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NO GREEN GROWTH WITHOUT INNOVATION

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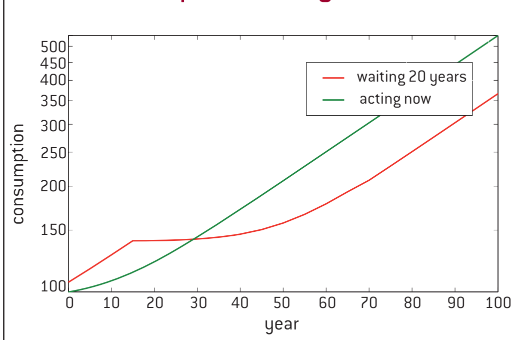
SUMMARY The 'green growth' debate is taking place in an oversimplified setting, largely disregarding the innovation factor. Technologies to mitigate climate change are being treated as given, or as emerging spontaneously, ignoring the fact that the portfolio of technologies available tomorrow depends on what is done today. This can easily lead to a misguided preference, either for subsidising the use of relatively inefficient technologies or for postponing action to later in the hope that new technologies will become available which will reduce the cost of fighting climate change. But the radical new emissions-free 'backstop technologies' we will need are not yet available, or else still far from the market. To foster their emergence the 'green innovation machine' must be turned on.

POLICY CHALLENGE

How can governments tackle climate change while maintaining reasonable growth, even in the short term? How can they turn on the green innovation machine? We find that 1. *both public intervention and private initiative are indispensable*: governments must initially redirect market forces towards cleaner energy before market forces can take over; 2. *climate change policy should combine a carbon price with high initial clean-innovation R&D subsidies*: the carbon price would need to be much higher if used alone; 3. *policymakers must act now*: delaying clean innovation policies results in much higher costs; 4. *developed countries must act as technological leaders* in implementing new environmental policies and should smooth access to new clean technologies for less-developed countries.

Consumption if acting now or later



1. GREEN GROWTH: ARE WE KIDDING OURSELVES?

With the reality of climate change no longer a contentious issue, the debate has shifted towards the growth consequences of climate-change containment. Developing countries do not want to engage in environmental policies which they see as constraining the process of catching up with more advanced countries. For their part, the United States and other developed countries are reluctant to take any steps which would jeopardise their own growth potential. And even in the European Union – a self-styled environmental leader – the crisis has made growth and jobs a higher priority than before.

Economists have not tackled this debate very well. Discussion has mainly revolved around the trade-off between immediate costs and long-term benefits of fighting climate change. The balance between the two depends upon the rate at which we should discount the future. Based on the assumption of a low discount rate, numerical simulations in the Stern report (2007) argue for immediate intervention, whereas other studies (for example by Nordhaus, 2000) assume higher discount rates and therefore call for postponing intervention.

Current approaches to green growth are taking place in an oversimplified setting, largely disregarding the innovation factor. Technologies to mitigate climate change are treated as given or as emerging spontaneously, ignoring the fact that the portfolio of technologies available tomorrow depends on what is done today. This perspective can easily lead to a misguided preference for postponing action to later in the hope that new technologies will become available that will reduce the cost of fighting climate change in the future.

Recent economic simulations (eg Carraro et al, 2009) confirm that, in order to keep the costs of mitigation and adaptation manageable and to safeguard reasonable levels of economic growth, we need to put into operation a sufficiently wide portfolio of technologies as soon as possible. The range of technologies we are talking about includes traditional renewables and energy-saving technologies, which typically require additional innovation as higher legal targets and standards 'bite', but for the longer term we also need radical new technologies – particularly so-called 'backstop technologies' – which are completely emissions-free. These technologies are not yet available or else still far from the market.

'Current approaches to green growth are oversimplified, and largely disregard the innovation factor.'

Unfortunately, too little has been done so far to turn on the 'green innovation machine'. In a companion Bruegel publication (Aghion, Veugelers and Serre, 2009), we take a look at the recent performance of the private green innovation machine. The available empirical evidence is disappointing. Despite a recent spurt, only 2.15 percent of total patents applied for worldwide are environment-related (2000-06). And with regard to the diffusion and adoption of green technologies, there is (too) little happening, particularly (though not exclusively) in the field of electricity generation and distribution, the business sector accounting for the highest level of carbon dioxide emissions.

In this policy brief, we discuss how government intervention should be designed in order to effectively turn on the private green innovation machine, and more generally to fight climate change, thus paving the way for 'green growth' – the optimum trade-off between 'catching' climate change in time while maintaining a reasonable rate of growth, even in the short term. We build on new insights from growth models of innovation and the environment. In particular, we use the insights from the model developed by Acemoglu, Aghion, Bursztyn and Hemous (2009), henceforth AABH[1], leading to a new assessment not only of the costs and benefits of environmental policies but also of what the optimal timing, speed and instruments of intervention should be.

2. POLICIES TO DIRECT INNOVATION FOR GREEN GROWTH

In the AABH model, the same goods can be produced using either clean or dirty technologies, and entrepreneurs typically select the more profitable of the two, taking into account the current state of technology in both and the (dis)incentives put in place for either/both by government. As long as the dirty technology enjoys an initial installed-base advantage, the innovation machine will tend to work in favour of further improv-

1. Box 4 sets out the basic characteristics of the model. A full account of the model can be found in the AABH (2009) Harvard, MIT, NBER Working Paper.

ing the dirty technology: people prefer to work at what they already know, and the clean technology may never take off at all unless government opts to intervene.

Governments therefore need to influence not only the allocation of *production* between clean and dirty activities, but also the allocation of *research and development* between clean and dirty innovation. This means that there are not one but two major issues that must be dealt with: the environmental externality generated by polluting production activities, as in the standard models, but also the fact that past or current technological advances in dirtier technologies make future production and innovation in clean technologies relatively less profitable.

Such a 'directed' technological change perspective introduces a new cost-benefit analysis to policy intervention. The cost of supporting cleaner technologies is that this may slow down growth in the short run, as cleaner technologies are initially less advanced. But the benefit from supporting cleaner technologies is that it will bring about greener (and therefore more sustainable) growth.

2.1 WHEN? COST OF DELAYING INTERVENTION

With directed technological change, delaying intervention not only leads to further deterioration of the environment. In addition, the dirty innovation machine continues to build on its lead, thus making the dirty technologies more productive and widening the productivity gap between dirty and clean technologies even further. This widened gap in turn means that a longer period is needed for clean technologies to catch up and replace the dirty ones. As this catching-up period is characterised by slower growth, the cost of delaying intervention, in terms of foregone growth, will accordingly be higher. In other words, delaying action is costly. Box 1 illustrates this.

BOX 1: DELAYING ACTION IS COSTLY

The AABH (2009) model calibrates the cost of delaying intervention. This cost is computed as the 'lost' consumption in each period expressed as a percentage of the level of consumption which would result from 'best-time' policy intervention.

Discount rate	1%	1.5%
Lost consumption, delay of 10 years	5.99%	2.31%
Lost consumption, delay of 20 years	8.31%	2.36%

Source: Calibrations from the AABH (2009) model

Not surprisingly, the shorter the delay and the higher the discount rate (ie the lower the value put on the future), the lower the cost will be. This is because the gains from delaying intervention are realised at the outset in the form of higher consumption, while the loss occurs in the future through more extensive environmental degradation and lower future consumption.

BOX 2: TWO INSTRUMENTS INSTEAD OF ONE

The AABH model allows one to calibrate the cost of using only the carbon price instead of a combination of a carbon price and a subsidy to clean R&D. This cost can be expressed as the amount of 'lost' consumption in each period expressed as a percentage of the level of consumption which would result from optimal policy, which involves using both types of instrument. Using a discount rate of 1 percent, this cost in terms of lost consumption amounts to 1.33 percent. With a 1.5 percent discount rate, this would increase to 1.55 percent.

An alternative way of showing the higher cost when using only one instrument (ie the carbon price), rather than a combination of carbon pricing and subsidies, is to express how high the optimal carbon price would have to be when used as a singleton relative to its optimal level when used in combination. Simulating this scenario in the AABH model reveals that the carbon price would have to be about 15 times higher during the first five years and 12 times higher over the following five years. The intuition behind the initial high differential is that the early period in particular is key to inducing the catch-up by clean technologies. Using only the subsidy instrument, while keeping the carbon-price instrument inactive, would imply that subsidies would have to be on average 115 percent higher during the first 10 years compared to their level when used in combination with a carbon price.

2.2 WHICH INSTRUMENTS: CARBON PRICING AND/OR R&D SUBSIDIES?

Because there are two problems to deal with, namely the environmental one and the innovation one, using two instruments proves to be better than using one. The optimal policy involves using (i) a carbon price to deal with the environmental externality[2] and, at the same time, (ii) direct subsidies to clean R&D (or a profit tax on dirty technologies) to deal with the knowledge externality.

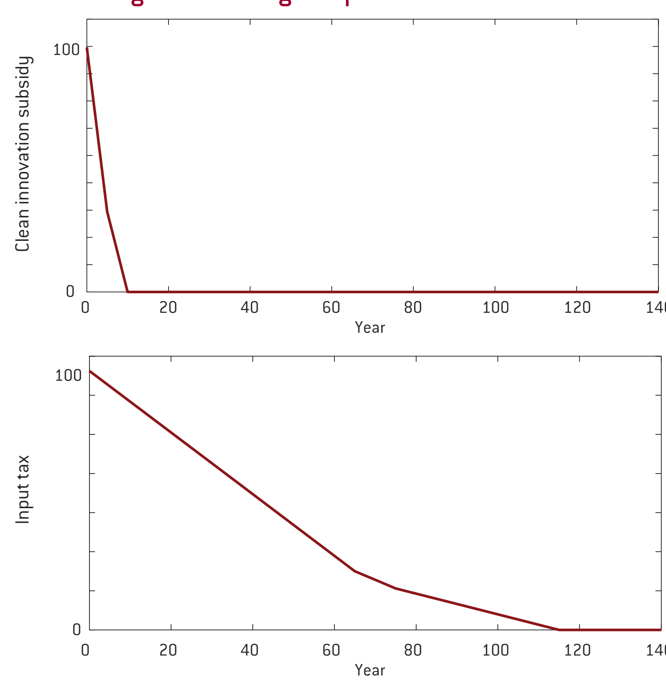
Of course, one could always argue that a carbon price on its own could deal with both the environmental and the knowledge externalities at the same time (discouraging the use of dirty technologies also discourages innovation in dirty technologies). However, relying on the carbon price alone leads to an excessive drop in consumption in the short run (Box 2). And because the two-instrument policy reduces the short-run cost in terms of foregone short-run consumption, it reinforces the case for immediate implementation, even for values of the discount rate under which standard models would suggest delaying implementation (Box 1).

The good news is that government intervention to trigger green innovation and growth (through pricing carbon and subsidising clean technologies) can be reduced over time (Box 3). As soon as clean technologies have gained sufficient productivity advantage over dirty technologies, the private innovation machine for these clean technologies can be left on its own to generate further, even better and more efficient, clean technologies. With cleaner technologies in place, the environmental damage problem, which the carbon tax is designed to address, gradually abates. However, the longer intervention is delayed, the longer it will need to be maintained.

BOX 3: GOVERNMENT INTERVENTION NEED NOT BE PERMANENT

Simulations with the AABH model indicate how the carbon price and the clean innovation subsidy should be set optimally over time. Figure 1 shows (i) that subsidies for new clean technologies should be granted immediately but can be quickly reduced as soon as innovation has taken off for these technologies; and (ii) that the carbon price can decrease over time. With the emergence of perfectly clean backstop technologies that have zero emissions, with the innovation gap between clean and dirty technologies eliminated and the environment rejuvenating, the environmental externality gradually disappears, thus reducing the need for a carbon price over time. Unfortunately, totally clean technologies will take time to become available, which in turn implies deferring the phasing out of carbon pricing.

Figure 1: Setting an optimal 'carrot and stick'



Source: Calibrations from the AABH (2009) model.

Results are for a discount rate of 1.5 percent. Taxes are proportional to the price of the dirty input;subsidies are proportional to the profits derived from clean technologies. Both are scaled to 100.

2.3 WHICH GOVERNMENTS SHOULD ACT? MULTILATERAL VS UNILATERAL INTERVENTION

At the heart of the current environmental debate is the issue of how to organise worldwide coordina-

2. A price for carbon to provide an incentive for carbon-saving investments is obtained most clearly through a carbon tax, provided the tax rate is set sufficiently high and is predictable in the long term. A cap-and-trade system can achieve the same result as a tax but requires a considerable amount of information and expertise to get the emission-allocation process right, creating more room for error and exposure to political pressure. In this policy brief we do not make an explicit case for one system over the other as long as the system chosen delivers a carbon price that succeeds in turning on the clean innovation machine.

tion of policy intervention. As the benefits of a reduction in CO2 emissions will be global, countries may be tempted to free-ride, thus avoiding the costs of intervention, or in the case of developing countries to argue that they need first to catch up economically with the developed world. But does it matter if some countries choose not to intervene to support a switch to clean technologies? Does it still pay to intervene unilaterally? And is it good policy to make one's own action conditional upon what commitments other countries make?

If one tackles the global-action issue from the perspective of directed technological change, new light may be shed on how developed and developing countries should debate and negotiate the implementation of a global environmental policy[3].

While some emerging countries such as China and Brazil are already part of the global innovation machine, most of the 'South', particularly the poorer South, can at best only imitate/adopt green technologies previously invented in the developed countries - where these are available at low cost. Thus if developed countries direct change towards clean technologies and subsequently facilitate the diffusion of new clean technologies to developing countries, a major step towards overcoming global climate change can be taken. Indeed it may not be necessary to price dirty-input production in the South in order to avoid a global environmental disaster: unilateral government intervention in developed countries can turn on the green innovation machine in the North, which will in turn allow the South to adopt the cleaner technologies developed in the North. The greater the innovation spillovers from North to South, the more active the South will be in implementing clean technologies rather than dirty ones. Thus, even in the absence of action by developing countries, a case can be made for policy intervention by developed countries only. A case can also be made for easing technology transfer from North to South and for improving the capacity of the South to effectively absorb technology from the North.

'It may not be necessary to price dirty-input production in the South to avoid global environmental disaster.'

But what about the international trade implications of unilateral climate-change policy? In a free-trade world, adoption of unilateral environmental policies – in particular taxing dirty technologies – risks creating a pollution-haven effect in other countries or regions (so-called 'carbon leakage'). These countries will automatically acquire a competitive advantage in producing with the dirty technology, specialising in the production of dirty goods which they can subsequently export to the rest of the world. Alternatively, multinational companies may decide to relocate their dirty production activities and innovation to countries taking no action and then export dirty goods and technologies to regions that have introduced environmental policies. This will not only create short-run environmental degradation, but will also deter, or reduce the pace of, clean technology take-up.

'Threats of carbon tariffs should be credible, as they may push others to emulate such policies.'

It is precisely to avoid such perverse effects of unilateral environmental policies that we first advocate a massive effort to make clean technologies available and affordable to poorer countries. Only to the extent that clean technologies are available at affordable cost should carbon tariffs – or the threat of them – come into play. But where the threat of carbon tariffs is made, it should be made credibly, as this may help to push others to emulate such policies and thus contribute to tackling what is a global problem[4].

3. DOES CURRENT CLIMATE-CHANGE POLICY MEASURE UP?

In the light of the preceding discussion, is current climate-change policy up to the job? There is some empirical evidence available on how the two pivotal policy instruments have been used to date: (i) carbon prices and (ii) public spending on green R&D. Here we briefly summarise the main findings reported in more detail in the parallel Bruegel publication (Aghion, Veugelers and Serre, 2009) referred to in section 1, with an emphasis on the European Union.

Regarding carbon prices, the evidence shows not only the low level of carbon taxes in many individual EU member states but also the

3. We focus the discussion on the developed 'North' versus the developing 'South', but the arguments may be extended to countries at different stages of development among the countries of the North, for example to EU member states that are still in the process of catching up.

4. An equivalent approach to taxing domestic production and imposing a carbon tariff would be to impose a carbon tax on dirty consumption no matter where the good comes from. But this may be more complicated to implement given the need to calculate the total carbon content of consumption. See eg Helm and Hepburn (2009) for more on this discussion. The discussion does not take into account the political sensitivities around border tariffs and their potential conflict with international trading rules.

high dispersion in the level of carbon taxes across EU countries, thus jeopardising their effectiveness. At EU level, the first phases of the EU's Emissions Trading Scheme (ETS) have established a carbon market but the carbon price is low, highly volatile and far from being predictable in the long term – a key feature to incentivise green innovation. The US and other major carbon-emitting countries are even further away than the EU from establishing an innovation-inducing carbon price.

'Public R&D spending for the environment and energy efficiency constitutes a very minor share of total public R&D spending.'

Regarding subsidies to green R&D, again the evidence shows the poor performance of the major jurisdictions, particularly the US. Public R&D spending targeted at the environment and energy efficiency constitutes a very minor share of total public R&D spending. Not only are public budgets for such R&D very limited and uncoordinated but they are not increasing over time. Only very recently do we observe signs of an increase in public R&D budgets in some countries.

Regarding technology transfer to developing countries, the limited evidence again suggests that insufficient action is being taken. Although the UN's Clean Development Mechanism (CDM) framework was designed to trigger technology transfer, only a limited number of these projects in fact involve technology transfer.

4. RECOMMENDATIONS FOR THE EU

There are some signs, particularly from the venture capital market, that the private green innovation machine might be ready to take off. However, in the absence of the right push from government this will be difficult, if not impossible. What follows are some game-changing guidelines for policy intervention to turn on the private green innovation machine, addressed not least to EU policymakers:

The carbon price must be high enough

A first key objective of EU policy should be to ensure that the price of carbon is set at an appropriately innovation-inducing level. This involves improving the European cap-and-trade system, ensuring that the mechanism generates a sufficiently high and durably predictable carbon price. As part of the EU's climate-change package, it is planned to make the EU's ETS more consistent and predictable in future. It should, however, be designed more explicitly to play a role in directing technological change. In addition, the EU should play a more active role in coordinating the carbon tax policies of individual EU member states in order to ensure an EU-wide carbon price.

'A first key objective of EU policy should be to ensure that the price of carbon is set at an appropriately innovation-inducing level.'

Vigorous backing for green technology

The EU should stimulate new technologies more vigorously by (i) subsidising the diffusion of existing green technologies; (ii) increasing public funding for green basic R&D, particularly for research into radical new backstop technologies, through the EU's R&D Framework Programme and other funding; (iii) coordinating member states' individual research programmes on climate change and involving non-EU partners. The receipts from carbon pricing can be used to finance research and development subsidies. This support should leverage the private innovation machine and thus be reduced as soon as these technologies come on stream. Particularly in the short term when we are still anticipating better technological alternatives to be available in the future, support schemes for currently available technologies should be time-consistent in order to avoid creating excessive gaps for new, more radically clean technologies to fill that are still in the pipeline.

Joined-up green regulation

The EU should coordinate on clear and time-consistent green regulations, standard-setting and public procurement among member states, thereby ensuring a large, integrated EU output market for green investments. Also, competition policy and single-market instruments should be used to ensure a more integrated and contestable EU-wide electricity generation and distribution market that is more able to absorb new, cleaner technologies.

Act globally

The EU should take a leading role on the international stage by developing a roadmap for establishing an international, innovation-inducing carbon price. This roadmap would include international linkage of the cap-and-trade systems of major players and would remove barriers to trading permits across different systems. At the same time, the EU should advocate and promote the development of an equitable financing scheme for climate-change action by less-developed

BOX 4: THE STANDARD MODEL VERSUS THE DIRECTED TECHNOLOGICAL CHANGE MODEL

The standard approach: Nordhaus

The neoclassical DICE model of Nordhaus is often used for evaluating the costs and benefits of environmental policy (or of the absence of it). In this framework, a consumption good is produced using capital and labour, and the productivity of these factors depends both upon a knowledge parameter which grows exogenously over time, and upon environmental quality. The environment is itself negatively affected by temperature, temperature increases with the emission of carbon dioxide, and the emission of carbon dioxide increases with production.

Environmental policy takes the form of a tax on CO2 emissions, which induces firms to reduce emissions but at the cost of also reducing production. Delaying policy intervention thus increases production and therefore consumption in the short run, but at the cost of environmental degradation which in turn calls for higher abatements (and therefore higher consumption reduction) in the future. In the DICE model, an input tax or a cap-and-trade policy brings about the optimal outcome. And unless we assume a low discount rate as in the Stern report (2007), immediate intervention is not optimal.

A new paradigm: AABH

Acemoglu, Aghion, Bursztyn and Hemous (2009), or AABH, develop a new paradigm where productivity growth is not exogenous but instead results from innovation. The main features and conclusions of the model can be summarised as follows. A consumption good can be produced using a clean and/or a dirty input, according to

$$Y = \left(Y_c^{\frac{\varepsilon-1}{\varepsilon}} + Y_d^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}$$

where ε is the elasticity of substitution between the clean and dirty inputs (we assume that $\varepsilon > 1$ so the two inputs are substitutable).

Only the production of dirty inputs harms the environment

$$S_{t+1} = -\xi Y_{dt} + (1+\delta)\, S_t,$$

where ξ is the environmental degradation caused by dirty-input production and δ is the regeneration rate.

The environment in turn affects the utility of people.

Inputs Y_j are produced with labour L_j and machines x_{ji} of quality according to

$$Y_j = L_j^{1-\alpha} \int_0^1 A_{ji}^{1-\alpha} x_{ji}^{\alpha}.$$

Initially the average quality of dirty machines A_d is higher than the average quality of clean machines A_c.

Continued...

Innovation can improve the efficiency of production of either type of inputs. Innovation results from the work of scientists who can try to improve either the quality of dirty machines or the quality of clean machines. More specifically the average quality of machines in sector j will grow according to

$$A_{jt} = \left(1 + \gamma \eta_j s_{jt}\right) A_{jt-1},$$

where s_{ji} is the fraction of innovators directing their research to sector j at time t, η_j is the probability of success in developing a new technology in sector j, and γ is the 'size' of an incremental innovation. This structure reflects the effect of 'building on the shoulders of giants', namely technological advances in one sector make future advances in that sector more effective.

Innovators will direct their efforts to the sector j where the expected profits from innovation Π_{jt} are the highest, where Π_{jt} is proportional to A_{jt}.

Where the dirty technology enjoys an initial installed-base advantage, the innovation machine will work in favour of the dirty technology. The clean technology may never take off unless the government intervenes. The laissez-faire equilibrium will lead to environmental disaster. Where the dirty technology is based on exhaustible resources, this may help to prevent such a disaster, as the dirty technology is eventually priced out of the market. But even in this case, the innovation machine left on its own works sub-optimally, favouring the dirty technology for too long.

A critical parameter for the effectiveness of policy intervention is the extent to which the dirty and the clean technology are substitutable. If the clean technology is not a good substitute for the dirty technology and environmental degradation has already progressed substantially, government intervention, even when designed optimally, may no longer be able to prevent environmental disaster.

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