Natural Resources
FORUM

Natural Resources Forum 27 (2003) 177–188

Environmental leapfrogging in developing countries: A critical assessment and reconstruction

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Abstract

It has been suggested in recent years that developing countries need not pass through the dirty stages of industrial growth that marred the past of today's developed countries. Instead, they may be able to bypass these by leapfrogging straight to modern, clean technologies as an integral part of capacity addition. This article critically reviews existing approaches to leapfrogging. It argues that they are not only characterized by considerable ambiguity, but also based on an incomplete understanding of the technological and policy requirements of cleaner industrialization. Consequently, the article goes on to offer a number of suggestions as to how current approaches might be advanced so as to better meet the challenge of leapfrogging. Amongst these suggestions is greater clarification of the specific targets for leapfrogging and policy intervention to accelerate the development of technological capabilities needed to select, absorb and innovate leapfrog technologies.

Keywords: Leapfrogging; Developing countries; Lock-in; Clean technology; Technological capabilities; Innovation; Partnerships.

1. Introduction

In the environmental debate, particularly in relation to climate change mitigation, it has been argued that developing countries need not adopt the dirty technologies of the past. Rather, they might well be able to "leapfrog" over them, opting instead for modern, clean technologies as an integral part of capacity addition (Anderson, 1996; Goldemberg, 1998; Hecht, 1998; UNDP, 1998; IPCC, 2000; World Bank, 2003). Doing so, it is suggested, will enable developing countries to avoid repeating the past experience of today's developed economies, and their path to industrialization with its legacy of environmental blight. Moreover, by leapfrogging straight to cleaner production paradigms from the outset, developing countries may also be able to avoid getting "locked" into hydrocarbon intensive technologies and infrastructures, as has happened to industrialized economies[1] (Rip and Kemp, 1998; Unruh, 2000).

These are bold claims, and appealing ones, as they suggest that many of the environmental problems commonly associated with urban industrialization may be a thing of the past. The question is whether leapfrogging is a realistic and achievable goal. Current approaches have generally given the impression that it is, provided a number of basic conditions are met. Among such conditions have been mentioned: strong incentives for firms to reduce their environmental impacts; participation of transnational corporations (TNCs) in the development process, and so on. The present article, however, argues that current approaches to leapfrogging may be overoptimistic. Meeting the objectives of clean development in industrializing countries is likely to prove considerably more complex and challenging than much of the existing literature would lead us to believe. Yet, in contrast to more radical critiques, which reject the very notion of technical fixes to environmental crises (e.g., see Booth, 1998), this article suggests that leapfrogging should not be abandoned as an environmental strategy. Rather, it asserts that the solution lies in defining new approaches, which are more sympathetic both to the development priorities of industrializing countries, and to their limited capabilities for technological upgrading.

The article develops these arguments in four parts. The first part briefly describes current approaches to leapfrogging in developing countries. The second part provides a critique of existing theories, focusing in particular on the ambiguous objectives, technological determinism and incomplete understanding of the process of technological

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[1] The idea of leapfrogging has been invoked in relation to a number of different technological opportunities — information-and-communications technology (ICTs), biotechnology, etc. (e.g., see Steinmueller, 2001; World Bank, 2003). In the present article, however, it specifically refers to a process involving technologies capable of bringing about reductions in resource use and/or pollution discharges.

change of current approaches. The third part of the article then offers practical suggestions for advancing current approaches in order to better meet the challenge of cleaner industrialization. Conclusions are given in the fourth part.

The article focuses mainly on the industrial sector. Not that this sector is the only, or even always the leading, source of environmental degradation in developing countries,[2] however, it is of particular significance in the context of leapfrogging, especially for the following three reasons. The first reason is that the extractive and manufacturing industries are widely held to be the most promising candidates for leapfrogging-type investments (Wallace, 1996; Rock, 2002). Second, along with the energy sector, extractive and manufacturing industries are at the forefront of international efforts to curb the growth of greenhouse gas emissions in developing economies. And third, the industrial sector is a leading source of employment, value-added and economic development in low-income economies, which means that the sector needs to feature in any strategy to reduce the environmental burden of the development path (Lall and Pietrobelli, 2002).

2. Conventional approaches to leapfrogging

Despite its being invoked by academics (Warhurst and Bridge, 1997), policy makers (Wilkins, 2002) and journalists (Coyle, 2002), there have been few attempts to define what leapfrogging actually means in practice. Nevertheless, the consensus is that leapfrogging implies a development strategy for industrializing countries to bypass the "dirty" stages of economic growth through the use of modern technologies that use fewer resources and/or generate less pollution. Broadly speaking, existing approaches maintain that achieving these goals requires five conditions to be met:

- A shift towards "clean" production approaches;
- Action from the outset;
- Technology transfer from developed economies;
- Strengthening the incentive regime; and
- International assistance.

2.1. Shift towards "clean" production approaches

The first of these conditions is a shift in the dominant environmental management approach from one based on end-of-pipe (EOP) technologies to one involving widespread application of clean technologies (Angel et al., 2000). This is believed to be important since, unlike EOP devices which simply transform and/or transfer pollution after it has been generated, clean ones prevent environmental damage in the first place through process efficiency and/or the recycling of residuals. In doing so, they go some way towards reducing the economic burden imposed by pollution-related health and/or ecosystem damage (World Bank, 2000); at the same time, cleaner production technologies also lower the cost of achieving environmental targets, thereby enhancing competitiveness and the ability of firms to participate in international markets. Cleaner production approaches are thus felt to be particularly well suited to developing countries, where there is an urgent need simultaneously to advance the goals of economic development and environmental protection (Luken and Freij, 1995; Heaton and Resosudarmo, 2000).

2.2. Action from the outset

Leapfrogging will require developing countries to invest in clean plant and equipment at an early stage of their industrialization path (Wallace, 1996; Weizsäcker et al., 1998; *The Economist*, 2001; World Bank, 2003). Failing to install cleaner technologies at this stage, particularly during what has historically been the most pollution-intensive phases of economic development, will result in rapidly rising levels of environmental degradation. Also, according to many analysts, it is likely to generate additional and unnecessary costs later on (O'Connor, 1996; Grubb, 1997) due to two factors. One is that, once installed, "dirty" technology can only yield an improved environmental performance by retrofitting EOP devices or — more costly still — by replacing it altogether with "cleaner" plant and equipment. The other factor here is the so-called lock-in effect. Investment in dirty technologies during the formative stages of industrialization may "lock" developing countries into an environmentally damaging technological path that, in the long-term, will be more costly and increasingly difficult to escape.

Lock-in effects are the result of increasing returns to adoption enjoyed by technologies that gain market share and include cost savings and design improvements from dynamic scale and learning effects; as well as positive network externalities arising from systemic relations between groups of users, producers and supporting infrastructures[3] (Metcalfe, 1997; Unruh, 2000). These benefits from wider adoption lend considerable advantage to established technologies, making it extremely difficult for new technological options to penetrate the market (particularly if they are incompatible with existing systems). According to many analysts, lock-in effects explain why hydrocarbon-intensive technologies continue to dominate in developed economies, despite the existence of a range of potentially superior low- and/or zero-carbon substitutes (Rip and Kemp, 1998).

[2] In many cities, vehicles and households are the leading sources of pollution (World Bank, 2000).

[3] This is based on the observation that technologies are more than manufactured objects. They are also part of larger technological systems made up of multiple, interdependent technologies and supporting infrastructures; the latter comprising the technical, economic and institutional relationships and structures that enable existing technologies to work together (Rip and Kemp, 1998).

Developing countries, by contrast, are believed to be uniquely placed to avoid lock-in, provided that they take action in the near term to invest in leapfrog technologies (World Bank, 1992; Topping et al., 1996; Wallace, 1996; Tolba and Rummel-Bulska, 1998; Loucks, 2002; Rock, 2002). This is because they have yet to install much of their productive capacity, and are thus less constrained in their choices by existing technologies and infrastructures.

2.3. Technology transfer from developed economies

Existing approaches commonly assume that the challenge of clean industrialization in developing countries can be met using the existing stock of commercially available technologies (e.g., see Anderson, 1996). However, because most of this equipment was developed and is owned by firms in developed economies, leapfrogging will require large-scale North–South transfers (Rajagopal, 1992; Barton, 1997; Goldemberg, 1998). In this context, many accounts point to the importance of the participation of transnational corporations (TNCs) in the development process. TNCs, it is claimed, routinely transfer cutting-edge ("clean") plant and equipment to their subsidiaries in developing countries (Warhurst and Isnor, 1996; OECD, 1997). In fact, given that many local firms lack the financial resources and expertise to adopt cleaner production approaches, foreign transnationals are often portrayed as the most likely vehicle for leapfrogging-type investments (Wallace, 1996).

2.4. Strengthening the incentive regime

Much of the literature maintains that leapfrogging will not take place automatically, but will require government intervention, especially strengthening incentives for the uptake of clean technologies. In practice, this requires two things. The first is economic policy reform, including the privatization of state-owned enterprises, trade and investment liberalization and the removal of so-called perverse subsidies (for water, energy, etc.). These are said to be important since the creation of open, competitive markets increase external pressures on firms to invest in modern plant and equipment, much of which happens to be characterized by high levels of environmental performance (World Bank, 2000; IPCC, 2001; Holliday et al., 2002).

The second action that governments in developing countries must take is to introduce strong legislative frameworks for environmental protection. In this capacity, many analysts stress the importance of avoiding the mistakes made by developed economies in the past (*The Economist*, 1998; UNDP, 1998). Here, it is argued, an overwhelming reliance on command-and-control instruments led to a costly clean-up approach to environmental management predicated on the widespread use of EOP technologies (Clayton et al., 1999; Heaton and Resosudarmo, 2000). Instead, what is required is policy leapfrogging, involving a shift towards the next generation of regulatory tools (Warhurst and Bridge, 1997). These include market-based instruments, which not only provide greater incentives for investment in clean technologies than the command-and-control type, but also allow developing countries to achieve environmental goals at a much lower cost. Next generation instruments mentioned in the literature also include various forms of self- and co-regulation, widely seen as providing a means of harnessing the entrepreneurial and innovative capabilities of the corporate sector, as well as the regulatory functions of civil society and market actors (World Bank, 1992; Panayotou, 1998; Hanks, 2002; Rock, 2002).

2.5. International assistance

Finally, it is often assumed that leapfrogging in developing countries will require assistance from developed economies (WCED, 1987; UN, 1993; *The Economist*, 2002), especially to support concessional financing for clean technologies, of which the high capital costs often discourage adoption, especially by small firms (Dasgupta, 2000; IPCC, 2000). More generally, assistance is required to overcome a lack of information on the availability, cost and performance of competing technologies (Worrell et al., 2001).

3. Critique of existing approaches

Much of the existing literature on leapfrogging sketches the broad characteristics and requirements of available strategies. However, it is argued here that existing approaches suffer from three major shortcomings:

- They have ambiguous objectives;
- They make simplistic assumptions regarding the availability, origin and possibilities of leapfrog technologies; and
- They are based on an incomplete understanding of the requirements of environmentally benign technological change in latecomer economies.

The rest of this section will elaborate on each of these in turn.

3.1. Ambiguous goals

A striking feature of existing approaches to leapfrogging is that, beyond the general goal of reducing the environmental burden of the industrialization path, they have remained surprisingly vague about more specific targets (e.g., see Wallace, 1996; Goldemberg, 1998; UNDP, 1998). Thus, very little has been said about the specific pollutants and/or resources that need to be prioritized, nor indeed the target level at which they must be stabilized.

This ambiguity entails two problems. First, it has obscured the requirements for leapfrogging, both in terms of technology and, perhaps more importantly, public policy. To take one obvious example: a deep leapfrogging strategy that seeks to achieve a GHG-neutral development path will call for the deployment of more radical energy technologies than a shallow one that merely attempts to reduce emissions growth by a few percentage points. Consequently, it will also require greater state intervention, for instance, in the form of fiscal support for the uptake of GHG-efficient technologies.

And second, the inability, or even refusal, to define the actual goals of leapfrogging exposes it to criticism from those who believe that it is little more than an attempt by business, bureaucratic and political elites to define a solution to the growing environmental crisis in developing countries that avoids fundamental shifts in wealth, industrial organization or behaviour (Adams, 2001; Sklair, 2001). This may or may not be true. The important point is that the general lack of clarity that surrounds much of the existing discussion means that the concept runs the risk of being devalued as a useful and practicable policy goal.

3.2. Simplistic assumptions about enabling technologies

A recurrent theme of the existing literature is that leapfrogging requires little more than for producers to deploy modern, commercially available, clean technologies originally innovated for use in developed economies (e.g., see World Bank, 1992; Anderson, 1996; Goldemberg, 1998). To be fair, there can be little doubt that by making use of these technologies, developing countries will be able to follow a less environmentally damaging development path than industrialized economies in the past. Nevertheless, the assumption that existing technologies are, in and by themselves, sufficient to enable leapfrogging in industrializing economies is challenged by three observations.

First, as acknowledged in countless studies that have examined the feasibility of sustainable growth in developed economies, achieving a fundamentally cleaner development path will only be possible with further technological innovation; particularly in the area of radical or discontinuous technologies[4] (Topping et al., 1996; Faucheux et al., 1998; Torrens and Stenzel, 1998; Arentsen et al., 2002; Holliday et al., 2002). This stems from the fact that the majority of today's so-called clean technologies are far from environmentally benign. Many, for example, generate significant quantities of potentially harmful residuals and only a handful lie outside the dominant hydrocarbon technology regime[5] (Allenby, 2000). Moreover, few of these fundamentally cleaner (radical) technologies are currently competitive with more conventional (dirtier) substitutes, suggesting a need for further investment to improve their cost and/or performance characteristics (Heaton and Resosudarmo, 2000).

Second, it is far from clear that environmental technologies transferred from developed economies are always well suited to the requirements of users in developing countries, particularly those in the small-scale sector (WCED, 1987; Rajagopal, 1992). Against this background, a growing number of academics and policy makers have suggested a greater role for indigenous firms which, it is argued, are better placed to develop and manufacture technologies that meet local needs than their foreign counterparts (Dooley and Runci, 1998; Wicklein, 1998; IPCC, 2001; Pachauri, 2002; Wilkins, 2002). Since local firms enjoy proximity to end users, they are better positioned to engage in the close, ongoing and iterative relationships that are now known to play a critical role in the successful innovation and commercialization of locally appropriate designs (Murphy, 2001; Romijn, 2001). Likewise, locally owned firms, particularly firms of low- and medium technology, are often capable of generating products at a fraction of the cost of firms headquartered in developed economies (Bennett and Vaidya, 2002). Consequently, they are ideally placed to meet the requirements of many users who not only lack the capabilities to master sophisticated technologies, but also the financial resources to purchase capital-intensive alternatives from transnational vendors (Dasgupta, 2000).

This, of course, should not be taken to imply that imported technology has no role in the leapfrogging process. On the contrary, in many large-scale industrial applications which require sophisticated, R&D-intensive process controls to achieve high levels of environmental performance, it is likely that the needs of users will often be best served by technologies innovated in developed economies. Nevertheless, the assumption that leapfrogging in developing countries can be wholly underpinned by such technologies is an oversimplification. In fact, it is increasingly recognized that excessive reliance on foreign firms and technologies will not only prove expensive, but may also be inimical to long-term growth and industrial development (Rajagopal, 1992; Rip and Kemp, 1998; Juma et al., 2001). As explained below, this will require developing countries to develop technological capacity of their own through local innovative activity. Therefore, providing a greater role for local firms in the innovation and manufacture of leapfrog technologies will be an important condition for leapfrog strategies that seek to advance both the goals of economic development and environmental protection.

The third and final reason to challenge existing approaches to leapfrogging is that they exclude end-of-pipe (EOP) technologies. In certain situations, EOP technologies may actually prove more cost-effective than cleaner production approaches. For example, where countries have already installed dirty production capacity, EOP retrofits are likely to be considerably cheaper than outright capacity replacement. Similarly, EOP approaches may be favourable where clean technology substitutes are more expensive, especially

[4] Radical or discontinuous technologies are defined as new technologies that fundamentally break with the dominant technological systems and trajectories (Faucheux et al., 1998).

[5] To take one example: gas-fired combined-cycle turbines, commonly cited as a clean alternative to coal-fired plants, generate markedly lower levels of carbon dioxide (CO_2) and sulphur dioxide (SO_2), but they still generate significant quantities of CO_2 and nitrogen oxides (NO_x).

in low-income countries where there is a need for approaches that achieve relatively large, low-cost reductions in discharges (World Bank, 1992). Finally, since many supposedly clean technological processes continue to generate harmful discharges, EOP technologies may be required alongside the clean ones to raise levels of environmental performance.

3.3. *Requirements for leapfrogging are underestimated*

Current approaches often assume that the principal, or even the only, requirement for the innovation and diffusion of leapfrog technologies are strong incentives in the direction of less environmentally damaging production (e.g., see Panayotou, 1998; World Bank, 2000). Yet recent work on technological change in latecomer economies suggests that, although necessary, incentives alone are an insufficient condition to guarantee leapfrogging-type investments (e.g., see Amsden, 1989; Hobday, 1995). Incentives need to be complemented by a range of capabilities which are needed by firms to respond to incentives in the direction of less environmentally damaging production (Rip and Kemp, 1998; Angel et al., 2000; Dasgupta, 2000; IEA, 2001; Murphy, 2001; Worrell et al., 2001; Rock, 2002; Wilkins, 2002). As acknowledged in many existing contributions to the literature, these include financial capabilities[6] which, given the capital-intensity of many clean technologies, are likely to be an important condition for environmental leapfrogging (IPCC, 2001).

However, equally important are so-called technological capabilities, broadly defined as the knowledge, skills and expertise required to manage the process of technological change (Lall, 1992). These are now known to play a crucial role in the identification, assessment and selection of technologies, including environmentally sound ones (IPCC, 2000). They are also required by firms in order to successfully absorb plant[7] and equipment under local conditions, as well as innovate and commercialize indigenous technologies of their own (Lall, 1987; Shin, 1996; Bell and Pavitt, 1997). In fact, a key lesson of the recent literature is that without sufficient capabilities, developing countries are unlikely to be able to make the leap to cleaner production paradigms, with or without a strong incentive regime.

And herein lies the challenge of leapfrogging. With a handful of exceptions, the level of capabilities in developing countries remains low (Felipe, 2000; Juma et al., 2001; Murphy, 2001; Lall and Pietrobelli, 2002). This indicates a need to build technological capabilities in order to support the innovation and diffusion of leapfrog technologies. History, however, suggests that this is neither easy nor straightforward (Bell and Pavitt, 1997). Unlike physical equipment or blueprints, the tacit knowledge, skills and experience that comprise technological capabilities cannot easily be transferred. Rather, they must be learnt — a lengthy, costly and uncertain process that requires not only conscious investment by firms, but also government intervention to support the development of a range of institutions (e.g., technology institutes, universities, etc.) and factor markets (i.e., for labour and capital) that are essential components of well functioning national technology systems (Lall, 2000).

Two critical questions arise here. The first is whether today's developing countries are in a position to accumulate the capabilities required to support the acquisition, mastery and even innovation of leapfrog technologies, especially within short enough timescales to avoid lock-in. A number of more optimistic writers on leapfrogging have given the impression that developing countries are indeed able to acquire the requisite capabilities. Examples quoted in support of this argument include especially the recent success of several newly industrializing economies in East and Southeast Asia in deepening their capability base within a relatively short time span (World Bank, 1993). Optimistic views of the possibilities for leapfrogging have also drawn attention to the enhanced opportunities available today to developing countries from the spectacular rise in foreign direct investment (FDI) over the past two decades. Such opportunities include access to a range of management and organizational capabilities possessed by leading TNCs and transferred to developing countries, either directly, through internal routes (i.e., from parent company to local subsidiaries and affiliates), or indirectly, via transnationals linkages with local suppliers and/or institutions (OECD, 1998; UNCTAD, 1999).

Unfortunately, there are good reasons to believe that optimism with regard to the easy feasibility of leapfrogging may be misplaced. To begin with, it is far from clear that the experience of the first-tier Asian newly industrializing economies can be replicated in developing countries today. For one thing, the development success of the first generation Asian "tigers" was predicated on a number of country-specific characteristics (competent, goal-directed and insulated bureaucracies, etc.) not found in many other parts of Asia, Africa and Latin America (Keefer and Knack, 1997; Felipe, 2000; Jomo, 2001). For another, many of the state interventions (trade protection, subsidies, procurement, etc.) that were used to promote local industrial development in the past are no longer available to developing countries under today's international trade and investment rules (Lall, 2002). Consequently, the scope for local learning may be considerably more circumscribed than suggested by more conventional accounts.

Likewise, the assumption that FDI can be relied upon to build technological capabilities has been questioned. Countering optimistic views of leapfrogging based on expectations of increasing FDI, stands the fact that a significant

[6] Financial capabilities are defined here as the ability to finance the purchase of capital equipment and/or related services, either through retained earnings and/or external borrowings.

[7] Defined here as the ability to effectively operate and maintain technologies, adapt them to local conditions and even improve their performance over time (Bell and Pavitt, 1997).

proportion of the increase in investment flows since the late 1970s has been received by a single country — the People's Republic of China — with much of the rest going to a handful of technologically more dynamic countries in Asia, Latin America and, more recently, Eastern Europe (World Bank, 2002). Moreover, many believe that this imbalance is likely to continue for some time to come, not least because the vast majority of developing countries lack the basic conditions favourable to transnational involvement, including: large domestic markets, an educated workforce, adequate provision of infrastructure and a stable macroeconomic environment[8] (Narula and Dunning, 2000; Booth, 2001; Lall and Pietrobelli, 2002).

Moreover, even for those countries that are successful in attracting substantial FDI, doubts remain over whether it contributes to the deepening of national technological capabilities. Thus, critics point to the fact that internalized modes of technology transfer by TNCs result in less technological learning than externalized ones, involving the purchase and/or licensing of foreign technology by local firms[9] (Pack and Saggi, 1997; Lall and Pietrobelli, 2002). Critics also question whether the vast majority of local firms possess sufficient capabilities to capture spillovers associated with the involvement of foreign TNCs (Felipe, 2000); this skepticism seems justified in view of recent empirical work which has found only limited evidence of positive spillovers in practice (Saggi, 2000; Hanson, 2001).

Proponents of FDI, of course, will claim that the lack of local learning is unimportant. The key factor is that foreign transnationals transfer leapfrog technologies to developing countries and, furthermore, operate them effectively in the local environment. This, however, overlooks the fact that even under the most optimistic scenario, TNCs are only likely to account for a relatively small share of capacity addition in the majority of developing countries. Many markets, especially for low value (commodity) items, will continue to be served by local firms which, lacking sufficient capabilities, are likely to invest in conventional (dirty) technologies as part of capacity addition and/or renewal (Dasgupta, 2000). Similarly, the preoccupation with FDI also ignores the positive links between the accumulation of indigenous capabilities and economic development, which will need to be harnessed if leapfrogging is to achieve win-win outcomes.

A second critical issue is whether, in seeking to build their capabilities, developing economies can avoid becoming locked into environment-intensive technologies and supporting infrastructures. Despite the optimism that surrounds much of the discussion about the leapfrogging possibilities of latecomers, avoiding lock-in is unlikely to prove easy or straightforward. This conclusion stems from the fact that the majority of developing countries continue to base their technology policies on the acquisition, absorption and incremental innovation of available technologies from developed economies, either through FDI, imports of capital goods and/or formal cooperation between firms (Vishwasrao and Bosshardt, 2001). These arrangements have proved successful in developing local capabilities, at least in the first tier of newly industrializing economies. However, reliance on foreign technology has also resulted in capacity being added within the very same technological regime found in developed economies[10] (O'Connor, 1996). As a number of commentators have pointed out, this is not entirely a bad thing: many of these imported technologies are, after all, markedly more efficient and less polluting than the ones that were used in today's industrialized economies during their equivalent stage of development (Rock, 2002). Even so, few of these technologies are capable of meeting the challenge of a radically cleaner development path which, many analysts now agree, will require developing countries to move on to an altogether less environment-intensive technological path.

4. Advancing existing approaches to leapfrogging

The previous section argued that existing approaches to leapfrogging suffer from a number of important shortcomings. Although calling into question the adequacy of policy prescriptions commonly advanced in the literature, it is not suggested here that leapfrogging is an unrealistic or inappropriate development strategy. On the contrary, a number of compelling reasons remain to accelerate the invention, innovation and diffusion of environmentally sound technologies in developing countries, both on economic and environmental grounds (World Bank, 2000; IEA, 2001). The challenge lies in identifying approaches that incorporate both environmental and development priorities, while addressing the limited capabilities for technological upgrading of developing countries. Four suggestions are outlined:

- defining more specific targets of leapfrogging;
- targeting priority sectors for investment;
- supporting the development of leapfrogging capabilities and technologies; and
- promoting cooperative partnerships between key actors.

4.1. *Defining more specific targets of leapfrogging*

An important first step of a viable leapfrogging strategy should be to define the short- and long-term objectives,

[8] This has been compounded in recent decades by the diminishing relative importance of traditional locational factors such as cheap labour and natural resource availability (Lall, 2002).

[9] This is commonly explained by the tendency of TNCs to transfer little more than basic know-how needed to operate and maintain imported equipment (UNCTAD, 1999).

[10] Correspondingly, it has led local firms to develop core capabilities within the same environment-intensive paradigm, limiting the scope for discontinuous change.

both in terms of targets (i.e., the specific types of environmental damage to be avoided/reduced) and depth (i.e., the level of acceptable discharges and/or resource consumption). Doing so will assist public policy makers in the development of supporting policies and programmes. It will also prime businesses about future technological opportunities and constraints, which is important since experience suggests that securing least-cost compliance with environmental goals depends on the existence of clear, long-term targets (Clayton et al., 1999; Burns, 2002).

4.2. *Targeting priority sectors for investment*

Developing economies characteristically lack many of the ingredients needed to initiate and sustain leapfrog-type development strategies (Easterly, 2001). It is therefore suggested that there is a need for more strategic approaches to leapfrogging that target and direct finite private and public resources towards key sectors.

Broadly speaking, sectors to be prioritized for leapfrogging should be selected on the basis of three criteria:

- significant contribution to leapfrogging targets;[11]
- long-term environmental consequences; and
- least cost.

First, leapfrogging should prioritize economic sectors that make a significant contribution to leapfrogging targets, or have the potential to do so.[12] Second, priority needs to be given to sectors where investment is likely to have long-term environmental consequences. This includes industries — such as iron and steel — with long capital-renewal cycles and high levels of technological inseparability. It also includes sectors — exemplified by electricity — characterized by pervasive network effects where there is a significant risk of lock-in to environmentally inferior technological trajectories.

And third, given the shortage of investment capital in many developing countries (Panayotou, 1998), least-cost strategies should be prioritized. In practice, implementing least-cost solutions is likely to require a more flexible and pragmatic approach than suggested by existing policies. Thus, in certain circumstances, it might make economic sense to opt for EOP over clean technologies: for example, where capacity is already in place. There may, however, be grounds for exempting immature and/or unproven technologies from this requirement, especially clean ones that offer potentially significant improvements in environmental performance. Many of these designs have yet to benefit from significant learning investments[13] and, consequently, require support in the short- to medium-term (IEA, 2001).

4.3. *Supporting the development of leapfrogging capabilities and technologies*

Existing approaches to leapfrogging rightly acknowledge the importance of creating a strong incentive regime that encourages end users to invest in more efficient, less polluting technologies. They also identify a range of economic (removal of subsidies, etc.) and environmental instruments well suited to achieving these goals, although there is probably a greater role for command and control tools in certain situations which, contrary to conventional wisdom, have been shown to be surprisingly effective in reducing emissions from large point sources (Rock, 2002). A key argument of the present article, however, is that a strong incentive regime alone may be insufficient, and must be accompanied by public and/or private policy measures.

The practical implications of this will, of course, vary with a country's specific objectives, as well as the level of capabilities amongst firms within target sectors, and indeed, the economy as a whole. In fact, as acknowledged elsewhere, measures to promote technological upgrading are likely to fail if they are not closely tailored to national circumstances (Jomo, 2001). Nevertheless, drawing from recent work on technology transfer for environmental protection (Hecht, 1998; IPCC, 2000; Wilkins, 2002) and technological learning (Lall, 1992; Hobday, 1995; Intarakumnerd et al., 2002), it is possible to identify two broad sets of policies that will be needed to support the leapfrogging process. The first set consists of functional interventions to create a macro-environment favourable to technological learning and innovation. Included here is the provision of national education and training systems, basic infrastructure (power supplies, transportation links, etc.) and networks of technical (e.g., standards agencies) and trade (e.g., export information) institutions that support firms in their efforts to develop capabilities; as well as a range of economic (e.g., monetary stability) and legal policies (e.g., intellectual property rights protection) that combine to make learning investments attractive (Ilori et al., 2002).

The second set of interventions are selective and will be needed to support leapfrogging in those sectors identified as playing a key role in a country's strategy. There is insufficient space here to go into significant detail in this regard. Therefore, only the most important aspects are discussed. The first type of intervention are targeted policies to attract foreign investors with strong capabilities in

[11] This will require additional investments in resource/pollution monitoring and inventories which in many developing countries remain weak and fragmented (World Bank, 2003).

[12] In the case of CO_2, for example, this is likely to include industries such as cement, pulp and paper and petrochemicals where a relatively small number of point sources commonly make-up a significant share of emissions; whereas in the case of particulate matter, it will include more numerous and dispersed sources, such as motor vehicles and household stoves.

[13] Defined as '. . . expenditures that need to be made to bring a new technology to the point of commercial acceptance' (IEA, 2001: 6).

leapfrog technologies; and particularly those in high technology, R&D intensive applications, etc., where local firms lack the resources, skills and experience to generate commercially viable substitutes. With a view to accelerating the development of capabilities in these areas, FDI policies should additionally be accompanied by measures to encourage positive technology spillovers from TNCs through, for example, local procurement schemes.

Recognizing the importance of local innovative effort, selective support should also be provided to indigenous firms engaged in the development and manufacture of leapfrog technologies. Indeed, experience suggests that, even for countries at relatively low levels of development, there is considerable scope for technological learning by producers involved in the production of medium-technology equipment (Bennett and Vaidya, 2002). Such assistance should fulfill three key functions. First, it should attempt to provide firms with the knowledge and information needed to initiate and pursue the innovation and commercialization of technologies on an ongoing basis (Romijn, 2001). Relevant examples in this regard include specialist technical training, facilitating the use of external consultants and assistance in preparing business plans.

Second, assistance should seek to overcome coordination failures by promoting linkages between producers and other actors within a technology system. Most obviously, these include customers, universities and research technology organizations, all of which have been shown to be strongly supportive of intensive technological learning. Yet, there is also a need to develop strong cooperative linkages between firms in the same or related industries, and particularly ones with capabilities in clean technologies. This means cooperative research consortia between local firms, as well as collaborative arrangements — ranging from joint ventures to licensing — between local and foreign firms (Intarakumnerd et al., 2002).

And third, there is a role for financial incentives in promoting the development of new leapfrog technologies and, equally important, the commercialization of existing ones that have yet to achieve substantial market share (Topping et al., 1996; Heaton and Resosudarmo, 2000; Wilkins, 2002). This can be achieved via a number of different routes: incentive payments, tax credits, the provision of public venture capital, and so on. The important point is that, whatever means are chosen, experience dictates that incentives need to be carefully targeted if they are to achieve their objectives. This implies, for example, restricting their use to applications where user requirements are poorly served by existing vendors and ensuring that financial assistance imposes strong commercial discipline on participants (Rip and Kemp, 1998; Forsyth, 1999; Adams, 2001; Margolis and Kammen, 2002).

Finally, there is a need for selective intervention to support the uptake of leapfrog technologies by local users. In practice, this will involve many of the same policies used to build innovative capabilities amongst equipment suppliers: the provision of information, training and consultancy support in the identification, selection, acquisition and absorption of leapfrog technologies; as well as innovative financing mechanisms that enable firms, and especially small ones, to purchase more sophisticated technologies (IPCC, 2000). It also means supporting those activities known to promote learning investments such as linking firms to new customers, assisting firms with specific operational problems, selective subsidies, and so forth (Romijn, 2001).

Of course, none of these interventions will be possible without a network of competent governmental (e.g., export promotion agencies, etc.) and non-governmental (e.g., technology intermediaries) organizations committed to advancing the goals of a country's leapfrogging strategy. Unfortunately, just as technological capabilities remain weak in many developing countries, so do many of the formal institutions required to support their accumulation. Therefore, an important complementary task for policy makers will be to strengthen the organizational infrastructure (Dooley and Runci, 1998). This will be especially important to the success of more radical leapfrogging strategies that will require the establishment of strong national technological systems capable of supporting the innovation and diffusion of leapfrog technologies throughout the economy.

4.4. Promoting cooperative partnerships between key actors

From the above, it should be clear that achieving the goals of leapfrogging will require the participation of a large number of private and public actors: firms, governments from developed and developing countries, multilateral development agencies, and so forth. Moreover, as suggested by recent work on national innovation systems[14] (e.g., see Nelson, 2000), it will require these organizations to interact and cooperate as part of broader networks (Juma et al., 2001). Accordingly, the present article suggests that goal-oriented partnerships between various actors in a technology system, both at the national, regional and international levels, is a critical unifying element of any leapfrogging strategy.

Beginning with the former, partnerships are needed between industry and other parts of the national science and technology infrastructure (universities, research technology organizations, standards organizations, etc.) which, as noted above, play a key supporting role in technological learning and innovation. No less important, leapfrogging will require cooperative partnerships between government and

[14] National innovation systems (NIS) are defined by Intarakumnerd et al. (2002: 1446) as '. . . the interactive system of existing institutions, private and public firms (either large or small), universities and government agencies, aiming at the production of science and technology (S&T) within national borders.'

industry, both in the setting, as well as the planning and implementation of environmental policies and targets. Experience suggests that by involving firms in these decisions, policy makers are likely to reduce opposition to environmental policies and, furthermore, evoke more innovative corporate responses that reduce overall compliance costs. At the same time, more cooperative approaches will enable governments to reorient their role from one of simply enforcing standards to facilitating and promoting more environmentally benign patterns of behaviour and investment at the level of the firm (Corral, 2002). For similar reasons, it will also be necessary to secure partnerships with civil society groups, which are likely to be important allies in the development and implementation of leapfrogging strategies (Hecht, 1998).

Partnerships will additionally need to be forged at the regional scale (Topping et al., 1996). Indeed, given the increasing regionalization of trade, investment and technology generation (Archibugi and Michie, 1997), there are likely to be advantages for individual countries by organizing leapfrogging strategies at this level. Recognizing these, a growing number of analysts point to the importance of regional partnerships between universities, research technology organizations and private firms in the research, development and commercialization of leapfrog technologies, including those well suited to the needs of firms in developing countries (Rock, 2002). These will allow participants to benefit, not only from economies of scale and scope, but also improved design and manufacturing capabilities (Wilkins, 2002). Therefore, such partnerships are likely to become a major part of broader strategies to develop competitive advantages in clean technologies.

Leapfrogging, and especially more radical strategies, will also need to be underpinned by regional partnerships in environmental policy. This is because stringent environmental policies — such as full-cost pricing of pollutant discharges — are likely to place local firms at a competitive disadvantage to their close rivals (Holliday et al., 2002). Consequently, if national governments are to avoid protracted opposition from industry, they will need to cooperate in the establishment of common regulatory standards.

Finally, leapfrogging will require partnerships at the international level. Foremost amongst these are partnerships between bilateral and multilateral donor agencies and governments in developing countries. These should go beyond the transfer of physical technology to support the development of a macro-environment favourable to technological learning through, for example, joint institutional capacity-building programmes. More selectively, partnerships need to be established at the project level to supply necessary financial and technical assistance, although experience suggests that these should be needs-driven by the recipient rather than supply-driven by the donor if they are to achieve successful and sustained outcomes (IEA, 2001; Fukuda-Parr et al., 2002).

Long-term support should also be given to promoting technological cooperation between actors in developing and developed economies involved in the research, development and manufacture of leapfrog technologies (World Bank, 2002). These might include, for example, collaborative R&D programmes between universities and RTOs, joint ventures between local and overseas firms with proven track records in clean technologies, and public-private partnerships between bilateral donors and vendors in the commercialization of existing technologies. These teamwork arrangements will be a key vehicle for the development of clean production capabilities, thereby helping developing countries to avoid the problems of technological learning based on environment-intensive technologies.

5. Conclusions

It is perhaps not surprising that the idea of latecomers being able to leapfrog straight to a cleaner production and consumption structure has met with a cynical response from certain quarters. After all, there is little evidence of this happening in practice, with many developing countries industrializing in the very same environment-intensive technological paradigm that has proved so destructive in developed countries (Perkins, 2001). Yet this should not divert attention from the fact that leapfrogging remains a worthwhile policy goal. Besides, it offers a promising strategy to advance and, moreover, reconcile two of the major challenges facing today's industrializing economies: economic development and environmental protection (Hecht, 1998; Easterly, 2001).

As the present article has argued, however, leapfrogging is likely to be considerably more difficult and challenging than current approaches generally suggest, especially where the objective is to achieve a fundamentally cleaner development pathway. Thus, in addition to implementing a strong incentive regime, developing countries will be required to build the capabilities needed to select, absorb and innovate technologies that lie outside the conventional (environment-intensive) technology paradigm. In fact, the viability of more radical leapfrogging strategies will ultimately depend on the ability of developing countries to become autonomous agents in the development of next-generation leapfrog technologies (Juma et al., 2001), pointing to a need for strong national systems of innovation. And because history suggests that accumulating the capabilities needed to support these activities is a lengthy process, leapfrogging must be seen as a long-term process, requiring ongoing policy support and guidance.

Above all, leapfrogging will require far-reaching political will. National governments will need political will if they are to challenge entrenched domestic and foreign interests whose preferences lie, to a greater or lesser extent, along a business-as-usual path. Political will is also required of developed economies if they are to provide the long-term financial and technological assistance that will be needed to support the leapfrogging process, particularly in its more radical form. This realization is, of course, hardly new. It has been a central theme of environmental debates for over three decades. Yet, it is one that all too easily gets lost in a discussion dominated by technical questions of how, rather than the more pertinent question of who.

Acknowledgement

The research for this article was supported by the UK Economic and Social Research Council (ESRC) under Postdoctoral Fellowship Ref. T026271127.

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