CHAPTER 2

EXPANDING FRONTIERS: FISCAL POLICIES FOR INNOVATION AND TECHNOLOGY DIFFUSION

Introduction

Global productivity growth and innovation have weakened over the past two decades (Figure 2.1, panel 1), and medium-term growth expectations have dimmed (Goldin and others 2024; see also the April 2024 *World Economic Outlook*). Innovation—defined as the invention and introduction of new or improved products and processes—is the ultimate driver of long-term productivity growth and better living standards because it expands the frontier of what is possible for society. Yet despite rapid advancements in digital technologies, innovation has become costlier to produce (Bloom and others 2020), unbalanced across sectors (Acemoglu, Autor, and Patterson 2023), and increasingly driven by applied rather than fundamental research that generates wide-ranging knowledge spillovers (Akcigit, Hanley, and Serrano-Velarde 2021). Moreover, the diffusion of innovation across countries and firms has slowed (Andrews, Criscuolo, and Gal 2016; Dabla-Norris and others 2023). While the contribution of emerging market and developing economies to innovation has grown, large cross-country technology gaps remain (Figure 2.1, panel 2).

Reversing the trend of declining productivity growth and lifting growth prospects is critical in the face of record levels of government debt, climate and demographic transitions, and long-standing development gaps. However, innovation in the low-carbon ("green") technologies needed to accelerate a reduction in carbon emissions has slowed in recent years (Hasna and others 2023), and the diffusion of existing low-carbon technologies to emerging market and developing economies faces obstacles. Looking ahead, advancements in emerging transformative technologies, specifically generative artificial intelligence (AI), present growth opportunities but also new challenges. Adoption of those technologies will likely be uneven and could widen divides across countries and firms, among other risks (see the April 2024 *Global Financial Stability Report*). Uncertainty also remains as to how quickly AI will translate into higher aggregate productivity.

Fiscal policies are key to pick up the pace of innovation for countries at the technology frontier.[1] Private investors often fail to capture the full social benefits of innovation, leading to insufficient research and development (R&D) efforts, particularly in fundamental research that drives innovation. This suggests a role for public policy to bridge the gap (Bloom, Schankerman, and Van Reenen 2013; see also the April 2016 *Fiscal Monitor*). Public support can be even more beneficial in sectors or technologies where innovation yields additional public goods, such as reductions in emissions and improvements in public health.

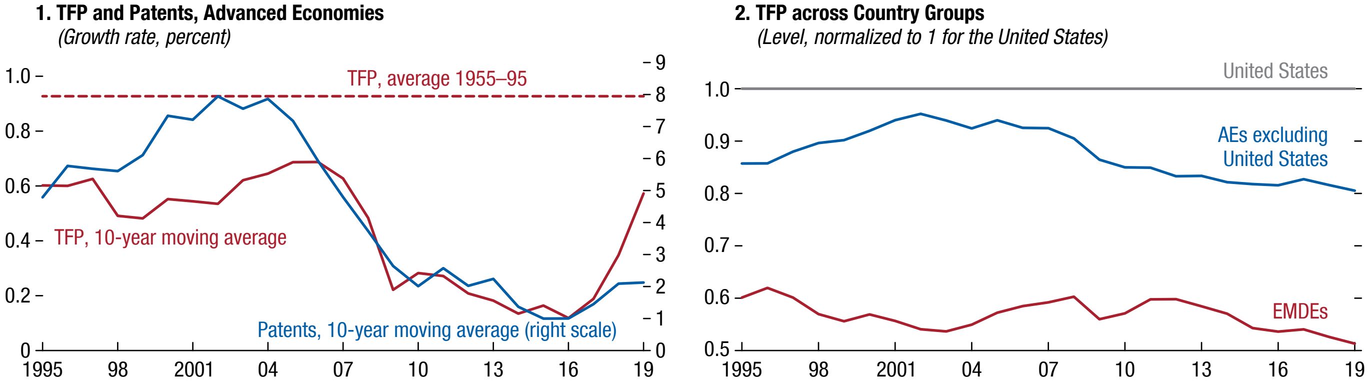
In recent decades, public spending on fundamental research has fallen behind the rising contribution of the private sector, which tends to be more commercially oriented and incremental in nature. More recently, many major economies have turned to a more directed approach motivated by concerns about economic and national security, using industrial policies to favor innovation in specific sectors, and limiting international diffusion of technologies. This raises important questions about the productivity benefits and costs associated with industrial policy.

Countries below the technology frontier, in turn, may lack the preconditions to adopt—that is, recognize, assimilate, and apply—technologies developed elsewhere, particularly green, digital, and AI technologies that require specialized infrastructure and skills. Even in advanced economies, most firms are not at the frontier, suggesting large payoffs from broader adoption of technology. Fiscal policies that remove barriers to technology diffusion can thus complement other structural and financial policies to speed up productivity growth and lift growth prospects.

This chapter examines the role of fiscal policies in promoting the diffusion of innovation and technology, with an emphasis on harnessing the potential of green and digital technologies. Given elevated debt levels and limited fiscal space in many countries (see Chapter 1),

[1]Countries at the technology frontier include mostly advanced economies and a few emerging market economies, although this can vary across sectors and technologies and over time.

Figure 2.1. Withering Innovation, Productivity, and Technology Diffusion



Sources: European Patent Office, PATSTAT; Penn World Tables; and IMF staff estimates.
Note: AEs = advanced economies; EMDEs = emerging market and developing economies; TFP = total factor productivity.

the chapter focuses on policy design features and assesses their growth and fiscal effects. The analysis tackles the following three questions:

- *Should governments play a role in the direction of innovation using industrial policy?* What are the costs and benefits of fiscal support for directed innovation in specific sectors?
- *What is the most effective mix of fiscal instruments to support innovation more broadly at the technology frontier?* How should policies be designed to support innovation? And what are the potential gains from such policies?
- *What fiscal policies can facilitate technology diffusion to countries and firms below the technology frontier?* How can barriers to the diffusion of green and advanced digital technologies in emerging market and developing economies be overcome?

The chapter shows that using industrial policy to promote innovation delivers returns only if social benefits (or “externalities”) are well measured, knowledge spillovers from subsidized sectors are high, administrative capacity is strong, and policies do not discriminate against foreign firms. A well-designed fiscal policy mix that supports innovation more broadly across sectors and emphasizes public funding for fundamental research can substantially boost long-term growth for economies at the technology frontier. While such policies pay for themselves in the long term, funding them may require countries with more limited fiscal space to reprioritize expenditure or improve revenue mobilization. For economies and firms below the frontier, facilitating technology adoption with strategic public investments and tax reforms should be the priority. The chapter focuses on domestic policies but also highlights the role of international coordination to catalyze cross-border knowledge spillovers.

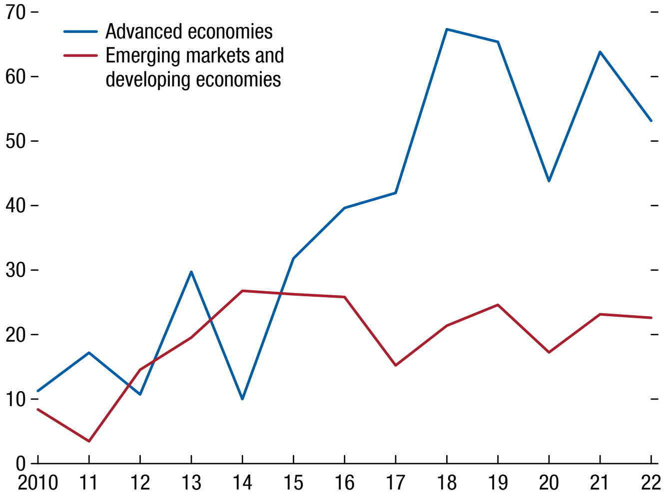
The diffusion of innovation and technology is notoriously difficult to measure. The chapter uses alternative measures depending on the specific analysis, including innovation inputs—such as R&D expenditures by the private and public sectors—and innovation outputs—such as growth in patents, and labor productivity or total factor productivity (TFP).[2]

Directing Innovation toward Specific Sectors

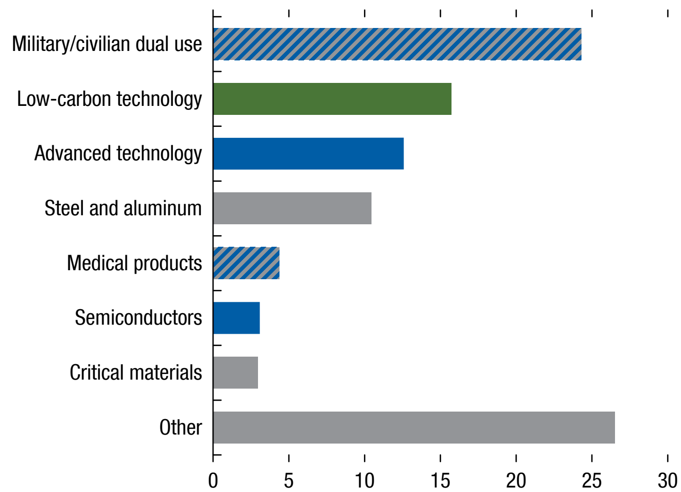
The recent strategic push for industrial policies in large economies (Figure 2.2, panel 1) has brought to the fore the question of whether and under what conditions governments should direct fiscal support toward innovation in specific sectors or technologies. Recent industrial policy initiatives in advanced economies—such as the CHIPS Act and Inflation Reduction Act in the *United States*, the Green Deal Industrial Plan in the *European Union*, the New Direction on Economy and Industrial Policy

[2]No measure is perfect—not all innovation is recorded as research and development or patented, while total factor productivity captures other channels such as improved allocative efficiency. The spread of digital products further complicates measuring total factor productivity, as the market prices of those products tend to be less representative of consumer value than is the case for other products.

Figure 2.2. Increasing Use of Industrial Policies for Innovation



Sources: Global Trade Alert database; Juhász and others 2022; and authors' calculations.



Sources: Evenett and others 2024; and IMF staff estimates.
Note: Green sectors are highlighted in green and high-tech sectors in blue. Sectors with blue and gray stripes include technologies that are both advanced and non-advanced economies.

in *Japan*, and the K-Chips Act in *Korea*—as well as long-standing policies in large emerging market economies such as *China*, share a strong emphasis on innovation in specific sectors, among other objectives. Most packages include fiscal incentives for innovation in green and advanced technology sectors (such as AI and semiconductors) (Figure 2.2, panel 2), with a heavy reliance on costly subsidies.

Governments may want to direct the course of innovation for various reasons, including addressing market failures—that is, externalities related to climate and public health, knowledge spillovers to other sectors, supply chain resilience, and national security (Table 2.1). Historical experience suggests that getting industrial policy right is a tall order (Box 2.1). Whereas policies may help some firms become more productive, they can also lead to inefficient allocation of resources. Indeed, an abundance of failed programs in countries with strong institutions shows that it is difficult to avoid policy mistakes. Even when projects succeed in transforming industries, such as Airbus in the *European Union* and electric vehicles in *China*, they can incur high fiscal costs and, in some cases, generate negative cross-border spillovers.

This section develops a model-based framework to assess conditions under which sector-specific fiscal

Table 2.1. Potential Rationales for Directing Innovation

Target	Rationale
Green innovation	Accelerate the development of green technologies, as current innovation can persistently determine the path of future technology.
Labor market effects	Discourage labor-saving technologies that disrupt labor markets (for example, generative artificial intelligence).
Spillovers to other sectors	Support sectors that generate more innovation spillovers to other sectors in order to lift productivity growth; laggard sectors can act as bottlenecks to aggregate growth.
Defense/self-sufficiency	Develop domestic innovation in strategic technologies (for example, civilian–military dual use).
International competitiveness	Develop domestic technologies to capture global market shares or improve terms of trade.
Local spillovers	Promote agglomeration spillovers from innovation hubs.

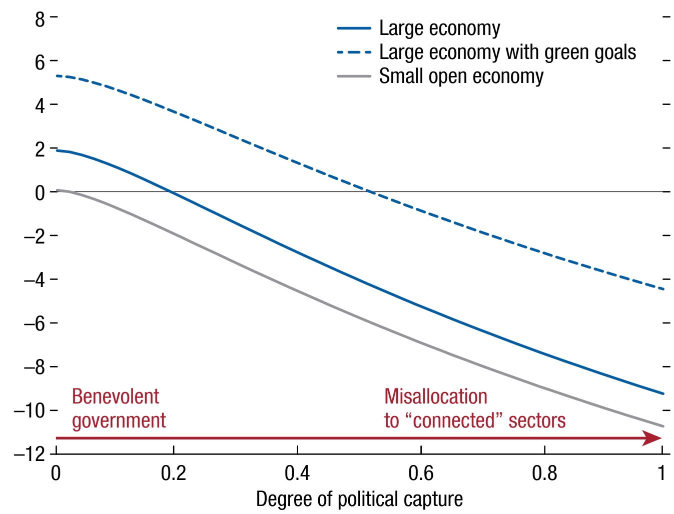
Sources: Acemoglu and others 2012; Acemoglu and Johnson 2023; Acemoglu, Autor and Paterson 2023; Bai, Jin and Lu 2023; Carlino and Kerr 2015; Hidalgo and Hausman 2009; and Liu and Ma 2023.
Note: The table summarizes commonly provided rationales for directing innovation. Not all of the rationales may be feasible in practice.

support for innovation is preferable to sector-neutral support ("horizontal" policies) (Online Annex 2.1).[3] Based on the framework, an important benefit of directed innovation is that it allows for targeting support to sectors that generate higher knowledge spillovers to other domestic sectors (measured by cross-sector patent citations). This, in turn, raises economy-wide innovation, productivity growth, and welfare. Targeting also allows for redirecting innovation to greener sectors, thereby reducing negative emissions externalities over time and further increasing welfare. In practice, however, support may not be allocated to the right sectors, lowering the benefits of industrial policies. For example, subsidies may be diverted to politically connected sectors instead of being solely driven by social returns. Benefits are also limited for sectors and countries that rely on foreign knowledge spillovers, as these are less likely to be affected by domestic innovation policy.

An illustrative simulation indicates the welfare implications of industrial policy. For a large, advanced economy (for example, the *United States*), targeting support to sectors with larger knowledge spillovers can increase welfare by 2 percent (in consumption-equivalent terms) compared to an equivalent amount of sector-neutral support (Figure 2.3). This estimate assumes there is no misallocation of fiscal support. The welfare gains rise to 5 percent when the government considers emissions-reduction goals and directs innovation to sectors with higher green intensity (measured by the share of green patents). This is because, in addition to promoting knowledge spillovers across firms, support for green innovation complements carbon pricing and other environmental policies in reducing emissions externalities (Box 2.2). Further, emissions are relatively easy to measure.

Implementation challenges, however, can lower the economic and social benefits of industrial policy. The model simulations show that as the degree of political capture increases, industrial policy can result in welfare losses even in a large economy with green goals (Figure 2.3).[4] In the analysis, the political

Figure 2.3. Simulated Welfare Impact of Industrial Policy
(Consumption-equivalent change relative to no industrial policy, percent)



Sources: Diez, Fan, and Villegas-Sánchez 2021; European Patent Office, PATSTAT; Liu and Ma 2023; World Intellectual Property Organization, Green Inventory; and IMF staff simulations.
Note: The figure presents simulations from an endogenous innovation model with a sectoral network, based on Liu and Ma 2023. The government chooses sectoral research and development subsidies to capture cross-sector knowledge spillovers (measured by patent citation linkages) and emissions-reduction goals (dashed line), but may favor politically connected sectors (proxied by sector markups). The lines in the figure show differences relative to sector-neutral support. For details, see Online Annex 2.1.

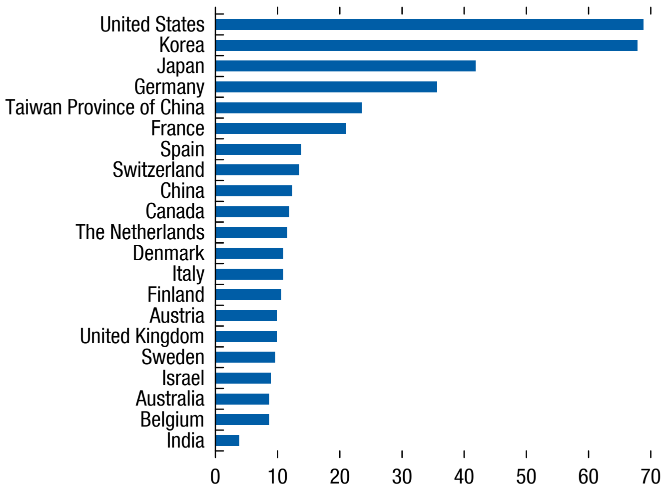
weight of a sector is proxied with market power, in line with evidence that firms with larger market shares tend to employ more politicians per worker (Akcigit, Baslandze, and Lotti 2023), and that political connections can drive the market valuation of listed firms and the allocation of government spending (Acemoglu and others 2016; Choi, Penciakova, and Saffie 2021). More broadly, the effectiveness of industrial policies can also be hindered by information asymmetries between the government and firms, such as mislabeling of projects, inefficient government administration, inertia in policies (Juhász, Lane, and Rodrik 2023), and uncertainty about—or misgauging of—the social benefits.

Not all countries benefit equally from industrial policy. The ability to influence cross-sector knowledge spillovers is generally more limited in small or more open economies because a larger share of their knowledge flows come from abroad (Figure 2.4) or are exported. More open economies are also less able to complement R&D support with production or demand-side subsidies, as they are more integrated in global markets and supply chains.

[3]The framework is based on a model of endogenous innovation with a sectoral network of knowledge spillovers (an extension of Liu and Ma (2023).

[4]In the model simulation, this occurs when the weight on politically connected sectors reaches 0.5, equivalent to a worsening of the allocation of resources by 10 percent of the gap between the *United States* and large emerging market economies (Hsieh and Klenow 2009).

Figure 2.4. Domestic Knowledge Spillovers, Select Economies
(Patent citations from own country, percent of total)



Sources: European Patent Office, PATSTAT; and IMF staff estimates.
Note: The figure displays the within-country average of domestic patent citations across all sectors. Patents are attributed to countries based on the location of their inventors. For details, see Online Annex 2.1.

Taking a representative small open economy at the technology frontier, where only 10 percent of knowledge spillovers originate domestically (compared with almost 70 percent in the *United States*), the simulations show limited gains from targeted support even in the absence of implementation frictions (Figure 2.3). However, the analysis also implies that small economies specializing in frontier sectors with mostly domestic spillovers can benefit from directing innovation (Figure 2.4). This could explain industrial successes in *Korea* and *Taiwan Province of China* (Cherif and Hasanov 2019). Moreover, smaller countries can coordinate their policies to account for the knowledge spillovers between each other (an example is the *European Union*'s Horizon Europe Program).

An important corollary of these findings is that geoeconomic fragmentation could be self-reinforcing and hard to reverse. This is because larger research-intensive economies tend to have more domestic spillovers and, as such, greater incentives to implement industrial policies, which often entail preferential treatment for domestic industries (Evenett and others 2024). As most of the stock of knowledge is imported even for most countries at the technology frontier, policies discriminating against foreign firms can prove self-defeating and trigger costly retaliation.

In sum, industrial policy for innovation can only be beneficial if the following conditions hold:

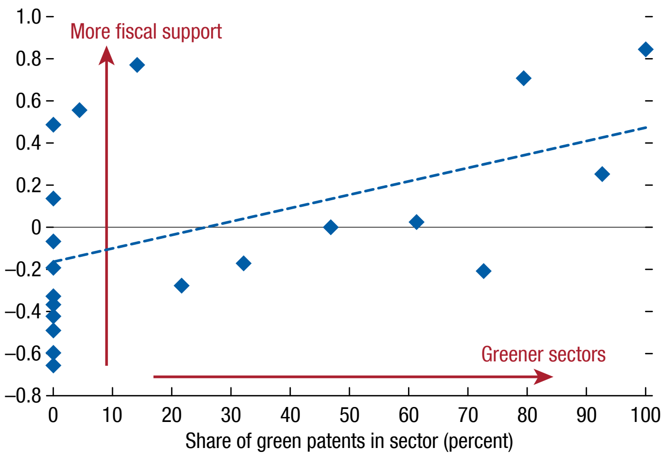
- Externalities can be correctly identified and precisely measured (for example, carbon emissions).
- Domestic knowledge spillovers from innovation in targeted sectors are strong.
- Government capacity is high enough to prevent misallocation (for example, to politically connected sectors).
- Policies do not discriminate against foreign firms, so as to avoid triggering retaliation by trade partners.

As with any model-based analysis, tractability demands that the framework leave out a number of factors that could affect the policy conclusions. One such issue is that welfare gains are calculated relative to the distribution of R&D support under no industrial policies. In practice, countries typically have in place innovation policies that directly or indirectly subsidize specific sectors (for example, place-based policies when sectors are geographically concentrated). As a result, comparing the optimal distribution with the actual distribution of innovation support could result in lower estimated gains than shown here. The simulation also assumes that governments take the path of foreign innovation as given. For large economies, knowledge spillovers to other countries could be beneficial if they improve the quality of imported products. On the other hand, knowledge spillovers could allow competitors to gain global market shares, spurring countries to restrict knowledge outflows (Garcia-Macia and Goyal 2020). As such, assuming that governments account for foreign knowledge spillovers could either amplify or mitigate the gains from industrial policy.

The analysis also sheds light on how to optimally allocate R&D across sectors. While greener sectors should receive more support given emissions externalities, the relationship is not linear (Figure 2.5). The degree to which innovation in each sector benefits other sectors also plays a big role. Not all green sectors are equally central in terms of their knowledge spillovers, and knowledge can spill over between green and brown sectors over time, diluting the effects of targeting green sectors.

Innovation policy in large economies has also focused on AI (for example, AI Next and AI Institutes in the *United States* and the *European Union*'s Partnership on AI, Data and Robotics), or on key inputs to AI such as semiconductors. The simulation results show that in contrast to green sectors, sectors

Figure 2.5. Optimal R&D Support by Sector
(Change in R&D relative to no industrial policy, logs)



Sources: Diez, Fan, and Villegas-Sánchez 2021; European Patent Office, PATSTAT; Liu and Ma 2023; World Intellectual Property Organization, Green Inventory; and IMF staff simulations.
Note: Simulations from an endogenous innovation model with a sectoral network, based on Liu and Ma 2023. The dashed line shows the average increase in a sector's R&D support (relative to uniform support) as the green intensity of the sector increases. Sectors are aggregated into 20 bins (shown in dots) and the *y*-axis is rescaled to a zero mean. R&D = research and development.

currently projected to be more exposed to AI may not necessarily warrant greater fiscal support because they do not generate higher spillovers, on average (Online Annex 2.1). Of course, innovation in AI technology could lead to higher research spillovers over time, including in health and green sectors with high social returns, which are not captured in the model. That said, global corporate investment in AI has soared more than 10-fold in the past decade (Maslej and others 2023). After decades of research, often funded by governments, AI technology has matured to the commercial adoption phase. More generally, an assessment of fiscal incentives for AI needs to consider not only their impact on innovation but also their implications for other objectives such as the government budget and labor market effects. As such, priority could be given to technologies that expand human capabilities and to facilitating AI adoption in sectors with higher social benefits.

Overall, these results point to the importance of exercising caution when using industrial policies for innovation. Even as multiple social goals—most prominently, reducing emissions—call for greater innovation in some sectors than others, implementing industrial policies effectively is challenging. It requires sufficient information, including on the nature of market failures, input-output linkages, supply chains, administrative capacity, and influence over global innovation flows. Governments deploying industrial policies should strengthen technical capacity to vet subsidized projects (see the discussion in the next section), establish clear benchmarks, conduct exhaustive assessment of fiscal costs and risks, recalibrate support as conditions change, foster competition, and seek international collaboration.

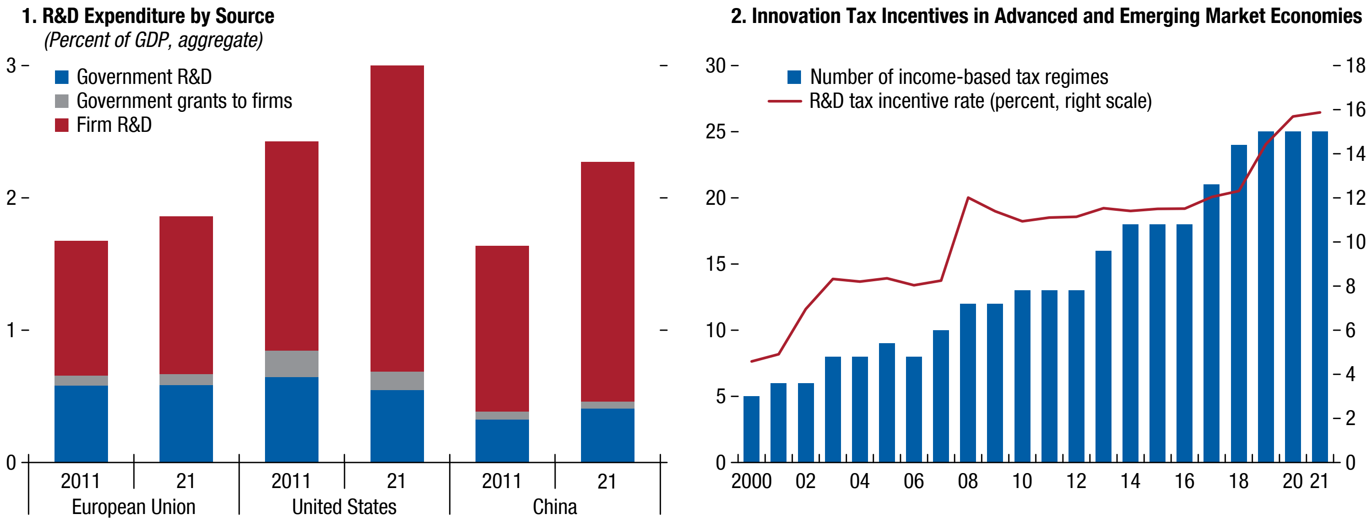
Promoting Innovation at the Technology Frontier

Directing innovation to specific sectors delivers gains under fairly restrictive conditions, and widespread use of industrial policies can entail large fiscal costs. This section discusses how advanced and emerging market economies at the technology frontier should design a broader innovation policy toolkit using cost-effective fiscal instruments at a juncture of limited fiscal space and appropriate targeting to account for the nature of research (fundamental versus applied), the innovation lifecycle, and firm characteristics (age, financing constraints).

The mix of innovation policy instruments used by governments has evolved over past decades. Government spending has been increasingly tilted toward incentivizing firm R&D. Whereas public R&D has remained stable at about 0.5 percent of GDP in Organisation for Economic Co-operation and Development (OECD) economies (Figure 2.6, panel 1), funding for fundamental research has stagnated even as the implicit subsidy rate to firm R&D expenditure from tax incentives (such as tax credits) has almost tripled since 2000 (Figure 2.6, panel 2).

Governments have also rapidly increased the use of other instruments such as patent boxes (used in 21 of 38 OECD economies as of 2022), which tax income derived from patents at a lower rate. Consequently, private sector innovation has increased (measured by firm R&D) but tends to be commercially oriented and incremental in nature even as innovation depends more on fundamental scientific advances funded by public research. How countries at the technology frontier can rebalance this using an appropriate policy mix is discussed in the next section.

Figure 2.6. Governments Shifting R&D Support to Tax Incentives for Firms



Sources: González Cabral and others 2023; Organisation for Co-operation and Development (OECD); and IMF staff calculations.
Note: Firm R&D includes that which is financed by firms (potentially supported by tax incentives but excluding government grants to firms). Government R&D is that which is financed by the government excluding grants to firms. The R&D tax incentive rate is based on implicit effective subsidies. Income-based tax regimes include patent boxes, among other instruments. The panel 2 sample consists of 40 countries including OECD economies plus *China*, *Romania*, *Russia*, and *South Africa*. R&D = research and development.

Designing an Efficient and Cost-Effective Innovation Toolkit

Governments need to design an innovation toolbox that effectively combines different instruments that account for economic efficiency, fiscal costs, policy objectives, and design features. The analysis of cost-effectiveness of commonly deployed budgetary instruments for innovation draws on a meta-study of existing literature and new empirical estimates. For each policy instrument, Table 2.2 shows the estimated increase in total R&D expenditure per dollar of fiscal cost, together with policy guidelines.[5]

Overall, public research, R&D tax incentives, and research grants (all highlighted in green in Table 2.2) are consistently found to be the most cost-effective tools. In particular, tax incentives and grants lead on average to almost one additional dollar in total R&D expenditure per dollar of fiscal cost, with slightly larger effects for financially constrained firms (Agrawal, Rosell, and Simcoe 2020). One benefit of tax incentives is that all private R&D activities get equal treatment. The drawback, however, is that private sector R&D decisions may not adequately address the complex knowledge spillovers associated with innovation. Policy objectives also matter: Grants can be more useful for start-ups (typically young and small firms) at earlier stages of the financing cycle, whereas tax incentives can be cheaper to administer but require that firms have sufficient internal funding.[6]

Public research is found to have the largest "bang for the buck," with more than one additional dollar in total R&D per dollar of fiscal cost. This is not surprising, as public research funding tends to focus on fundamental research, which has high knowledge spillovers benefiting more sectors in more countries, and for a longer time than applied research by firms (see the October 2021 *World Economic Outlook*). Overall, subsidies are especially useful for supporting the research component of R&D—the early phase of the innovation process when knowledge spillovers tend to be larger (see the April 2016 *Fiscal Monitor*). Tax incentives can complement these subsidies by providing across-the-board incentives to all firms investing in R&D. The different innovation tools can also work together to reinforce synergies between firms, universities, and public research institutes (Arora

[5]Online Annex 2.2 discusses the estimates based on the literature, while Online Annexes 2.3 and 2.4 describe the empirical approaches.

[6]These can include tax credits, enhanced allowances, accelerated depreciation, and special deductions for labor taxes or social security contributions.

Table 2.2. Budgetary Instruments to Promote Innovation

Instrument	Impact on Total R&D per Dollar Spent: IMF Staff Estimates	Impact on Total R&D per Dollar Spent: Literature	Policy Guidelines
R&D tax incentives	[0.7,0.9]	[0.2,1.5]	Better for mature firms and for horizontal support Preferable if tax credit is refundable
Patent boxes (intellectual property regimes)	Small	~0	Induce profit-shifting/excessive patenting BEPS Action 5 reform effect still uncertain[1]
R&D grants	n.a.	[0.5,1.5]	Better for younger firms and for targeting sectors with high social returns
Public R&D	[1.2, 1.5]	>1	Better for fundamental research and for targeting sectors with high social returns
Moonshot projects	n.a.	Inconclusive	Can have strong relocation effects

Sources: Organisation for Economic Co-operation and Development (OECD); and IMF staff estimates. See Online Annex 2.2 for literature sources.
Note: Instruments found to be most cost-effective are highlighted in green. IMF staff estimates are based on an ordinary least squares panel regression with country and year fixed effects, controlling for macroeconomic factors and the corporate income tax rate. The sample consists of 40 countries including OECD economies and *China*, *Romania*, *Russia*, and *South Africa* during 2000–21. Intervals in brackets refer to the 25th and 75th percentiles of the coefficient distribution, respectively. All coefficients in the table are statistically significant at the 95 percent confidence level. For more details on IMF staff estimates, see Online Annexes 2.3 and 2.4. For the literature estimates, see Online Annex 2.2. n.a = not applicable; R&D = research and development.
[1] The OECD/Group of Twenty Base Erosion and Profit Shifting (BEPS) Project Action 5, effective since December 2015, requires firms benefiting from intellectual property regimes to conduct substantial R&D activity in the country offering the patent box.

and others 2023), increasing the cost-effectiveness of innovation and higher education policies.

Combining these results with estimates of the output response to R&D from the literature, the implied fiscal multiplier—*the increase in output per dollar of fiscal cost*—is 3 to 4 over the long term for the most effective tools (Online Annex 2.5). This implies that increasing fiscal support for R&D by 0.5 percentage point of GDP (or about 50 percent of the current level in OECD economies) through a combination of public research funding, grants to firms, and tax credits could raise GDP by up to 2 percent. The GDP impact reflects the complementarity between public and private research. The innovation policy mix also lowers the public-debt-to-GDP ratio by about 0.5 percentage point over an eight-year horizon, as the initial increase in debt from higher fiscal spending is gradually offset by higher GDP and revenue (Online Annex 2.5). However, while innovation policies can pay for themselves in the long term, countries with limited fiscal space may need to raise revenue or reprioritize other spending to finance the short-term costs of those policies (see Chapter 1).

These estimates are based on the observed effects of existing policies for an average OECD economy. Fiscal costs and growth effects will vary depending on the policy mix adopted, the human capital base, and other country characteristics. For instance, the reduction in the debt-to-GDP ratio will tend to be larger in economies with higher initial debt ratios. Tilting support toward public research, which entails large knowledge spillovers but is underfunded, could yield larger payoffs at a lower cost and over a longer period. Moreover, GDP gains from subsidies could be higher if targeting is improved and domestic innovation spillovers are high, as discussed in the previous section.

Indeed, policy design and targeting are critical to driving productivity and growth payoffs. The world's top 2,500 R&D investors account for close to 90 percent of global business R&D expenditure and 60 percent of patent filings for all technologies (Amoroso and others 2021), and the share of innovation done by more established firms has been growing relative to entrants (Garcia-Macia, Hsieh, and Klenow 2019).[7] Social returns to innovation can be considerably smaller if large firms or market leaders use defensive patenting to cement market power and block more innovative competitors, suggesting that tax incentives must be kept simple to maximize take-up across firms. Incentives also tend to be more cost-effective when they only reward incremental R&D and avoid favoring incumbents or state-owned enterprises.[8] Public funding for research and grants

[7] This concentration of innovation is particularly pronounced in high-tech sectors such as software and computer services, pharmaceuticals, and biotechnology. See Akcigit and Kerr (2018), Argente and others (2020), and Akcigit and Goldschlag (2023) for a discussion of how large established firms can impede innovation.

[8] Tax incentives for innovation may become less effective because of the global minimum tax agreed upon by the members of the Inclusive Framework. This occurs, for instance, if tax relief reduces the effective tax rate below the global minimum rate of 15 percent (IMF 2023).

is better suited to target specific types of innovation or sectors, including nonmarket sectors, but, as discussed earlier, such funding requires sufficient administrative capacity.

The effectiveness of other fiscal instruments in driving innovation and productivity growth is less clear cut. "Moonshot" projects that focus on a single mission (Mazzucato 2018) can catalyze resources for narrow goals (for example, developing vaccines against COVID-19), but evidence on their broader efficacy is inconclusive. Patent boxes or intellectual property regimes, which offer preferential tax treatment to income from protected intellectual property assets (for example, patents, trademarks, or copyrights), tend to reward more established and less financially constrained firms. They have also been prone to profit shifting by multinationals in the past, leading to a small overall impact on domestic innovation activity. Firm R&D spending increased after the 2015 international tax reform required firms benefiting from patent boxes to conduct substantial R&D activity in the country offering the patent box (Online Annex 2.3). However, a quasi-experimental regression analysis suggests that these gains were limited to countries that had adopted patent boxes before the reform (Online Annex 2.4).

Overall, R&D tax incentives that reward expenditures or inputs are preferable to patent boxes for outputs, especially since AI-driven business models increase the potential for large established firms to take advantage of preferential tax rates on intellectual property.

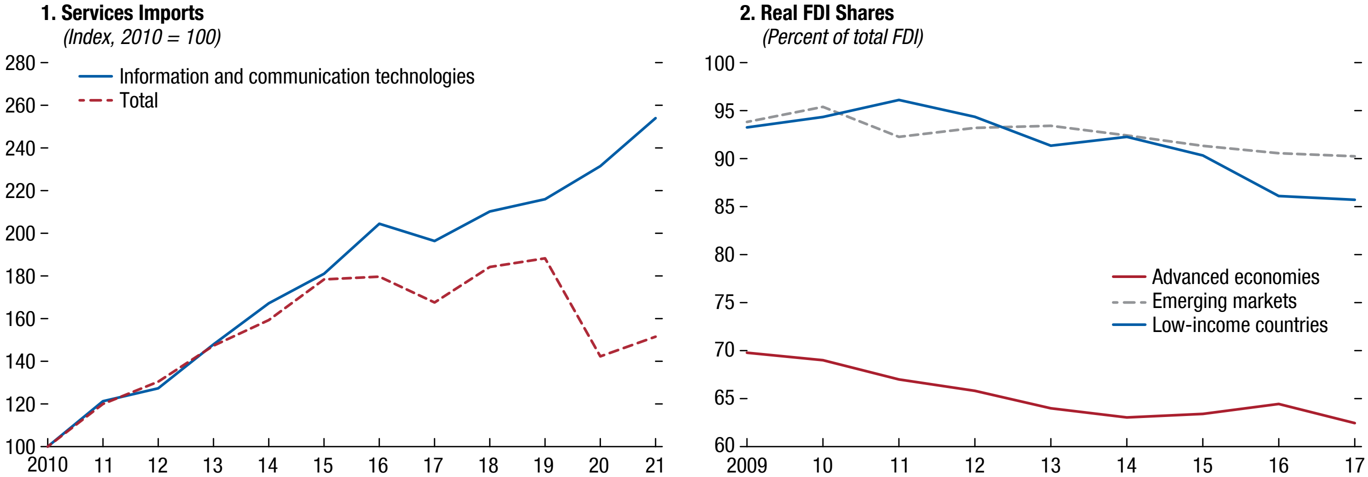
Complementary Pro-Innovation Policies

Fiscal instruments are not the only policies that drive innovation. Further, a sizable fraction of innovation is not formally classified as R&D or patents and as such not directly affected by fiscal incentives. This highlights the importance of a broader pro-innovation policy mix:

- *Broader fiscal policies* can have a strong effect on innovation (Akcigit, Baslandze, and Stantcheva 2016) and potentially reinforce direct innovation incentives. A well-designed corporate income tax system, with generous loss carryforward rules and refundable tax credits, can best provide risk sharing throughout the innovation lifecycle and alleviate financing constraints, especially for start-ups (Hall 2022). More generally, developing a coherent and simple tax system—characterized by broad bases and low rates while instituting systematic evaluation—is critical to foster innovation. On the expenditure side, public procurement should be sufficiently open, transparent, and flexible to avoid discriminating against innovative firms. Sound fiscal frameworks and institutions are needed to implement a cost-effective policy mix.
- *Structural and competition policies* should strike a balance between lowering barriers to entry for new innovative firms and maintaining robust competition, especially amid rising corporate market power and concentration (Akcigit and others 2021), while securing the intellectual property rights of successful innovators. Even when well-calibrated, intellectual property rights confer temporary monopoly power, which delays the widespread dissemination of innovation to competitors and slows technology adoption. This could, at times, run counter to society's broader goals. Policies should ensure a level playing field for different types of firms, including state-owned enterprises.
- *Trade policies* should strive to support open markets that allow a free exchange of ideas, key to advancing research at the frontier and facilitating scientific collaboration across borders. Fragmentation could lead to large productivity losses by hindering the exchange of knowledge (Baba and others 2023).
- *Financing policies* should improve access to financing vehicles across firms, which usually take the form of equity, as innovation is risky and produces intangible assets that are harder to use as loan collateral (Garcia-Macia 2017) but may also require different tools along the innovation lifecycle (Armitage, Bakhtian, and Jaffe 2023).

Fiscal policies also need to ensure that the gains from innovation are broadly distributed across society, as technological progress does not always "lift all boats." Technological advances offer prospects for higher productivity and stronger growth but can lead to structural change that creates new jobs and sectors while displacing and transforming others. Brollo and others (forthcoming) discuss the upgrades to social protection and tax systems needed to manage the effects of disruptive technological transformation.

Figure 2.7. Services Imports and Real FDI in Emerging Market and Developing Economies



Sources: Organisation for Economic Co-operation and Development/World Trade Organization, Balanced Trade in Services dataset; and IMF staff calculations.

Sources: Damgaard, Elkjaer, and Johannesen 2024; and IMF staff calculations.

Note: In panel 1, indices are constructed for the aggregate value of imports of all services and for that of information and communication technology services. Panel 2 shows average shares of real inward FDI in total inward FDI positions across country groups. Real FDI equals total FDI excluding FDI in the same country with no productive activities, including little or no physical presence, employment, production, and no other activities other than holding and financing. FDI = foreign direct investment.

Accelerating Technology Diffusion across Countries and Firms

Worldwide, innovation is highly concentrated—the top seven economies at the technology frontier account for more than half of global R&D spending.[9] Homegrown innovation is costly, but economies below the technology frontier (largely emerging market and developing economies) can benefit from foreign knowledge spillovers to accelerate their growth potential and develop their own innovation capacity. Broader technology adoption across firms is also needed to narrow productivity gaps between top firms (those at the technology frontier) and laggards.[10] The role of fiscal policy in facilitating these processes in the face of ongoing climate and digital transitions is discussed in the next sections.

[9]According to the United Nations Conference on Trade and Development's Frontier Technology Readiness Index, the top seven frontier economies are (in the order of the index) the *United States*, the *United Kingdom*, *Germany*, *Korea*, *France*, *The Netherlands*, and *Sweden*, although *China* has risen to become a major contributor to R&D spending. The index ranks countries based on five areas: information and communications technology deployment, skills, R&D activity, industry activity, and access to finance.

[10]Even in advanced economies, most firms are not at the frontier. For example, in *Australia*, only 2 percent of businesses operate at the global frontier (Productivity Commission 2023).

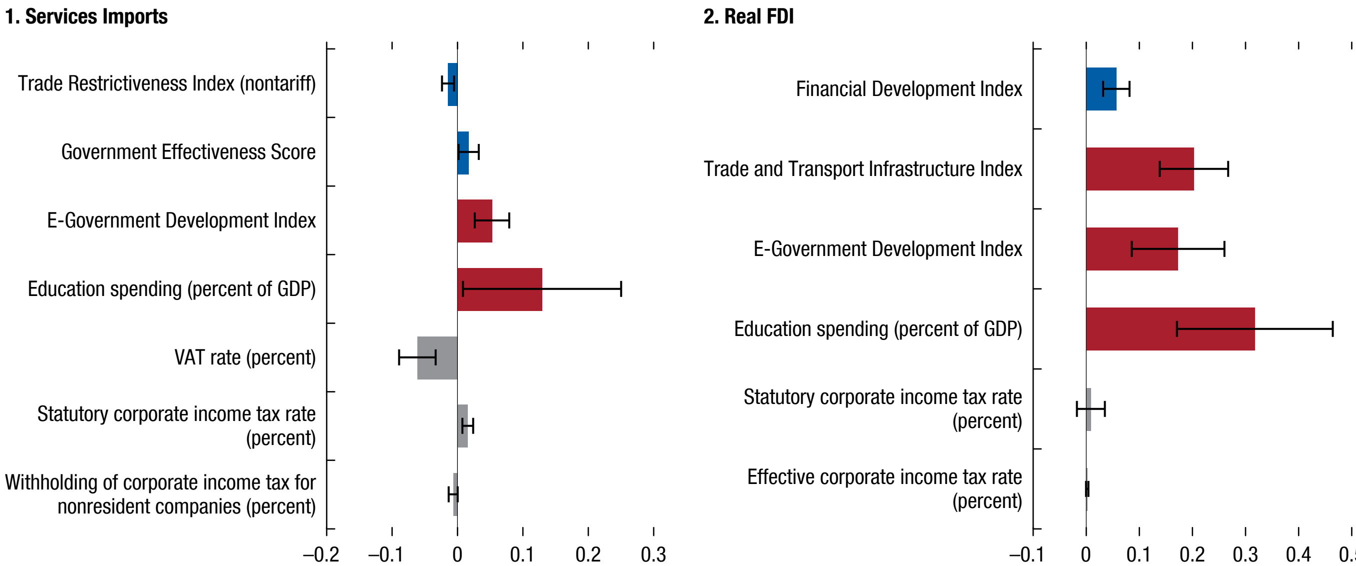
Channels of Cross-Border Diffusion to Emerging Market and Developing Economies

Cross-border technology is diffused through flows of goods, services, capital, people, and information (Keller 2010). Two distinct channels for sharing innovation stand out in the context of ongoing green and digital transformations:

- *Imports of services.* The diffusion literature has primarily focused on trade in goods, but cross-border trade in services, and particularly digital services (Figure 2.7, panel 1), has grown faster than trade in goods, accounting for a quarter of global gross exports in 2023. Boosted by innovations in information and telecommunications, the globalization of services has defied geoeconomic fragmentation and is considered the new driving force of global integration (Georgieva and Okonjo-Iweala 2023).
- *Real foreign direct investment (FDI).* Multinational affiliates receive technology from parent firms (Carr, Markusen, and Maskus 2001), including green, digital, and AI-enabled technologies, which then diffuse that technology to local firms through investments.[11]

[11]The scale of real FDI—physical investment made by multinationals—is not reflected in traditional FDI data (Figure 2.7, panel 2), which measure financial flows of multinationals, including flows that have no direct correspondence with real investment. For instance, traditional FDI data include conduit FDI flows that pass through multiple countries before generating real investment somewhere else, estimated at about 40 percent of global FDI (Aykut, Sanghi, and Kosmidou 2017; Damgaard, Elkjaer, and Johannesen 2024).

Figure 2.8. Determinants of Services Imports and Real FDI into Emerging Market and Developing Economies
(Coefficient estimates)



Sources: Damgaard, Elkjaer, and Johannesen 2024; GeoDist (CEPII); International Bureau of Fiscal Documentation; IMF, April 2023 *World Economic Outlook*; IMF, World Revenue Longitudinal Database (WoRLD); Organisation for Economic Co-operation and Development, Balanced Trade in Services database; Penn World Tables; World Bank; UN E-Government Knowledgebase; and IMF staff calculations.
Note: The figure panels show estimated coefficients from augmented gravity equations for the monetary value of bilateral services imports and (log) bilateral inward real FDI positions. Estimates for services imports are obtained from a Poisson pseudo maximum likelihood panel regression for 70 emerging market and developing economies during 2009–21. Estimates for real FDI are from a panel regression for 21 emerging market and developing economies during 2009–17. Each estimate can be interpreted as an "estimate times 100 percent" increase in services imports or real FDI position after a unit increase in the corresponding explanatory variable. All indices are standardized on a yearly basis. The whiskers indicate 95 percent confidence intervals. FDI = foreign direct investment; VAT = value-added tax.

An initial step establishes the link between these channels of knowledge transfer and innovation activity and productivity in recipient countries. Analysis of a panel of emerging market and developing economies provides evidence that knowledge spillovers through real FDI stimulate domestic patent activity, and that both services trade and FDI increase domestic productivity (Online Annex 2.6). Notably, services imports stimulate greater diffusion than goods imports. By making increasing use of available foreign knowledge embodied in these channels, emerging market and developing economies can boost their own innovation activity and increase productivity through the adoption of existing technologies.

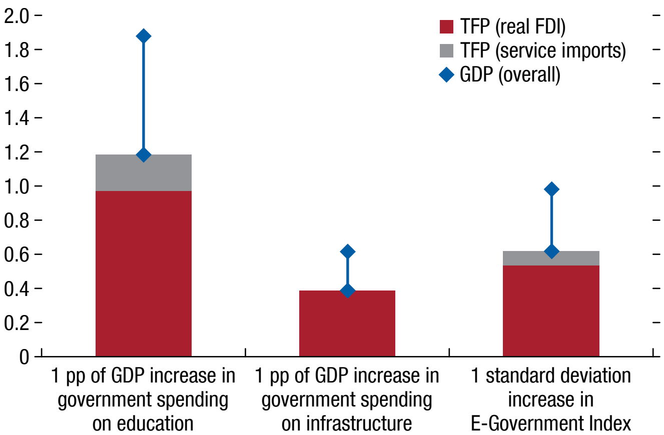
Technology diffusion through trade and investment is not automatic. Economists have long emphasized that assimilating and productively using foreign know-how requires absorptive capacity (Cohen and Levinthal 1990; Comin and Mestieri 2018). This points to an important role for fiscal policies in supporting innovation diffusion and adaptation, as discussed in the next section.

Supporting Diffusion with Public Investment

Public spending policies can help maximize the absorption of existing innovations on the technology frontier, including by facilitating trade in services and real FDI. A gravity model of the determinants of services imports and real FDI flows to emerging market and developing economies is used to disentangle the contribution of specific policies. Policies aimed at building human capital and improving connectivity through better digital and physical infrastructure are estimated to be key determinants (Figure 2.8; Online Annex 2.6).[12] For instance, a 1 percentage point of GDP increase in education spending in emerging market and developing economies is associated with a 13 percent

[12]The gravity model allows for gauging the role of fiscal policies in facilitating the bilateral flow of trade and capital between countries at the technology frontier and recipient emerging market and developing economies. The model controls for standard determinants such as size, income levels, geographic distance, technological differences, and other nonpolicy factors (such as price differentials and regulatory frameworks).

Figure 2.9. Effect of Enhanced Public Investment on Productivity and GDP
(Percent change)



Sources: Damgaard, Elkjaer, and Johannesen 2024; IMF, April 2023 *World Economic Outlook*; Organisation for Economic Co-operation and Development/World Trade Organization, Balanced Trade in Services database; Penn World Tables; UN E-Government Knowledgebase; World Bank; and IMF staff calculations.
Note: The figure shows the estimated impact of policy changes on growth in TFP and GDP in emerging market and developing economies through real FDI and services imports channels. These combine estimates from diffusion regressions for TFP with augmented gravity models for services imports and real FDI. Blue markers indicate the range of changes in GDP growth, depending on the response of capital. FDI = foreign direct investment; pp = percentage point; TFP = total factor productivity.

increase in their services imports and a 32 percent increase in real FDI inflows.[13]

Upgrading digital infrastructure and skills can enable emerging market and developing economies to share in the productivity gains from digital technologies, including AI (OECD 2022; Calvino and Fontanelli 2023). Enabling policies include government support to achieve universal connectivity by incentivizing or directly investing in building internet infrastructure and making internet access more affordable. While education spending matters, the quality and adaptability of education systems can make a difference. Programs to promote digital literacy and technical skills can help close digital adoption gaps. GovTech—upgrades in the technologies used by governments—can further lower barriers to diffusing knowledge by improving the efficiency of public spending and the delivery of education services.[14]

The productivity and growth dividends of public investments in these areas can be significant. Combining the estimated effects of policies with their impact on productivity in recipient countries suggests that a 1 percent of GDP increase in education spending (closing the gap between advanced and emerging markets and developing economies) can boost GDP by 1.9 percent over the medium term (Figure 2.9; Online Annex 2.6). Similarly, improving the quality of trade and transport infrastructure in an average low-income country to bridge one-third of the gap with emerging market economies—with an estimated average fiscal cost of 1 percent of GDP—increases GDP by 0.6 percent.[15] These estimates only account for the effects of investments through increased services imports and real FDI, and their overall impact could be much larger.[16]

Strategic public investments can therefore lead to large payoffs over time but must be supported by sound public investment management frameworks. This demands carefully selecting investment projects to ensure high economic and social returns and strengthening fiscal frameworks and institutions to improve spending efficiency. Public–private partnerships can support the execution and financing of projects, but they require strong capacity to reduce risks to the budget. For low-income developing countries and some emerging market economies, tighter budgets and elevated debt levels will likely continue to constrain investment, which points to the need to improve domestic revenue mobilization (as discussed in the next section).

Not all countries are equally likely to benefit from international technology transfers. Technology needs in many low-income countries can differ from the technologies used in more research-intensive economies (Acemoglu and Zilibotti 2001; Moscona and Sastry 2022). This technology mismatch causes productivity to persistently differ across countries and cluster in places that are similar to the economies where research takes place. Foreign aid can be an important conduit for R&D spillovers to developing economies, but coordinated investments in R&D on technologies more suited to their environments may be needed.

[13]Government spending on education in emerging market and developing economies averages about 5 percent of GDP, implying that a 1 percentage point of GDP increase is equivalent to a 20 percent increase in education spending.

[14]An increase in internet use from 10 to 90 percent of the population is associated with a rise in average primary and secondary education scores of up to 25 percent (Amaglobeli and others 2023).

[15]Based on the World Bank's estimates of public investment spending on infrastructure for a sample of more than 70 developing countries over 2010–18 (Foster, Rana, and Gorgulu 2022).

[16]For example, for every dollar spent on education, as much as $10 to $15 could be generated in economic growth (UNESCO 2012).

Climate change could also be a driver of future technological mismatches, particularly in agriculture. As such, resolving technology mismatches should be at the center of global R&D policy to combat climate change.

Tax Policy to Facilitate Diffusion (and Pay for Spending)

Bolstering tax policy and administration can also help overcome barriers to technology diffusion to emerging market and developing economies, while also mobilizing needed revenue to finance public investments. Consumption taxes and corporate income taxes (CITs) are the most important revenue sources for emerging market and developing economies. For instance, value-added taxes (VATs) account for 33 percent of their tax revenue, whereas CITs account for more than 15 percent, with a relatively large share of the latter contributed by multinationals. Given the importance of these revenue sources, the analysis points to three key priorities (Figure 2.8; Online Annex 2.6):

- *Strengthening the VAT to raise revenue from rising services imports is preferable to turnover taxes.* Countries should use the VAT to mobilize revenue from growing services imports, instead of relying on turnover-based taxes such as digital services taxes levied on gross revenues from social media platforms, internet search engines, and online marketplaces. Estimates suggest that the current revenue yields from a digital services tax are low, and that the expansion of such taxes could deter entry by smaller firms, contributing to higher market concentration in the tech sector (Dabla-Norris and others 2021).[17] VAT administration should adapt to emerging challenges in taxing imported services, particularly those in digital forms (Brondolo 2021), through simplified collection mechanisms (for example, reverse charge and vendor collection).
- *Scaling back ineffective corporate tax incentives can help pay for public investment.* The empirical evidence suggests that statutory CITs and effective CIT rates for multinationals do not significantly affect real investment flows to developing countries (Figure 2.8). Instead of using ineffective investment tax incentives, developing countries should focus on improving governance and invest in fundamentals to facilitate real FDI and services imports (see the April 2016 *Fiscal Monitor*; see also Online Annex 2.6). This point is reinforced by the global minimum tax currently being implemented by several countries that will make certain tax incentives redundant (IMF 2023). Fiscal proceeds can be sizable: removing CIT incentives could raise tax revenue by almost 1 percent of GDP in emerging market and developing economies (Vazquez and Miguel 2022).
- *Strengthening CITs to limit profit-shifting by multinationals will safeguard revenue.* Despite advances in global tax cooperation, the rise of complex, intangible, and technology-heavy business models has created challenges for taxing corporate profits in countries where multinationals do most of their business. Developing countries should strengthen their CIT policies with robust withholding taxes on outbound payments for services imports—which are estimated to reduce firms' incentives to inflate costs and lower CIT liabilities—and simplified anti-tax avoidance rules (IMF 2023; see also the April 2022 *Fiscal Monitor*).

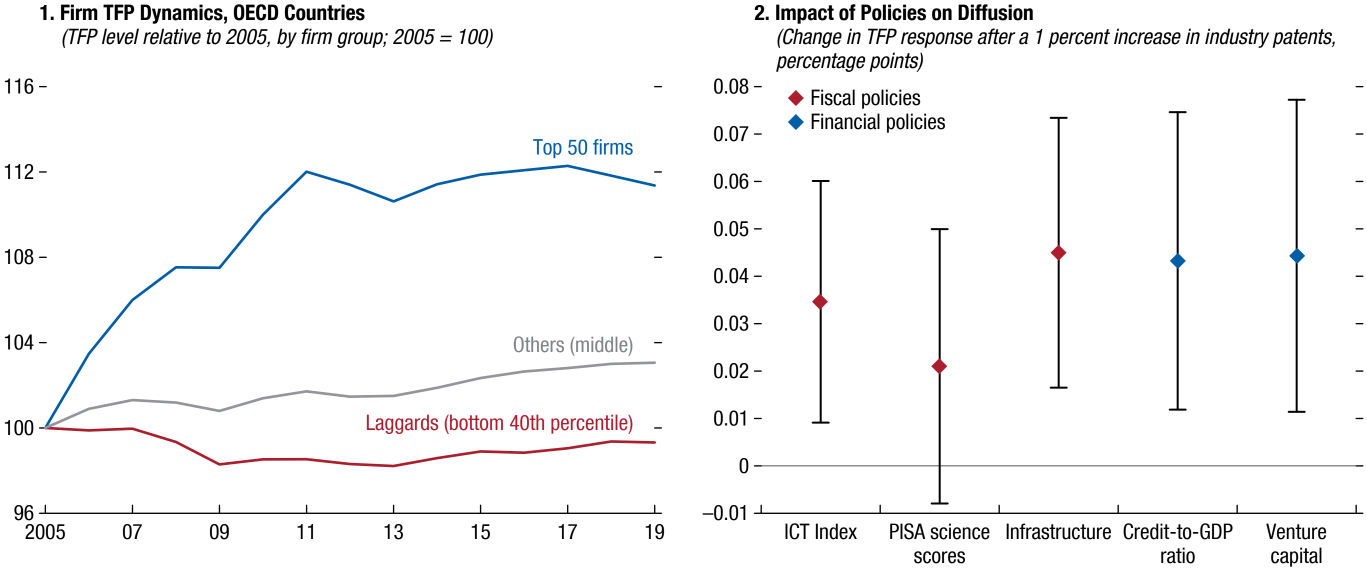
Facilitating Technology Diffusion across Firms

While the preceding section highlighted the role of fiscal policies in driving cross-border technological spillovers and their effects on productivity, this section and those that follow explore the role of fiscal policy in facilitating technology diffusion across firms. Slowing diffusion of technology from frontier firms to laggards—defined here as firms in the bottom 40 percent of the country-specific firm distribution—is a main culprit behind the aggregate productivity slowdown in many countries (Andrews, Criscuolo, and Gal 2016; Figure 2.10, panel 1). Diffusion from top firms in the digital sector has been particularly weak and is a trend that could intensify with the uneven penetration of AI and other digital technologies (Berlingieri and others 2020).

Fiscal policies can help speed up technology diffusion from firms at the technology frontier to laggard firms. Analysis of a large sample of firms from advanced and emerging market economies shows that frontier innovation in an industry (measured by global patent growth in that industry) plays a role in boosting productivity growth of individual firms, implying that, on average, innovation partly diffuses within industries

[17]Digital service taxes could also result in retaliatory tariffs between market and residence countries of digital service providers.

Figure 2.10. Firm TFP Gaps and the Impact of Policies on Diffusion to Laggards



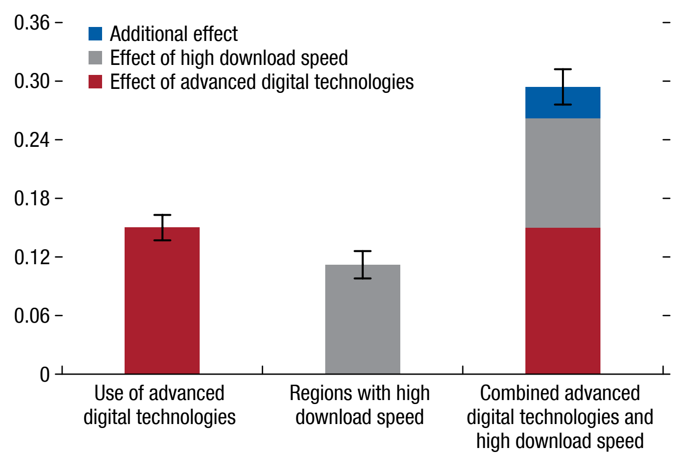
Sources: European Patent Office, PATSTAT; IMF, Financial Development Index; IMF, October 2023 *World Economic Outlook*; Orbis; World Economic Forum 2019; The Global Competitiveness Report 2019; and IMF staff estimates.
Note: Panel 2 shows the estimated coefficients from a panel regression model for 43 countries over 1995–2020. The dependent variable is log changes in TFP. The coefficient displayed shows the percent increase in growth of log TFP after a 1 percent increase in the growth of global patents for firms in countries where the policy variable is one standard deviation higher than the sample average. Whiskers indicate 90 percent confidence intervals. Coefficient estimates are for laggard firms only, with laggards defined as firms with TFP below the 40th percentile of TFP distribution by country, sector, and year. Policy and structural variables are standardized. Coefficients in red and blue refer to variables related to spending policies and financing policies, respectively. Standard errors are clustered at the country-industry level. ICT = information and communication technology; OECD = Organisation for Economic Co-operation and Development; PISA = Programme for International Student Assessment; TFP = total factor productivity.

(Online Annex 2.7).[18] Further, public investments in education and physical and digital infrastructure are associated with faster diffusion to laggard firms (Figure 2.10, panel 2).

For example, enhancing infrastructure quality in an emerging market to the average level in advanced economies can almost double the impact of global patent growth in lifting the TFP of laggard firms. This is corroborated by evidence from Europe: gains from digitalization are larger for firms located in regions with better digital infrastructure and faster internet speeds (Figure 2.11). This suggests that public investment can amplify the effect of advanced digital technology in boosting firm productivity (European Investment Bank, 2024).

[18]To distinguish high-value inventions from the large number of patents that get filed globally, patent growth in the analysis is defined in terms of the growth of international patent families, with a patent family consisting of all the patents that cover the same invention, and with the family containing patents that have been filed in more than one jurisdiction.

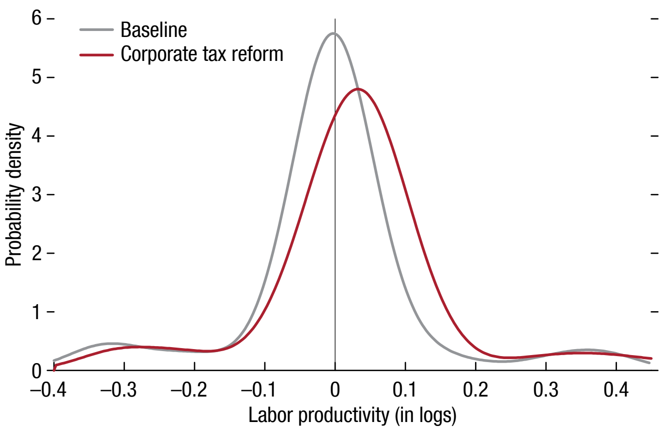
Figure 2.11. Effect of Digital Adoption and Digital Infrastructure on Firm Productivity in the European Union
(Labor productivity in logs)



Source: European Investment Bank 2024.
Note: Based on an ordinary least square regression controlling for firm size, firm age, country, and sector (three groups of European Union countries and four macroeconomic sectors). Regions with high download speed are defined by Eurostat as NUTS 2 regions with average download speed higher than the median download speed across all regions. The whiskers indicate 95 percent confidence intervals. NUTS = nomenclature of territorial units of statistics.

Figure 2.12. Simulation of the Labor Productivity Impact of Corporate Tax Reform across Firms in Emerging Market Economies

(Probability density function, percent; productivity in logs)



Sources: Capelle and others 2023; Compustat; and IMF staff simulations.
Note: Based on a heterogeneous-firm general equilibrium model with different capital vintages, calibrated to *Brazil*, *China*, *India*, *Indonesia*, *Malaysia*, *South Africa*, and *Thailand*. The reform includes a 12 percent tax deduction rate on investment in the newest vintage of capital, financed with a 5 percentage point increase in profit taxes. The resulting gains in aggregate labor productivity and consumption are 2.7 and 3.4 percent, respectively.

A broad policy mix affecting incentives and capabilities is needed to boost technology diffusion to laggard firms. This includes robust competition policy that ensures a level playing field and adequate financing policies. Evidence suggests that the availability of credit and venture capital is associated with stronger diffusion to laggard firms (Figure 2.10, panel 2), as these firms tend to be smaller and have less shareholder funds. Regional initiatives can complement domestic policies to prioritize acceleration of green and digital diffusion, particularly for countries with limited fiscal space.

Accelerating Diffusion with Targeted Fiscal Incentives

Countries can also use targeted incentives to foster the uptake of new technologies. Illustrative simulation based on a model of firms that can invest in older or newer capital vintages (Capelle and others 2023) shows that targeted fiscal incentives for technology upgrades can lift productivity across firms. For example, a revenue-neutral corporate tax reform that shifts the tax burden away from frontier investment can encourage 30 percent of local firms in emerging market economies to upgrade technology (Figure 2.12). This leads to higher aggregate labor productivity, consumption, and welfare over the medium term if local knowledge spillovers are considered.[19] To maximize their impact on accelerating diffusion, incentives need to be well communicated (regarding their horizon, coverage, and eligibility criteria), transparently presented in budgets under a strong governance framework, and effectively implemented.

Targeted fiscal incentives are increasingly being used to promote domestic adoption and production of green technologies. Removing barriers to green diffusion is key, as many of the low-carbon technologies already exist. The model simulation shows that tax reforms to encourage technology upgrades reduce greenhouse gas emissions, as newer technologies tend to emit less. Incentives to stimulate diffusion of green technologies should be embedded in a broader mix of fiscal climate-mitigation policies—combining carbon pricing with phasing out fossil fuel subsidies, building public infrastructure, strengthening procurement, and reducing bureaucracy (Box 2.3).

Conclusion

Global growth has weakened, and productivity has slowed despite rapid advancements in AI and other digital technologies. Improving growth prospects is essential in the face of high government debt, population aging, climate change, and large convergence gaps across countries. But promoting long-term growth can be challenging in a fiscally constrained world. Carefully designed fiscal policies to stimulate innovation, together with measures to broaden technology diffusion, can deliver faster productivity and economic growth for all countries.

The recent turn to industrial policies to support innovation in specific sectors and technologies is not a panacea for higher productivity growth. Such policies are only advisable when the social benefits can be clearly identified (for example, emissions reductions), knowledge spillovers from innovation in targeted sectors are strong, and sufficient administrative capacity is in place. Higher subsidies for green innovation may be warranted given the imperative to decarbonize economies, but these should be

[19]Challenges can arise in designing and implementing targeted subsidy schemes because they require a careful delineation of eligibility criteria and effective monitoring to prevent "relabeling" (firms reclassifying unqualified spending to benefit from preferential treatment).

transparent, focused on environmental objectives, and complemented with robust carbon pricing, and should avoid discrimination against entrants. In general, governments deploying industrial policies should invest in administrative capacity, recalibrate support as conditions change, and foster competition.

For advanced and emerging market economies close to the technology frontier, a well-designed pro-innovation fiscal policy mix can substantially lift productivity, boost GDP, and reduce debt-to-GDP ratios over the long term. This entails a complementary mix of public investment for fundamental research, grants for innovative start-ups (especially in high-social-return sectors like green technologies), and tax incentives to encourage applied innovation across firms, alongside strengthened linkages between business and research and education institutions. Complementary structural, competition, trade, and financial policies are needed to provide a level playing field, avoid concentration of market power, and ensure adequate access to financing along the innovation cycle, particularly for long-horizon green energy projects.

Emerging market and developing economies below the technology frontier should focus on a well-calibrated policy mix to facilitate adoption of existing technologies. Investments in and more effective implementation of digital infrastructure, education, and training programs can accelerate diffusion, including to laggard firms. Removing barriers to diffusion of green technology requires investing in key complementary infrastructure, alongside adequate carbon pricing that aligns private sector incentives and helps to finance these initiatives. As digitalization enables new forms of cross-border trade and FDI, taxation of these activities will need to be adapted to facilitate diffusion while generating revenue. Priorities include using a broad-based VAT instead of tariffs or turnover taxes, scaling back costly tax incentives, and closing loopholes that allow for international tax avoidance.

Reaching the world's full innovative potential and accelerating technology diffusion will not be possible without protecting and deepening international collaboration. Inward-looking industrial policies lead to a costly race in subsidies and trade restrictions. Economies farther away from the technological frontier will lose the most, given their reliance on foreign technology. Coordinating innovation policies is critical to catalyze cross-border spillovers and boost innovation capacity and global economic growth. Not all foreign technologies benefit developing countries, however, so addressing technology mismatches should be at the center of global innovation policy, especially to combat climate change.

Box 2.1. Industrial Policies for Innovation: Lessons from Historical Cases

This box reviews cases of industrial policy for innovation and their varied outcomes. Policy mistakes are common, and initiatives that do successfully transform industries often grapple with high fiscal costs and, in some cases, negative cross-border spillovers.

Airbus in the European Union (EU). EU governments have invested heavily since the 1970s to develop a continental champion of commercial aircraft: Airbus. Governments initially provided subsidized loans, and later reimbursable advances linked to sales, which share downside risk with government (Olienyk and Carbaugh 2011). Government support was motivated by the "natural monopoly" features of aircraft production, with strong scale economies provided by high fixed costs and learning by doing (Baldwin and Krugman 1988). The EU also had an interest in repatriating profits that previously accrued to the quasi-monopoly of US-based Boeing, even if the entrance of a new producer meant lowering production efficiency globally (Brander and Spencer 1985).

Through successful innovation in industrial processes, Airbus managed to break Boeing's monopoly. According to Neven, Seabright, and Grossman (1994), Airbus benefited Europe, earning a rate of return between 6 and 11 percent, and likely generating positive innovation spillovers to other firms. But it also had some negative cross-border spillovers. While aircraft producer prices only dropped by 3.5 percent, Boeing's profits fell by more than $100 billion, competitive pressures from other US producers decreased, and commercial aviation's production costs rose because of Boeing's reduced economies of scale and scope. Moreover, the *United States* reciprocated the EU's intervention with increased support for Boeing, eventually leading to lengthy trade disputes at the World Trade Organization (Irwin and Pavcnik 2004).

Electric vehicles in China. China made a strategic decision to prioritize electric vehicles in 2009, when the market was still virtually nonexistent, with the Plan to Adjust and Revitalize the Auto Industry (Branstetter and Li 2023). Key goals were technological self-reliance, avoiding dependence on oil imports, and reducing emissions (Gomes, Pauls, and ten Brink 2023). The government initially leveraged public procurement and required carmakers to prioritize electric vehicles. Later, the government introduced various incentives for consumers (subsidies, tax breaks, and free license plates), estimated at $50 billion from 2011 to 2019 (Li and others 2020) and supported infrastructure development (for example, charging stations). Competition gradually increased as the government allowed foreign companies to manufacture in *China*, favoring consumer choice.

These efforts helped Chinese manufacturers reach (and expand) the technology frontier and become global sales leaders by the time foreign demand for electric vehicles took off. However, assessing the program's net benefits is not straightforward. Supply-side incentives are hard to quantify, and while some subsidies have been phased out, the overall fiscal cost may have increased over time with the booming market size (electric vehicle purchase tax breaks are expected to cost $72 billion over 2024–27). There is also evidence of excessive entry, with hundreds of domestic producers in early years leading to a wave of consolidations and exits (Branstetter and Li 2023). Finally, the benefit of lower emissions from vehicles has been partly offset by increased coal-based electricity generation (Rapson and Muehlegger 2022).

Less transformative cases. The history of industrial policy for innovation is also filled with projects that failed to be transformative and were eventually discontinued, including in economies at the technology frontier.

Japan's Fifth Generation Computer Systems Program was a government-industry research consortium set up in 1982, funded by the government and tasked with developing parallel computers for artificial intelligence. The objective was visionary, but the design and timing limited success. A narrow focus on the university system failed to attract a diverse pool of researchers, while the project's long horizon discouraged firm participation and patenting. Competing technologies developed faster than expected, and the project ended after 13 years (Odagiri, Nakamura, and Shibuya 1997).

The *United States* created the Synthetic Fuels Corporation (SFC) in 1980 after the energy crises of the 1970s to finance (through direct loans and guarantees) private projects that developed commercial synthetic fuel plants. The SFC was allocated a large budget (3 percent of 1980 GDP spread over 12 years), but take-up was limited by conflicting conditionality (in terms of both project scale and geographic diversification), and the program's economic justification waned when oil prices normalized. When it was terminated in 1986, the SFC had used only about 1 percent of its budget.

Box 2.1 *(continued)*

France's Minitel was a precursor to the internet launched in 1980. At its apex, it provided more than 26,000 services (including online purchases) to about 25 million users. The state-owned telephone company provided the terminals for free, collected revenue from user charges, and granted permissions for new services. But because it was a centralized system, Minitel failed to penetrate foreign markets and soon became obsolete because of the internet. Despite still being profitable, the system shut down in 2012.

Notably, even though these specific projects were abandoned, their sectors eventually became commercially viable, underscoring the difficulty for governments to pick the right projects at the right time and successfully implement all of the steps needed for widespread adoption. More generally, assessing industrial policies for innovation requires going beyond success stories and considering the full sample of attempted projects. It also requires using a comprehensive measure of net fiscal costs, which includes both direct subsidies for innovation as well as other producer and consumer subsidies, and contingent liabilities from public lending, minus any additional revenues.

Box 2.2. Fiscal Support for Green Innovation

This box discusses the effects of fiscal support for green innovation and outlines design principles for green research and development (R&D) subsidies, including adequate targeting, transparency, and coordination with other policies and trade partners.

Tackling climate change requires a drastic reduction in emissions, which is possible only if global energy consumption transitions to predominantly zero-carbon-emissions energy sources. Technological advances to drive down the cost of clean energy are a key part of any strategy to minimize the economic impact of that switch. Recent empirical studies find that R&D subsidies and other expenditure tools such as feed-in tariffs can be effective in accelerating green innovation (Newell 2015; Bettarelli and others 2023; Hasna and others 2023). A one-standard-deviation increase in the Organisation for Economic Co-operation and Development's green R&D support index is estimated to raise the number of green patents by about 15 percent after six years (Figure 2.2.1).

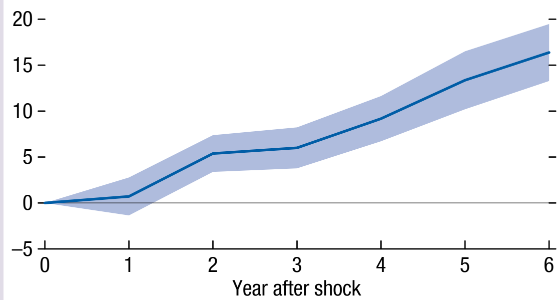
Green R&D subsidies should be uniquely targeted to environmental objectives, complementing core decarbonization policies (Black, Parry, and Zhunussova 2023). They should be time-bound, cost-effective, and transparent, and administered within an appropriate institutional framework to minimize implementation risks. Subsidies should also be consistent with countries' legal obligations under the World Trade Organization, minimize adverse spillovers, and avoid barriers to technology transfers, especially to developing countries (see Box 2.3).

Fiscal support should also be carefully targeted along the innovation cycle and complemented with financing policies where needed. For example, higher subsidies may be appropriate for fundamental research and early-stage technologies that generate more knowledge spillovers or face tighter financing constraints (Armitage, Bakhtian, and Jaffe 2023).

However, governments should also avoid a "valley of death" in financing for intermediate-stage technologies, when some projects become unsuitable for either venture capital or project finance given long horizons for adoption and large fixed costs and risks (Khatcherian 2022). More broadly, governments should bundle the multiple instruments for green innovation into a coherent policy package that addresses coordination problems (for example, convergence on standards and the integrability of networks), provides the necessary infrastructure, trains the workforce, and shapes clear processes for financing and assessing compliance.

Figure 2.2.1. Impact of Green R&D Support on Green Innovation

(Change in green patents, percent)



Sources: Bettarelli and others 2023; International Renewable Energy Agency; Organisation for Economic Co-operation and Development (OECD); and IMF staff estimates.
Note: Cumulative change in green patents at the country-sector level after a one-standard-deviation increase in the green R&D support Index (R&D subcomponent of technology in the OECD Environmental Policy Stringency Index). For details, see Bettarelli and others 2023, Section 4.1. The figure shows the point estimate (line) surrounded by 90 percent confidence bands (shaded area), with standard errors clustered at the country-sector level. R&D = research and development.

Box 2.3. Addressing Barriers to the Diffusion of Green Technology

This box discusses how fiscal policies can help overcome barriers to diffusing green technologies, using the power sector as a case study to illustrate policy options to lower the cost of investment and other barriers.

Various obstacles hinder the diffusion of green technologies to emerging market and developing economies (see the October 2023 *Global Financial Stability Report*). High capital costs as a result of shallow domestic credit markets, low creditworthiness of electricity purchasers, and other macroeconomic risks increase the relative costs of green technologies (Black, Parry, and Zhunussova 2023; Gautam, Purkayastha, and Widge 2023; IEA 2023). Energy pricing regimes favor fossil fuels because of the lack of carbon pricing and the presence of large fossil fuel subsidies (see the October 2023 *Fiscal Monitor*). Other barriers that contribute to low domestic uptake include (1) missing complementary infrastructure (for example, charging stations for electric cars and electricity transmission connecting prospective renewable generation sites to end users), (2) limited understanding of adoption costs and benefits, and (3) imperfect power sector regulatory and market design.

A coordinated and coherent mix of fiscal policies can help reduce these barriers and stimulate imports of green technologies and foreign direct investment (Hasna and others 2023; see also the October 2023 *Fiscal Monitor*). Combining carbon pricing with phasing out fossil fuel subsidies and revenue-neutral "feebates" or tradable standards remains the primary policy tool to reduce emissions and incentivize the adoption of green technology (see the October 2019 and October 2023 *Fiscal Monitor*).

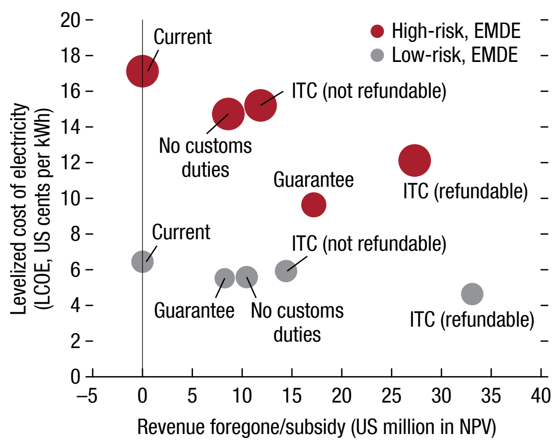
Other non-price market failures and affordability barriers need to be addressed differently. Public procurement and direct spending on infrastructure, compensating for its underprovision in markets, helps the private sector deploy and produce green technologies (Jaffe, Newell, and Stavins 2005; Pigato and others 2020). Means-tested subsidies that lower upfront costs either through rebates or concessionary interest rates can improve affordability, equity, and financial inclusion, although their fiscal costs need to be managed. These measures should be carefully designed with clear strategic objectives and articulated within a policy mix (Altenburg and Assmann 2017).

The power sector requires special attention because of its market structure and importance for economy-wide decarbonization and development. Decarbonizing the transport, industry, and construction sectors through green electrification requires large renewable energy investments. However, these investments only become profitable after a decade, and electricity can seldom be traded across borders. Investors are therefore exposed to the host country's macroeconomic risks but require certain long-term revenue in a stable currency to raise financing (IEA/IFC 2023; IRENA 2023). These issues are exacerbated when the primary electricity purchaser is a state-owned entity with a poor credit rating.

The policy mix to address power-sector-specific barriers is analyzed by modeling the levelized cost of electricity for a stylized 100 megawatt solar power project (Figure 2.3.1). The results show that policies that reduce the cost of capital, such as guarantees and improved macroeconomic stability, are most effective

Figure 2.3.1. Alternative Policies for Renewable Electricity: Benefits and Costs

(Levelized cost of electricity, in cents of US dollars/kWh)



Source: IMF staff estimates.
Note: Revenue foregone is estimated by comparing government revenue under the existing fiscal regime to that of the reform option. The levelized cost of electricity is the minimum price needed for the investor to achieve its required return on investment. Bubble size reflects the investor's cost of capital according to Climate Policy Initiative 2023, which is 25 percent for a high-risk country and 12 percent for a low-risk country, lowered to 15 percent and 10 percent for each with a guarantee. While not explicitly shown, the guarantee results in a contingent liability for the issuer equal to the difference between the net present value of payments for electricity at the investor's discount rate before and after the guarantee. The ITC is assumed to be 30 percent of capital costs, and custom duties are about 25 percent for key project capital inputs. EMDE = emerging market and developing economy; ITC = investment tax credit; kWh = kilowatt hour; NPV = net present value.

Box 2.3 *(continued)*

for countries with high credit risk and limited fiscal space. Guarantees, however, result in a contingent liability, requiring fiscal risks to be carefully managed. Countries with lower credit risk can also consider other well-designed and cost-effective fiscal incentives, including investment tax credits.

Customs duties on green technology are highly distortionary because they impose a cost early in a project's lifecycle and are invariable to its underlying profitability, underscoring the need for open trade policies in developing countries. Advanced economies, in turn, should avoid export restrictions on green inputs and, together with multilateral development banks, provide concessionary financing through guarantees to promote investment and help de-risk a jurisdiction as well as technical assistance (see the October 2023 *Global Financial Stability Report*).

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