Chapter V
National policies for green development

Summary

- Technological innovation is at the heart of sustainable development. "Catching up" with industrialized countries requires strong technology policies. A green sustainability-oriented national innovation system (G-NIS) should be an integral part of developing countries' national development strategies.
- Widespread adaptation and diffusion of green technologies require effective government industrial policies to "crowd in" private investment. Green technologies should be treated as infant industries, with appropriate support, including public sector investments in infrastructure, subsidies and access to credit.
- Building an innovative economy is not about overcoming price distortions or enforcing property rights. An innovative economy is based on interactive learning, information exchange, timely availability of finance and other resources, and coordination among firms, universities, research centres, policymakers and other actors.

Introduction

Green technologies have the potential to create new industries and jobs

Technological innovation is at the heart of economic and social development. Building technological capacities can help developing countries "catch up" with more advanced countries, and innovation policy must play an important role in facilitating sustainable development. The present chapter argues that green sustainable development-oriented innovation policies should be an integral part of countries' national development strategies.

The use of green technologies can have many benefits for developing countries. It can improve domestic infrastructure, help reach underserved communities that lack access to electricity, clean water and sanitation, and create jobs. Since many green products are initially developed in industrialized countries, technology transfer from developed to developing countries is a necessary part of this process. However, the conventional view that technology is developed in the North and simply transferred to the South is misleading. Technology transfer involves more than the importation of hardware: it involves the complex process of sharing knowledge and adapting technologies to meet local conditions. More broadly, innovation is not limited to new breakthroughs: most innovation involves incremental improvements and adaptations of existing technologies.

Technology transfer involves more than the importation of hardware

Innovation, in this sense, is widespread in many emerging market and developing countries. China and India, in particular, have become global leaders in some green technologies, such as solar photovoltaic (PV) panels, wind turbines, and electric and hybrid-electric vehicles, in part because they were able to improve and adapt existing technologies and production processes. Some low-income countries have also begun to develop domestic technological capacities, successfully adapt green technologies, and build new industries, such as the solar PV industry in Bangladesh.

Private investors are unlikely to invest in many new technologies without government support

In all cases, government policies have played important roles in the innovation process. Private investors are often unlikely to invest in many new technologies without government support, especially when these technologies are not cost-competitive with the technologies that are already in place. This is the case for many green technologies, in part because market prices do not fully incorporate the societal costs of using brown technologies, such as greenhouse gas emissions and other environmental risks, with which green technologies compete. Typical market-based solutions to this have been carbon taxes or "cap and trade" schemes aimed at incorporating the societal costs into market prices, along with strong intellectual property rights to encourage investment in green technologies. However, higher energy prices due to carbon taxes can have the perverse effect of disrupting economic development in poor countries, and strong property rights can impede knowledge transfer and inhibit innovation. Furthermore, this approach comes up against an affordability wall in most developing countries, which must nevertheless participate in this technological makeover as they attempt structural change over the next few decades.

Building an innovative economy is not about overcoming price distortions and enforcing property rights

More broadly, building an innovative economy is not about overcoming price distortions and enforcing property rights. An innovative economy is based on interactive learning, information exchange, and coordination among firms, universities, research centres, policymakers and other actors. The national innovation system (NIS) approach, which emphasizes the importance of these relationships, thus provides a more useful framework than a market-based approach for analysing innovation policy. A green sustainability-oriented NIS (G-NIS), which integrates the public-goods nature of many green technologies into the NIS framework, is particularly useful for innovation policymaking in the context of long-term sustainable development.

Green technologies should be treated as infant industries

This framework suggests that active industrial policies are necessary for the adaptation and diffusion of green technologies. Green technologies should be treated as infant industries, with appropriate support, including public sector investments in infrastructure, subsidies and access to credit (Ocampo, 2011b). Policies should also be designed to encourage interaction and knowledge-sharing among domestic and international firms, research institutes, universities, policymakers and other actors. Other policy suggestions based on a green systemic approach could encompass innovative sources of equity-linked financing and long-horizon green country funds.

Catching up with industrialized countries requires strong technology policies. The G-NIS approach emphasizes that policymakers do indeed need to make choices on how to best support innovation, and suggests a framework for government decision-making and investment.

Market and systemic failures

Many economists argue that the role of government is to correct market failures. In contrast, in an NIS or systems approach, the role of government is to correct systemic failures, which might include market failures, but can also include weak relationships between agents or institutions which are difficult to capture in traditional economic models. A systemic analysis also focuses on how changing incentives in one area negatively affect incentives in others.

Uncertainty, externalities and public goods-related problems

All investment is uncertain, but investment in innovation is particularly uncertain as the future outcomes of today's investment projects are unknown.[1] Innovation is also confronted with a public goods-related problem. Knowledge in its pure form is a public good, insofar as it is available to everyone and its use by one person does not limit its use by others. Hence, it is difficult for private firms to appropriate the full returns from research activity. In the market failure approach, patents are meant to confer a degree of ownership of the fruits of new knowledge by granting the innovators fixed-term monopoly rights.

The systemic approach, in contrast, emphasizes that strong intellectual property rights can also undercut knowledge-sharing, thereby impeding innovation. Further, even when such institutional mechanisms exist, investors still underinvest in research and development (R&D) (Mani, 2002). A typical policy response is to fund basic research through grants or public research institutes. The systems approach, however, might also suggest joint research grants to encourage collaboration among universities, research institutes and firms.

Innovation of green technologies is subject to heightened uncertainty, externalities, path dependencies, and additional public goods-related problems

Innovation with regard to green technologies is subject to heightened uncertainty, externalities, path dependencies, and additional public goods-related problems. Investment risk is heightened, since there is greater uncertainty about what the entire market, not just the specific technology, will look like in the future. Green technologies compete with brown technologies currently in use, most of which have large environmental externalities and other social costs that are not factored into market prices. As discussed above, carbon taxes and cap-and-trade schemes were supposed to be so designed as to address these issues. It appears, however, that the increase in price needed to cover all the externalities would likely be so large as to prove politically unfeasible (Mowery, Nelson and Martin, 2010). For developing countries, these schemes can be problematic, as they would raise the price of existing energy sources and other inputs, which could disrupt economic development, at least until new energy sources became available. And they can be particularly problematic, given the potential impact of higher energy prices on the poor. Industrial policies to encourage diffusion of green technologies provide an alternative policy prescription. Furthermore, there are opportunities in some poor countries for leapfrogging, which industrial policies could encourage.

Green technologies compete with brown technologies currently in use

There are also path dependencies associated with existing carbon technologies that are difficult for new technologies to overcome, even when the new technologies are potentially superior. For example, existing technologies have large sunk costs in infrastructure, which constrain their replacement. New technologies often have high operating expenses and are often less reliable in the early stages of development. This is true of most green technologies, even those like wind and solar PV that have longer histories (Mowery, Nelson and Martin, 2010.) It can also be difficult for any one new technology to overcome the dominant technology "regime" and change what is often an entire system, such as the energy system (Smith, 2009). Furthermore, existing technologies tend to serve entrenched interests, making it difficult for policymakers to support new technologies at the expense of existing ones.

Green technologies also have additional public goods-related problems. As discussed above, green technologies support infrastructure, reach underserved communities and promote equity, increase energy, food and water security, and have the potential to

1 Current market prices cannot convey accurate information about firms' investment (in other words, there are no futures markets for knowledge).

create new industries and jobs (Cosbey, 2011a). However, private investors tend to under-invest in green technologies because they are unable to capture these public benefits in their investment returns.

Finally, financial markets tend to be myopic and to be characterized by boom-and-bust cycles, which can be particularly severe in new illiquid investment sectors, such as green technology (Stiglitz and others, 2006). For example, although "green investment funds" had raised a large amount of capital prior to 2007, most experienced significant withdrawals during and after the financial crisis, as discussed below. Cyclically oriented financing cannot be counted on to support long-term sustainable development, and policymakers should focus on alternative forms of investment.

Systems of innovation

National innovation systems

Every country has a national innovation system, whether or not policymakers are conscious of it

The concept of a national innovation system (NIS) was first introduced in the 1980s (Nelson and Winter, 1982; Freeman, 1997). Although the general concept of a national innovation system is widely accepted (Nelson, 1993; Lundvall, ed., 2010; Metcalfe, 1994), there is no single definition. According to a broad definition, such as the one given by Edquist (2004), the NIS is "all important economic, social, political, organization, institutional, and other factors that influence the development, diffusion, and use of innovations". Hence, every country has an NIS, whether or not policymakers are conscious of it. It is a dynamic system that develops and changes over time. While it is not created by Governments, government policies can strengthen (or weaken) its efficiency.

Sector-specific green innovation systems

Sectoral innovation systems address differences in the innovation process across economic sectors

Innovation of green technologies covers a wide range of economic sectors, including energy, transportation, agriculture, industrial production, materials, buildings, water, and waste management (Johnstone, Hascic and Popp, 2010). These sectors differ with regard to characteristics such as firm size, the role of foreign direct investment (FDI), skill requirements, capital intensity, and the degree of integration into the global market. For example, while the energy sector tends to be dominated by a few large firms, agriculture in developing countries involves many small rural land holders, which can make knowledge-sharing and diffusion of innovation particularly challenging. An agricultural innovation system thus needs to focus on informal actors, such as community networks (Gallagher and others, 2011; Juma, 2011). Sectoral innovation systems (Malerba, 2002; Malerba and Nelson, 2008) address differences in the innovation process across economic sectors.

Because sector-specific innovation systems are specialized, they can be particularly useful as frameworks for sector-specific policy analysis. Chapters II and III examined energy and agricultural innovation systems; the discussion of both types of systems is fairly well developed in the literature (United Nations Conference on Trade and Development, 2010; Grübler and others, forthcoming bis; Juma, 2011). There is a significant literature on other sector-specific systems as well, such as chemicals, pharmaceuticals and electronics, but more research is needed on other sector-specific green sustainability-oriented innovation systems.

However, sole reliance on sector-specific systems could overlook economy-wide linkages especially relevant to green innovation since the impact of environmental externalities in one sector can affect other sectors. For example, hydroelectric plants are a clean energy source, but often have negative externalities, such as displacing people, harming agriculture, reducing fish populations, and deforestation.[2] On the other hand, they can also have positive externalities, such as lowering the risk of floods and providing irrigation for agriculture. A national system, especially one that is sustainability-oriented, provides a framework for promoting better understanding of all the relations and trade-offs involved in hydroelectric plants compared with other forms of energy. Though policymakers might consider many of these implications in any case, a green, sustainability-oriented national innovation system (a G-NIS) would provide a systematic framework for doing so.

Sole reliance on sector-specific systems could overlook economy-wide linkages

"Greening" national innovation systems

Greening an NIS involves incorporating unique features of sustainability into the systems framework.[3] There is a greater role for government and non-governmental organizations in a G-NIS framework because of the public-goods nature of green technologies. Although government policies are important in an NIS, particularly in the early stages of the development process, they are particularly important in a G-NIS, given the lack of domestic markets for green technologies. A G-NIS approach emphasizes incentives and industrial policies geared towards creating market demand throughout the innovation cycle (such as feed-in tariffs, low-interest loans and public procurement), which are not generally necessary for an NIS (Stamm and others, 2009). Because of the enhanced uncertainty associated with green technologies, policymakers might need to emphasize greater risk-sharing between the private and public sectors so as to stimulate private sector investment. In addition, the G-NIS takes account of environmental and other externalities, and incorporates technological, industrial and environmental policies within one framework.

A green innovation system emphasizes incentives and industrial policies geared towards creating market demand

Although G-NISs differ by country, based on existing institutions, human capital, business environment, infrastructure, geography and general level of development, they possess elements in common, as depicted in figure V.1. The innovation process is at the centre of the G-NIS. The actors in the system include firms, government agencies, universities, research institutes, training institutes, consumers, financial and non-financial institutions, private foundations and civil society.

Relationships and interactions among actors are crucial to the innovation process. These relationships include networks of innovators, research clusters, and coordination among universities and firms, upstream and downstream suppliers and their customers, and buyers and sellers. Institutions and infrastructure are the backdrop that shapes the innovation process; they are depicted as such as the light red circle in figure V.2. Industrial policies, such as public procurement, tax schemes and subsidies, define incentives for the actors and also shape the system.

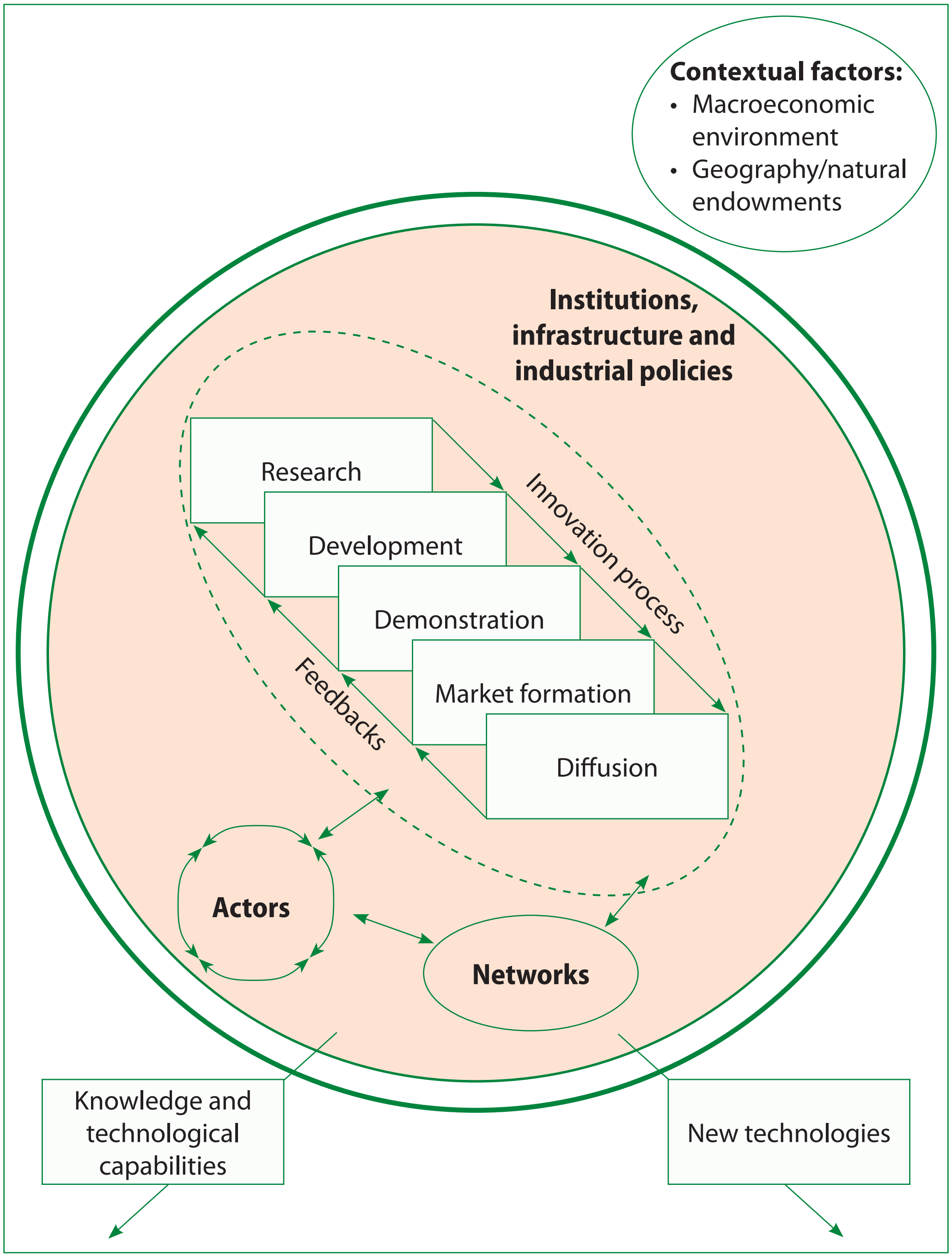
Knowledge, increased capabilities and new technologies are important outputs of the system. These can be viewed as positive externalities of the system and are depicted in figure V.2 as arrows emanating from the G-NIS to the rest of the economy. The

Knowledge, increased capabilities and new technologies are important outputs of the system

2 The building of hydroelectric plants also leaves a significant carbon footprint.

3 The concept of a sustainability-oriented innovation system was first introduced by Stamm (Stamm and others, 2009; Rennkamp and Stamm, 2009) and the system was referred to as an SoIS.

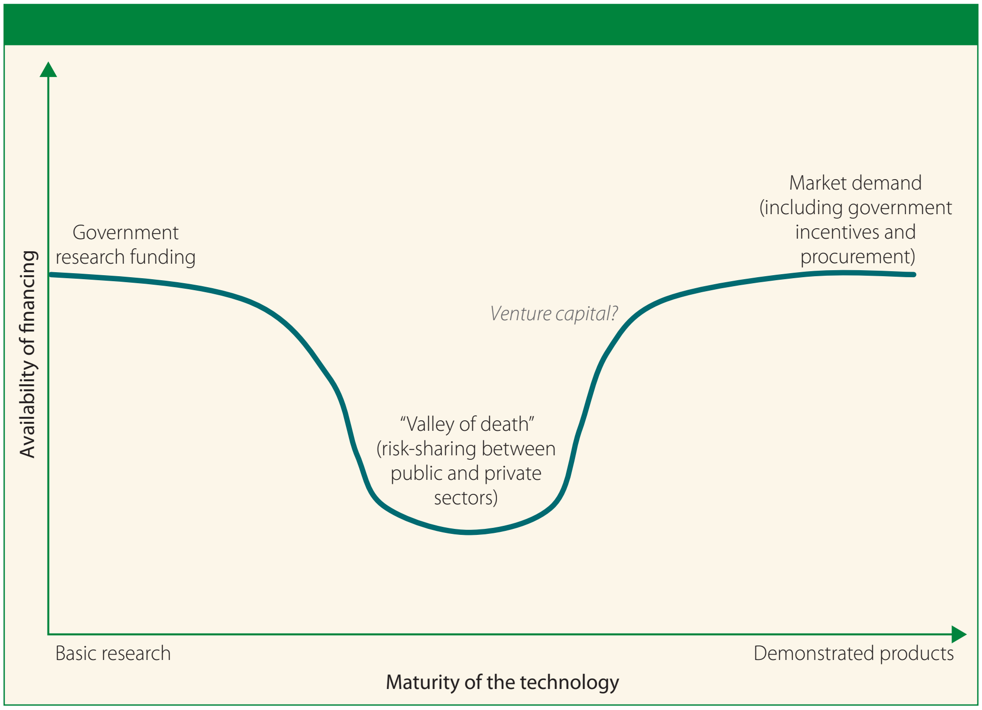
Figure V.1
The innovation system



Source: UN/DESA.

remaining element of the G-NIS comprises contextual factors, such as the macroeconomic environment, geography and natural endowments. These are positioned exogenously to the system, and determine the context within which policies will or will not be effective.

Figure V.2
G-NIS financing



Sources: UN/DESA; and World Bank (2010a).

The innovation process

There are five phases in the innovation process. Market formation is added to the usual four phases

The innovation process is composed of interdependent phases (Mowery and Rosenberg, 1979), which feed back into one another, as depicted in figure V.1. The literature typically refers to four phases in the process: research, development, demonstration and diffusion (RDD&D). Following Grübler and others (forthcoming bis), "market formation" is added to the usual four, since markets for new green products do not automatically develop after the diffusion stage.

The five phases do not necessarily follow in order: some are sometimes skipped or inapplicable to a given technology or process (Gallagher and others, 2011; Grübler and Messner, 1998). In addition, there are feedbacks between stages, so that phases often occur simultaneously. For example, during the diffusion process, end-users provide producers with feedback, which should lead to product improvements and further adaptations.

Basic research, development and demonstration (RD&D)

Figure V.2 depicts the development phases (RD&D) of the innovation process, along with the type of financing typically available for the different phases. The government is often the main actor in basic research, through funding for universities or public research laboratories. In the United States of America, Europe and, more recently, China, many technological breakthroughs of the past decades, including innovations in aeronautics and electronics, were facilitated or funded by Governments (United Nations, Department of Economic and Social Affairs, 2008).

The government is often the main actor in basic research, while development and demonstration are based on entrepreneurial experimentation within firms

Development and demonstration, which are based on entrepreneurial experimentation, generally take place within firms. Entrepreneurs potentially continue to acquire commercially useful product-related information during these phases, which then feeds back into research. For example, several types of wind turbines were experimented with before the three-blade vertical-axis turbine was developed. Similarly, the development of hybrid vehicles entailed entrepreneurial experimentation among Japan's car manufacturers (Grübler and others, forthcoming bis).

However, financing for these advanced stages of product development is generally limited, particularly in the so-called valley of death, for which the investment risk is still high, but government financing often limited (Gallagher and others, 2011). Funding for this stage often comes from the entrepreneur's own savings or from family members. Venture capitalists tend to fund projects that have already been demonstrated in the marketplace, although they have been hesitant to take risks associated with some investments in green technologies, especially in developing countries, as discussed below. Thus, the development phase of many technologies—and particularly green technologies—needs to be supplemented by government policies.

Market formation and diffusion

In the case of green technologies, market demand is primarily determined by government policies

Diffusion and widespread use of technologies are a critical part of the innovation process, and are usually financed by the private sector. However, many clean energy technologies fail to transition from product development to diffusion not necessarily because of technological problems, but because they are too expensive relative to existing brown technologies or too difficult to integrate into existing systems (owing to path dependencies) or scale up, or because of lack of market demand for other reasons.

As discussed in chapter II, historically, market formation of new energy products focused on creating protected "niche" markets. These markets shield products from full commercial competition in the initial stages of product development, based on the expectation that some end-users would be willing to pay a higher price for high-quality technologies, and that as a result these technologies will not need to be subsidized. However, as there are few niches today in which cost-insensitive end-users are willing to pay for environmental public goods, this strategy is less appropriate for green technologies.

Policies aimed at market formation include environmental regulations

The role of government in the market formation stage can be critical to overcoming barriers to market formation and diffusion. As discussed below, policies aimed at market formation include environmental regulations, minimum production quotas, public procurement policies, subsidies and feed-in tariffs, as well as risk-sharing policies designed to encourage greater private sector investment.

Coordination and networks

Because innovation is based on interactive learning, information exchange, coordination and feedback are important throughout the innovation process. Indeed, innovation, adaptation and diffusion are dependent on such interactions. Coordination between researchers and firms is critical, as are interactions between firms and networks and clusters. Further, interactions between domestic and international firms facilitate the ability of domestic firms to tap into global knowledge and build domestic capacities. Interactions among government agencies, firms, research institutes, universities and civil society can help inform policymaking.

Cooperation among universities, research institutions and firms

Knowledge is not automatically transferred from university and research centres for commercial application

There is evidence that cooperation among universities, public research organizations and firms is likely to stimulate private sector R&D (Jaumotte and Pain, 2005), and that when such interactions do not exist, there is likely to be less innovation (Soete, Verspagen and ter Weel, 2009). In countries with high levels of innovation, such as the United States, Sweden and Singapore, these linkages tend to be strong. However, knowledge is not automatically transferred from university and research centres to commercial applications. In the newly industrialized countries in Asia, Governments made efforts to help stimulate these relationships (Kim and Nelson, eds., 2000), through, for example, grants for collaborative R&D, as well as science and technology parks.

In many developing countries, however, the linkages between universities and firms are weak. In Mexico, R&D is concentrated in universities, but the universities do not necessarily interact with private firms (Casas, 2005). In Africa, universities tend to be centralized, and are often unknown to producers not located nearby (Metcalfe and Ramlogan, 2005). Incorporating private sector inputs in education policy, as in several newly industrialized countries and some Latin American countries, can stimulate greater cooperation between firms and universities, as discussed below. In addition, collaborative R&D projects, joint conferences and seminars, and policies that encourage mobility of researchers between the public and private sector can help address this problem. For example, in Sweden, university professors are mandated to interact with firms and stakeholders outside the university, in addition to engaging in teaching and research (Edquist, 2006).

Networks, clusters and science parks

Learning and knowledge spillovers tend to be stronger with geographical proximity (Walz, 2010; Archibugi and Pietrobelli, 2003), and knowledge transfer between firms is often informal (Grübler and others, forthcoming bis). Clusters and networks of firms that encourage interactions among firms' personnel can facilitate knowledge spillovers.

Least developed countries form regional R&D networks and engage in South-South collaboration

Research networks are also important for information-sharing, and several emerging market and developing countries are taking steps to build such networks. Colombia has created a network of national research institutes whose goal is to develop sustainable energy technologies, and universities in Singapore have been developing green construction and water technologies (Cannady, 2009). Least developed countries, however, often do not have the resources or critical mass needed to build such networks. These countries should therefore form regional R&D networks and engage in South-South collaboration to leverage the resources of all members. For example, several Central African nations recently formed a university network of researchers engaged in work in the medical field (Cannady, 2009).[4] Regional networks could also offer valuable opportunities to leverage resources of wealthier countries.

To the extent that geographical proximity encourages increased knowledge spillovers, local science parks, which co-locate domestic and foreign firms, universities, research centres, laboratories and related businesses, can be used to facilitate green innovation. Science parks have been established successfully in both developed and emerging market economies and are being planned in several African developing countries, such as Senegal (Tavares, 2009) and Ghana. There has been some discussion of also building regional science parks in Africa as an alternative to national parks. For example, a project

4 See http://www.edctp.org/Networks-of-Excellence.641.0.html.

being run by the United Nations Educational, Scientific and Cultural Organization (UNESCO) is examining the possibility of setting up a science park in Nairobi, which will then serve as a model for other such "technopolises" across Africa (United Nations Educational, Scientific and Cultural Organization, 2011a).

Science parks can also offer support services, financial services and infrastructure (including buildings, meeting rooms, telephone, Internet, power and transportation), although business incubators can also assume this role, as discussed below. In addition, in some countries, such as India, firms in science parks are exempted from import duties and quotas, as well as from capital controls on repatriating currency.

The most important function of a science park is to foster interactions among actors

Experience suggests that the most important function of a science park is to foster interactions among actors. However, policymakers have sometimes focused on the physical presence of the park at the expense of fostering interactions and knowledge spillovers. Without a deliberate effort to encourage interactions, there is a risk that science parks will end up as real estate operations, instead of contributing to innovation and development. On the other hand, if linkages or industry clusters already exist, it might not be necessary to build an expensive science park as a means of bringing actors together. Other means of encouraging interactions and sharing may be more useful and affordable. Lower-cost options could include setting up resource centres, and technology transfer centres for firms in or near universities, and organizing frequent conferences and seminars in order to bring together domestic and foreign scientists, engineers, entrepreneurs, practitioners and policymakers. Furthermore, it is possible that, over time, virtual science parks will replace physical parks. However, to the extent that (as noted above) the goal of the park is to encourage interactions among actors, the importance of physical proximity cannot be underestimated. It is therefore unlikely that physical parks will be completely replaced by virtual counterparts, at least for the near future. While it is possible to organize "online conferences and dialogues", sustaining interactions and virtual networking appears to be more difficult.

International networks and technology transfer

Technology transfer is effective only if supplemented by indigenous research and domestic capabilities

Because much green technology is developed globally, international interactions play an important role in transferring technological knowledge. This can be facilitated through traditional forms of technology transfer, although it could also include other forms of knowledge sharing, transfer and collaboration. Traditional mechanisms for technology transfer are FDI, imports and licensing. Experience demonstrates, however, that these measures are effective only if supplemented by indigenous research and domestic capabilities (Li, 2008; Fu, 2008; Mani, 2002). Indeed, one primary motive for engagement by developing-country firms in domestic R&D is the desire to acquire knowledge developed elsewhere (Cohen and Levinthal, 1990; Grübler and others, forthcoming bis). Such indigenous research is not necessarily limited to basic research in a university or institute and may very well include "learning by doing" and experimentation.

Traditional mechanisms for technology transfer are foreign direct investment (FDI), imports and licensing

Today, countries also make use of alternative methods for technology transfer, such as joint R&D with international companies, outward FDI (including the acquisition of foreign firms by domestic entities), R&D overseas in existing knowledge centres, global joint ventures, movement of people through migration and foreign education, and participation in global value chains to gain access to knowledge transferred within the supply chain (Lema and Lema, 2010; Fu, Pietrobelli and Soete, 2010). Scientific journals and conferences provide access to international research, and much technical information is available on the Internet. In addition, traditional measures, such as FDI and joint ventures, have at times been accompanied by investment requirements and other policies to promote more efficient technology transfer, as discussed below. Some of these mechanisms may be quite different from those utilized by Organization for Economic Cooperation and Development (OECD) countries. Although certain mechanisms (such as outward FDI) require more resources, this is not the case for all, and less developed countries should therefore not exclude these forms of knowledge transfer.

FDI and investment performance measures

Technology spillovers through FDI can occur through several modes, such as movement of trained labour from foreign to domestic firms, vertical spillovers between foreign or domestic suppliers and their customers, joint ventures between foreign and local firms, and transfers between foreign firms and their local affiliates. However, from the foreign firm's perspective, the purpose of FDI is to generate a profit, not to transfer technology, and often firms will try to limit, rather than promote, knowledge transfer (Fu, Pietrobelli and Soete, 2010).

The empirical evidence for the effectiveness of knowledge spillovers from FDI is mixed (Fu, Pietrobelli and Soete, 2010). In countries like Singapore and China, where there is evidence of positive spillovers, they are likely the result of explicit policies pursued by the Government (Mani, 2002; Lema and Lema, 2010). China, for example, implemented local content requirements that required foreign firms to purchase inputs from domestic sellers, and, in some cases, also imposed training requirements and mandated joint R&D programmes. Mexico, on the other hand, which did not have such policies in place, was less successful in capturing spillovers from FDI. One estimate is that domestic firms in Mexico provided only about 5 per cent of the inputs for foreign firms, while firms in China provided over 20 per cent (Gallagher and Shafaeddin, 2010).

Knowledge spillovers from FDI are likely the result of explicit policies pursued by the Government

In addition, there is a risk that FDI can reduce or crowd out indigenous R&D (Organization for Economic Cooperation and Development, 2002). In China, this phenomena has been attributed to competition for talent between foreign and domestic firms (Fu and Gong, 2011), which is likely to be even more pronounced in countries with more limited technological capacities. The movement of workers between foreign and domestic firms could help counteract this tendency somewhat, at least over a longer time-horizon. In China, clusterings of innovative foreign firms were more likely to lead to knowledge spillovers (Chen, Li and Shapiro, 2009), which is a further argument for the establishment of science parks or lower-cost alternatives.

Technology transfer through imports: Kenya and Bangladesh

Importing machinery and equipment is generally regarded as another mechanism for technology transfer. However, it is not clear how effective this mechanism is insofar as importing machinery does not necessarily mean that countries have mastered how the machinery is designed. Countries first need to service, maintain and "reverse-engineer" the machinery to understand the technology embedded within it, which requires local capacities and indigenous R&D.

The cases of solar PV in Bangladesh and Kenya provide contrasting studies on technology transfer through imports. Both countries have rural populations that suffer from poor access to electricity; both have ample sunshine, which enables solar home systems (SHS) to be somewhat competitive with alternative sources of energy in rural areas; in both cases, private firms imported SHS; and both have had relative success in SHS

Bangladesh first imported solar home systems, and then used the opportunity to build a local servicing and manufacturing industry distribution. However, only Bangladesh used the opportunity to build a local manufacturing industry.

In Kenya (see box V.1), the dealerships that initially imported the solar equipment in the early 1990s had very little technical expertise; imports were plagued with quality problems, which domestic firms lacked the expertise to service. As of 2009, most technicians still lacked sufficient technical training (Hankins, Anjali and Kirai, 2009). The lack of domestic competencies also meant that Kenya lacked the institutional capacity to implement and enforce standards. In addition, lack of domestic financing meant that the systems reached mainly the wealthiest rural population. Further, local firms did not engage in indigenous research or significant adaptation.

Box V.1

Solar PV in rural Kenya

Kenya's off-grid solar PV household system (SHS) market is a commercial market, with very little government involvement. It represents vibrant solar markets, with 150,000 units having been sold in 2004 and close to 300,000 in 2009 (REN21, 2010). Yet, despite this relative commercial success, the industry has been plagued by quality problems (Jacobson and Kammen, 2007), owing to a lack of domestic expertise and capabilities as well as a weak regulatory framework.

Kenya had begun to import solar PV household systems in relatively significant numbers in the 1990s. However, the development of the industry was hampered by the above-mentioned lack of domestic expertise. For example, only 17 per cent of solar technicians were able to correctly size the battery for an SHS (Duke, Jacobson and Kammen, 2002). A significant portion of the imported panels were of extremely poor quality and many households that purchased the poor-quality systems lost most or all of their investment (ibid.). As of 2009, the training of technicians remained weak, with the estimated 2,000 installation technicians who service SHS generally lacking in sufficient formal training (Hankins, Angali and Kirai, 2009).

Despite the quality problems, demand for the systems has continued to grow owing to the lack of viable alternatives in rural areas. However, financing is limited and, when available, tends to be prohibitive, adding up to 80 per cent to the overall cost of the systems (Ondraczek, 2011). Purchasers of SHS are thus among the wealthiest rural households, with almost half of the SHS owned by the top 10 per cent of the rural population (Jacobson, 2005). Because of the lack of financing, demand for SHS has also tended to be "component-based", meaning that suppliers sell pieces at a time, rather than entire systems, which has compounded quality problems (Hankins, Anjali and Kirai, 2009).

In response to pressure from local users, the Kenya Bureau of Standards drafted performance standards for solar products. However, the Bureau did not have the necessary expertise to design and enforce these standards. As there are still no domestic accredited laboratories in Kenya, the accreditation for quality standards takes place abroad (Jacobson and Kammen, 2007), which inevitably increases domestic costs and limits potential feedback between consumers and suppliers. As of 2009, enforcement of standards is still weak, which has led to a market perception among consumers of solar PV of its being "second rate" (Hankins, Anjali and Kirai, 2009). As regards building domestic industries and ancillary services, most of the parts for SHS are still imported, although there are three domestic manufacturers of local batteries and nine manufacturers of lamps (International Energy Agency, Photovoltaic Power Systems Programme, 2003).

Source: UN/DESA.

Bangladesh has begun to export solar panels to Africa

The case of Bangladesh (see box V.2) contrasts starkly with that of Kenya. Owing to its vocational education system, Bangladesh had a stronger human resource base at the outset than Kenya. Grameen Shakti (SK), a subsidiary of Grameen Bank, invested in building local capacities: trained engineers taught less skilled workers how to service the units. It also engaged in in-house research, which reduced costs and helped SK develop ancillary business. Bangladesh used its microfinance network to finance SHS and reach

Box V.2

Importing solar PV in Bangladesh

The solar household systems (SHS) industry in Bangladesh partnered with microfinance institutions, international organizations and the Government. Grameen Shakti (GS), a subsidiary of Grameen Bank, began importing solar home units in 1996. By 2010, it had sold 650,000 to off-grid rural customers in Bangladesh (Gallagher and others, 2011).

The establishment of a standardized technical and vocational infrastructure over 50 years ago created a base of expertise, which enabled the development of the industry. The vast majority of field engineers who sell, install and maintain SHS in Bangladesh have received a diploma in engineering from the Bangladesh Technical Education Board. These engineers, many of whom are women, also train less educated women on how to construct and repair component parts of solar PV systems, which creates a positive effect cascading down to less educated workers.

Financing for SHS sales is generally conducted through microfinance. To aid in this effort, the Government set up the financial institution IDCOL (Infrastructure Development Company Limited) in 1997, with financing from the World Bank. IDCOL works with partner organizations (such as GS), which sell the units and provide financing to customers. To ensure quality standards, these organizations are required to sell components approved by a technical standards committee, including experts from Government, the rural electrical agency and the technical university.

In addition to being involved in sales, GS is engaged in indigenous research, which has helped GS reduce the cost of the panels, adapt the technology and develop accessories, such as a mobile phone battery charger (Chhabara, 2008). Initially, most of the panel components were imported, but today, all the parts are produced domestically. In this regard, Rahimafrooz, a local firm that initially manufactured lead-acid batteries for the systems, has expanded its operation to include exports to Nepal and Bhutan. More recently, Rahimafrooz set up the first solar panel assembly plant in Bangladesh (Parvez, 2009) and has begun to export panels to Africa (Ahmed, 2011); in addition, it has signed a memorandum of understanding with TATA BP Solar on building a 5 megawatt (mw) solar power plant in Bangladesh (Daily Star, 2010), thereby further building international linkages.

In addition to creating employment through these new manufacturing industries, the off-grid solar sector has created thousands of jobs in rural Bangladesh. GS itself employs more than 7,500 individuals and operates 45 technology centres run by women engineers. These centres have trained over 3,000 rural women who generally lack access to other income-generating opportunities.

Source: Gallagher and others (2011).

broader populations. The Government set up a State-owned infrastructure development company and set standards to support financing and ensure quality. At the same time, companies in Bangladesh took advantage of the growth of the sector to provide ancillary services. Today, all the components of the systems are produced domestically. Further, Bangladesh has set up its first solar assembly plant and begun to export panels to Africa.

The cases of Bangladesh and Kenya offer several lessons on the use of imports to effect technology transfer. First, in Bangladesh, domestic capabilities were crucial for the servicing and operation of units, as well as for building ancillary businesses and spurring employment and growth. The experience of Bangladesh demonstrates the importance of vocational education, on-the-job training, and the role that women can play in fostering green innovation. Second, in Bangladesh, indigenous research helped cut costs and led to successful adaptation, as well as the development of new businesses. Third, regulators need institutional capacity to be able to enforce quality standards. Fourth, coordination among university, regulators and foreign and domestic firms was an important element in Bangladesh's success, whereas these linkages were weak in Kenya. Finally, in Bangladesh, the Government enforced quality standards and developed a rural energy development fund to overcome financing shortfalls.

Licensing and alternative modes of technology transfer: China and India

The third traditional mechanism, licensing agreements, has been used fairly extensively for green technologies. The effectiveness of licensing for knowledge spillovers is dependent on local capabilities and R&D.

Licensing agreements have been used for green technologies

Both China and India used licensing agreements as part of their initial investments in clean-energy wind and solar technologies, and supplemented licensing with indigenous research, often conducted in collaboration with domestic universities and research institutes supported by subsidies and public investment. Over time, licensing shifted to co-development with foreign partners, as firms attempted to build learning networks (Lema and Lema, 2010).

Companies can develop strategic partnerships with international firms and universities through collaborative R&D

Although there were differences in strategies (firms in China focused on building domestic learning networks, while companies in India focused on international learning networks), companies in both countries developed strategic partnerships with international firms and universities through collaborative R&D. For example, India's wind company Suzlon built R&D centres and manufacturing units in Germany, the Netherlands and the United States in order to tap into foreign expertise (Lewis, 2007a). While China's wind turbine industry was initially focused on the domestic market, the solar industry concentrated on exports to take advantage of government subsidies for solar energy in developed countries, emphasizing the importance of international markets to domestic innovation systems (Fu, 2011).

Both countries also benefited from human resources trained abroad. Many of the leaders in China's most important solar firms had spent time studying abroad, and either returned to China to start their own firms or were recruited to join existing ones (Gallagher and others, 2011).

From brain drain to brain gain

The cases of China and India point to a potential role for the diaspora in transferring international knowledge. However, many developing countries experience the reverse effect: outmigration of skilled labour to developed countries, which has increased rapidly over the past two decades (Docquier, Lohest and Marfouk, 2007). From the perspective of building domestic capabilities, the challenges for policymakers are first, how to keep educated people from leaving by developing opportunities at home; and second, how to draw those participating in the diaspora back to the country, or find other ways to encourage them to share their expertise and skills and form business linkages (United Nations Conference on Trade and Development, 2007).

Some advanced emerging markets and newly industrialized economies, such as China, the Republic of Korea and Taiwan Province of China, have set up programmes to encourage emigrants to return. China has set up more than 100 special high-technology parks to draw back nationals from overseas (Dahlman, 2008). In Taiwan Province of China, there is a State information clearing house for potential employers and returning researchers, with airfare and other subsidies for those who return (Davone, 2007).

The ability to draw back diaspora members can be an important element in knowledge transfer

However, the effectiveness of many of these strategies is conditional on a country's level of development (United Nations Conference on Trade and Development, 2007). While newly industrialized countries such as China can take advantage of the temporary migration of students and workers to develop scientific capacities, very few African countries are in this position. Nonetheless, as difficult as it is to draw back diaspora members, the ability to do so can be an important element in knowledge transfer, and could be especially important for countries with weak education systems. In fact, a number of countries have programmes that encourage citizens to obtain their student education abroad by financing it, on condition that those students bring home their skills by working in the home country, generally in the public sector, for a number of years after graduation, or after acquiring work experience.

To attract new generations of scientists, policymakers need to build a scientific infrastructure accompanied by changes in culture by promoting innovation and collaboration (Tole and Vale, 2010). In essence, steps that countries should already be taking to spur sustainability-oriented innovation could help attract the diaspora, thereby creating a virtuous cycle.

Education

Education can play multiple roles in a G-NIS. It can influence consumption choices and teach consumers about the environment; build skills necessary for innovation, technological adaptation and the institutional capacity; raise awareness among policymakers; and generate positive externalities, such as the positive benefits conferred by educated parents (particularly women) on their children (Schultz, 2002).

Partnerships with the private sector can help policymakers determine an appropriate education strategy

Building the technological capacities necessary for green innovation requires both learning-by-doing and formal education. Countries need to orient their education systems towards developing a skills base for innovation across sectors, such as agriculture, energy and transportation, and should (as this chapter argues) develop vocational training, although the nature of educational reforms will, of course, depend on a country's economic structure, fiscal means and level of development. In addition, non-traditional forms of education can increase coordination between educators and firms, as well as enhance access to and lower costs of education.

Partnerships with the private sector can help determine the most appropriate education and training strategy for a country. For example, in the Republic of Korea, the partnership of the private and public sectors played a role in the development of Government-led investment in the vocational training system (Hawley, 2007). Similarly, Governments in several Latin American countries have forged successful partnerships with private companies aimed at improving technical education (Alvarez and others, 1999). These partnerships can also help strengthen interactions between agents in the economy.

Education, consumption and environmental behaviour

Information campaigns and civil society mobilization can raise public environmental sensitivity and responsibility, and foster sustainable behaviour in areas such as energy conservation and recycling. Studies have shown that educating consumers regarding their energy consumption patterns can reduce consumption (by about 11 per cent in the United States, according to one study), by switching from high- to low-energy items (Gardner and Stern, 2008).

Education for conservation can impact consumer and firm behaviour

Education for conservation can have an even greater impact on firms. A United Nations Industrial Development Organization (UNIDO)-United Nations Environment Programme (UNEP) programme focused on training, awareness creation and policy advice has led to significant savings by firms through conservation. For example, in Kenya, the paper manufacturer Chandaria Industries experienced savings of 40 per cent in energy, 48 per cent in materials and 181 per cent in water through involvement in the programme.

Carbon dioxide (CO_2) emission intensity was reduced by 28 per cent, waste water by 64 per cent and waste intensity by 62 per cent (United Nations Industrial Development Organization, 2010).

Formal education

Vocational schooling can be particularly useful in building technological skills

There is some debate regarding whether developing countries should focus their efforts on improving primary, secondary or tertiary education. Primary education is critical for developing a semi-skilled labour force. In low-income countries with large rural sectors, it can be vital for equipping farmers with the basic skills necessary to their being informed on and implementing sustainable agricultural and forestry practices. However, while the significance of achieving universal primary education is highlighted by its inclusion as a Millennium Development Goal, secondary, vocational and tertiary education are just as important in the field of green technology. Secondary education can provide core skills and knowledge needed for countries' economic growth. Vocational schooling can be particularly useful in building technological competencies; successful vocational education also provides important links between education and industry. For example, in both Bangladesh (see box V.2) and China, the presence of a pool of workers trained in vocational schools was instrumental for the development of domestic solar PV industries (Gallagher and others, 2011). In Brazil, the National Employers' Federation is a major provider of high-quality training in areas with labour-market shortages.

Governments may benefit from targeted interventions in scientific fields

However, the provision of vocational education can be relatively costly; in sub-Saharan Africa, for example, it is up to 14 times more expensive than general secondary education (Johanson and Adams, 2004). Thus, Governments may benefit from targeted interventions in scientific fields. Tertiary education, especially in science and engineering, can help countries become globally competitive and build technological capacities (World Bank, 2010b).

Recent progress in education in developing countries

Many technical and vocational programmes suffer from weak linkages to employment markets

An assessment of educational outcomes reveals huge variations among and within countries at all levels of education. Overall progress towards universal primary education in the past decade has been encouraging, with the net enrolment ratio having reached 87 per cent at the end of the school year, 2008, in the developing world (table V.1). Nevertheless, UNESCO (2011b) estimates that over 50 million children will still be out of school in 2015 and that in many countries the quality of education remains weak. Despite some improvements, secondary school enrolment remains a problem in many developing regions (table V.2). Countries vary enormously in respect of coverage of technical and vocational education. However, many technical and vocational education programmes suffer from underinvestment, poor quality and weak linkage to employment markets. Tertiary enrolment in developing countries has increased, but remains relatively low in many regions, with enrolment being only 6 per cent in Africa.

Lower female access to education remains a problem in many parts of the world. Although gender disparities have been narrowing in developing countries, they are still pronounced in technical and vocational education and in scientific and technical fields in tertiary education (Hyde, 1993). On the other hand, in some countries, such as Bangladesh, training of women has been critical in building the green technology sector (see box V.2).

Table V.1
Primary enrolment, 1999 and 2008

Percentage

	Net enrolment ratio		*Gross enrolment ratio*	
	School year ending		*School year ending*	
	1999	*2008*	*1999*	*2008*
World	**82**	**88**	**98**	**107**
Developed countries and areas	96	95	103	101
Europe	97	96	105	103
North America	94	93	101	99
Australia and New Zealand	95	97	100	105
Japan	100	100	101	102
Developing countries and areas	80	87	98	108
Africa	61	77	81	100
Asia (excluding Japan)	85	90	100	110
Latin America and the Caribbean	92	94	121	116
Oceania	..	..	81	..

Source: United Nations Educational, Scientific and Cultural Organization Institute for Statistics (Montreal, Canada).
The gross enrolment ratio (GER) is defined as total enrolment at a specific level of education: regardless of age, expressed as the proportion of the population in the official age group corresponding to this level of education. The gross enrolment ratio may exceed 100 per cent because of early or late entry and/or grade repetition.

Innovative approaches to education

There are a host of new mechanisms designed to lower costs and improve access to education, many of which can focus on vocational training. These innovative approaches supplement the formal education system and focus on the skills necessary for green jobs.

At the primary level, partnerships connect schools in Africa with the United Kingdom of Great Britain and Northern Ireland (United Kingdom of Great Britain and Northern Ireland, British Council, 2011). Access to secondary education can be expanded through distance learning via television or other media, utilized by many Latin American countries (World Bank, 2007b). Costa Rica has focused on vocational training for small enterprises through government collaboration with non-governmental organizations and businesses in creating a one-year technical vocational degree (Alvarez and others, 1999). At the tertiary level, distance learning can drastically lower the cost of high-quality education, as demonstrated by Mexico's virtual Millennium University (Alvarez and others, 1999). The use of e-learning programmes and satellite schools in higher education has the added benefit of not necessitating the physical relocation of students to developed countries and can thereby lower the risk of brain drain. Community learning centres can be used to enhance basic education, train teachers, develop local businesses and strengthen civil society, offer access to information and communications technology (ICT) tools, and provide populations in small villages with valuable information (United Nations Educational, Scientific and Cultural Organization, 2011a).

Use of e-learning programmes and satellite schools in higher education can lower the risk of brain drain

In many countries, there is a shortage of skilled labour, such as engineers, maintenance staff and site managers in green economy sectors, although the needs vary by sector. For example, sustainable agriculture is knowledge-intensive and requires farmer training through extension services, farmer field schools and/or adult literacy campaigns, as discussed in chapter III.

Table V.2
Secondary, vocational and tertiary enrolment, 1999 and 2008

Percentage

	Secondary		*Tertiary*		*Vocational*	
	Gross enrolment ratio		*Gross enrolment ratio*		*Share of technical/ vocational in total secondary education*	
	School year ending		*School year ending*		*School year ending*	
	1999	*2008*	*1999*	*2008*	*1999*	*2008*
World	**59**	**68**	**18**	**27**	**11**	**11**
Developed countries	98	99	54	70	17	16
Developing countries and areas	52	63	11	20	9	10
Africa	32	41	8	10	12	10
Asia (excluding Japan)	53	66	11	20	..	..
Latin America and the Caribbean	80	89	21	38	11	11
Oceania	34	..	4	..	..	..

Source: United Nations Educational, Scientific and Cultural Organization Institute for Statistics (Montreal, Canada).

Labour market policies

Education and training need to be accompanied by labour-market policies that encourage an appropriate match between job-seekers and employers. Governments can help facilitate labour mobility and job searches through various interventions, including vocational training, as discussed above, and employment services, competency assessment programmes and skills certification (World Bank, 2010b). These policies can have the ancillary benefit of leading to increased knowledge spillover and faster technology transfer. Costs associated with a transition to a green economy, including unemployment arising from the shift from high-carbon industries, will need to be minimized through targeted measures such as worker retraining, potentially backed by international-level support through development assistance, including Aid for Trade.

Green development requires effective labour-market institutions, including various forms of protection for workers

Building the appropriate skills base for a green economy needs to be accompanied by effective labour-market institutions, including various forms of protection for workers. Green jobs need to entail decent work, with adequate wages, safe working conditions, job security and worker rights (United Nations Environment Programme, 2008). Jobs in some sectors considered green, such as the electronics recycling industry in Asia and the biofuel feedstock plantations sector in Latin America, actually expose workers to environmental and other risks. Recycling, for example, is an important sustainable industry in many developing countries: In China, 1.3 million people are employed in the formal waste collection system, an additional 2.5 million are informal workers or scrap collectors, and as many as 10 million people are involved in other areas of recycling; and in Brazil, half a million people are involved in materials collection activities (United Nations Environment Programme, 2008). Yet, recycling jobs are often hazardous, with safety and environmental rules non-existent. Labour-market institutions and regulations need to address these issues.

Institutions, industrial policies and infrastructure

There are a wide range of institutions and fiscal incentives that can promote or impede innovation. Institutions comprise laws, rules and established social and cultural practices that affect incentives and behaviour (Edquist, 1997),[5] such as patent laws, cap-and-trade systems and regulations. As elsewhere in the G-NIS, there should be two-way relationships between these elements and the rest of the system. Domestic institutions and existing infrastructure set incentives and affect how the actors behave. Infrastructural or institutional rigidities that arise can hamper innovation.

Public sector investments in infrastructure could be required to support industrial policy efforts

Because of the lack of market demand for sustainable technologies, government industrial policies designed to stimulate private sector investment need to be at the heart of the G-NIS. Such policies treat green economy activities as "infant industries", requiring appropriate support, including regulatory requirements, government procurement, subsidies (preferably performance-related and time-bound), access to credit and, possibly, some level of trade protection, as discussed in chapter VI. In many countries, public sector investments in infrastructure would be required to support these industrial policy efforts. In addition, the policy framework should include a government agency structure that can facilitate the establishment of stable but flexible institutions.

Regulation

Regulations should be designed to be innovation-friendly

Regulatory mechanisms, such as targets and standards, are often designed as tools to limit or prohibit certain forms of behaviour (United Nations Environment Programme, 2011). However, regulations should also be designed to be innovation-friendly. Environmental regulations, such as limits placed on emissions, pesticides in food, pollution and water contamination, have the first-order effect of improving the environment, but can also be drivers of domestic demand for green technologies.

Targets are already being utilized in many developing countries. For example, renewable energy targets, which set goals for green energy, usually at 5-20 per cent of total energy consumption, are used by 45 developing countries (REN21, 2010). However, the effectiveness of these targets varies by country, and many countries are likely to miss their 2010 targets. An alternative measure used in many countries, particularly those with public energy companies, is to mandate energy companies to source a certain percentage of energy from renewable sources (Kempener, Diaz Anadon and Condor Tarco, 2010). These more direct targets are somewhat easier to manage and enforce.

Standards can create demand for green technologies

Standards, including energy-efficiency codes for buildings and air, water, and fuel efficiency standards, can create demand for green technologies, while improving the environment and health. For example, fuel efficiency standards in China led to the adoption of and improvements in fuel efficiency technologies (Gallagher, 2006). Similarly, water safety standards can stimulate the development of systems for safely storing and treating water, for example, through waste-water recycling and desalinization, or improve on traditional or local-based technologies, such as harvesting rainwater. Such standards can be implemented progressively over time if necessary, through regulation that has been announced in advance, to give agents time to adjust.

5 Note that this list does not include organizations (such as government agencies), which are categorized as actors.

One effective programme for setting standards has been Japan's Top Runner Programme for appliances, discussed in chapter II. This programme is based on collaboration among various actors. The most energy efficient product on the market sets the "Top Runner Standard", which all corresponding manufacturers and products will aim to achieve in the next stage. Energy efficiency standards are then set by the Ministry of Economy, Trade and Industry and its advisory committees, comprising representatives from academia, industry, consumer groups, local governments and mass media.

Other regulations include outright mandates. For example, the Republic of Korea has a policy of "extended producer responsibility" which requires companies to recycle packaging. This programme has increased recycling by 14 per cent and estimated savings by $1.6 billion (United Nations Environment Programme, 2011). Other mandates include direct requirements for green technologies. For example, Bangladesh mandates the utilization of solar PV in new construction; Israel mandates utilization of solar hot water; and other countries, such as Brazil, have mandates for biofuels.

Quantity-based restrictions can often reduce risk more effectively than price-related interventions

Economists are traditionally partial to price-based mechanisms, such as taxes, over quantity-based regulations, such as those mentioned above. However, the case to be made for price-based interventions is far from clear-cut, and theoretical work in economics has shown that quantity-based restrictions can reduce risk more effectively than price-related interventions (Stiglitz and others, 2006). Further, quantity-based interventions are typically easier to administer than more complex price-based incentives, making them particularly useful tools for countries with weak administrative capacity.

Government procurement, subsidies and other incentives

Government procurement, such as purchases of clean bus fleets, is designed to create market demand, subsidies and tax credits are designed to lower an investor's initial investment, while feed-in tariffs (FITs) are designed to guarantee a higher return. Many of these instruments are already utilized by developing countries. Green investment tax credits are used in 18 developing countries, public investment is used in 17, while feed-in tariffs, which guarantee prices to clean energy producers above the existing market price, are used in 17, including Algeria, Mongolia, Sri Lanka and Uganda (REN21, 2010). Many of these mechanisms have been criticized for locking in subsidies that then become politically difficult to remove, although putting time limits on them can help reduce this risk somewhat.

Industrial policies can also be used to accelerate changes in behaviour

Industrial policies can also be used to accelerate changes in behaviour and practices. If well designed, some of these tools can have multiple benefits. For example, paying farmers for carbon sequestration would remove CO_2 from the atmosphere (mitigation), enhance soil resilience (adaptation) and improve production by improving crop yields (Ocampo, 2011a).

Carbon instruments

Another set of instruments are designed to incorporate environmental externalities into carbon technologies to "get prices right", thereby making sustainable technologies more competitive with existing technologies. These include cap-and-trade policies and carbon taxes. As discussed above, both sets of policies are particularly problematic for poor developing countries, as the likely increase in energy costs could disrupt economic development, at least until new energy sources are available.

Cap-and-trade is a quantity control, since it limits the amount of carbon that firms can produce; but it has been designed to be more in line with market mechanisms than the regulatory controls discussed above. The advantage of a cap-and-trade system versus priced-based mechanisms, such as a carbon tax, lies in the fact that a cap puts a legal limit on pollution, while the tax sets a price under the assumption that quantity will adjust, based on the higher price. A carbon tax has the advantage of raising revenue for the government. In addition, some studies have indicated that under certain conditions a carbon tax is more likely to spur innovation (Scotchmer, 2010).[6]

Strong administrative capacity is needed to implement cap-and-trade schemes

Perhaps most importantly, for developing countries without strong administrative capacity, domestic cap-and-trade schemes could be extremely difficult to implement. The 2007-2008 financial crisis revealed the ease with which financial markets could be manipulated, even in the most advanced markets; hence, the risk of manipulation, market failures and distorted incentives would be extremely high in most developing countries. Moreover, with respect to getting prices right, it is likely that both carbon taxes and cap-and-trade programmes would have to be so large as to be politically infeasible (Mowery, Nelson and Martin, 2010).

Investment requirements and trade protection

Many newly industrialized economies used investment requirements to build domestic industries

In addition to price incentives and quantity restrictions, many newly industrialized economies used investment requirements and protectionist measures to build and protect domestic industries. For example, both India and China adjusted customs duty requirements to protect the development of domestic solar and wind industries (Lema and Lema, 2010). China also imposed investment requirements on FDI, including local content, joint venture, local hiring and mandatory seminar requirements, with the goal of encouraging technology transfer from foreign to domestic companies (Lewis, 2007a; 2007b).

International intellectual property rights can limit technology transfer and the ability to engage in domestic innovation

However, as discussed in chapter VI, these measures, as well as many of the quantity and price incentives discussed above, might be considered illegal under World Trade Organization rules, which could potentially limit policy scope and thus make it difficult for developing countries to "catch up". In fact, according to Gallagher and Shafaeddin (2010, p. 37): "OECD governments have begun to dub China's policies as 'forced transfers' and have undertaken investigations and task forces in order to eliminate or reduce them". Further, international intellectual property rights can limit technology transfer and the ability to engage in domestic innovation, although the extent will depend on the economic sectors involved, the economic activities and the level of development, as discussed in chapter VI.

Infrastructure and business environment

To spur innovation, industrial policy measures need to be supplemented by public sector investment in domestic infrastructure. Such investment can have multiple benefits. For example, public sector investment in clean transportation or in energy, water and sanitation services can reduce poverty, improve health and create a better investment climate.

6 According to Scotchmer, when the demand for energy is inelastic, cap-and-trade regulation may lead to incomplete diffusion of a new technology, whereas tax regulation offers an incentive to fully diffuse the innovation.

Countries can support business incubators and technology transfer centres

Innovation and entrepreneurial activity also require facilities, legal and businesses services, and access to telecommunications services. An alternative for countries that do not have a supportive infrastructure is to build business incubators and technology transfer centres capable of providing these services. These can be either independent or structured as elements in a science park, as is the case in Tunisia (World Bank, 2010b).

A second important element is the nature of the business environment, which is influenced by the extent to which bureaucracy impacts the ease of doing business. Although every context differs, in general, the government should focus on reducing the red tape that unnecessarily impedes entrepreneurship, while distinguishing between those regulations that serve a purpose and those that simply foster inefficiency. For example, investors might view regulations that require documentation of environmental risks as being simply red tape, even though these regulations are a necessary element of a country's regulatory framework.

Government agencies

Institutions in many countries, such as those in Africa, are subject to rigidities, which make it difficult for them to respond to the changing needs of a developing economy's innovation system (Oyelaran-Oyeyinka, 2005). While overcoming institutional rigidities can be difficult, a government agency structure that is designed to promote innovation can better manage a G-NIS and thus help overcome some of these obstacles.

The goal is to leave in place the flexibility of a diffused governmental organization, while maintaining coordination

The Economic Commission for Africa (ECA) (United Nations, Economic Commission for Africa, 2007) identified three types of structures for government agencies: pluralist, coordinated and centralist. Pluralist structures have independent government agencies and ministries with no coordinating mechanism, an arrangement that could lead to a high cost in terms of overlap and gaps. In the coordinated system, government departments initiate their own programmes, but a coordinating body nevertheless exists. This type of structure has tended to lead to rivalries among ministries and its effectiveness is being called into question by many of the OECD countries that have utilized it. In a centralist system, the full range of green technological projects and issues are coordinated by a single ministry. An inter-ministerial committee formulates policy, approves the technology budget and oversees all decisions related to technology policy. The goal is to leave in place the flexibility of a diffused governmental organization, while maintaining a central coordinating body.

The Economic Commission for Africa (United Nations, Economic Commission for Africa, 2007) concluded that the centralist system is the most appropriate structure for developing countries, such as those in Africa. Given that a G-NIS is a complex system, a coordinating body is likely to play an important role in designing policy. However, in a G-NIS framework, it is important to include all key stakeholders in the design process, including the private sector and civil society. There is no one-size-fits-all solution, and which structure is most relevant will depend on the specifics of the country.

Whatever structure is chosen needs to be coupled with mechanisms for monitoring and evaluation so as to limit the capture of politicians by the private sector. It is also important to ensure the connection between the coordinating body and the highest political authorities, since without a strong visible political commitment, short-term urgent priorities in other areas can displace attention and resources.

Financing

One of the most important functions of the G-NIS is to mobilize the capital needed to finance innovation. In theory, the government would finance public goods, such as infrastructure and possibly education, and leave the rest to the private sector. However, as discussed earlier, the lines blur with regard to investments in innovation of green technologies because of their status as public goods.

Which source of financing makes the most sense for a country will depend on its financial market structure and the level of risk in the project. There are also international public funds available to help countries finance investments in green technologies, including through the United Nations Framework Convention on Climate Change,[7] the World Bank Group, and other sources of aid as discussed in chapter VI.

Private sector green funds

So-called green funds have tended to be myopic and extremely pro-cyclical

So-called green funds are mutual funds and hedge funds that invest in sustainable technologies. However, these funds tend to be myopic and extremely pro-cyclical, increasing during boom periods and falling during economic downturns. This is partly because the fund managers themselves are short-sighted, and partly because their own funding sources tend to grow during boom periods and collapse during economic recessions (Stiglitz and others, 2006). For example, investors redeemed $1.2 billion from renewable energy funds in the first 10 months of 2010 as changes in regulation and the credit crunch dimmed the outlook for solar and wind projects, after those funds had grown by $1.2 billion in 2009 (Sills, 2010). In essence, these funds are green hot money and Governments should be wary of the type of financing they offer.

Venture capital

Generally, venture capital has not been available for investments in green technologies in developing countries owing to the high risks involved

Venture capital (VC) is the form of financing typically used in the diffusion stage of the innovation process, not least because many venture capitalists can assist in business development. Unlike green funds, VC tends to have relatively long lock-ups, meaning that investors cannot withdraw their investments for a period of 7-10 years.[8] Generally, VC has not been available for investments in green technologies in developing countries owing to the high risks involved, as discussed above. Although a significant amount of VC had been raised for investments in green technology prior to the financial market crisis, most of the funds were invested in developed countries. Approximately one quarter of the funds were never deployed at all, because green investments had been viewed as too risky—even in developed countries (World Bank, 2010b).

Microfinance institutions and microfinance

Microfinance can play a role in reaching rural populations which currently lack access to electricity, clean water and cooking stoves. Microfinance and micro-consignment[9] are

7 United Nations, *Treaty Series*, vol. 1771, No. 30822.

8 Nonetheless there is evidence that investments of venture capital in R&D are somewhat pro-cyclical (Barlevy and Tsiddon, 2006; Ouyang, 2009).

9 In micro-consignment, the consumer pays off the price of the product over time, with the distributor owning the product until it is fully paid off.

currently being used for solar lamps, water purifiers and stoves (Rosenberg, 2011). Further opportunities exist in the areas of cleaner cooking products, biofuels and low-emissions agriculture (Rippey, 2009).

Some microfinance institutions have set up subsidiary companies to provide financing for clean energy products

Several microfinance institutions, such as Grameen Bank in Bangladesh, have also successfully set up subsidiary companies which use their microcredit networks to extend loans for clean energy products, such as off-grid solar systems, as discussed in box V.2. Much of the financing for these loans comes from banks set up by government or multilateral institutions. Similarly, Sri Lanka's renewable energy project is based on a network of microfinance institutions that work with solar companies (REN21, 2010).

Foreign direct investment

FDI can be a source of long-term investment. Although there is evidence that FDI is also somewhat pro-cyclical (Stiglitz and others, 2006), it is significantly less so than portfolio investment. However, as discussed above, to be effective in technology transfer, FDI needs be supplemented by domestic policies designed to encourage knowledge spillovers.

Long-term institutional investors

Long-term investors include domestic and international pension funds, as well as sovereign wealth funds (SWFs).[10] Although funds differ, all of these investors tend to have relatively long investment-horizons, and can, to some extent, avoid succumbing to the myopia discussed above. In addition, because SWFs and public pension funds represent citizens, many of them are conscious of the need to behave in a socially responsible way: green investments can enhance their legitimacy and reputation in this regard (Bolton, Guesnerie and Samama, 2010).

Several large public pension funds and sovereign wealth funds have begun to invest in clean energy projects

Pension funds tend to be relatively conservative investors, since their liability structure is based on future payments to pensioners, which are meant to be relatively stable. Therefore, it could be difficult for pension funds to invest in the earlier stages of green technological innovation in developing countries, owing to the high uncertainty associated with many of the projects. Nonetheless, several large public pension funds, such as the public sector funds of Canada and the Netherlands, have begun to invest in clean energy projects. Government policies that emphasize risk-sharing policies could be particularly important for these investors.

Moreover, several SWFs have also already made significant green investments. Most SWFs have a mandate to preserve and transfer wealth to future generations. Therefore, green investments make sense to them from an asset-liability perspective, since the risks associated with climate change can be seen as a potential liability to nation States (Bolton, Guesnerie and Samama, 2010).

Private and public sector risk-sharing

There is enormous uncertainty associated with the innovation process and the lack of markets for many green products

As the above analysis makes clear, the main impediments to private sector investment in green innovation are the enormous uncertainty associated with the innovation process and the lack of markets for many green products. Mechanisms designed to facilitate

10 However, many seemingly long-term investors, such as pension funds (both domestic and international), manage their investment with a short-term bias.

sharing of risk between the government and the private sector can be used to overcome these impediments to some degree. These include traditional forms of risk-sharing, such as public-private partnerships, as well as more innovative mechanisms, such as equity-linked financing, rural funds and national green long-horizon funds.

Public-private partnerships (PPP) and development banks

Both the government and the private sector invest jointly in public-private partnerships, and share the costs of the projects. In the United States, public-private partnerships are an important component of government innovation policy (Audretsch, Link and Scott, 2002) and have been particularly helpful in overcoming the risks associated with the introduction of new technologies into the market. A prominent example is the 1986 United States Clean Coal Technology Program, which was created to address the acid rain problem. The industry covered almost two thirds of the project costs, and a Department of Energy (DOE) study found that "cost sharing between (the) DOE and industrial collaborators frequently improved the performance of RD&D programs and enhanced the level of economic and other benefits associated with such programs" (National Research Council, 2001).

Public sector development banks provide an alternative funding channel for long-term investment in many developing countries. Development banks have been important in Brazil, China and India, particularly in infrastructure. Local public banks, often dedicated to financing rural projects, are one such source of financing. These banks usually lend through private companies, non-governmental organizations and microfinance groups and, more recently, have lent through rural energy funds. In the case of both public-private partnerships and development banks, it is important that mechanisms be set up to judge their effectiveness and minimize potential abuse.

It is important to set up mechanisms to judge the effectiveness of and minimize potential abuse in public-private partnerships

Rural renewable energy funds

Rural energy funds have been set up in countries such as Bangladesh, Mali, Senegal and Sri Lanka (REN21, 2010). These funds have the triple advantage of reducing poverty, improving infrastructure (including access to electricity) and stimulating investment in green technological adaptation and diffusion. Rural funds tend to combine financing with advice on engineering, project management and feasibility studies.

Equity-linked financing

Many government policies discussed in this chapter and elsewhere, such as government subsidies, tax breaks and low-interest loans, are transfers from the government to private sector firms, meant to "crowd in" private investment. In essence, taxpayers subsidize private sector activity, but if the firm succeeds, the entrepreneurs earn all the profits.

Risk-linked financing provides an alternative to outright grants or low-interest loans. Similar to a gross domestic product (GDP)-linked bond (Griffiths-Jones and Sharma, 2006), equity-linked loans or bonds allow the lender (in this case, the government) to share in the potential upside of successful projects.[11] If the firm fails, the

Risk-linked financing provides an alternative to outright grants and low-interest loans

11 The financing could be structured as a loan (with non-voting equity warrants attached), whose repayment would be based on the success of the venture. In the event of success, the firms' owners could buy out the government's stake at a price on the basis of pre-agreed rules.

country's taxpayers lose their investment—but that loss is similar to what they would have paid out in traditional subsidies; however, if the firm succeeds, the government will have a financial stake in the firm and the taxpayers will be compensated for the risks they have taken. These are relatively simple structures that can provide low-risk financing for firms, while still ensuring that taxpayers are compensated for their investments.

National green long-horizon funds

National green long-horizon funds can be set up to enable the sharing of risk between the public and private sectors and the "crowding in" of private investment

Much attention has been focused on global funds for clean technology, which constitute an important part of the global effort to combat climate change, as discussed in chapter VI. From a domestic perspective, long-horizon domestic clean energy funds could be part of the G-NIS framework. Such funds would raise capital from long-term investors. One unique aspect of the structure is that the investors with shorter time-horizons would not be allowed to participate in the fund.[12] The government would either invest alongside private investors, or give a guarantee and put up a fraction of the capital. Either way, the government would maintain some equity in the fund to compensate for its share of the risk-taking, so that taxpayers could earn returns on the investments.

Investors would likely be drawn to the fund for several reasons.[13] First, they would have a stake in a field with enormous potential, but with reduced risk. Second, with the government taking the same risks as the investor, the government and investors' interests would be more or less aligned, thereby making it much less likely that the government would put in place policies that harm the fund's investments. Thus, one type of political risk usually faced by investors would be removed. Third, because Governments establish the regulatory and policy framework, they tend to have inside knowledge of what type of projects makes the most sense for their country. This is particularly relevant in the case of green technologies where market demand is primarily determined by government policies, thereby making the government a valuable co-investor.

The government can also derive several advantages from this type of structure. First, the government can leverage its own investments and attract investors who normally might not invest in the early phases of the innovation process. Second, the fund would likely be off balance sheet, since, for accounting purposes, it would be treated as an investment rather than as an expenditure. The implication is that it would not affect the budget, and the government could possibly issue "green bonds" to finance additional projects. Third, the fund—unlike the usual fiscal incentives, many of which are giveaways to investors—would enable the government to keep an equity stake in the projects it finances.

The investment strategy of the fund would focus on innovation. Nevertheless, the question still remains, how will the fund go about choosing which investments to finance? The answer to this question is particularly significant in the present context, because it offers insights relevant to the broader question of how a government should go about choosing its investments.

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12 As measured by their liquidity provisions.

13 As the fund will invest in direct equity, the existence of a well-developed bond or equity market would not be a prerequisite for its workability.

Policy implications

A framework for government decision-making

There is a continuing debate on how a government should intervene in markets. Some argue, pointing to the success of East Asia, that government should select or target particular activities or firms. Others point to government failures, and argue that government interventions are meant to improve markets without favouring specific activities (Lall and Teubal, 1998), such as by setting standards and letting the private sector make the decision on how best to meet those standards. Yet, while standards are an important tool, they are unlikely, as discussed above, to be sufficient to spur innovation of green technologies to the extent necessary. Without other forms of government support, it is unlikely that clean technology markets will develop; thus, Governments still need to subsidize green technologies. Hence the question remains, how does the government choose which technologies or sectors are to be subsidized?

The objectives of the G-NIS suggest several general guidelines. First, the government should commit to sustainably oriented investments. Second, it should give priority to investments in infrastructure that might be critical to "crowding in" private investment. Third, it should look to investments that have positive externalities elsewhere in the system, with higher potential for learning spillovers. While a more detailed answer to the question will inevitably depend on the specific characteristics of a country, this chapter sets out a framework for responding to it through use of an analogy to financial asset management (which is one reason that the fund construct above is so useful).

When it has unique insight into the appropriateness of certain investments, a Government should take advantage of that knowledge to direct investment choices

Grübler and others (forthcoming bis) have suggested that Governments should create a diversified portfolio comprising a blend of technologies, based on a granular approach, which spreads risk across a broad range of smaller-scale innovations without the Government's being required to make premature selections of a few capital-intensive projects. However, larger projects are sometimes the most appropriate, especially for small economies and developing countries, and the small, diversified approach would preclude this option. Further, a diversified portfolio is the best approach for investing only if the following conditions are satisfied: (a) the returns of the investments are uncorrelated, and (b) the investor does not have any unique knowledge or comparative advantage over other investors. If an investor has unique knowledge, it is likely more profitable to invest on that information than to diversify. Venture capitalists invest all the time in more concentrated portfolios while still maintaining a degree of diversification across multiple investments. Many of these investments are in fact based on educated guesses regarding what government policy will look like.

Similarly, when a government or a non-governmental organization has unique insight, like the Government of Brazil in respect of sugar and biofuels or Grameen on the potential for solar in rural Bangladesh, it can—and should—take advantage of that knowledge. More broadly, a diversified index fund approach makes sense when a Government does not have unique insight; a more concentrated venture capital-type approach (which nonetheless still maintains some degree of diversification) makes sense when the government does have that insight.

Building insight at the government level is, of course, not always straightforward. Government learning is an interactive process based on experimentation. Feedback from private sector innovators, research labs, suppliers and demanders are a crucial part of the decision-making process. The G-NIS emphasizes the importance of interaction between policymakers and the private sector, universities, and research institutes, which can further enhance government decision-making. Furthermore, most Governments know more than any other actors about future regulatory structure, legal framework and players in the system, and often have more information on various existing projects in relevant sectors.

As in the private sector, not all government investments will be profitable and some will fail

As in the private sector, not all government investments will be profitable and some will fail. After all, more than 50 per cent of new businesses in the United States fail in the first four years of their existence (Shane, 2008). Successful venture capitalists are right only part of the time,[14] while the gains of the winners compensate for the failures of the losers. However, particular investment failures do not mean that the strategy itself is a failure. It is important to change perceptions of the meaning of government failure. A country fund structure, as discussed above, could be helpful in doing so, since it incorporates individual decisions into a larger framework. In addition, as the fund would likely be managed by an independent manager, it could also help address some of the issues associated with government mismanagement.

Governments should be judged on the success of overall strategies and not on the success of specific projects

Nonetheless, government failures do exist, owing to mismanagement, incompetence and/or fraud. History has shown that without a strong governance structure, government programmes can become riddled with favouritism and cronyism. Well-structured rules for assessment and monitoring investments are a crucial element in the innovation process. In the newly industrialized countries in Asia, for example, effective policies were linked to mechanisms set up to judge their effectiveness, with a flexible policy regime capable of adapting to failed policies (Kim and Nelson, eds., 2000). Implementing such a strategy is no doubt difficult, but improvements in the structure of government agencies can be a step in the desired direction.

Policy reforms under the G-NIS

The G-NIS provides a coherent systemic framework for understanding innovation policies

Strong technology and innovation policies are needed to meet the challenges associated with achieving sustainable green growth. The G-NIS provides a coherent systemic framework for understanding innovation policy. Policies within the G-NIS should correct inefficiencies in the *system,* rather than specific market failures. For example, if systemic inefficiency is due to a lack of coordination between universities and firms, the Government might offer grants for joint R&D, deploy the funds needed to start a science park and/or encourage mobility between research institutions and firms.

Policy choices will depend on the specificities of a country, including the level of development and administrative capacity

Nonetheless, one size does not fit all, and policy choices will depend on the specificities of a country, including the level of development and administrative capacity. Table V.3 sums up many of the policy measures discussed throughout this chapter and provides some general examples of how policies might apply to countries with weak, medium and strong administrative and innovative capacity. Overall, policies in the G-NIS should promote technological capacity-building, technological transfer, interactive learning and entrepreneurship based on education, knowledge spillovers and learning-by-doing.

Industrial policies are at the heart of the G-NIS. There will, of course, be some failures associated with these policies, but it is time to reassess the meaning of government failure so as to judge government performance from a broader perspective—one that is focused on the importance of building long-term sustainable green growth.

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14 Some estimates put the proportion of the time that successful venture capitalists are correct at as low as 10 per cent (Grübler and others, forthcoming bis). Based on back-of-the-envelope estimates, the figure, while possibly higher than 10 per cent, is likely less than 50 per cent.

Table V.3
A sample of green technology policy options for countries at different levels of development and administrative capacity

	Administrative and innovative capacity		
	Weak	*Medium*	*Strong*
Formal education	Primary and secondary education, emphasis on vocational training; begin to strengthen tertiary education, including educating some people abroad	Primary, secondary, and tertiary education; emphasis on vocational training; strengthening of tertiary education	Higher demand for capabilities; greater emphasis on tertiary education, including at the postgraduate and doctorate level
Technology transfer	FDI and global value chains in conjunction with domestic research and policies; encourage joint ventures with foreign firms and mobility between firms	Reverse engineering of imports, FDI and global value chains in conjunction with domestic research and policies; encourage joint ventures with foreign firms, mobility between firms and return of diaspora members	Outward FDI; joint research with international firms; sharing of scientific research
Other industrial policies	Emphasize regulations and quantity-based incentives; possible investment regulations; investments in infrastructure	Wide range of quantity- and price-based incentives; possible investment regulations; investments in infrastructure	Wide range of quantity- and price-based incentives; focus on domestic and export markets
Additional market formation policies	Public procurement	Public procurement, feed-in tariffs	Public procurement, feed-in tariffs
Other risk-sharing mechanisms	Public-private partnerships; development banks; country funds; equity-linked financing; rural infrastructure funds	Public-private partnerships; development banks; country funds; equity-linked financing; rural infrastructure funds	Public-private partnerships; development banks; equity-linked financing; country funds; rural infrastructure funds
Focus on building linkages between…	Universities and firms; regional knowledge networks; science parks; movement of people	Universities and firms; regional knowledge networks; science parks; movement of people	Build international knowledge networks; joint R&D with international firms; outward FDI
Intellectual property rights	Weak intellectual property rights regimes	Advantages to both weak and strong systems	Likely a stronger system; though still encourage knowledge-sharing in key sectors

Source: UN/DESA.