The Coalition of Finance Ministers for Climate Action

# Low-carbon innovation and industrial strategy: analytical tools and frameworks for Ministries of Finance


## S-Curve Economics, University of Manchester, and University of Exeter

**Simon Sharpe and Anna Murphy, S-Curve Economics; Frank Geels, University of Manchester; and Jean-Francois Mercure, University of Exeter**



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The debate among economists about whether governments should have industrial strategies is an old one. One view is that governments should focus only on strengthening the fundamentals of their national economies, through actions such as investing in research, education, skills, and infrastructure, strengthening the rule of law and regulations that promote competition, and lowering corporate taxes. Others believe that governments should go further, and take actions designed to increase national competitiveness in particular areas of the economy.

## The context: a global transition

The low-carbon transition is bringing this choice to the forefront of many governments' thinking. Change in the global economy is already happening on a significant scale. Clean power made up around 80% of new electricity generation capacity added globally in 2023 (IEA, 2024a), and electric vehicles were 18% of global car sales (IEA, 2024a). The International Energy Agency has predicted that global demand for coal, oil, and gas will begin to fall before the year 2030: what has long been one of the most valuable sectors of the global economy is moving from growth to contraction (IEA, 2023). As clean technologies replace fossil fuels in power, transportation, buildings, industry, and agriculture, change will ripple through the global supply chains associated with each of these sectors.

The transition presents not only new opportunities for economic growth and development but also risks. Countries that have held strong competitive positions in fossil fuel-dependent industries cannot be sure of maintaining their market share as these industries undergo the structural shift to new technologies. There is a risk not only of stranded assets but also of stranded industries, regions, and communities, with a multitude of negative consequences for productivity, taxes and social spending, and wellbeing. Importantly, countries cannot opt out of this situation by deciding not to decarbonize their economies. The transition is a global one; it is changing the economic context, and governments must decide how to respond.

For Ministries of Finance, these technological changes have important implications for how to achieve the low-carbon transition cost-effectively, and the structural changes that follow could strongly affect tax revenues, public spending needs, and economic productivity.

## The policy questions

Faced with this context, some governments may still decide that the "horizontal" approach of focusing only on economy-wide fundamentals is right for their country. For those that wish to take a more proactive approach to low-carbon industrial strategy, there are two main policy questions:

1. In which technologies, sectors, or areas of economic activity should one aim to build national competitiveness, in the context of the low-carbon transition?
2. Which policies will likely be most effective in increasing national competitiveness in these areas?

These are strategic questions to which the answers cannot be certain. Competition inherently involves uncertainty. For example, many countries have expressed a desire to build capacity for the production of green hydrogen, but how much demand for this fuel will there be? Various technologies could be used for the decarbonization of steel production, but which of these will dominate global markets? Battery electric vehicles (EVs) are already clear front-runners in the road transportation transition, but what share of the market in manufacturing them can any country individually expect to have? Analytical tools and frameworks can at best provide a partial guide for these kinds of questions, indicating which choices may be more likely to succeed and which less so.

MoFs are not usually in charge of innovation or industrial policy, but they can, and often do, play a role in key areas including setting strategic objectives, using fiscal policy to support the growth of new industries, working with other parts of Government and the private sector to ensure that policies enable private investment, and ensuring financial transparency and accountability (Coalition of Finance Ministers for Climate Action 2023, p. 66). These roles, and the analytical challenges MoFs face as a result, are no different in the low-carbon transition from the roles and challenges they have taken on when countries have adopted proactive industrial policies in the past.[1] What is unusual about the low-carbon transition is the common commitment of all countries to move toward the same goal—a net zero emission world economy—making this global economic trend unusually foreseeable.

## Analytical tools for identifying where to focus…

When considering where to build national competitiveness in the context of the low-carbon transition, a good starting point is to assess the likely direction of technological change in the global economy. Analysis of the learning curves of clean technologies—the relationship between cumulative deployment and cost—can inform this assessment. Research has shown that for many technologies, this relationship is relatively consistent over long periods of time, meaning that past data can give some insight into likely future performance (Way et al., 2022).

Technologies that show rapid cost reduction, and that can plausibly be part of a zero emissions solution in one of the greenhouse gas-emitting sectors, may be considered more likely to dominate global markets in future than technologies with either slower cost reduction or only a partial emissions reduction. Examples of the former include solar photovoltaics (PV), wind turbines, batteries and electrolyzers. Examples of the latter include biofuels, carbon capture and storage, and nuclear power (Way et al., 2022).

After forming a view on which technologies will likely be central to the transition in each sector, it is possible to consider the changes up and down the related global supply chains that will likely follow. Input-output (IO) analysis can be used to indicate how changes in relative demand for different technologies, fuels, or materials in one sector could translate into changes in demand in other sectors, potentially informing policy decisions on investment, infrastructure, or skills.[2]

To identify the products in which a country is currently competitive, analysts often calculate the revealed comparative advantage: a measure of the products a country is relatively successful in exporting. This can be complemented with a comparison of productivity in different sectors. A country will likely be competitive in a sector where it has both high productivity and relatively high exports.

In the context of structural change in the global economy (and of national economic development) it is not enough to know the areas of activity in which a country is currently competitive. Governments also want to know the areas in which their country *could become* competitive. Economic complexity analysis attempts to address this question by combining the revealed comparative advantage with a measure of proximity, or relatedness, between different products (Mealy and Teytelboym 2022).[3] This measure is based on patterns in historical data that show how often a country that successfully exports one product also successfully exports another. The implication is that a country has a greater chance of developing competitiveness in products closely related to those in which it is already competitive. (For example, having strengths in electronics and semiconductors will likely increase a country's chances of becoming competitive in manufacturing solar panels). In addition, a measure of

1 See for example the experiences of Hong Kong, Indonesia, Japan, Malaysia, Republic of Korea, Singapore and Taiwan, as documented in Birdsall et al. (1993).
2 There are several IO and multi-regional IO (MRIO) databases at the global level. Some well-known ones are GLORIA, EORA and EXIOBASE. The UN, World Bank and IMF also have their own IO tables. Each have their own spatial-temporal resolutions, different level of disaggregation, and different pros and cons in the methods they use. Coverage is generally poor for low- and middle-income countries (LMICs) so a lot of information is estimated.
3 The Green Transition Navigator is an interactive tool that analysts can use for country-specific economic complexity analysis, available at https://www.lse.ac.uk/granthaminstitute/the-green-transition-navigator/. Examples of the technique's application are available at https://atlas.hks.harvard.edu/. Harvard Growth Lab uses a slightly different methodology focusing on green supply chains rather than individual products or components, explained in the report Growth through Inclusion in South Africa (Hausmann et al., 2023), and with the open source tool available at https://public.tableau.com/app/profile/ellie.jackson4706/viz/HarvardGrowthLabGreenGrowthDashboard_16923636797240/GreenGrowthDashboard?publish=yes.

“product complexity”[4] can be used to assess the value of diversifying into different product areas: more complex products tend to be associated with higher economic growth (Hidalgo and Hausmann, 2009). High-complexity products include electronics and chemicals; low-complexity products include raw materials and simple agricultural products.[5]

Economic complexity analysis can be complemented with simpler measures to provide additional context: how large is the global market for a given product, and how quickly is that market growing?

Gravity models of international trade predict trade flows between countries based on the size of their economies and the distance between them.[6] Comparing a predicted trade flow to an actual trade flow can indicate, to a first approximation, whether there is potential for trade to be increased. This analysis can be done at the product or sector level, by aggregating exports of specific products or product categories. This can provide some indication of the sectors in which a country may have the opportunity to increase its exports, and of which countries could be viable as destination markets.

## …and their limitations

All of these analytical tools have limitations. Analysis of technology learning curves cannot predict the impact on global markets of technologies that have not yet been developed. IO analysis may be misleading if it fails to represent the changes in relationships between sectors that occur as a result of structural change. Economic complexity analysis can be misleading if the trade patterns on which it is based reflect a country’s political economy more than its actual economic strengths. Gravity models typically assume static relationships between countries over time, and do not anticipate changes in comparative advantage, technologies, and supply chains. None of these tools explicitly considers the future actions of competitors.

Any government choosing to use these analytical tools should be aware of their limitations and should complement the quantitative analysis with an assessment drawing on qualitative knowledge of national industries, skills, resources, and places. Governments should also consider the strategies of competitor countries, which are often stated publicly in political speeches and policy documents. This can help to inform a judgment on how realistic it may be to aim for competitiveness in a given sector.

Table 1 provides a summary of the tools discussed above.

## Conceptual frameworks for understanding the role of policy

The question of which policies are likely to succeed in building national economic competitiveness (in a specified area of activity, rather than generally) demands not only different analytical tools from those with which governments may be most familiar, but also a different set of conceptual frameworks.

A foundational difference is that between the conceptual frameworks of market failure and market shaping. The market-failure framework is concerned with removing obstacles to the efficient allocation of economic resources at a fixed point in time.[7] In that sense, it is a static framework. It can be used to determine whether or not there is a rationale for policy in contexts where a government has no specific objective for the direction of innovation, growth, or structural change in the economy. A limitation that has long been recognized is that, where multiple market failures are present, correcting one of them does not necessarily improve economic efficiency, and actions that introduce additional

4 The definition of complex products is product few other places are able to make competitively (low ubiquity). This is often because the product is technologically sophisticated but can be because of market structure or other dynamics.
5 https://atlas.cid.harvard.edu/rankings/product.
6 For a practical guide to gravity modeling for international trade, see https://unctad.org/system/files/official-document/gds2012d2_ch3_en.pdf.
7 “Efficient” in this context refers to the theoretical concept of Pareto optimality, in which no economic actor can be made better off without another actor being made worse off. This does not mean the distribution of economic resources is necessarily equal, “fair,” or socially advantageous.

deviations from the theoretically optimal conditions may in fact improve economic outcomes (Lipsey and Lancaster, 1956). In other words, in these conditions the reliability of the framework breaks down.

**Table 1. Summary of analytical tools**

| Analytical tool | What it does | Key limitation |
|---|---|---|
| Technology learning curves | Predicts how fast technologies will likely improve, based on past data trends | For new technologies, data is often insufficient |
| Input-output analysis | Shows how changes in demand in one sector could affect other sectors | May fail to anticipate changes in relationships between sectors |
| Revealed comparative advantage | Shows which products a country has been relatively successful at exporting | May not be a good guide to the future if global markets change |
| Economic complexity analysis | Suggests products in which a country has potential to become competitive | May be misleading if current trade patterns do not reflect fundamental strengths |
| Gravity models | Indicates sectors and markets in which a country may be able to increase its exports | May fail to anticipate effects of changes in technology and global supply chains |

The market-shaping framework is appropriate when the aim is to achieve economic change in a particular direction. In this sense, it is a dynamic framework. It can be used to consider whether policies are consistent with the desired direction, such as eliminating greenhouse gas emissions from the economy, or building competitiveness in clean technology supply chains. Whereas the presumption of the market-failure framework is that a policy intervention is only justified if it addresses a market failure, under the market- shaping framework, an intervention can be justified if it prepares for change that is likely, creates change that is desirable, or avoids change that is undesirable (Kattel et al., 2018).

There are many ways in which the two frameworks can lead to similar conclusions. For example, the market-failure framework can justify the use of fiscal policy and other forms of policy to promote innovation in new technologies (overcoming information failures and taking advantage of "positive spillovers"), to reward or penalize activities that advance or damage public interests (positive or negative externalities), such as those that affect air quality or greenhouse gas emissions, or to invest in infrastructure with cross-sectoral implications (addressing coordination failures) (Coalition of Finance Ministers for Climate Action (2023, p.65; see also Stern et al., 2022).

However, there are also important ways in which they can lead to different conclusions. In the early decades of development of solar PV, policies such as public procurement and deployment subsidies were not typically seen as justified by the market-failure framework, since there were much cheaper ways to reduce emissions at those moments in time (for example, by using carbon pricing or efficiency regulations to make coal power plants more efficient). However, these policies could be justified by the market-shaping framework, since they guided investment and innovation in a desired direction. The outcome, of solar PV providing what the International Energy Agency has called "the cheapest electricity in history," may be seen as desirable regardless of the existence of the market failure of greenhouse gas emissions. While the market-failure framework has often been used to argue that carbon pricing must be the most efficient way to support decarbonization (since it internalizes the externality of greenhouse gas emissions), the market-shaping framework does not create any strong assumptions about which policies will be effective or efficient.

Conceptual frameworks for innovation-driven industrial strategy can be used as a rough guide to the kinds of policies that might be effective in building competitiveness in the context of the low-carbon transition. The smart specialization strategy framework suggests that countries should focus on sectors where they have strong and distinctive capabilities, and it emphasizes a process of stakeholder dialogue, exploratory innovation projects, and policies to deploy the most successful technologies more widely (Foray, 2018). The green industrial policy framework recognizes the low-carbon transition as an important global economic trend, and suggests a portfolio approach to support clean technologies in their earliest stages of development, market-creating policies to support the deployment of clean technologies from first deployment through to wider diffusion, and a continual process of collaborative learning between business and government in which constraints and opportunities are identified and policies are revised and adapted (Rodrik, 2014, 2023; Aiginger and Rodrik, 2020; Veugelers et al., 2024).

The mission-oriented industrial strategy framework suggests that governments should build national competitiveness by driving innovation in a direction that addresses a significant societal problem (Mazzucato and Kattel, 2023). It recommends the development of a range of policies to support innovation at each stage of a technology's development, including "demand-pull" measures (such as public procurement, subsidies, regulations, and taxes) as well as "supply-push" measures (investment in research, development, and demonstration), and policies to cross the gap between research and commercialization (such as public equity investment or concessional lending). These measures should cut across policy fields, economic sectors, and research disciplines, engaging whatever capabilities are relevant to achieving the mission's goal.

MoFs can be directly responsible for some of these measures, such as tax credits, grants, loans, credit guarantees, or performance-based incentives for the manufacturing or use of new technologies, or allowances for accelerated depreciation to incentivize investment in new equipment. They can also have a strong influence over policies led by other parts of Government, such as infrastructure investments, trade policies, and research and development programs, either directly though processes of interdepartmental consultation, or indirectly through the allocation of departmental budgets.

China's policies in the automotive sector are an example of innovation-driven industrial strategy (Zhang et al., 2023; Altenburg and Assmann 2017). The Government aimed to increase the competitiveness of its car industry, and identified a direction of innovation—toward EVs—that was aligned with many countries' commitments to address climate change. Policies included support to research and development of EV technologies, piloting demonstration projects at the city level, purchasing subsidies, public procurement, investment in charging infrastructure, and mandates requiring manufacturers to achieve a rising proportion of EVs in their sales. These "innovation-driven" industrial strategy frameworks can be used together with the multi-level perspective on transitions, a conceptual framework for understanding how technology transitions take place, and which policies are suitable for advancing a transition at each of its stages.

The main limitation of all these frameworks is that at best, they can only indicate the kinds of policies likely to be successful, and not the specific policies in a given situation.

When it comes to implementation of innovation-driven industrial strategy, one challenge is the need for strong governance and administrative capabilities, and for sustained political commitment. Without these attributes, and appropriate resources, it will be more difficult for a strategy to succeed. Even with all the right capabilities, commitment and resources, there will still, by definition, be a risk of failure, since industrial strategy is a competitive exercise, the success of which also depends on the strategic actions by other countries and firms.

The key principles of the conceptual frameworks discussed above are summarized in Table 2.

## Analytical tools to inform policy choice

Models that simulate processes of change in the economy can to some degree inform the selection of policies intended to build low-carbon competitiveness. Technology diffusion models can indicate which policies are more likely to achieve rapid deployment of a new technology—for example, comparing the effects of clean technology purchase incentives, carbon taxes, efficiency regulations, and clean technology mandates.[8] This is relevant to competitiveness because if a country has some industrial capabilities in producing a technology, the growth of a domestic market for it can help to develop those capabilities further.

**Table 2. Key principles of the conceptual frameworks**

| Conceptual framework | Key principle |
|---|---|
| Market failure | Policy is justified when it addresses a market failure (an obstacle to the efficient allocation of resources at a fixed point in time) |
| Market shaping | Policy can be justified if it prepares for change that is likely, creates change that is desirable, or avoids change that is undesirable |
| Smart specialization strategy | Countries should focus on sectors where they have strong and distinctive capabilities, and use stakeholder dialogue, exploratory innovation projects, and policies to deploy the most successful technologies more widely |
| Green industrial policy | A portfolio approach should be used to support clean technologies in their earliest stages of development, and market-creating policies should be used to support the deployment of clean technologies from first deployment through to wider diffusion, in addition to a continual process of collaborative learning |
| Mission-oriented industrial strategy | Innovation should be driven in a direction that addresses a significant societal problem, using a combination of “supply push” and “demand pull” policies to support innovation at each stage of a technology’s development |

Agent-based models can be used to test policies by simulating the responses of industry or investors. This can include testing the effect of different policies in combination, e.g., clean technology deployment subsidies together with concessional lending (Andreao et al., 2023). Agent-based models of the global market in an economic sector of interest can represent the interactions between policies in different countries, which could provide insights into the outcomes of competitive strategies.[9]

Macroeconomic models of various kinds can be used to project changes in labor demand in different sectors of the economy as a result of the low-carbon transition. Often, these models assume that labor demand is met by labor supply—in other words, whatever jobs are created are filled by appropriate people (García-García et al., 2020). Models that explicitly represent the labor market can explore the interactions between labor supply and demand and other factors such as wages, skills, and geography, showing how these factors may lead to unfilled positions, or unemployed people (Del Rio-Chanona et al., 2021; Berryman et al., 2023).[10] This can inform skills policy, which can be an important component of industrial strategy. When macroeconomic models are linked to sector-specific technology diffusion models, they can be used in combination to inform choices between alternative clean technology deployment policies, such as those mentioned above.[11]

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8 The Future Technology Transformations model is one such model.
9 For example, the Angolan Ministry of Finance has used an agent-based model, the Integrated Sustainable Development Goals Model, to test policy scenarios and inform the National Development Plan, evaluating options for achieving the SDGs. The model was used to evaluate 17 different (budgetary and non-budgetary) policy interventions across domains such as health, education, environmental action, agriculture, industry, infrastructure, energy, water, and sanitation. Officials from the Ministry of Finance, Ministry of Economy and Planning, and National Statistics Institute have trained in the use of the model, and the model is gradually being integrated in the national planning process. See the case study by Sharpe et al (2024).
10 For an open source tool that builds on these papers, see https://vis.csh.ac.at/labor-transitions-in-net-zero/.
11 The E3ME-FTT macroeconomic model has been used in Czechia to assess the economic and social impacts of different elements of the European Green Deal, enabling the Czech government to better understand how different policy designs and stringencies could affect the Czech economy at the macro level (in terms of GDP and employment) as well as in more detail at the sectoral level, and to design domestic policies to reinforce the positive impacts of European policies. See the case study in Sharpe et al. (2024).

While conceptual frameworks can only provide guidance as to the *kinds* of policies likely to be effective as part of a low-carbon transition or industrial strategy, models provide quantitative outputs that can suggest whether one policy will likely be more cost-effective than another, or what level of stringency is required for a policy to be effective. However, models in any of these categories are only as good as their input assumptions, data, and the degree to which they realistically represent the economic systems of interest, and they are only as insightful as the analysts who interpret their outputs.

The outcomes of any innovation and industrial policy are subject to large uncertainties. Technology development, consumer choices, investor confidence, and the actions of other countries, are only a few of the many sources of uncertainty likely to be relevant to the success of any low-carbon industrial strategy. For this reason, overreliance on quantitative models can be risky. Analysts can sense-check and complement model outputs by comparing them with other forms of knowledge, including empirical studies of the effectiveness of low-carbon transition policies that have been implemented around the world. Governments can also use scenario analysis as a structured way of exploring uncertainty. This can, for example, be used to consider how an industrial strategy would perform in a variety of possible conditions that could be created by the actions of competitor countries.

**Table 3. A description of the tools discussed in Sharpe et al. (2024)**

| Tool | Function |
|---|---|
| Technology diffusion models | Can be used to compare the (cost-)effectiveness of deployment policies such as taxes, subsidies, efficiency regulations, clean technology mandates |
| Agent-based models | Can test how policies may influence industry or investors (while industry and investors also react to each other's actions) |
| Macroeconomic models | Can indicate the likely macroeconomic outcomes of industrial policies |
| Scenario analysis | Can be used to consider how an industrial strategy would perform under different conditions, such as may be created by the actions of other countries |

## Improving the tools and building capacity to use them

Many of the analytical tools discussed in this section (for a description see Table 3) are available to any government that wishes to use them. The conceptual frameworks described above are easy to access but can be difficult to implement. Research studies providing learning curve analysis of clean technologies are publicly available. Scenario analysis benefits from skilled facilitation, but it does not have to involve extensive data. IO analysis and economic complexity analysis require detailed data but are not technically difficult.

Economic models that are well-suited to informing low-carbon industrial policy are less available and accessible. Technology diffusion models and agent-based models that represent the sectors where the low-carbon transition will take place, in enough detail to usefully inform policy, are not yet well developed or widely available. Nor are models capable of simulating the effect of the transition on labor markets. Investment in the further development of such models would be valuable, to give governments access to a more diverse and helpful set of tools to inform industrial strategy in the context of the transition.

MoFs can build capacity within Government by providing guidance and training to officials on the use of relevant conceptual frameworks and analytical tools. Developing models requires good data, programming skills, and time; since these can be in short supply within governments, MoFs can also signal their needs for new capabilities to the community of academic researchers and international organizations. Governments can also benefit from sharing experiences in the application of qualitative tools, such as scenario analysis, to improve their understanding of best practice.

## Case study: identifying green growth opportunities: South Africa's use of economic complexity analysis[12]

Economic complexity analysis was used in South Africa to identify opportunities for competitiveness in emerging supply chains critical to the global low-carbon transition.[13] The analysis compared the closeness of value chains for a range of clean technologies, as well as products throughout each of those value chains, with South Africa's areas of current and potential comparative advantage.[14] It was complemented with stakeholder consultations and qualitative research.

The analysis revealed strong low-carbon growth opportunities for South Africa. Opportunities to become competitive in products such as batteries, EVs and green hydrogen were considered to be grounded not only in the plentiful natural resources of solar, wind, and minerals, but also in existing industrial capabilities in metals, electronics, machinery, and chemicals. While, for batteries, South Africa had an existing comparative advantage in products *across* the supply chain, for green hydrogen South Africa was competitive in some parts of the value chain but would need to invest significantly to become competitive in others—a more challenging "strategic bet".[15] South Africa's Industrial Development Corporation[16] used the analysis to inform its policy positions on the transition to EVs, and its engagement with the automotive sector.

The Treasury is now using this analytical approach to review and evaluate sector-specific industrial plans and policies, and to inform the next iteration of green growth strategy development. The Treasury is considering complementing this with strategic Foresight studies to generate insights into emerging and likely trends.[17] Recognized challenges include: the method's focus on economic growth but not job creation and inequality reduction; the need for other tools to address constraints such as high costs of capital; and the need for more coordinated policies across Government departments to build competitive value chains.

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12 This case study was written by Anna Murphy with contributions from Ketan Ahuja and Tim O'Brien (Harvard Growth Lab); Georgina Ryan (National Treasury of South Africa); and Rian Coetzee, Phiwe Marumo, Pamela Mondliwa and Khethollo Morolong (IDC).
13 Undertaken with support from the Harvard Growth Lab.
14 This differs from other approaches for economic complexity, which identify comparative advantage in individual green products, but not value chains. See, for example, Mealy and Teytelboym (2022).
15 See the work by Hausmann et al (2023) as part of the two year project Growth through Inclusion in South Africa. https://growthlab.hks.harvard.edu/policy-research/south-africa#:~:text=South%20Africa's%20Green%20Growth%20Potential,world%20will%20need%20to%20decarbonize.
16 A national development finance institution owned by the SA Government and the key implementing agency of the country's industrial policy.
17 See NACI Foresight reports. https://www.naci.org.za/index.php/foresight-reports/.

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