Chapter 4

Making green sources of growth more inclusive

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A Green Growth Strategy pursues economic growth combined with significant improvements in environmental quality and sustainable resource use. Such a policy requires a shift in production and consumption, which is potentially costly for major production sectors, certain types of households or entire economies. Technological change can reduce the cost but the extent of cost reductions depends on the nature of knowledge spillovers and technology policies. With appropriate burden-sharing rules and complementary policies, low-income groups and countries can gain, thus making green growth inclusive. We discuss several aspects of the mechanisms behind inclusive green growth and the policies that could support it.

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Introduction

In 2010, Ministers of 34 countries committed to develop a Green Growth Strategy, which aims at pursuing economic growth while preventing environmental degradation, biodiversity losses and unsustainable resource use (OECD 2010, p. 9). The OECD's Green Growth Strategy focuses on policy options for making a cleaner, low-carbon economy compatible with growth by looking at ways to spur eco-innovation and by addressing other key issues related to a transition to a greener economy, such as jobs and skills, investment, taxation, and trade and development - in addition to correcting prices to reflect externalities. The Green Growth Strategy is intended to be a flexible policy framework that can be deployed in a wide variety of countries in various stages of development.

Such a strategy works better if it is internationally adopted on a large scale and nationally supported by and targeted to the main sectors and socio-economic groups. In other words, the strategy requires inclusiveness. First, this is because many environmental problems and resource scarcities are global phenomena. Whether policy initiatives by some countries are effective depends on the policy response elsewhere. Second, while green policies are more affordable for the rich, the cost could fall disproportionately on the poor. If green policies in the rich parts of the world result in lower growth and fewer development opportunities in the poor parts of the world, the policy can hardly be called sustainable. Therefore the overlap between green policies and "inclusive growth policies" has to be studied.

This paper discusses some of the possible conflicts and complementarities between green policies and inclusive growth, as well as the implications for policy making. I focus mainly on the interaction between technology policy and environmental policy, as well as on the question of how these policies must be different across rich and poor countries in order to be effective.

Technology plays a large role in the debate about green growth. With the technologies that are currently available, it is hard to maintain high growth rates and reduce harmful emissions from energy use for the simple reason that a large part of the global economy is fuelled by fossil fuels. Large numbers of people living in developing countries depend on renewable natural resources (water and land) that are increasingly over-exploited due to population pressure and economic growth, while others have only recently made the transition to modern energy systems and may therefore become locked into the same fossil fuel dependence as richer countries. Switching to new non-fossil energy sources is costly in most sectors in the world. Producing more at reasonable cost while using fewer natural resources and less pollution-generating energy sources therefore requires new technologies that are cleaner or more efficient in the use of conventional inputs. The key question is where these new technologies should come from. Will they be developed as a by-product of growth and development? Will resource scarcity and pollution policies induce the technical change or are specific technology policies needed? In the international context, the question is will green technologies diffuse to parts of the world where different growth and development patterns prevail and where such policies are not implemented.

The structure of the paper is as follows: first I shall discuss the objectives of an inclusive green growth strategy; then I shall argue that three types of changes are necessary for such a strategy to succeed; finally I shall discuss the policies that can bring about these changes.

Green growth - feasible and desirable?

The OECD's Green Growth Strategy is motivated by the desire to build a sustainable economy, especially in the wake of the financial crisis of 2008, which has made a return to robust growth and the avoidance of collapse more desirable than ever before. And so you might ask: how could a polluting resource-depleting economy ever be compatible with these goals? Well, green growth seems to be the only long-run answer to the financial crisis.

It is nevertheless easy to be sceptical about the idea of green growth. Some might claim it is an oxymoron. The degradation of environmental quality and natural resources, as well as the rise of atmospheric greenhouse gases seem to have been a side-effect of economic growth, and therefore it is often said that only by stopping the unprecedented growth in resource use and emissions can we stop environmental problems. To stop environmental degradation, economic growth does not need to be stopped; however, it does need to be de-linked from growth in material input flows through the introduction of new energy sources and new technologies that are more resource-efficient. The extent to which this is possible (in the short run and in the long run) is not yet clear. However, it seems less productive to speculate on the strength of the trade-offs between growth and green, than to try to find policies that combine growth and greening of the economy.

Few things can be said with certainty. Over history, growth has been remarkably robust, and environmental and resource-related problems have been overcome, although not without major crises and transitions. Over the long term, growth typically takes the form of an ever-growing population that can be sustained. Although per capita average income remains almost stagnant, aggregate production from the earth's finite resources rises - not declines - as a rule. It is only over the past few decades that population pressure and growth in material input usage have both reached historically unprecedented levels. In fact, after centuries of slow population growth and glacially slow increases in per capita income, it is only in the last few decades that the world economy has combined per capita income growth for a majority of people with population growth in virtually all regions (of course, the very richest countries are the exception here because of population ageing). Due to the green revolution in agriculture, growth has been land-saving at a pace that is faster than ever before in history. Per person, less land is needed to produce food. However, population levels have increased fast enough to still raise aggregate land demand. Certainly, growth has been energy-consuming in the sense that it has increased per capita energy use. GDP has grown faster than energy use, which indicates a relative de-linking of GDP and energy. If anything, from the perspective of the physical resource constraints in the global economy and from an historical perspective, growth (of both population and per capita production) seems to be exceptionally fast - maybe faster than is compatible with sustainability. In this case, green growth would mean slower growth; inclusive growth would mean mainly redistributive growth.

At the same time, technological change has been exceptionally fast over the past decades. Recent history has shown that technology should not be considered as something that slowly develops in a way that is disconnected from society and the economy; rather it offers great potential for solving problems. Technology develops differently under different economic conditions and responds to economic policies: it is endogenous rather than exogenous. However, the implications for sustainability are not clear as technology can be devastating for the environment (*i.e.* resource-consuming) or friendly to it (*i.e.* when replacing scarce resources). Hence, what matters is the direction of technical change: are there sufficient incentives to develop the type of technologies that we desire in the global economy, that contribute towards greening the economy and making growth more inclusive? How can these incentives be affected by policies? Are “market-based” policies, such as tax incentives, sufficient or is direct regulation more (cost-)effective?

Before moving to policies, we should be a bit more explicit about the goals that we want to pursue. In particular, we need to ask if it is growth or something more encompassing that we should aim at? The OECD (2010) interim report outlines a broad range of policy goals. Not surprisingly, the Green Growth Strategy prioritises “sustainable development”. The latter term, which became a key policy target after the Brundtland report (WCED, 1987), is defined most commonly as meeting the needs of the present without compromising the ability of future generations to meet their own needs. The decision to focus on growth rather than development should be understood in the light of the practical applicability and political viability of the strategy.

Policy is likely to be most successful in areas where "growth" and "sustainability" are complementary.

On the one hand, equating growth and development seems to run against the message from the Sarkozy report (Stiglitz *et al.*, 2009), which attracted so much attention by discussing the fundamental difference between economic production (*cf.* the level and growth of GDP) and well being (*cf.* sustainable development). On the other hand, sustainable development without growth has drawn criticism ever since the term "sustainable development" became a part of common speech. In particular, one specific (narrow) interpretation of sustainability is maximising the well being of the generation that is worst off, which prevents growth by construction. Development with growth is less specific and more palatable, but only if - in accordance with the recommendations from the Sarkozy report - the metric of growth encompasses things that we care about: useful consumption goods, public goods, leisure time and so on. GDP is not such a metric but there are ways to construct "green GDP" figures. Part of the development of the Green Growth Strategy therefore requires that we make the use of these new or expanded metrics more common in decision making.

It is not only the "growth component" that needs further qualification as the label "green" also has many meanings: pollution abatement, resource conservation, even equity and social objectives. A choice of priorities has to be made here as well. Currently climate change attracts most attention but it is still not clear at all how much policy attention and effort should be devoted to it (*cf.* The Copenhagen Consensus reports). More traditional environmental problems concern air pollution, water scarcity, land erosion, loss of biodiversity and vulnerability to natural disasters. It is hard to quantify how the size of these problems compares with the relatively recently recognised problem of climate change and therefore which prioritisation this implies. Nevertheless, both old and new environmental problems have to be addressed in the policy portfolio. In the short term, more people, especially the poor, will suffer from land and ecosystem degradation or indoor air pollution than from climate change, but the future burden of the latter might have a big impact on the poor if no immediate action is taken. Furthermore, traditional problems and climate change are interacting: reducing CO_2 emissions yields co-benefits in the form of less air pollution and positive health effects, and this can be significant for the poor in the short term.

How big is the climate change impact relative to other environmental problems? Stern (2007) labels climate change as the biggest market failure currently before us. Yet estimates of the mean cost of global warming can be called small, with a "consensus" of around 2% of GDP for a three degree Celsius warming (see Tol, 2010, for a concise overview of damage and abatement costs). This number amounts to one or two years of lost growth in the world economy. Of course, this number is an average in many respects and therefore not very relevant (and it is only partly a "greened" GDP measure). It is an average over time, over regions and over possible scenarios. What matters in the end is the relative cost at which these climate change effects can be avoided. The average cost is lower than the average damage, which means that based on a cost-benefit analysis, climate change action seems justified. However, the cost-benefit analysis tends to become less favourable very quickly if less than perfect policies are implemented to address the problem. Moreover, it is questionable if conventional cost-benefit analysis can be applied to a problem with the pervasiveness and timescale of climate change (Van den Bergh, 2004) and in the presence of small probabilities on big-impact events (Weitzman, 2009).

In this area one needs to be visionary; precautionary action should prevail over inertia as long as there are no unambiguous signs that the policy is a waste of money. Moreover, climate change may affect the world economy in a disastrous way through low-probability, high-cost events (*e.g.* permafrost melting or a shutdown of the thermohaline circulation). Climate change mitigation policies should perhaps be seen as insurance policies in the first place. Although global warming seems to be partly irreversible already, the cost of reducing climate change is relatively low worldwide as well, justifying action that is moderate in terms of loss of GDP.

With so many uncertainties remaining, an important line of action must focus on reducing the uncertainty about possible outcomes, and possible costs and benefits of climate policy. Since it seems unlikely that we can quickly reduce uncertainty about the physics behind climate change, the best strategy seems to be reducing the uncertainty about the cost of several possible solutions, in particular through research into new energy sources and less conventional measures like carbon capture and geo-engineering. Ideally this technical research will yield a bigger menu of "no-regret" options (*i.e.* solutions that will have benefits even if the climate problem is of a different nature than anticipated).

A large part of the controversy centres around the position of developing countries in the climate change debate. Average statistics that summarise the damage of climate change hide the factors that seem to work against the fate of the poorest countries. Relatively speaking, developing countries in already-warm regions suffer most from climate change: their incomes will be affected to a larger degree, and yet due to their "low" weight in total world income, their plight does not show up in the average figure. Furthermore, uncertainty of cost estimates is bigger for developing countries than for developed countries. Dell *et al.* (2008) find econometric evidence for a permanent slowdown of the growth rate in less-developed countries (LDCs) of 0.6 percentage points, which easily amounts to a decade of lost growth (in terms of consumption equivalents). The cost of mitigating climate change might easily become unacceptably high for these countries as well, given the large gap between sustainable fossil energy use and the level of energy use that brought industrialised countries to their current welfare levels.

How important is the North-South divide? The North caused the problem, and wants to get rid of it. Moreover, if any region has the means, knowledge, and institutions to cope with climate change, it is the North. The South could help the North, but only if it is fully compensated by the North. At least in the coming decade when emerging countries will continue their relatively fast pace of economic growth, they may be more willing to join climate change agreements in the future, maybe even according to a pre-set participation time line (*cf.* Frankel, 2009). For developing countries, a markedly different strategy may be needed to that for richer countries. *First*, "grow now - abate later" sounds irresponsible towards future generations, but only if we mean the future generations of rich countries: future generations in the South will be helped by growth, and current emissions in most of the South are still too small to be of a direct concern, compared with the emissions of the North. *Second*, adaptation to climate change seems inevitable. Since individuals do not always have the means or the knowledge to make the long-term investments that are needed for adaptation, due to several market imperfections, there is an "adaptation-deficit" that has to be addressed. However, the long-term policy might be different and might call for both much more and early attention to green policies: if being green is the norm in the future, a country should build its green future now and avoid locking in old technologies.

What changes are required for green growth and for whom are they costly?

Three things are required for growth without deteriorating the environment: substitution, technical change and transformation.

First, through substitution, economic activity can shift away from dirty resource-intensive activities. On the input side, polluting inputs are replaced by less harmful inputs; on the output side, consumption shifts to less-polluting consumption goods. These shifts require a sufficiently high and possibly rising relative price of resource inputs and polluting inputs, possibly through taxes. Low-emission energy replaces polluting sources of energy, waste is reduced and cities become more compact.

One important question is the cost of this substitution. Environmental regulation makes green sectors emerge at the cost of polluting sectors. The environmental gains may be less visible and accrue to a diffuse group, while the old sectors lose employment and profits. Standard economic reasoning indicates that the loss from the declining sectors is not fully offset by the gains in the new sectors: if this were the case, the shift would have occurred even in the absence of environmental regulation. In contrast, according to the so-called Porter hypothesis, firms could gain from the policy. Negative costs arise if firms are initially operating an inefficient process: the environmental regulation increases attention to inefficiencies and improves profitability, even competitiveness. What is somehow puzzling in this reasoning is why firms need environmental regulation to become aware of their inefficiencies. Despite anecdotal evidence in favour of the Porter hypothesis, empirically the mechanism is not very robust as there is little evidence of systematic gains from environmental regulation on firms (Brännlund and Lundgren, 2009).

A similar mechanism is documented for improvements in energy efficiency. Households and firms are often not aware of the cost-saving potential of energy-efficient devices, such as light bulbs or fuel-efficient cars. They appear to apply an irrationally high discount rate, weighing the up-front investment costs very heavily against the long-term returns; or similarly, applying a very short pay-back period. As a result, they fail to pick the low-hanging fruit. However, awareness of energy-efficiency improvements can change very quickly, possibly guided by energy price spikes, market dynamics or policy actions. Low-hanging fruit is therefore quickly harvested and not many negative-cost options to environmental policy persist.

Hence, environmental policy is costly, but of course only in a narrow sense. The cost should be seen as the investment cost for improvements in the environment. Unless environmental policy is designed to be overly strict or implemented with an inefficient instrument, the benefits exceed the cost so that the overall gain is positive. What really matters is the closeness between those who receive the benefits and those who pay for the cost. In the Porter hypothesis and the low-hanging fruit discussion, the two groups coincide and only the net benefits matter for decisions. However, such a situation is rare. After all, environmental problems reflect externalities, with one party inflicting damage on another party without this damage being reflected in market prices. Then again, environmental problems differ greatly depending on the distance between the two parties involved.

If we think of local pollution in a small geographical area with homogeneous economic agents, for example, a village that depends on the proceeds from land that is threatened by erosion and overharvesting, environmental policy is costly for all group members, but also beneficial for all group members. No conflict needs to arise if coordination failures can be solved. The work by Elinor Ostrom shows how local communities in certain circumstances have indeed solved coordination problems. The other extreme is the example of climate change, in which those who pay and those who benefit are far apart, both in a geographical sense and over time. Coordination is definitely more challenging here, and the dynamic and international aspects of environmental policy are much more demanding.

Environmental policy also becomes intertwined with income distribution and inclusiveness. In a general case involving dispersed winners and losers from environmental policy, one could design a policy package of various measures in such a way that costs and benefits are, in the end, evenly distributed, or that the poorest groups bear the smallest costs and experience growth in income or a reduction in poverty.

Second, innovation can make substitution towards environmentally friendly activities cheaper. Innovation takes time and requires investment since new technologies need to be developed. The fruits can be reaped later. However, not all innovation makes it easier to reduce pollution. For example, by the "rebound effect", improvements in energy efficiency make energy-using appliances effectively cheaper to operate and therefore may increase their use, thus increasing the demand on energy. Other examples come from cost reduction of energy-intensive goods, for example, progress in the automobile industry or ICT production. Below we will return to the question of what stimulates "green" innovation.

The cost of innovation is hard to predict as it relies on how useful the new technologies will be in the future. Furthermore, part of the costs and benefits are hidden due to the presence of spillovers (on which more below). What matters in the context of green growth is how costly is the redirection of innovation into a sustainable path, compared with the business-as-usual scenario without redirection, and for whom is it costly? Of course, the same caveat applies as outlined above: the (upfront) cost of changing to green innovation is to be matched by (future) gains, and some sectors will lose for other sectors to gain. New jobs opportunities will be created in energy-efficient sectors that employ the new technologies; however, it will be at the cost of old sectors.

Third, transformation - defined as a drastic change in practice - is needed for green growth. In particular, new General Purpose Technologies (GPTs) need to be developed that relate to energy supply and materials. GPTs can potentially be applied in a wide variety of sectors in the (world) economy; they can be further improved over time and supplemented by complementary innovations. The switch from an economy based on fossil fuels to one based on renewable energy is such a major change that it is likely to have pervasive effects throughout the economy. A transformation may also be difficult and costly because the changes that need to occur across different sectors have to be coordinated. The economy is currently locked into a certain GPT and its associated pollution, mainly because past investments have been made in the old GPT. This puts the old GPT at an advantage relative to a new GPT because the latter's infrastructure has to be first built to replace the old. However, new technologies may actually be introduced quickly because of this pervasiveness. The large potential market of a GPT based on renewable energy creates increasing returns to scale, which implies that a small cost reduction for the GPT will make a large market take interest in it. Instead of a slow diffusion and gradual learning, a sudden change (or tipping point) may be the outcome.

While it is hard to predict whether gradual change and learning curves are more relevant and realistic than big transformations and tipping points, we can be sure that both pathways require a combination of innovation and substitution. Hence in the rest of the paper I will concentrate on the latter two mechanisms behind green growth.

Growth driven by environmentally friendly technological change: a framework for understanding green growth and associated externalities

To identify where policy is needed, it helps to identify the main interactions between growth and resource use. I shall focus on the two most direct sources of interactions and associated externalities: environmental externalities and knowledge spillovers.

Long-term growth is driven by input growth and technical change. Inputs not only include labour and capital but also resource inputs and polluting inputs, thus bringing the environmental aspects into the picture. Technological change can enhance or reduce the demand for resources and polluting inputs, thus opening up the possibility of "green growth", *i.e.* growth without deteriorating the environment. The main question is how does the current availability and regulation of inputs, as well as deployment of technologies, affect future inputs and future technology. Technological change responds to profit incentives and builds on previously developed knowledge, and it is this dynamic interaction that should create green growth.

Growth in capital and growth in labour services are the proximate sources of growth; however, improvements in technology that enhance the productivity of inputs are at least as important. The total of small and large process and product innovations over time raises the value of aggregate production. Behind the aggregate growth pattern is a complex pattern of sectoral developments. New products or even sectors replace old ones, certain sectors grow faster than others and technological change may be more important in some sectors than others. The uneven impact of technological change across products and sectors can be called biased technical change. One possibility is that technological change will occur mainly in skill-intensive sectors, causing demand to shift to these sectors, and resulting in an increase in the wages of skilled workers (*e.g.* Acemoglu, 2002). Similarly, technological change could occur mainly in resource-intensive or polluting sectors, with the result that pollution increases. This type of resource-using (or pollution-using) technological change is not an exception. In fact, the rise of fossil fuels as a main source of energy is an expression of this. Empirical estimates show that various sectors in various time periods have experienced energy-using technical change, while in others energy-saving technical change has been dominant (Jorgenson and Fraumendi, 1981; Sue Wing, 2008).

To understand green growth, we need to know whether growth can be driven by resource-saving or pollution-saving technical change and, if so, how this type of technical change comes about. In particular, we need to know how various types of technological change are related to resource use and environmental policies.

Due to negative externalities, resource use is inefficient and pollution is excessive in the absence of regulation. Environmental policy, *i.e.* reductions in emissions and resource use, reduces input use in the economy. Lower input use means lower output, although the loss in output can be limited if factor substitution is easy. Unfortunately, elasticities of substitution between energy inputs and other inputs are low (Van der Werf, 2008), so that energy reductions are typically costly. Induced technical change may reduce the cost of environmental policy and higher energy prices may spur innovation in energy-efficient applications, as we will discuss below. However, other types of innovation may be crowded out by environmental policy: if the resource-base of the economy is smaller because less energy can be used, then the market for innovation shrinks. If externalities are more or less equally important in both types of innovation, the crowding-out effect dominates and the aggregate rate of innovation falls in response to environmental policy (Smulders and De Nooij, 2003). In this case, "greener" means slower growth. "Greener" goes together with faster growth only if the positive externalities are relatively large in the "green" sectors to which innovation shifts in response to environmental policy (Gerlagh, 2008). Crucial for policy evaluation is therefore to know how large the relative spillovers are in green sectors versus brown sectors.

Technical change is the result of deliberate efforts by innovators, including firms, which spend resources on improving technologies. Hence, technical change is endogenous. The direction of technological change is to some degree a matter of choice: firms choose what part of their production process they want to improve and in what type of markets they would like to introduce new products. As a result, R&D might be directed towards certain types of innovations. Whether technological change is pollution-using or pollution-saving depends on the profits that entrepreneurs expect to reap. High energy prices make energy-efficient devices more attractive to consumers and expand the market for them, and this may in turn attract innovation. This phenomenon goes under the label of Induced Technical Change. Newell *et al.* (1999) found that the energy-efficiency of air-conditioners improved faster in times of high energy prices, although a substantial part of the improvements were autonomous. Similarly, Popp (2001) finds that two-thirds of the change in energy consumption with respect to a price change is due to simple, price-induced factor substitution, while the remaining third results from induced innovation.

Not only does the (expected) market size matter for specific innovations, like energy-efficiency improvements, but also the cost and technological opportunity for specific innovations relative to innovations in other directions. This means that "green innovation" may be more difficult and costly since firms lack the required background or "knowledge base".

The knowledge base from which R&D builds can be seen as a repository of ideas that have previously been developed, usually by a large group of firms, engineers and scientists. Each innovation contributes to this "spillover pool" and makes subsequent innovation easier. In general, the knowledge spillovers affect private net returns to innovation and cause them to be different from the social net returns. The concept of knowledge spillovers as the main externality in R&D is well developed in the literature on innovation (Griliches, 1979) and growth (Romer, 1990). When thinking about the direction of technological change, it is important to know more about the exact nature of these spillovers. Are the spillovers within-sector or across-sector? Are they mainly national or international?

With spillovers mainly restricted to certain types of innovations, coordination failures can easily arise. If energy-efficiency improvement requires specific knowledge that is not used in other types of R&D, and this specific knowledge is lacking, starting to develop efficiency improvements is likely to be difficult. If all firms avoid innovation in this direction, the knowledge base never becomes established. Hence, the combination of path dependency and coordination failures may prevent green innovation taking off. Path dependency arises because current research and innovation typically builds on previous research and innovation. Coordination failure and free riding arise because firms learn from each other: there are inter-firm knowledge spillovers.

However, if knowledge spillovers cross technology fields, energy-efficiency improvements might build on general principles that have been developed elsewhere and coordination failures are less likely.

Green growth requires boosting "eco-efficiency" and "energy efficiency", the development of emission-free technologies and the introduction of a cradle-to-cradle principle in production chains. Can these innovations be developed from knowledge about other types of innovations or is highly specific knowledge required? This is a question that cannot be answered yet. Research on R&D spillovers has focused mainly on geographical spillovers and only in a limited way on inter-industry spillovers (Wolff, 2011, for a recent overview of results). The main finding of the patent-based literature is that spillovers are international in scope but are also diminishing with geographical distance.

Jaffe (1986) is the seminal paper on inter-firm spillovers. He first constructs a measure of technological similarity of firms and then constructs firm-specific knowledge spillover pools by adding up the R&D by other firms, giving firms that are technologically more similar a higher weight. Firm-specific knowledge spillover pools turn out to be a significant positive determinant of R&D performance. This provides the evidence for inter-firm spillovers: firms learn from other firms, and they learn mainly from other firms that are active in similar technology fields.

Unfortunately, the implications for "green R&D spillovers" are not immediately clear from Jaffe's evidence. The basis for the spillover weights is the patent classification system, which is technology-based rather than product-based. There is no direct connection as to how the technology classes that are identified match the technologies that are important for green R&D.

Popp (2002) looks specifically at knowledge spillovers related to green innovations. Using patent citation data, he finds that innovation directed at energy improvements builds on the total stock of knowledge embodied in the (quality-adjusted) stock of patents for energy efficiency improvements. However, he also finds that there are diminishing returns associated with this knowledge stock. This finding implies that start-up costs for eco-innovation reduce over time as more specific knowledge is accumulated and - due to diminishing returns - stabilise at a lower level.

Nevertheless, what remains untested is whether breakthroughs in other technology fields, *i.e.* outside energy efficiency improvement, could also significantly reduce innovation costs in energy efficiency. De Serres *et al.* (2010) notice that this hypothesis might be relevant when they write:

> *"Some of the fundamental breakthroughs in energy technologies, such as the use of smart grids and the growing penetration of ICT, come from very different areas and sectors than energy. Hence, spending on the development of more generic technologies, such as materials technologies, nanotechnologies and ICT, may be even more important than focusing too narrowly on energy or environmental R&D."*

Even strong spillovers from "dirty" to "clean" industries may be relevant. One example comes from the oil industry where pipe technologies reduce extraction and distribution costs for fossil fuels. This means that improvement in pipe technologies results in "dirty" (resource-using) technical change. One important clean technology option would be carbon capture and storage (CCS). Improvements in CCS would be resource-saving (since they reduce atmospheric CO2). However, CCS requires improved pipe technology, which can be learned from the oil industry.

Green growth policies: technology policy versus environmental policy

There are two main externalities that call for policies: the pollution (or green) externality and the R&D (or technology) externality. The green externality is the fact that a clean environment has no price and is over-exploited. As a result, emissions are too high and call for environmental policies. Spillovers in R&D imply insufficient spending on innovation and call for technology policies.

First-best policies would get the prices of R&D and emissions right. R&D subsidies and emission taxes or markets for emissions would do the trick. Although the idea is simple and intuitive, the translation of this policy prescription to the real world situation is not straightforward. The main problem arises with the possible interaction between the two types of instruments. Are specific subsidies for green innovation needed? Are emission taxes to be differentiated according to opportunities for green innovation? In a second-best setting, should we put more emphasis on technology policy or on environmental policy?

Let us first consider the case in which technology policy is not available, but various other policy instruments are available and already applied. The pre-existing tax structure can be inefficient with respect to environmental and innovation goals. In particular, fossil fuel energy is subsidised and energy-intensive sectors are exempted from certain taxes. Removing environmentally harmful subsidies helps the environment, helps the government budget and frees up revenue for growth-promoting and efficiency-enhancing policies. The gains from tax reform can be large (*e.g.* OECD, 1999; Van Beers and Van den Bergh, 2009). General principles of tax reform are that efficiency gains are likely to materialise if: (i) environmentally harmful activities are taxed, instead of environmentally friendly activities being subsidised; and (ii) market-based instruments are used that generate revenues that can be employed ("recycled") to reduce other, distortionary taxes, such as labour taxes (Bovenberg and Goulder, 2002). The tax reform should also consider removing trade barriers and barriers to foreign direct investment (FDI) since they may be major barriers for technology diffusion.

Let us now turn to a situation in which many policy instruments are available, in particular both environmental taxes and technology subsidies. We may now ask if these two instruments are interdependent in an optimal setting. The emission tax on pollution should reflect the marginal social damage, while the R&D subsidy should reflect the wedge between the private and social returns to R&D. This wedge is a result of the spillovers, and hence a result of the nature of technology. The more spillovers there are, the larger the subsidy. However, spillovers cannot be anticipated in advance. All we know is that spillovers are likely to occur, but we do not know by how much. Moreover, spillovers are likely to differ across sectors, products and technologies. It is therefore impossible to determine the specific wedge for every R&D activity and subsidise accordingly. The practical solution is to have a generic R&D subsidy and to try and find reasonable, specific rules to supplement the generic subsidy (*cf.* patent law which generically protects inventions for 20 years, while from a welfare-maximising perspective, the patent length should differ to account for technology/sector-specific externalities). The question is whether environmental R&D justifies such a supplement.

Green innovation should get a larger subsidy if the social-to-private benefit ratio is larger than that for other innovation. At first sight this seems too complex to determine. If green innovation is possible in a variety of sectors, with an associated wide range of degrees and potentials for learning and spillovers, it seems hard to imagine a systematically larger wedge for green innovation. The best guess would be that green innovation has on average the same wedge. Grimaud, Magné, and Lafforgue (2011) make an "agnostic" assumption in this spirit: they calibrate a model in which innovation in energy efficiency, alternative energy and CCS has the same private-social return wedge, and they assume in addition that this wedge is constant over time. The optimal R&D subsidy is therefore generic and constant over time in their simulations. They find a surprising lack of interaction between environmental and R&D policies: adding R&D subsidies to an environmental tax hardly affects emissions (but does affect welfare), while subsidies without environmental taxes hardly affect emissions. The latter is due to the fact that emissions come from a non-renewable resource stock and resource owners will want to deplete this stock until the extraction costs equal the price of alternative energy. Nordhaus (2002) and Popp (2004) make similar assumptions with respect to the fixed wedge between social and private returns to R&D and also find small effects of R&D policies on emissions.

Recent research has shown that R&D policies have substantially bigger effects if the spillovers from different types of R&D are modelled in a more detailed way. This literature finds that specific green technology subsidies are justified even when environmental taxation is in place.

Acemoglu *et al.* (2009) distinguish between green and brown firms, which both produce a similar good, but only the former produce without emissions. Firms can reduce their cost by undertaking R&D. Without environmental taxes, brown firms are cheaper because they have a longer history of cost-reducing R&D. Brown firms learn from other brown firms, and green firms learn from other green firms, both to the same degree; both types of firms also have the same cost of R&D. Without environmental policy, only brown firms undertake R&D since they have a larger market. Thus, brown firms become even more productive over time and capture an even larger market: the economy becomes locked into a more polluting industry structure and the productivity gap between brown and green goods simply becomes wider. This path dependency is a result of the lack of spillovers between the two types of firms.

Efficient environmental policy requires both pollution taxes and R&D subsidies in this model. Pollution taxes internalise the damage from emissions and shift demand to clean goods. R&D subsidies internalise the spillovers among green firms. Although both green and brown firms face spillovers under perfectly symmetric conditions, the R&D subsidy still must be larger for the green firms. R&D effort has to be completely redirected from the dirty to the clean sector.

Although the model is quite specific in particular, only two sectors are distinguished and only one of them innovates at any point in time), the main mechanism of the model is quite general. R&D subsidies should be bigger if the ideas that they generate benefit more producers. This is an expression of the well known Samuelson (1954) condition for public goods: the social value of the innovation, which is a public good as far as it benefits many firms, equals the sum of the benefits that all the firms derive from it in the form of knowledge spillovers. With environmental policy, there will be a substitution to green methods of production and as a result more firms (or firms with larger markets) will benefit from spillovers from green R&D. Hence, the total value of spillovers is bigger. For R&D related to polluting sectors, the opposite happens. Thus, the R&D subsidy for green technologies is larger. Hart (2008) has already pointed this out.

Heggedal (2008) discusses the implications of diminishing returns on developing new knowledge in a specific field, here to be interpreted as green technologies. When a new technology field is opened, progress may initially be relatively easy, but will run into diminishing returns later on. In particular, the initial progress may be easy to absorb by other firms so that spillovers are relatively large in the early stages. Evidence for this is provided by Popp (2002). Large yet falling spillovers imply that high initial R&D subsidies may be optimal; the subsidies can be phased out later on. In Heggedal's setting, an exogenous event creates new technological opportunities, for example, a breakthrough in nanotechnology or carbon capture. This is very different to the setting in Acemoglu *et al.* (2009), in which green technologies never make a "jump" akin to Heggedal's breakthrough - instead it is policy that has to jumpstart their green technology. In Heggedal's setting, the breakthrough could easily be a non-environmentally friendly breakthrough, maybe nanotechnology with great increases in productivity but harmful effects on living organisms. In this case, additional technology support is justified on efficiency grounds for brown, rather than green, technology! Of course, emission taxes are still justified as well. In normal cases, the positive technology shock raises the efficient emission tax through an income effect. As a result, efficient green policy has to shift from technology instruments to environmental instruments. However, it is also conceivable that the pollution-using breakthrough lowers the efficient pollution tax. Intuitively, a high pollution tax would kill too many of the opportunities opened up by the brown breakthrough (Smulders and Di Maria, 2008).

Green growth meets inclusive growth: national policies

We shall now consider the links between green growth and inclusive growth. In particular we shall consider how green growth policies can enhance - or be reinforced by - investment in skills, education, poverty reduction and employment opportunities.

If there is a need to combine inclusive growth and green growth somewhere, it is in the rural areas of low-income countries. Currently 25% of the population in developing countries - almost 1.3 billion people - make their living on "fragile lands", which are defined as "areas that present significant constraints for intensive agriculture and where the people's links to the land are critical for the sustainability of communities, pastures, forests and other natural resources" (World Bank, 2003). The major part of these people's income depends on the land or coastal areas (fishery), so that making resource use more sustainable both reduces poverty and increases opportunities. The main problem is that the poor are asset-deprived, having no claims to the land on which they depend, no access to education and no access to credit. More powerful groups control the resources; commercial interests lead to deforestation, land degradation and fish stock depletion, depriving the poor of their livelihood. Barbier (2008) discusses the policy options. Tax reform and reduced support for cattle ranging, forestry and large-scale agriculture is needed to remove the bias against the poor. Once the local communities can manage their own natural resources, coordinated sustainable resource use may become established. Payments for eco-service systems may not help the asset-deprived poor, but may be a solution in situations with more equally distributed land ownership. Land reform might be needed otherwise. Education and credit market improvements may improve the bargaining position of the poor and reduce their need to over-harvest the resources themselves, thus escaping the "poverty-environment trap".

The poor in urban areas, including low-skilled workers in richer countries, face a different situation: their opportunities are linked more to the world market and the international division of labour. Their jobs depend on international competitiveness and price competition. For them, environmental policy may be quite costly. If the policy takes the form of reduced emissions and higher energy costs, their production becomes less competitive. Switches to greener products almost certainly increase the demand for skills, disadvantaging low-skilled workers. In general, the transition from resource-based growth to green growth implies a transition to a more knowledge-based economy. In this respect, green growth is non-inclusive for the low-skilled. This calls for major supplementary policies in terms of skill formation, training and education. Once green technologies become standardised, they might move down the skill ladder again and benefit the poor. Policies that stimulate entrepreneurship could speed up this transition.

The poor are not only low-skilled workers in the main; they are also low-income consumers with a distinctive consumption pattern. They spend a relatively large proportion of their income on material goods and are thus hurt relatively more by emission taxes than the non-poor. This implies that the poor face a higher cost of reducing their emissions, both as a consumer and as a worker. At the same time, they may depend relatively more on natural resources, especially in poor countries where harvested resources (from land, fuel, wood) supplement income and protection against air pollution and heat stress is less affordable for them.

Table 4.1 sets out the schematic difference between two income groups. It is clear that green inclusive growth requires that the poor be somehow exempt from emissions reductions and that most of the burden be placed on the rich, while the benefits accrue to both groups.

Table 4.1. Distributional effects of environmental policy

	Abatement cost	Environmental benefits	Capacity to reduce emissions
Poor	high ↓	high	low ↑
Rich	low ↓	low/high	high ↑

Note: The arrows denote direction of change when pollution-saving technology becomes available at low cost.

Source: Author.

What can be concluded about the within-country sharing of the burden of environmental policy? In the absence of full redistribution, poor individuals should abate less (and be favoured with a lower energy tax). However, the cost of greening the national economy would be lower if there was trade in abatement options, such that rich individuals would receive tax exemptions when they take care of abatement in poor neighbourhoods. This sounds abstract, but there is a variety of ways to generate such a transfer. One possibility is to levy a uniform energy tax on fossil energy and use the proceeds to subsidise the building of alternative energy infrastructure in poor neighbourhoods. In a first-best situation, earmarking and subsidising of goods without positive externalities cannot be optimal, but in the second-best setting (in which no personalised lump-sum transfers are available), investing in energy infrastructure seems to be a feasible and relatively less distortionary way of redistribution.

The link between income distribution and the burden of environmental policy is also relevant in richer countries. For example, in the United States an energy tax is likely to be regressive and thus energy taxation would worsen the income distribution (equity) if not compensated by redistributive measures. Carbon taxes are usually thought to be regressive (see Büchs *et al*., 2011, for a survey of the literature), but this is not generally the case because there are two opposing forces at work. On the one hand, the expenditure side matters: energy is a basic good (not a luxury good - although flying might change the picture) so energy taxation disproportionately affects poor energy users (*i.e.* the price index of their consumption basket increases relatively more). On the other hand, there is an effect through income: if high-income groups derive their income mainly from energy-intensive industries, then the rich are the ones mainly hurt by taxation. In the US study by Oladosu and Rose (2007), coalminers are relatively rich so they spend relatively little on energy; however, their real wage still falls because their earned income is very sensitive to energy taxation.

The picture necessarily varies over countries. In Africa, the elite own natural resources. When this is oil resources, a global carbon tax is pro-poor. In Latin America, the elite hold land and therefore the green policies in the form of bio-fuel subsidies are pro-rich.

Technological change has a big role to play when dealing with distributional issues. The introduction of energy efficient appliances (but also low-emission cooking stoves) largely reduces the abatement costs of the poor and enhances their capacity to contribute to environmental improvements (Table 4.1). Hence, technology-driven green growth may very well be inclusive for the poor.

Green growth meets inclusive growth: international policies

We shall now consider the links between green growth and inclusive growth in an international context. In particular, we shall consider how environmental policies can be compatible with growth in the low-income regions of the world. We shall focus on climate change policies since climate change poses the main challenges in terms of international coordination. How should green growth policies be designed to reflect the differences in opportunities and needs across rich and poor countries?

The first key question is how the abatement efforts should be divided among different countries. The standard economic recommendation is to impose a tax on harmful emissions of a global pollutant, with the tax uniform for all emitters across both sectors and regions. The idea behind this is that one unit of greenhouse gas emissions does the same harm, no matter where it is emitted. A given target of damage reduction is therefore cost-effectively met if the total cost of reductions is minimised, which requires equal marginal costs at all sources. However, we should be careful in specifying what we mean by cost. Of course, ideally this is cost in terms of welfare or utility, rather than "(international) dollars". Hence, welfare-cost-effectiveness requires the marginal utility of emissions (or, equivalently, the marginal utility loss from emission reductions) to be equalised across sources. Poor LDCs have higher marginal utility from production and consumption than rich LDCs, and hence face high abatement costs. The money-equivalent carbon tax in the poor countries should be much lower than in the rich countries (Eyckmans *et al.*, 1993; Chichilnisky and Heal, 1994). Surprisingly, the differentiation of the carbon tax is derived from an efficiency argument, since it maximises the sum of utilities. It is not motivated by equity concerns *per se* - in other words, the differentiation is not designed as a policy tool to affect the income distribution.

Note that this argument is about burden sharing in a second-best world. First, if transfers were possible, the first best in achieving global welfare maximisation would be to redistribute income to poor countries such that the marginal utility from production becomes equalised and uniform carbon taxes are again optimal. Second, the Chichilnisky and Heal argument starts from a missing market: each country has its own abatement options and there is no trade in these options. The Kyoto protocol has introduced a kind of trade in abatement, in the form of the Clean Development Mechanism (CDM). When developed countries (DCs) finance abatement in LDCs, the former can replace high-cost domestic abatement by low-cost foreign abatement, and the LDC gets a transfer that is at least sufficient to cover the cost of abatement. However, CDM is under considerable attack. Monitoring problems and "additionality requirements" make it imperfect, and this, together with the low transfers from rich to poor, ensures that the Chichilnisky and Heal argument maintains its force.

However in the future, the argument may lose ground. Growth is faster and more robust in many low-income countries compared with that of high-income countries. The OECD Development Centre (2010) reports that a remarkable and significant shift in wealth has become increasingly pronounced, from the old rich to the new emerging countries. Convergence between poor and rich regions has accelerated since the early 2000s and a growing number of countries have joined the group of converging countries. With smaller income gaps, efficient carbon taxes should converge internationally. A successful inclusive growth strategy will simply speed up the international income convergence process, thus stimulating cooperation in climate change action.

Furthermore, actual taxes on fossil energy should not only reflect the damage from global warming, but also consider local, country-specific damages. A country's attention to energy security and its potential desire for a reduction in fossil fuel dependence depend on the level of its own supplies of fossil resources. Local air pollution from energy use must be regulated and damage from this source could become an important concern in countries like China and India. It is these co-benefits of reducing local air pollution that provide an argument for low income countries to start taxing energy even before the income gap with richer countries is closed. The increase in household income and the change in life-style in emerging countries not only lead to expanded demand for material consumption goods, but also for immaterial goods, such as air quality and health.

Unquestionably, health-driven environmental regulation is important for all countries, even the poorest of the world. Ikefuji *et al.* (2010) compare the impact of fossil fuel usage on global warming and on local health. Aerosol particles related to energy usage cause lung and other respiratory diseases;

temperature increases affect malaria incidence. They find that in a Nash non-cooperative setting, poor warm regions suffer disproportionately from these health effects and they show that this has a significant impact on the poor regions' willingness to reduce emissions.

Extending the argument outlined above - that within a country, the poor cannot be expected to bear a large share of the burden of national environmental policy - we could argue that we cannot (yet) expect the poorest countries to incur costs to reduce their emissions. Instead, it should be rich countries that mainly finance any reduction in emissions in LDCs, whether this means substitution to cleaner goods and processes or by introducing new technologies ("Annex B countries" in the parlance of climate negotiations). The issue then is to find out how much has to be done in the North and how much has to be financed by the North in the South in order to minimise the (aggregate net present value) cost of green policies. Let's first look at where to reduce emissions and then concentrate on where to introduce green innovation.

Some experience has been cumulated with CDM as a policy tool to reduce emissions in countries other than those that bear the cost of reductions. Together with stimulating and facilitating foreign direct investment (FDI), CDM is also a policy tool for technology transfer: firms from Annex B countries get emission reduction credits for investments in non-Annex B countries that reduce emissions. The investment often involves technology transfer.

With CDM, abatement becomes cheaper on average because abatement can take place first where it has the lowest marginal costs. However, this is only the "static gain" from technology transfer. The dynamic gain, in the form of knowledge spillovers, may be more important. Lovely and Popp (2008) show that access to better pollution control technologies results in countries adopting environmental regulation at lower levels of per capita income over time. By allowing more FDI and CDM, the knowledge base on which domestic firms can build expands and this reduces the cost of environmental policy. The problems with CDM identified above typically refer to the static part of the story. The dynamic gains may very well offset the static losses.

The policy to enhance LDCs' knowledge base in green technologies is a long-term policy. In the short term, these countries will initiate their own emission reductions on a much smaller scale. It will also take a longer time before the knowledge base can be effectively exploited. The bottleneck is the limited absorptive capacity of the recipient country. Absorptive capacity describes a country's ability to do research and to understand, implement and adapt technologies that arrive in the country. It depends on the technological literacy and skills of the workforce, and it is influenced by such factors as education, the strength of governing institutions, and financial markets (World Bank, 2008). Countries with greater absorptive capacity are more likely to receive spillovers from technology transfer.

Rosendahl (2004) derives some insights about when LDCs should think about green technology policies. He considers the situation that technological innovation (in the green direction) takes place mainly through learning-by-doing and he argues that in LDCs less learning takes place. The interpretation is that the DCs have the capacity to do R&D, and R&D will be more if the base is larger. So R&D to reduce abatement costs will increase with abatement, and hence with the carbon tax. The result is that in a second-best world with only carbon taxes (*i.e.* no technology subsidies), the carbon tax has to be higher in DCs than in LDCs. In other words, it is optimal for the world as a whole if the LDCs delay their implementation of a green policy. Note that the traditional view seems to be the opposite: LDCs have cheap abatement options (*e.g.* replace coal plants, cover methane fields) and therefore should do more abatement. The learning-by-doing argument is more about the timing: it is an argument to postpone abatement in the South while moving abatement forward in the North. Only in the long run, when cheaper technology has been developed in the North and has diffused to the South, should both regions reduce to the same degree.

One could wonder whether the analysis will change if the assumption of learning-by-doing in abatement was replaced by R&D-based cost reductions in abatement. From the seminal study by Goulder and Mathai (2000), we know that learning-by-doing calls for early abatement action, while R&D calls for a strategy of "first innovate, then abate". Suppose the North can do R&D but not the South. If so, the North should heavily invest in R&D first to reduce abatement cost, and then both regions can postpone abatement until the new abatement option comes on line. However, the crucial question is whether the North is still the only player in the world when it comes to improving abatement technologies. China and India are becoming serious technology players, certainly when judged by R&D expenditure per unit of GDP. The key question is, again, whether green innovation mainly benefits from R&D in general or one in green R&D. If the latter, there is no reason not to do R&D in LDCs.

Conclusion

A successful green growth strategy needs to cover a wide range of policies in order to deal with the specific characteristics of the countries in which it is applied, as well as the existing institutions and regulations in those countries, and the relevant nature of the environmental problems involved, which can range from short-term local problems to the long-term global problem of climate change. Inclusive green growth requires attention to the role of the poor within countries and the burden-sharing between rich and poor countries. We have reviewed some of the possible policies, complementarities and opportunities for inclusive green growth and have focused on the interaction between the growth and the environmental improvements that arise from new technologies. Technology development can, in principle, help the environment and at the same time stimulate growth and reduce poverty, but this requires a balanced package of measures, as well as international coordination, appropriate burden-sharing rules and time-lines. However first and foremost, it requires international commitment to putting green inclusive growth on top of the policy agenda. While a first step has been made in this direction, it does not seem obvious that the political economy aspects of green growth will support enough further action in the future.

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