive technologies. Addressing these challenges is crucial to avoid relocating environmental externalities upstream.

More broadly, by emphasizing the heterogeneous and disaggregated effects that individual CCMT patents can have on the production and trade of specific goods, our multilayer network approach offers a powerful tool for informing green transition policies. It allows policymakers to (i) identify which green technologies are most likely to spill over into which productive sectors, (ii) understand how long it may take for such spillovers to materialize, and (iii) detect which sectors could become key entry points into emerging green markets. This level of granularity enables targeted industrial policies that leverage each country's current technological capabilities, supporting diversification into less polluting industries or upgrading current ones toward greener production.

References

[1] C. A Hidalgo et al. "The product space conditions the development of nations". In: *Science* 317.5837 (2007), pp. 482–487.

[2] A. Tacchella et al. "A New Metrics for Countries' Fitness and Products' Complexity". In: *Scientific Reports* 723 (2012), pp. 1–7.

[3] E. Pugliese et al. "Unfolding the innovation system for the development of countries: coevolution of Science, Technology and Production". In: *Scientific reports* 9.1 (2019), pp. 1–12.

[4] F. Saracco et al. "Inferring monopartite projections of bipartite networks: an entropy-based approach". In: *New Journal of Physics* 19.5 (2017), p. 053022.

[5] L. Grandell et al. "Role of critical metals in the future markets of clean energy technologies". In: *Renewable Energy* 95 (2016), pp. 53–62.

[6] R. Herrington. "Mining our green future". In: *Nature Reviews Materials* 6.6 (2021), pp. 456–458.

[7] International Energy Agency (IEA). *The Role of Critical Minerals in Clean Energy Transitions*. Tech. rep. Paris: International Energy Agency, 2021.

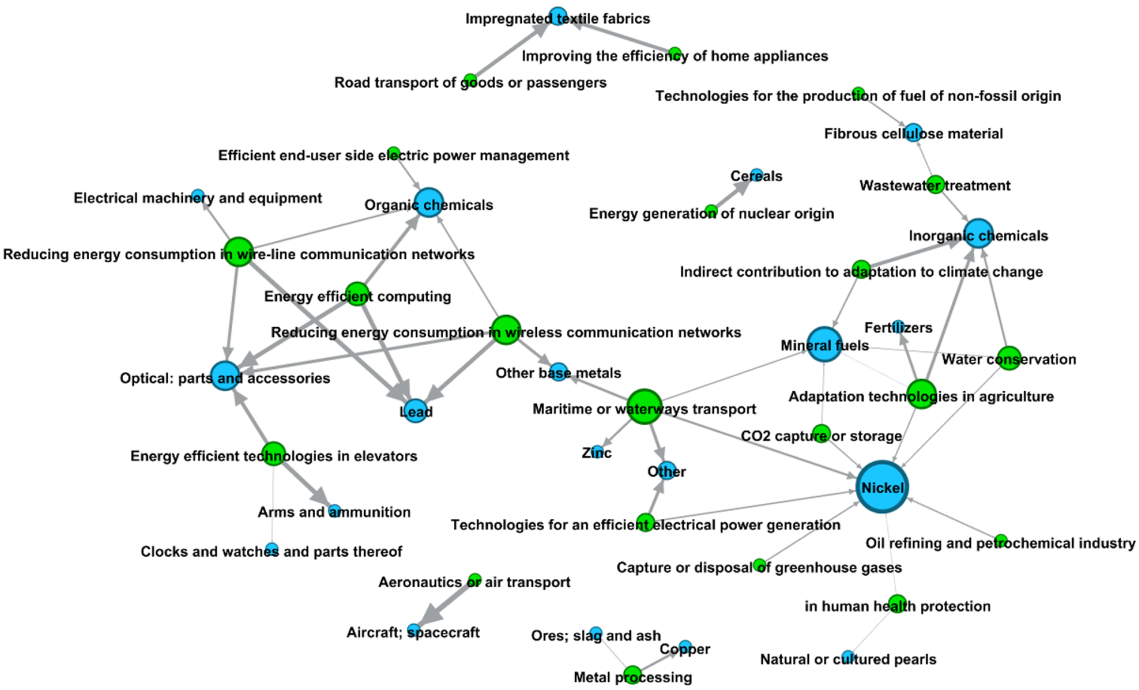

Figure 1: Directed network from green technologies (green nodes) to exported products (blue nodes) for a time lag $\Delta T = 0$. Products aggregation: 2-digit level of the Harmonized System. Nodes' size depends on their degree.