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Policies for Dynamic Change and Transition: Lessons from Economic History and Economic Theory

How can we foster the rapid and radical changes which are necessary if we are to bring down the immense risks of climate change? What are the appropriate public policies? In examining these questions we must recognize that much of the theory of public policy in economics, which will prove valuable here, is focused on incentives to move in positive directions rather than on the pace of change itself. As we have seen, speed is of the essence here, and we must examine policies from a much more dynamic perspective than is usual for public economics. The economic policies that can guide the first stages of the transition to a low-carbon and dynamic economy are fairly clear. The policies, together with relevant institutions, should not only be well designed from the perspective of incentives, equity, and feasibility, but they should also be stable and credible so that they provide long-term reliable signals to investors and entrepreneurs, thereby stimulating investment, growth, efficiency, and innovation. As we have seen in the last chapter, we can look forward to a new wave of innovation, invention, and creativity.

From economic history we can learn about past waves of technological change. Some countries, particularly in East Asia, have achieved rapid transformation in recent decades. Economies have changed rapidly with the onset of war and often in the recovery from war. Some relatively new sectors such as information technology have demonstrated an extraordinary pace in their scope and nature of change. These experiences can inform the development of policies to foster the structural change necessary for a low-carbon transition. Part II of this book assembles and applies some of the analytical toolkit necessary for the construction of policies to promote the rapid transformation required to tackle climate change. Chapter 3 examines basic economic principles and perspectives for designing policies for fostering dynamic structural change. Section 3.1 sets out the lessons from public economics concerning market failure, as well as lessons from economic history and Schumpeterian ideas on technology, innovation, and growth. It looks at a broad range of relevant market failures in order to propose market-based policies that can foster the necessary entrepreneurship and investment. It also draws out lessons from economic history and from experiences of innovation, growth, and technological change. It recognizes the close relationship between mitigation, adaptation, and development, and considers the different roles of governments and businesses in transitioning to a low-carbon economy. This will be a transformation driven by private-sector investment from the small farm or firm to the big company. But it will be government policy, including its stability and credibility, that frames the environment for that investment (section 3.2) and sets out a range of pricing and regulatory instruments to encourage the low-carbon transition (section 3.3). Sections 3.4–3.8 discuss the important role that policies play in fostering the affordable and safe sources of energy that will be central to the transition; the risks, and their perception, that accompany the continued extraction of new and unconventional fossil fuels; and what policy can do to unlock the vast potential emissions reductions.

Modern public economics, applied with the appropriate breadth and depth and recognizing the scale of the challenge, can take us a long way in terms of how to see the issues and the necessary policies. But, as chapter 4 demonstrates, the tasks at hand are much greater in scope and depth than is reflected in most modeling in the literature on the economics of climate change. Indeed, much of that modeling is so narrow as to exclude most of the key issues involved in the dynamics of change. Further, the assumptions made in most of the modeling on potential damages from climate change, the processes of growth, and costs of transition often give the immediate conclusion that climate action should be modest or weak. Many of these simplistic attempts to shoehorn the deep and dynamic issues into inappropriate or narrow models can be profoundly misleading.

Chapters 5 and 6 take up key ethical perspectives. The issues raised by climate change cover the short, medium, long, and very long term. Evaluation of outcomes at different points in time is at the heart of decision-making. I argue that we must engage in open, sound, and honest decision-making to explore the basic ethical issues at stake. This involves in chapter 5 an examination of the ideas of discounting which arise when thinking about outcomes occurring at different times. This in turn involves an understanding of basic welfare economics, capital theory, and market failures. Such an understanding tells us quickly that attempts to read off ethical values for the issues at stake here from market observations are likely to be deeply misleading.

In chapter 6, I go beyond the more standard economics of welfare usually adopted by economists to examine broader moral perspectives. The standard economic approach is indeed powerful and relevant here, but there is a whole range of moral philosophy that is also relevant. It is in some respects much deeper than the standard welfare economics approach and includes ideas of rights, justice, liberty, and virtue. In both chapters 5 and 6, we recognize that there are fundamental issues of intragenerational distribution alongside and intertwined with the intertemporal issues.

3.1 Policies for dynamic change and transition

3.1.1 Lessons from economic history

We saw in chapter 2 that the scale of necessary change requires a transition to low-carbon activities and investments across all sectors and regions, equivalent in scale and speed to a new energy-industrial revolution. The driving force in most past radical economic transitions was transformative technology. The economic historian Chris Freeman described five waves of such change (see figure 2.1). His work of the 1960s and 1970s, such as *The Economics of Industrial Innovation*, pioneered the reintroduction of the ideas of Joseph Schumpeter and Nikolai Kondratieff on how radical economic change takes place.[1] He, Richard Nelson, and others effectively rebuilt the study of innovation. These ideas have been expressed in more modern literature using the idea of general-purpose technologies, those with wide applications across the economy, such as those based on coal, electricity, and the Internet.

Change does not, however, come from technology alone. Other economic, philosophical, and political factors may be important too and, some might argue, would be logically prior. Analyses of past transitions, including the UK industrial revolution beginning in the eighteenth century, have emphasized increases in the relative prices of labor; social, scientific, philosophical, cultural, and institutional developments following the Enlightenment; and increases in both cooperation and competition.[2] Such factors could generate an environment and incentives to create and adopt the new technologies, and could be (or initiate) the forces that propel transition forward. In these explanations, policy does not have a central role. That the transitions occurred, however, suggests that public policy and institutions at least did not act in a way that actually prevented them. How far an "enabling environment" was deliberately fostered or created is an interesting subject for research.[3]

While I shall argue that there are likely to be important similarities with past waves of technological change, there are also important differences in the new wave being considered here. First, policy to correct market failure is now central. Second, some of the benefits, while immense, will not immediately be seen by those involved. Many of the benefits of low-carbon technologies accrue, in large measure, to parties other than the user: examples include the reduction in climate risk; increased energy security; greater efficiency; reduced pollution and improved air quality; and the protection of biodiversity and ecosystems.[4] That is why, compared to those that preceded, there is a much stronger, indeed crucial role for policy to manage and accelerate this transition.

There are several relevant and substantial market failures as a result of which markets are not giving efficient signals. This will be a revolution driven by markets and private investment—but *only* on the necessary scale and speed if these investments take place in the context of public policy that helps markets do their job of discovery and resource allocation.

The study of transition in nonenergy sectors can also provide valuable lessons for policy. I have seen at first hand the effects of the green revolution in India in the 1960s and 1970s, driven in large measure by public research and development.[5] One recent study by Henderson and Newell looked at innovation in several nonenergy industries, including agriculture, chemicals, the life sciences, computers, semiconductors, and the Internet.[6] Innovation in these industries was transformational and in some cases very rapid; for example, the prices of personal computers fell by around 35% per year for comparable computing power over the decade to 2002. In each of the sectors, Henderson and Newell identify factors common to the transitions. The first is well-funded and carefully managed research and development programs, including government-private partnerships. We should include here demonstration and deployment as in agricultural extension schemes, which played a strong role in the green revolution of the 1960s and 1970s. The second is rapid growth in demand, which may involve policy to support demand. The third is strong policy to promote vigorous competition, including the entry of new firms and the diffusion of technology.

Beyond the private sector, lessons from past "social" transformations, including the provision of clean water supply and sewerage infrastructure in London, could also be helpful for informing the design of policy, given the "public goods" nature of the low-carbon transition.[7] Often in these cases the recognition of the problem through stark and harsh reality is a crucial factor. In the 1950s I lived through the London smogs that killed thousands from air pollution and sometimes reduced visibility to a few meters. This prompted radical regulation and prohibited untreated coal, with speedy and impressive results.

The nature of past transitions has involved great uncertainty and a period of dynamic and relatively rapid change involving creative destruction (in the language of Schumpeter) where old ways of doing things are destroyed and replaced by new ones. The low-carbon transition is likely to display many similar characteristics: we are likely to see incumbent industries either decline rapidly or invest in an attempt to innovate, compete, and survive; and we are likely to see new industries emerge rapidly. And the political economy of those who may see loss or dislocation in their economic activities can produce strong resistance. There is an important role here for policy to help manage disruptions, from the decline of existing industries to supporting change in those that seek to transform themselves, and to provide appropriate regulation on new industries to lessen instability and avoid bubbles.

3.1.2 Lessons from economic theory

Externalities and market failure

The very brief look at economic history points to the need for a dynamic analysis of public policy to manage the issues of fostering a transition on this scale and at the pace required.

Much of public economics has been focused on "comparative statics."[8] Thus we recognize what is wrong with existing structures and outcomes, and ask what policies could give better structures and outcomes. That is indeed a major part of what is needed from the analyses here, though crucially we also have to focus on the pace of change. We need to build on our existing public economics to make it much more dynamic. Nevertheless much of the existing body of theory is very useful; in particular, the analysis of market failure provides a crucial foundation.

The fundamental problem driving the need for a rapid low-carbon transition is the emission of greenhouse gases. Greenhouse gases impose an externality, meaning they involve an activity with direct impact on the production and consumption possibilities of others. Uncorrected by policy, they are associated with a market failure in the sense that markets do not give efficient incentives for dealing with them. When we emit GHGs we damage the prospects of others, and unless appropriate policy is in place, the emitter does not bear the costs of the damage and disruption caused by the emissions.[9] In other words, markets fail: they generate prices that do not give accurate signals about where to devote resources for their most productive use, and prices do not reflect the true cost to society of our economic activities. GHGs entail a unique externality for several reasons: they are global in scope and impacts; they involve significant uncertainty and risk in the scientific chain of causation; they are long-term; they are governed by a stock-flow process and thus it is difficult to react quickly if mistakes are made; and the effects are potentially huge and irreversible. As argued in *The Stern Review*, "climate change is the greatest market failure the world has ever seen":[10] the impacts are likely to be immense, and we are all involved in both causes and effects.

The GHG externality can be corrected via carbon taxes, cap-and-trade schemes, and regulation. Combinations of all three are likely to be necessary, depending on circumstances. But if it is to incentivize action on the scale required, policy must go beyond the fundamental GHG market failure; this must be examined in the context of a collection of other market failures. Developing a better understanding of these market failures as a group is crucial for effective policy. All too often we hear that all we need is to correct the GHG externality, then all else will follow through market processes. Correcting the GHG externality is indeed fundamental and must be the starting point for policy, but to argue that this is all that is necessary is to fail to understand how markets work and the basic principles of public policy. Not to correct market failure is to undermine markets and to limit the enormous potential they have to drive change. An unwillingness to act on market failure is the anti-market position. However, government failure, such as misdesign, incompetence in administration, a predatory state, and the dominance of vested interests, can also be a serious issue. Policy should be examined from a perspective which includes an understanding of the limits and frailties of public policy and institutions. But the further market failures relevant here are substantial, central to the issues, and cannot be ignored.

Policy for the key market failures

Different market failures point to different instruments as possible remedies. If well designed, the collection of instruments should be mutually reinforcing. Each package requires careful analysis in the context of local circumstances, abilities, and institutions. I cover simple principles only here: application to particular circumstances requires the hard work of serious practical and theoretical analysis.

Six market failures, followed by corresponding policy correctives, are examined here. Their relevance and importance should be clear. I set out briefly the conceptual basis for each of the failures and then examine relevant policies to tackle them. They are: (i) greenhouse gases—a negative externality because of the damage that emissions inflict on others; (ii) research, development, and deployment—ideas, examples, and investigations are "goods" in the public domain that can be disseminated and give guidance to others; (iii) imperfections in risk/capital markets—it is clearly impossible for individuals or firms to borrow or lend as much as they wish, on given market terms, independent of how much they borrow, for reasons of imperfect information, enforcement, collateral, etc.; (iv) networks, related to externalities but with special community and technological structures—these essentially involve a set of coordination issues, since opportunities for any one individual depend on the actions of others; (v) information—during rapid change many will not be aware of possibilities nor of all that is happening; and finally, (vi) co-benefits—many actions on climate change bring benefits beyond market rewards to participants, such as aggregate energy security, cleaner air, and protection of ecosystems.

• *Greenhouse gases*: a combination of carbon taxes, carbon pricing through cap-and-trade systems, and regulation of GHG emissions.

• *Research, development, and demonstration/deployment*: tax incentives for private research, development, and demonstration; feed-in tariffs for deployment;[11] direct public investment and public-private partnerships in R&D institutions. On the research side, R&D issues are important for public policy across the economy, but are of special importance in relation to climate change because of the scale of the risk, the dangers of delay, and the fact that the use of low-carbon discoveries is itself a public good in the sense of reducing emissions. Global R&D energy expenditure is one-half what it was in the late 1970s.[12] On deployment, subsidies and incentives, in particular feed-in tariffs, have been fundamental in promoting investment by driving down renewable energy investment risks and thus technology costs over time. In pure volume of deployment, the successes with solar PV, and potentially its subsequent technology cost reductions (see chapter 2), would likely not have been as quick or effective without generous and robust incentives from feed-in tariffs in Germany, Italy, and Spain.[13]

• *Imperfection in risk/capital markets*: risk sharing/reduction through guarantees or specialist insurance (e.g., political risk or export guarantees), provision of equity, renewable energy support (e.g., feed-in tariffs or market-based mechanisms based on quotas), carbon price supports (e.g., floors). Investors face risks inherent in capital markets by investing in a variety of new situations: e.g., new technologies, new policy environments, new return profiles. Some of the most important risks can be managed, at least to some extent, by the tools above; however, the nature of capital markets means it is impossible to cover all of them. Investors and entrepreneurs will create new business models in the context of the investment climate and opportunities that develop from the move to a low-carbon economy—for example, different models of asset ownership such as leasing for rooftop solar panels.[14] Green investment banks are a relatively new yet important addition to the institutions working on this; they are especially important in this case because of the scale and long-term nature of much of the investment (see section 3.1.5 for more details). More generally, the presence of a national or multinational development bank in an investment will reduce the policy and governmental risk perceived by an investor (see below for further discussion).[15]

• *Networks*: energy (including electricity, gas, and perhaps carbon dioxide in the future), public transport, zero-carbon transport options like bicycles or electric cars, telecommunications (e.g., broadband Internet), recycling, community-based insulation schemes. Networks and related infrastructure are important everywhere, but are especially crucial for the low-carbon transition. National and local government policy frameworks, which place an emphasis on planning and coordination, are prerequisites for such networks to develop and function effectively. For example, adding renewable energy generation requires substantial change in the way networks are operated. Expansion of electric vehicles will require recharging infrastructure. Rapid bus transit systems require careful control of road space and routes.

• *Information*: labeling and information requirements on cars, domestic appliances, and capital goods and products more generally. A demand-side approach to energy will become an increasingly important element of future energy systems, but requires clear information on pricing structures and attributes of systems and machines.

• *Co-benefits*: valuing ecosystems and biodiversity, valuing energy security, regulation of causes of air and water pollution and more dangerous activities. This could reduce pressure on resources that are commonly severely mispriced, such as energy, water, land; it is a basic principle of public economics that policies that reduce demand for underpriced goods are beneficial. That is not a substitute, however, for reforming those prices.

We should not see these policies in terms only of static reallocations or corrections. Policy concerns the dynamics of change and learning. This is about fostering and accelerating a transition to a more attractive low-carbon growth path. Interventions of this kind to correct market failures are pro-market: they are about making existing markets work better, allocating investments more efficiently, and creating new markets. As I have emphasized, failure to act to overcome crucial market failures is anti-market. Thus it is odd to find some of those who understandably champion the virtues of entrepreneurship and competition opposing action on environment and resource management, and failing to understand this basic logic of markets. Of course, governments and bureaucracies can and do make a mess of some policy actions, but the stakes are so high here, and the market distortions so severe, that inaction is likely to be severely distorting and damaging, indeed devastating for those living in the future.

We do not rehearse the detailed arguments on policies relevant to the above six failures, with the exception of a short discussion on carbon taxes and markets toward the end of this chapter. There is a substantial and valuable literature on all of these market failures and policies toward them. We will focus instead on four issues often underplayed by economists: values, standards, institutions, community. Economic history suggests that such issues are central to processes of change.

3.1.3 The role of values

Making sound policy is not just about the analysis and implementation of incentives and/or information in relation to market failures, vital though they are. How social and personal responsibility and values are understood is also crucial. Thinking through the consequences of unmanaged climate change helps us understand not only the evidence but also the values that we bring to that evidence. And public discussion of what constitutes responsible behavior helps us clarify and perhaps change what we think.[16] This may involve setting our own notions of responsibility, rather than gaming the system to extract maximum individual gain. We are more than the narrowly interested, fully informed, instantly calculating, relentlessly maximizing individuals with totally clear objectives assumed by first-year undergraduate economic theory.

Public reasoning on policy and how to behave is itself part of policy as well as part of policy formation. For example, if we realize that our actions can maim and kill, and picture how this might happen, we might change these actions. If we compare an action which risks killing a child today, such as reckless driving, with one which has a delayed action but the same effect, we might regard them as morally equivalent and change our behavior. Drunk driving has decreased not only because incentives (punishments, sanctions) were put in place to take account of the externalities (dangers), but also because we understood that the risks it brings to others as well as ourselves makes it irresponsible behavior. Similarly, more people are willing to adjust smoking habits in response to a growing realization of the possibility of harming others. Other issues on which public reasoning and standards of behavior are part of, indeed central to, policy include alcohol, drugs, health in general, noise, recycling. These are issues on which public policy goes beyond the sticks and carrots of price and cost mechanisms and works, at least in part, via information and discussion. When it comes to GHGs and climate change, information and public discussion can have a profound effect on what individuals see as responsible. Economics has paid too little attention to the role of public discussion of values and responsibility in the making of policy.

3.1.4 The role of standards

Standards, whether mandatory energy performance, efficiency, or emissions standards or building regulations, could be useful in tackling several of the relevant market failures (for example, GHGs, learning and discovery, financial risks, information, co-benefits). Well-designed physical standards can provide clarity and reduce uncertainty, providing confidence to promote investment, a focus for innovation, and scale that can bring down costs.

The setting of strong standards gives great scope for improvement in energy efficiency, in particular standards such as those for new appliances or lighting and building renovations or retrofits. For example, it has been estimated that India could eliminate blackouts within five years, and increase the value of national output by around 50%, through strong energy efficiency standards.[17] New-vehicle emissions standards, particularly in the US (see figure 3.1), have brought remarkable improvements at modest cost. China's expected growth in the next decade could double its GDP, effectively adding another economy: making the new China efficient is of great importance, and standards could play an important role.[18] The design of standards must take reasonable timescales into account, although industries often overemphasize or overestimate how costly meeting those standards will be or how long it might take.[19]

3.1.5 The role of institutions in dynamic change

That there are important imperfections in risk and capital markets is well recognized, if not always well understood. Why in this case might new institutions with strong public involvement be necessary? Why, for example, a "green investment bank" or something similar?

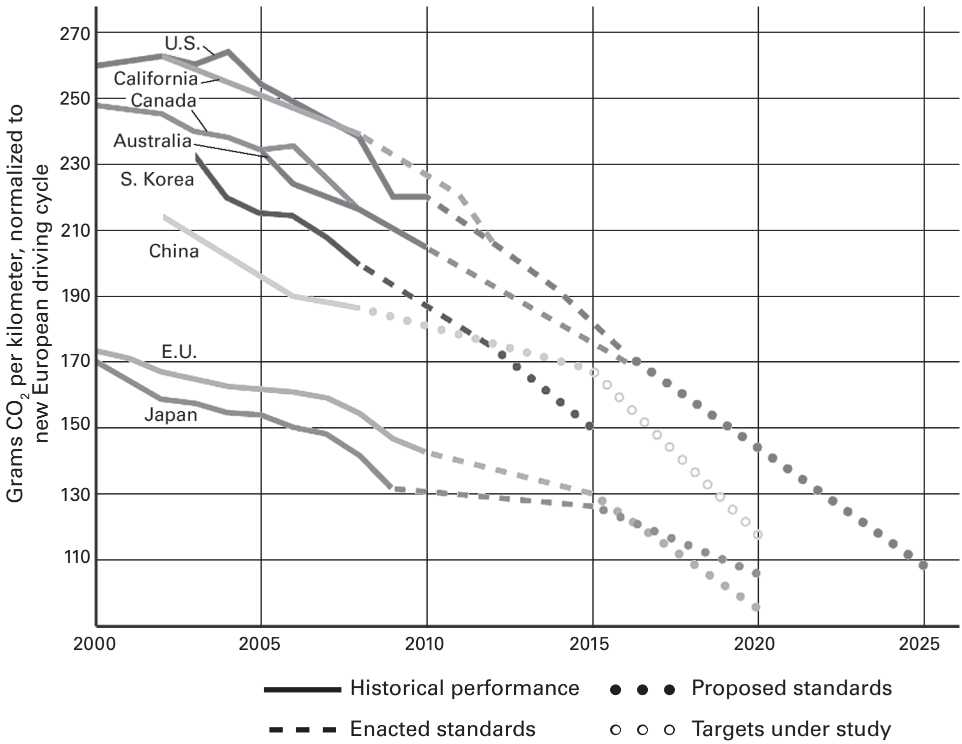

Figure 3.1
Historical CO_2 emissions performance and current or proposed standards (new vehicles) for selected countries. Source: Climate Works (2011b).

A green investment bank differs from existing private financial institutions in five key ways. More generally, these differences also distinguish well-designed development banks, national or international, from private financial institutions. (1) The presence of a green investment bank reduces policy risk (governments are less likely to chop and change policy if a public long-term investment bank is involved in major low-carbon infrastructure projects). (2) It can develop focused banking and sectoral skills in new and important low-carbon infrastructure areas. (3) It has a capital and ownership structure that allows for longer investment horizons. (4) It has the ability to provide a broad range of risk-reducing and risk-sharing products including loans, political risk guarantees, equity, and so on, in attractive and credible packages. (5) It has special convening powers and strong networks to put together different coalitions and sources of finance. A private-sector financial institution might be much more comfortable than a competitor with a green investment bank as convenor.

None of these should sensibly be regarded as a subsidy—they are strengths designed into, and associated with, a particular creative and new institution. They are strengths that overcome market failures, particularly around risk and information. Such an institution, through the transparency and confidence it promotes, can leverage large amounts of private-sector investment, perhaps four, five, or more times the public commitment.[20]

The green investment bank in the UK has set sectoral priorities for investment, including offshore wind power generation; commercial and industrial waste processing and recycling; energy from waste generation; nondomestic energy efficiency; and support for the Green Deal (a program for energy efficiency in buildings). But having priorities should not lead to rigidity: this is an area of innovation and change. It must be ready to identify and take opportunities as a good investment bank does. In doing so, it can wield a crucial instrument of a new and innovative bank: the power of the example. Helping show what works and what does not work will be absolutely crucial in promoting the vital transition to a low-carbon economy.

Policy for dynamic change has much to learn from the experience of the European Bank for Reconstruction and Development (EBRD), whose mandate was, and is, the promotion of a transition to an open market economy in the countries of central and eastern Europe and the former Soviet Union. (The EBRD's area of operation has now expanded to Turkey and parts of North Africa.) I had the good fortune to be chief economist at the EBRD from 1994 to 1999, and had the opportunity to be closely involved with the design and implementation of key strategies and operating principles. I participated directly in putting the five advantages described above to use to promote investment and the change they fostered.

The EBRD's operations are guided by three principles:[21] (1) sound banking, meaning that project returns are commensurate with the risks, (2) additionality, meaning that the investment would not have happened commercially without the Bank's participation, and (3) transition impact, supporting projects where investments and examples help to improve markets and build the institutions and behaviors which underpin the market economy and promote future change. The last of these principles could be replaced by low-carbon or green impact in the case of a green investment bank.

Some might ask whether it is possible to follow the first and second of these principles without subsidy—because with perfect markets a new institution, which was indistinguishable from existing institutions, could not make investments profitably which existing institutions have not already taken. But we all know that capital markets are very far from perfect, particularly in terms of long-term investment and risk, and the new institution has particular characteristics. This means that the intersection of the sets of investments embodying respectively "sound banking" and "additionality" is not empty. This is particularly relevant for the green investment bank.

Together, policies for the GHG externality, research, development, and demonstration/deployment, networks, capital and property markets, information, co-benefits, and so on can, if well directed and stable, and in combination with good institutions (particularly on finance), deliver change.[22] A number of studies find that a portfolio of different policies, some broad and some targeted, can facilitate innovation and lower costs of emissions reductions more effectively than any single policy instrument.[23]

In essence, sound policy + strong institutions + responsible governance + well-functioning infrastructure = a healthy investment climate.

3.1.6 The role of community, collaboration, and networks

The role of the community is often undervalued in policy. Only with the involvement of community can we recycle and reuse. Communities can promote car-sharing schemes or the use of public transport, and give scale to policies such as the Green Deal. Community leaders who install energy efficiency measures and solar power on their rooftop will provide valuable opportunities to share, learn, and discuss. Communities, working as towns, cities, states, or in rural areas, may collaborate to set their own energy or emissions targets and show their feasibility, and thus provide examples which can be a powerful influence on national government policy.

Community schemes are also an excellent way of aggregating efforts. A village could collaborate to produce electricity locally, for example by installing wind turbines or solar PV, and share in the benefits. Other villages may then learn from or copy their model. Community renewable energy projects can promote deployment and overcome objections. Without community involvement even well-designed policy is unlikely to achieve its full potential. In London, Brixton Energy led the development of three solar PV projects on local buildings totaling 134 kW in power capacity; the projects included investors from the community, and a portion of the revenue will be delivered back into the community.[24]

By working with communities and promoting imaginative ideas for sharing benefits (or compensation schemes), local infrastructure projects can overcome opposition in constructive ways. This insight is relevant to a wide range of infrastructure projects at both large and small scales, including for instance energy generation and energy networks. Such projects often face substantial, particularly local, opposition. In France, for example, nuclear or airport projects can come with benefit-sharing/compensation schemes that make them much more attractive to local communities than the compensation possible through the narrow legal structures of the UK.[25] Similarly, in an effort to speed up the deployment of new transmission lines across the country, Germany supports community-led cooperatives to take a lead role in owning shares of the projects and earning a strong return for the local area.

3.2 Policy uncertainty and credibility

Uncertainty and lack of credibility in future policy and institutional and structural systems can have major implications for the pace and scale of investment and innovation. This is true for investment in general but is of special importance where radical change is involved and where investments have long-term horizons and lock-ins. Government policy can be a key source of this risk, but it can arise also from government and institutional structures, including political systems, behavior of administrations and bureaucracies, courts, and so on.

A number of authors have wisely made this point: "Stable rules that are not changed retroactively are a necessary condition in order to provide an appropriate risk-adjusted return to induce private capital to flow to low-carbon investments."[26] Similarly, "The government must convince firms that it will not renege on its promises once investment costs are sunk. A credible carbon policy … solves the time-inconsistency problem and provides … a degree of security that promises will be met."[27] Or from a private investor perspective: "Investors will become increasingly concerned about regulatory risk and thus countries that deploy a transparent, long-lived, comprehensive and consistent (TLC) set of policies will attract global capital."[28] When I was chief economist of the EBRD (1994–1999) and the World Bank (2000–2003), I laid special stress on the investment climate as of profound importance to the quantity and quality of investment and growth.[29] Credibility and consistency of policy are crucial to a good investment climate.

Recent changes to solar feed-in tariff policy across European countries have led to much industry instability. Unanticipated changes in the rules of the game can have serious implications for the future credibility of government policy, including a permanent loss of investor confidence. The solar feed-in tariffs, particularly in Germany, were a great success in terms of the scale they encouraged, driving down costs. Reduction in costs can indeed be a reasonable basis for tariff revision, but it is important that the rules for tariff revision are clear (and as predictable as possible) so that the investment uncertainties that can result from abrupt policy changes are kept to a minimum.[30]

It is not just renewable energy policy that suffers from policy changes. In the 2014 UK budget, the government altered existing carbon pricing policy by freezing the carbon floor price for several years from 2016,[31] in order, it was argued, to protect consumer energy bills. The floor was originally planned to reduce uncertainty for low-carbon investors by supplementing the EU Emissions Trading System price with an additional amount, rising in increments from £16 ($25) per tonne of CO_2 to £30 ($48) in 2020 and £70 ($110) in 2030. Instead, the carbon floor price will be frozen at £18 ($29) until at least 2019/2020. The result is a loss of revenue for the government and puts a question mark over its seriousness about such policies, and thus over carbon prices in the future.

Policy stability does not rule out revision or price changes, but the basis of revision should be predictable, clear, and reasonable. In the UK, perceived policy risk generated by government, on top of macroeconomic uncertainty, is raising the cost of capital and discouraging investment across the economy as a whole, particularly in (but not restricted to) the low-carbon power sector. Major investment in the low-carbon economy on the scale required is unlikely to materialize if there is a perceived risk of policy U-turns. In contrast, credible long-term policy signals could leverage finance and unlock private investment in renewable energy, smart networks and communities, energy efficiency, and low-carbon vehicles on a great scale.

Given that governments may be in power only a few years, we should ask how longer-term commitments could be credible. One answer is institutional.[32] While total certainty can never be on offer, some institutional and legal structures can reduce uncertainty. The Climate Change Committee in the UK is one example, setting out decarbonization targets 15 years or more ahead in the context of legislation which has a 40-year horizon. Infrastructure Australia sets out long-term strategies in a process involving the commitment and participation of the states as well as of federal structures. Similar logic on rules-based approaches and institutions was behind the move toward independent central banks which focus on rules and evidence in setting monetary policy, rather than leaving such policy to the discretion of the minister of finance of the day.[33]

3.3 Setting carbon taxes

Carbon taxes, tradable quotas (cap-and-trade schemes), and regulations are three policy instruments commonly proposed, or currently used, to price or control greenhouse gases. Each has advantages and disadvantages, and choosing among them depends on circumstances. Sometimes combinations will make sense. A key consideration is that the carbon price should be at a level consistent with the scale of ambition, i.e., achieving emissions reductions consistent with a 2°C path. There is a huge literature on these choices, and I will indicate just some of the issues here. In a certain world, at the "optimum," setting a carbon tax or setting a carbon quantity and allowing the market to determine the price would be equivalent. But the world is not certain, and we cannot have both price certainty and quantity certainty.

Carbon taxes, emissions trading, and hybrid schemes

A carbon tax imposes a fixed price on greenhouse gases and provides an incentive to reduce emissions to the point where the marginal cost of emissions reductions is equal to the tax. An advantage of a tax is that it provides some price certainty, which is valued by economic agents.

However, setting the level of the tax in relation to the scale of the ambition is very difficult in practice if we try to set it by following the standard marginal rules in simple economic theory. In principle, we must estimate both the marginal social cost (MSC) of greenhouse gases, i.e., the cost to (world) society of emitting one extra unit of emissions, and the marginal abatement cost (MAC), i.e., the cost of reducing emissions by one extra unit. Basic economic theory suggests that carbon prices should be set where the MSC of greenhouse gases and the MAC are equal; thus the damage from an extra unit of emission just balances the cost of preventing it.

Doing this is fraught with problems. Estimating MACs requires, among other things, assumptions about future technologies and their development. This is very difficult, partly because the pace of technological innovation is impossible to predict and partly because the pace of innovation will depend on the credibility and design of policy, which influences the levels of investment. It also requires governments, which set taxes, to have good information about MACs across the economy.[34]

Estimating MSCs is even more challenging. We must recognize that emissions of CO_2 increase the concentration of stocks of greenhouse gases for a very long period into the future. Thus, the social marginal cost will depend very sensitively on: (1) assumed future growth paths of the economy and of emissions, both of which are highly endogenous in the sense that they are strongly influenced by current and future decisions and cannot be seen as an "external" input into current policy; (2) distributional values both within and across generations; and (3) assumptions on the nature and magnitude of, and presumed attitudes toward, risk and uncertainty. The result is that it is possible to construct a variety of assumptions, all with some plausibility, representing different possible behavior and scenarios that could give a very large range of possibilities for the marginal social cost of emissions. Such calculations can therefore give only very weak guidance to policy. Most importantly, our choice here is not a marginal one. We are choosing between very different paths of growth or decline which will take us in very different directions.

One way round this is to try to guess at marginal technologies relevant to the scale of ambition defined by emissions reductions likely to be associated with a 2°C target. If, for example, 20 years from now, carbon capture and storage (CCS) was likely to be in the activity mix, a future carbon tax sufficient to support that technology could make sense.

An alternative route is a quantity-based quota scheme, which carries, in principle, the advantage of overall certainty about total quantity of emissions.[35] Given that the problem is indeed the level of emissions and concentrations, greater certainty about quantity has theoretical advantages in terms of outcomes. Prices can then be determined as follows. According to rules for their distribution, a fixed quantity of permits is allocated to firms participating in the scheme (usually one permit represents the right to emit one tonne of CO_2e greenhouse gases). These permits can then be traded on a market, with the price of permits or emissions being determined by supply and demand.[36] The price of tradable quotas in the market, like a tax, will provide an incentive to reduce emissions to the point where the marginal cost of emissions reductions is just equal to the permit price. If the firm wishes to emit more than its allocation, it must purchase, at the market price, permits equal to its extra emissions.

The operation of the European Union Emissions Trading System has illustrated some of the problems that can arise. Essentially it was undermined first by an excess of permits, with firms exaggerating their starting-point emissions to gain initial allocations, and then by an unwillingness to adjust quotas downward when the sharp recession of the late 2000s reduced demand. Not surprisingly, prices crashed as the supply of permits was much too high, mismatching the low demand. One way forward to keep down uncertainty and to maintain progress in the low-carbon transition is a carbon floor price, where the carbon price reacts to demand and supply parameters yet is prevented from going below a certain predefined price level.[37] In this way, the policy can operate like a tax (analogous to the floor) within the flexibility of a cap-and-trade scheme. And the revenue is potentially both stronger and more predictable.[38]

Alternatively, Taschini et al. discuss different designs or proposals for the management of the supply of permits to reduce price variability.[39] They argue that a price-based approach is the simplest and most transparent mechanism to make the EU Emissions Trading System responsive to future extreme and unanticipated variations in allowance demand due to changes in economic circumstances and technological advances. The ultimate objective of such a mechanism is to mitigate the impacts of excessive oversupply and undersupply in the market and not to micromanage the market by attempting to identify optimal levels of demand and supply. Clarity, simplicity, and transparency are imperative.[40]

Australia's experiment with carbon pricing is instructive. Though structured as an emissions trading scheme, the legislation provided for an initial three-year "fixed price period" (1 July 2012–30 June 2015), with the price set at AU$23/t$CO_2$e in the first year and rising to AU$24.15 and AU$25.40 in the subsequent two years, respectively (so that it *functioned* as a moderately rising carbon tax). On 1 July 2015, the scheme would have converted automatically to a fully floating price (i.e., functioning as an emissions trading scheme). Economic analysis by O'Gorman and Jotzo of the scheme's effect on the electricity sector during its first two years of operation, when the price was fixed, found that the scheme was effective at reducing emissions:[41] in the National Electricity Market, electricity demand declined by 3.8%, the emissions intensity of electricity supply by 4.6%, and overall electricity emissions by 8.2% compared with the two-year period before the carbon price; and the authors estimate that between 11 and 17 million tonnes of the CO_2e savings (cumulatively over the two years) were attributable to the impacts of the carbon price. Sadly, the scheme was repealed by the subsequent Abbott government in July 2014 due to its ideological opposition to carbon pricing and apparent low level of interest in issues of climate change.

Regulation

Regulation, such as setting emissions or energy efficiency standards to be achieved for certain classes of product or infrastructure, or requiring that certain pollution control technologies be used, can be a direct or indirect means of reducing greenhouse gas emissions. Such regulation imposes an implicit carbon price on affected economic agents, since they incur costs in ensuring that the relevant product or infrastructure meets the regulated requirement. Arguments based on very simple models have suggested that regulation is a more costly means of achieving a desired environmental outcome than market-based instruments, because the marginal cost it imposes on those it regulates will, in general, vary among them. So in principle, under certainty, total costs of the overall amount reduced could be lowered by reallocating reductions on the margin from those with a higher marginal cost of reduction to those with a lower. However, regulations can have major advantages in an uncertain world (the real world) in the form of clarity and predictability. They can generate the investor confidence to enable emissions reductions or technological transitions to be achieved quickly. The relative effectiveness and cost-effectiveness of market instruments relative to regulation depends on a number of conditions, including the scale and nature of uncertainty around future costs and innovations, institutional capacity to operate complex price schemes or enforce regulation, political factors such as the influence of vested interests or ideologies, and the predictability or otherwise of future policy settings.[42] Comparing regulation and price-based policies involves deeper economics than the very simple models based on certainty.

Regulation can be an effective alternative when political constraints preclude the adoption of market-based schemes. For example, with the collapse of the cross-party coalition to support cap-and-trade legislation in the United States, following the House of Representatives' passage of the 2009 Waxman-Markey Bill, the Obama Administration has pursued, among other measures, regulatory approaches through the federal Environmental Protection Agency (EPA). Using its existing authority under the Clean Air Act to regulate pollution, including, as upheld by the Supreme Court, carbon dioxide and other greenhouse gases, the EPA has set regulatory standards for the fuel economy of cars and light trucks, and has developed proposed CO_2 intensity standards for both new and existing power plants (discussed further in chapter 7).[43]

Carbon pricing, "leakage," and border adjustment measures

Some of the prospects for reducing emissions in industry, including increasing energy efficiency, appear to hold great promise. Yet some in industry are resisting change, particularly within countries that are taking strong action to impose carbon prices. There are concerns that this action could lead to "carbon leakage" from relocation or reallocation of production to countries with weak climate or environmental policy, resulting in free-riding and with impacts on industrial competitiveness in carbon-intensive industries, such as steel and chemicals. These concerns are usually exaggerated as there is little evidence of actors, such as industrial firms, moving to "dirty" places after the introduction of climate policy in their current home. Indeed, climate and environmental policies are only one of many determinants of plant and production location decisions.[44]

Competitiveness impacts have been studied extensively, and there is little evidence of significant impacts for most industries.[45] While political movement to place a price on carbon has been slow on a national or regional basis, much of the global emissions are covered by some sort of mechanism. And a potential investor would be looking not only at current policies in a country but at what might be there a decade or two in the future.

As policies on emissions advance, measures can be put in place to assist energy-intensive and trade-exposed industries that may find the transition more costly and difficult, such as free allocation of permits which can be adjusted over time. There is strong evidence of rapidly changing technologies and cost reductions for those who innovate, while industries (and countries) that fall behind may eventually find dirty products shut out of markets. Thus adjustments would need resources to support those who face dislocation because of process changes and possibly to help transitions toward new activities.

These concerns about leakage have nevertheless led some to suggest that countries that remain "dirty" and are deliberately moving slowly in the transition should be subject to "border adjustment measures." These would require importers of energy-intensive goods, where high-carbon or dirty energy is used, to pay an additional tax or to purchase emissions allowances at the border. They might also involve restrictions on the "importing" of offsets and allowances from other trading schemes.[46] The threat of border adjustment measures could provide an incentive for countries with large carbon-intensive industries to take stronger comparable action on emissions. Such taxes have a sound justification in theory—a country refusing to tax or price a costly activity like emitting GHGs is indulging in a covert subsidy. While border adjustment measures could serve as a cover for implicit protectionism, their justification in theory should not be doubted. Neither, in my view, should be their potential to accelerate a badly needed radical change.

3.4 Technological progress within hydrocarbons: the implications for climate policy

We saw in chapter 2 that technical progress in low-carbon technologies had, in some cases, been very rapid and that more is likely to be on the way. But technical progress occurs in hydrocarbons too. We also briefly described recent advances in fracking that have led to a natural gas boom and relatively low US wholesale gas prices. Technical advances are likely to go beyond gas and would be a factor in lowering prices across many forms of hydrocarbons relative to what might otherwise be the case. For example, fracking technology can also be used to recover oil that was previously too hard and costly to extract, and there have been advances in methods for extracting oil from oil sands. Of course, whether prices actually fall in the medium term depends both on demand and on climate change policies, among other things.

Relatively low gas prices from fracking in the US have seen a switch away from coal and falls in US emissions. However, at least in the short run, the switch may have little impact on global emissions—there is evidence the US is exporting cheap displaced coal to Europe, where it is substituting for more expensive European gas.[47] Further, as discussed in the next section on unconventional gas, leakages of gas in the process of extraction and use can offset its advantages over coal at leakage rates of around 3%, which is less than leakages observed in some examples.

A concern is that new extraction processes, for instance unconventional oil, are themselves more energy-intensive than conventional approaches, given the energy (and water) needed to extract usable resources. A study by the Post Carbon Initiative on unconventional shale or tight oil reported that while new conventional oil returns 25 units of energy for every one unit invested, oil sand returns only 3–5 depending on the extraction method.[48] And there are also suggestions that the low energy return is linked closely with higher carbon emissions than conventional processes.[49] Extraction of oil from sands requires the injection of steam into the sands to reduce the viscosity of the oil. In Canadian oil sands projects, the steam is produced by burning gas "uncaptured."[50]

All this discussion of advances in hydrocarbons must keep in mind the constraint on extraction and use of hydrocarbons, the problem of so-called "unburnable carbon."[51] Progress that leads to more efficient and less emissions-intensive use of hydrocarbons can help us, but if that advance only leads to increased extraction we will have to decide between leaving the hydrocarbons in the ground, missing global emissions targets, or moving CCS much faster than seems to be the case currently.

Advance in the incumbent industries is a common feature of past energy-industrial revolutions: innovation in sailing ships accelerated as the steam engine transformed the shipping industry, for example, although sailing ships ultimately lost out. In this revolution, as competition from the alternative low-carbon technologies increases, the incumbents are likely to innovate. They are also likely to accelerate the extraction of fossil fuels in anticipation of future stronger carbon policies. This effect has been called the "green paradox,"[52] and has led some to argue for the superiority of quota- and quantity-based policy approaches over price-based approaches.

When combined with the need for strong emissions reductions, technical progress in hydrocarbons has several implications for policy.

First, if hydrocarbons become cheaper, this implies the need for a higher carbon price and a more stringent regulatory/policy mix to maintain the emissions reductions required for a given climate-responsible path. However, a carbon tax that is expected to rise rapidly in the future to ensure that global emissions budgets are not exceeded may create an incentive to accelerate extraction of hydrocarbons further in the near term, amplifying the "green paradox." Raising the price quickly now would be an answer. Thus, a carbon trading scheme with a strong quota can help.[53] Hydrocarbon rents could then, to some extent, be defended by moving strongly on CCS and lowering its cost. A strong carbon trading regime also has benefits for national treasuries and for the public from the increased revenues it will generate (from price floors or auctions of permits).

A second factor is the problem of unburnable carbon (as a reminder, to achieve a 2°C path only around 30% of current known reserves, totaling around 2,800 billion tonnes of CO_2, can be burned "uncaptured" between now and 2050, with some suggesting a more cautionary 20%).[54] With exploration and future proving of reserves, the fraction that can be used will fall further. This is likely to have serious implications for valuations of these reserves, particularly for coal and oil firms, and interesting work is being done on finding out what impact it could have on the companies and governments who own or control these resources. For example, HSBC provides estimates of the "value at risk" for major publicly listed European hydrocarbon companies under the

"30% uncaptured" scenario. Among these they find that Statoil has the highest exposure to potentially unburnable oil reserves.[55]

In a similar fashion, the Carbon Tracker Initiative has been focusing efforts on increasing public understanding of the impact that a carbon budget can or should have on investor decisions and the valuation of companies. Their 2013 report looks specifically at the risk of wasted capital and stranded assets given the carbon budget.[56] As I said in the foreword to this report, "smart investors can see that investing in companies that rely solely or heavily on constantly replenishing reserves of fossil fuels is becoming a very risky decision."[57] These types of analysis suggest the investment community is starting to recognize the threat to value, or value-at-risk, from the carbon constraints implied by a 2°C path. Cost reductions in extracting hydrocarbon and increased extraction will make the fraction that can be used unabated still lower. But at present, hydrocarbon valuations in the world market seem to be operating on the assumption that climate policies will be very weak and medium-term carbon prices close to zero, which is a stance also, apparently, shared by the world's largest publicly traded oil and gas company, ExxonMobil.[58] Essentially they are arguing that while their valuations of their assets would be contradicted by sensible climate policies, they are banking on the failure of good sense on the climate front. If that assumption is right, the world is headed in the direction of deeply dangerous climate change. If that assumption is wrong, as I hope it will be, then valuations will have to change radically.

Third, advances in hydrocarbons, when combined with emissions constraints, have implications for the development and deployment of carbon capture and storage. These advances strengthen the case for CCS considerably, especially if governments act to promote hydrocarbons and are slow to implement a policy mix consistent with a responsible emissions path.[59] For the medium term, the IEA assumes CCS costs of $35–50 per tonne of CO_2 avoided for coal-fired power plants and $53–66 per tonne of CO_2 avoided for gas-fired plants.[60] CCS costs are higher than that now, so substantial and credible carbon prices would be required to accelerate deployment. An alternative would be to mandate CCS across a range of industries, including power; it would likely generate a rapid fall in costs of CCS. The IEA estimates that around 3,000 large-scale CCS projects need to be operating by 2050, yet the pace of deployment this implies seems improbable, given current rates of progress. To get there, much stronger and more credible policy, whether it be a carbon price, mandating, increased R&D funding, or enhanced planning processes (or likely a combination), is needed to promote extensive deployment, innovation, and learning and drive the costs of CCS down.

Fourth, cheaper hydrocarbons could displace currently more expensive low-carbon sources if carbon prices are low and policy to promote low-carbon alternatives lacks credibility and clarity. There are difficult questions here around which low-carbon technologies should be supported via, say, direct assistance or feed-in tariffs to help tackle market failures around R&D or capital markets. One answer is to foster a broad range of technologies, since there are advantages in diversity when the pace of technical advance and cost reduction are hard to predict. Another perspective is to focus on establishing a strong carbon price and let markets decide on the low-carbon technologies that come to market. That should be an important part of the story, but we have seen that carbon prices can be unreliable, and the market failures are not simply around emissions. Or perhaps greater regulation is required, through renewable targets, for instance, which tilt in favor of technologies with low running costs, low pollution and risk to populations, and which may run into less political opposition than, say, CCS. In my view, a combination of these three approaches—strong support for a portfolio, a stronger carbon price, and stronger regulation—makes sense, although the balance is likely to vary with political and economic circumstances.

Fifth, advances in hydrocarbons still further strengthen the already very strong case for removal of fossil fuel subsidies. Such subsidies have a number of severely damaging economic impacts, including encouraging overconsumption, crowding out or preempting more worthwhile public spending, and depressing private investment.[61] They are also in many countries regressive, with middle and upper classes benefiting more than poorer groups.[62] Reforms to reduce these subsidies would have many benefits, including improving fiscal positions of governments.

Global fossil fuel subsidies are difficult to measure, as support is provided in a range of complex ways, including through tax concessions, rebate schemes, and price controls. The international Organisation for Economic Cooperation and Development (OECD) has produced estimates for its member countries (mostly developed) by examining budgetary transfers and tax expenditures relating to fossil fuels, and suggests these are likely to have been in the range of $55–90 billion per year over the period 2005–2011.[63] The IEA and IMF also produce fossil fuel subsidy estimates using a price gap method, which measures the difference between domestic fuel prices and an international reference price.[64] The IEA estimates worldwide fossil fuel subsidies at $523 billion in 2011, up from $412 in 2010.[65] The IMF estimates subsidies at $480 billion in 2011.[66] The IMF extends its analysis by accounting for negative externalities from energy consumption, e.g., from emissions, which are priced at $25 per tonne CO_2 (a very low estimate),[67] and road congestion, accidents, etc., which push up "subsidies" in rich countries. On this basis, fossil fuel subsidies are estimated at $1.9 trillion (the equivalent of 2.5% of global GDP and 8% of total government revenue). The extension of the IMF calculations is theoretically sound: to allow something for free that is very costly in terms of damages to others is quite reasonably described as a subsidy. If congestion pricing were to be introduced, then the subsidy estimate would be revised accordingly.

On a more regional basis, the EU recently estimated that fossil fuel subsidies across the 28 member states had been approximately €10 ($12.5) billion per year in the period 1970–2007 and averaged €14 ($17.5) billion in the period 2008–2012.[68] Similarly they estimate external costs from generating electricity from different technologies, such as depletion of natural resources or impact on climate change. In 2012, these external costs totaled €200 ($250) billion. The same report suggests that indirect/external costs for coal-fired generation could be of the same magnitude, or more, as the direct costs of generation.[69]

At the same time, there is an important role for supporting low-carbon technologies to promote innovation and learning and unlock investment for deployment; the support would be designed to correct the market failures associated with the publicness of learning and problems of capital markets. For instance, solar PV learning rates (and thus cost reductions) improved massively after solar PV was first deployed on a large scale in Germany, Italy, and Spain, before being rolled out to a greater extent in China (see chapter 2). Such supporting measures should be seen as interim measures while carbon prices, networks, supply chains, and skills are built.

Worldwide subsidies to renewable energy technologies are far lower than subsidies for hydrocarbons. They were estimated by the International Energy Agency at $88 billion in 2011, an increase of 24% on 2010, and around $45 billion in 2007.[70] Of the 2011 total, solar PV, bioenergy, wind (offshore and onshore), concentrated solar power, and other electricity-generating technologies accounted for $64 billion, and biodiesel and ethanol production accounted for the remainder.[71] The level and nature of support for renewable energy are a matter for both decision and research, but the arguments in favor of strong support are powerful.

We have seen that the combination of technical advances in hydrocarbons and the urgency of action on emissions reductions points in strong policy directions, embodying a strong carbon price or its equivalent, because of the way hydrocarbon cost reductions may prolong our reliance on fossil fuels. It warns again and more strongly of the problem of unburnable carbon and overpriced resources. It strengthens the case for pushing ahead with the development and cost reduction of CCS. It underlines the case for supporting renewables. It strengthens the case still further for removing fossil fuel subsidies.

At the same time, we should recognize that a switch from coal to gas, for which technical advance has been strong, could lower emissions in the short run and has done so in the US in the last decade. Some have referred to gas as a bridge from coal to a low-carbon future. There are a number of important issues here, some of which are examined in the following section.

3.5 Unconventional gas

Unconventional gas has loomed large in public discussion in recent years. Views about unconventional hydrocarbons, particularly involving "fracking" for shale gas, vary widely but are also changing. Two contrasting perceptions of unconventional gas are common.

On the one hand, many see unconventional gas as holding great promise for reducing emissions in the electricity sector, largely based on the role it has played in the US in recent years. In the US, the share of gas in electricity generation increased from 19% to 27% between 2005 and 2013, and the share of coal decreased from around 50%

to 39%.[72] The impact on US energy-related emissions has been substantial: although CO_2 emissions from gas in the period between 2005 and 2013 increased by 18%, total emissions from fossil fuels fell by around 10%.[73]

It is important, however, to examine carefully the causes and implications of these changes. Unconventional gas was only part of the cause. The rapid transition in the relative shares of coal and gas in the US energy mix was made possible by falling domestic gas prices due to the unconventional gas boom, but also by stronger Environmental Protection Agency regulations on emissions from coal, and by spare gas generation capacity on the network.[74] Similarly, the change in US emissions over that period is difficult to connect with any one factor alone. It is likely to have been caused by a combination of decreasing energy demand caused by economic recession; high prices of coal; fuel switching in the power sector from coal to both gas and renewable energy; and stricter emissions and fuel efficiency regulations on transport and buildings.[75] Growth in US renewable energy investment and renewable electricity generation, for example, has remained particularly strong over this period of increased unconventional gas use, influenced in part by renewable portfolio standards in 29 states and renewable energy tax credits. Viewed as a whole, the US example demonstrates that changes in the relative prices of gas and coal (in this case driven mainly by technological advances in unconventional gas), accompanied by strong regulation and policy, can lead to rapid transformation of a sector, notwithstanding long-lived and locked-in capital. But gas was only a part of the story of emissions reductions.

On the other hand, many see unconventional gas as a problematic energy source for a number of reasons. In particular, there is growing attention at the local level to potential environmental impacts of unconventional gas drilling, including water pollution from faulty well construction, fracking fluids, or gas migration; leaks and spills from surface operations; earth tremors; methane leakage from wells and emissions of ozone precursors, diesel fumes, and other hazardous pollutants from operations; land disturbance from operations with large numbers of wells required; and noise pollution and local traffic congestion.[76] Moreover, fracking uses water very intensively and can thus accentuate water shortages in some regions and add to problems of water mispricing.

Where water is transported by trucks, there may also be difficult congestion and noise issues.

Some in government and business and some public commentators see these risks as manageable and support the rapid development of unconventional gas; others see them as insurmountable barriers. As with other technologies, key issues and claims should be considered carefully. Let us consider, in turn, three arguments commonly made for promoting unconventional gas (focusing on the potential role of gas in the low-carbon transition): (1) unconventional gas will lower gas prices and energy costs; (2) a gas-for-coal switch can play a major part in the emissions reduction story; and (3) unconventional gas will come online rapidly and act as a bridge to low-carbon energy.

1. "Unconventional gas will lower gas prices and energy costs."

New lower-cost sources of production of a commodity will lower prices relative to what might otherwise have occurred. But that does not imply that prices everywhere will fall radically relative to what we see now. There is great uncertainty around future supply and demand and the structure of gas markets. It is reasonable to suppose that these markets will become more global and see prices converge. This introduces large uncertainties into future price forecasts.[77]

Gas prices in the US, for example, which are currently low due to the shale gas boom, are expected to rise (see figure 3.2) as domestic demand increases and gas becomes more tradable. The extent of the rise is very uncertain and will depend, in part, on whether and how rapidly the US reenters the global market. The IEA suggests the US could begin exports of liquefied natural gas to Asia as soon as 2015,[78] where prices are much higher at around $14–16 per mmBtu, compared to around $3.50–4.50 per mmBtu in the US today (2014).

Outside the US, gas is internationally traded and the price is set in international markets.[79] Extra production in a single country, for example the UK, is unlikely to have a huge impact on prices in that country unless the producers discover a new resource that is economical to extract and so large that it strongly depresses the world market price (this is analogous to prices in global coal and oil markets). A rush to build new gas plants for electricity generation may see countries like the UK locked into highly uncertain international gas prices for decades to come.

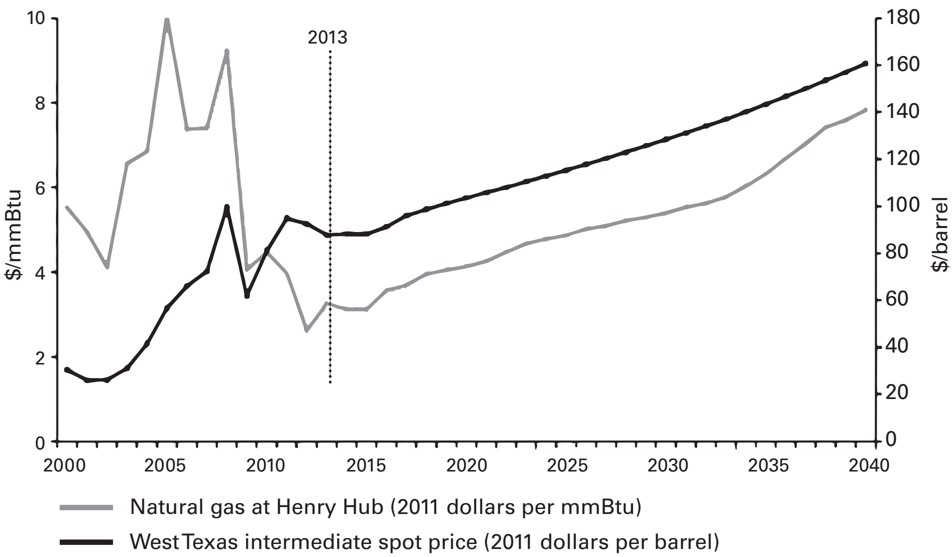

Figure 3.2
US oil and natural gas prices, historical and projected. Source: EIA (2013).

It is also not clear what the extraction costs for unconventional gas are likely to be in different countries. As with oil extraction, marginal extraction costs will differ by location. Some areas will have a high marginal cost of extraction (perhaps Western Europe) and others a low marginal cost (the US). We have yet to discover the extent of sources with low marginal cost. And politics will look different in different places; for example, because concerns differ on local environmental impacts, with tougher regulations likely to raise extraction costs and impact prices.

2. "A gas-for-coal switch can play a major part in the emissions reduction story."

An illustrative calculation indicates what a switch (shutting down all coal worldwide and replacing it with gas) could save in CO_2 emissions per annum. Total CO_2 emissions from fossil fuel combustion were around 31 billion tonnes in 2011.[80] Electricity and heat generation emits 13 billion tonnes CO_2 per annum, and of this coal accounts for 9.5 billion tonnes per annum. Per unit of energy generated, gas emissions are around 50% those of coal (ignoring, for the moment, life cycle emissions, which are discussed below). If all coal is replaced by gas, we could cut emissions by 4–5 billion tonnes CO_2 per annum. For a 2°C (50–50 chance) path, global CO_2 emissions from energy need to fall from around 30 billion tonnes per annum today to around 25 billion tonnes per annum by 2030.[81] Therefore gas for coal could make a very significant contribution to the necessary reductions. Considering all global greenhouse gases (measured in CO_2e) across all sectors and over the longer term, the percentage contribution is much smaller. For a 2°C path, global emissions need to fall from around 50 billion tonnes CO_2e per annum today to below 35 billion by 2030 (and to well under 20 billion by 2050); gas for coal could contribute only about a third of the necessary reductions to 2030.[82]

Importantly, the above calculations do not include the life cycle emissions from gas, which can be much higher depending on the amount of methane that escapes from the upstream processes of drilling and piping the gas (i.e., the amount of "fugitive" emissions).[83] Estimates of leakage rates vary and there is a lack of reliable data,[84] but fugitive emissions from the conventional gas life cycle have been estimated at between 1.7% and 6% of total production,[85] exceeding methane emissions from coal 3.2–11.3 times.[86] For unconventional gas, fugitive emissions have been estimated at 30–50% higher than those for conventional gas (at 3.6–7.9% of total production). These estimates are being actively debated and examined.[87] The emissions advantages of gas over coal could be canceled out if leakage of methane were more than 3% of total gas production.[88] Thus the advantages, in terms of GHG emissions, from coal to gas appear to depend very sensitively on the ability to control leakage. They also depend on how quickly gas could come online, to which I turn now.

3. "Unconventional gas will come online rapidly and act as a bridge to low-carbon energy."

Whatever the potential role of gas in reducing emissions once it has come online, in considering the role of gas in any low-carbon transition we must also consider issues of timing and sequencing. Outside of the US, shale gas is unlikely to come online rapidly. The US shale gas boom took three decades to develop, and there were fewer constraints—geographic, legal, economic, and political—than are likely to be faced in Europe. Nations such as France and Germany have banned fracking, and high population density in Europe implies that it would be difficult to move rapidly from drill site to drill site as each well is depleted; such movement has been a feature of the US experience.[89] Shale gas that comes online twenty years from now would be very late to be an effective bridge given the urgency of reducing emissions. Twenty years from now we will have to substitute lower-emissions technologies for gas, or apply CCS, if the necessary emissions reductions are to be achieved. And, as argued in chapters 1 and 2, strong action in the next twenty years is crucial to achieving a path that avoids dangerous climate change.

There are, therefore numerous grounds for questioning whether gas will be a source of emissions reductions on the scale, within the time, and at the price that would justify the more optimistic claims made about its role in a low-carbon transition.

We can be sure, however, that if unconventional gas is to play any significant role in emissions reductions, the climate impacts (e.g., upstream fugitive emissions) and the local environmental and social impacts will need to be very well regulated and managed. With this in mind, the IEA released a set of "Golden Rules" to ensure that unconventional gas is developed in an "acceptable" way.[90] These stress the importance of strong regulatory and policy controls; transparent reporting, measuring, and monitoring of impacts on the environment and local communities; and choosing drilling sites carefully to avoid methane leakage.

Finally, it should be noted that *conventional gas* has a significant role to play in the future energy mix over the next two or three decades, particularly as backup source of supply for variable renewable energy. But there is a danger of overreliance on unabated gas. Locking in to unabated gas for decades to come could be very costly both in terms of gas prices and the climate. Lock-in to gas may also reduce energy security, possibly increasing reliance on imported energy, when the origins of large fractions of supply lie in places that may be seen as politically difficult or unstable. Diversity of energy sources, from a variety of locations and technologies, is valuable in the face of uncertainty. Diversity should include wind and solar, which are very secure geopolitically, have zero fuel costs, and are low-carbon. And diversity should also be understood to include the demand side and a more efficient use of energy in the first place. While, if managed well, a switch from coal to conventional gas could be a worthwhile part of the story, it cannot be the dominant focus of emissions reductions. If it does become the main focus, we risk, from lack of attention elsewhere, locking in emissions at levels inconsistent with carbon budgets.

3.6 Sources of energy: perceptions of risk and public support

Embracing a broad range of technologies for the transition makes sense. We cannot predict with certainty how costs will change. Different technologies provide different energy profiles—for example, nuclear provides primarily base load—and contribute to a system in different ways. Ruling out technologies may turn out to raise costs of the transition in the longer run and increase vulnerabilities. A portfolio approach seems wise. But support for some low-carbon technologies can change, as can perceptions of their risk. The Fukushima Daiichi nuclear disaster in 2011 shifted public perceptions on nuclear power across the world, with major adjustments to energy policy in some countries in the weeks and months following. Public opposition to nuclear energy in Italy and Germany strengthened considerably; Germany decided to close several older nuclear plants immediately and committed to a total phase-out of nuclear by 2022. In Italy, a referendum on nuclear energy was held just months after Fukushima, with 94% of the electorate (in a high voter turnout of around 55%) voting for a ban on the construction of new plants.[91]

Evidence suggests that changes in attitudes and perceptions following events like Fukushima may be temporary.[92] Whether opposition proves to be temporary or persistent, rapid policy adjustments caused by such events may have wide-ranging and often unexpected implications. Germany's policy shift has seen greater coal use. And as more nuclear plants shut over the coming years, it is likely that coal will fill a large part of the gap, with 12 new plants planned by 2020. The lesson is that a relatively rapid phasing-out of low-carbon plant (here nuclear) has significant implications, with, in Germany's case, increasing emissions and possible medium- or long-term lock-in to unabated coal.[93]

It is important to consider risks associated with different technologies carefully. Energy-related accident and fatality statistics are one indicator of risk. Over the period 1969 to 2000 there were around 20,300 fatalities from accidents in the coal industry and 20,200 fatalities in the oil industry.[94] The burning of coal is likely to be responsible for millions of deaths per year from air pollution.[95] Hydroelectric power was responsible for around 30,000 flooding deaths in one incident when the Banqiao Reservoir Dam in China failed in 1975. In comparison, over the same period, Chernobyl was the only severe nuclear accident, with around 35 direct fatalities.[96]

Attitudes toward low-carbon technologies are also shifting. There is evidence of increasing support for renewables. For example, a UK Department for Energy and Climate Change survey in March 2013 revealed slight but steady growth in support for renewable energy sources to provide the UK's electricity, fuel, and heat, remaining firmly between 79% and 82% over the four previous quarterly surveys.[97] However, support should not be taken for granted as resistance to some renewable energy technologies remains, particularly to onshore wind, where objections largely concern impacts on landscapes, wildlife, and habitats.[98]

At the same time, awareness of and support for less visible low-emissions technologies, such as CCS, is low. This is in spite of the expectation that CCS could be important in the future, although it is currently some way from being commercial at current carbon prices. Awareness of CCS in the UK increased from 36% in the first quarterly Department for Energy and Climate Change survey to 41% in March 2013, and only 57% of those aware of CCS support its use in the UK.[99]

In general, people round the world seem not to be well informed about the roles, pros and cons, and risks of different technologies. The choice among them and the related choices of the pace of decarbonization are crucial issues. There is a profound responsibility to try to promote serious and informed debate, in particular one that looks at the risks of different technologies, and indeed of climate change. That responsibility lies, among others, with political leaders, schools and universities, religious leaders, civic organizations, and the media.

3.7 Unlocking energy efficiency potentials

Energy efficiency is the most powerful area for action for emissions reductions: as we saw in chapter 2, the IEA has suggested that energy efficiency is likely to account for close to 40% of the total cumulative emissions reductions required through 2050 for a 2°C path.

There is great scope for action across countries and sectors, and progress is already evident.[100] But the first question to ask on energy efficiency is the following: If resources can be saved at modest cost or effort in relation to the savings, then why are people not already taking the opportunities? Action to improve energy efficiency faces many challenges and has, in many cases, been slower than hoped.[101] There are many barriers and market failures that prevent faster action.

Some commentators[102] have provided a taxonomy of energy efficiency barriers, based on a literature review and extensive surveys, grouping them into three broad categories: economic, behavioral, and organizational. Economic barriers include unevenness in the effectiveness of energy-efficiency technologies (they are not cost-effective in all applications, or returns on investment are hard to evaluate from a cost savings perspective); hidden costs (e.g., management time and information-gathering costs); perspectives on risk that encourage high risk aversion; high private discount rates; and a range of market failures (caused by imperfect market information, split incentives, adverse selection, principal-agent relationships).

Behavioral barriers include bounded rationality (i.e., cognitive limitations), myopia in instinctive preferences for the immediate, narrowness of values, inertia, lack of trust, and weak ability to process information. Often these combine to constitute a general reluctance to take decisions, or create a desire to take decisions to avoid the "bother."

Organizational barriers in firms include those around lines of responsibility (the person responsible for energy efficiency may lack power, funds, and management support), and there may be a nonsupportive organizational culture. Nonetheless, there are many examples of some of the world's leading-edge companies successfully incorporating environmental and sustainable thinking into their core business strategies.[103] Organizational barriers in local implementation can include failure to coordinate within a neighborhood when such coordination can provide major economies of scale, for example by insulating a large number of buildings. There are further organizational issues around the need to integrate complementary services necessary for action: for example, insulation can require coordination of building services, finance, local government, technical advice, energy suppliers, and so on.

Policy can tackle many of these barriers. It can include regulation, provision of information, and economic instruments.[104] These often need to be combined if they are to be effective. In 2011, the IEA provided a list of 25 energy efficiency policy recommendations, including mandatory building codes, regulations on lighting, and standards on appliances regarding fuel economy and appliance labeling.[105] In 2013 this list was narrowed to four policies with the greatest potential for rapid action, where barriers are lower and where some success is already evident: minimum energy performance standards for new heating and cooling systems in buildings; fuel economy standards and labeling for new light-duty vehicles and freight trucks in road transport; minimum energy performance standards for more efficient appliances and lighting in residential and commercial buildings; and standards for more efficient electric motor systems in industrial applications.

Private firms can innovate to try to overcome problems of coordination and scale. Energy efficiency companies provide some specialist services. Local authorities can help coordinate to generate scale economies. Private, or green, banks can provide information, coordination, and finance. Financial institutions such as green banks can help channel finance on a larger scale.

Given the great potential for energy efficiency together with the slow take-up, the study of ways of accelerating action is of the highest priority. Good examples will be key. So too will be a deeper understanding of the obstacles.

3.8 Nonenergy sources

Emissions from nonenergy sources, such as land use change and forestry, agriculture, and waste, account for around 30% of global emissions (see figure 2.2). Action across these sources and across all countries is vital to emissions reductions on the scale required; a focus only on energy could not be sufficient.

As we saw in chapter 2, there are many opportunities for emissions reductions across nonenergy sources, such as in agricultural practices. Reducing deforestation (and also restoring degraded forests) is one of the cheapest emissions reduction options. With global emissions from deforestation at roughly 5–10 billion tonnes of CO_2 per year, and the average cost of avoiding deforestation at around $20 per tonne or less, this implies a market worth potentially over $100 billion per year. Around a quarter of these emissions could be avoided at around $5 per tonne of CO_2 or less, making this a cheap abatement option.

There are also opportunities to reduce emissions from waste, e.g., capture of methane from landfill and from farm digesters (tanks that hold animal waste) that can be used to generate heat or electricity or to power vehicles; opportunities to reduce fugitive emissions, such as from gas production (estimates show that the US natural gas industry loses more than $2 billion per year through leaks and venting);[106] and opportunities to reduce emissions from industrial processes. The UK has been particularly successful here, mostly through technical advances that sharply reduced nitrous oxide emissions in adipic acid production (mostly used in nylon production).

Examples of actions and related policy were set out in chapter 2, section 2.5, and will not be repeated here. Important policy elements are agricultural extension to raise productivity and the understanding of new methods, public infrastructure for working with water and erosion control, working with local communities to create participation in forest management, and so on. International financial assistance can play an important role, including carbon payments for forest protection and expansion. Throughout such policies it is important to recognize that actions for mitigation, adaptation, and development/poverty reduction are likely to be interwoven, as we saw in section 2.8. These are vitally important areas for development and for the climate, and our brevity of treatment here should not be taken in any way as suggesting any lack of importance: on the contrary.

3.9 Conclusions

If adopted in a transparent and stable manner that provides investors and entrepreneurs with long-term confidence, the right climate policies will likely trigger exciting new waves of global investment, innovation, and discovery. This transition to a low-carbon economy would, in many respects, constitute a new industrial revolution. The economic policies to accelerate these changes and guide the critical next decades are fairly clear. But just as we learn about technologies, organization, and design along the way, so too will we learn about policies. Since *The Stern Review* was published in 2006, the world has had a great deal of experience in what constitutes good and bad, or more or less effective, policy.

In summary, the lessons we have learned from this chapter are:

- The Schumpeterian perspective on the history of economic change should be central to our understanding of the role of policy in tackling climate change. Policy, from this perspective, has a crucial role to play in accelerating the energy-industrial revolution that is necessary if the world is to tackle climate change efficiently and effectively, and in managing the effects of this revolution so that its benefits (and costs) are fairly shared.
- An important role of policy is to make markets function better. On climate change, this means identifying the various sources of market failure associated with climate change and its mitigation. There are six key market failures: (i) greenhouse gas externalities; (ii) publicness of ideas, including R&D; (iii) networks; (iv) capital markets, especially for the long term; (v) information in a world of changing technologies; and (vi) co-benefits, such as to health and ecosystems.
- Specific policies and institutions for reducing emissions should include a combination of carbon pricing (carbon taxes and/or emissions trading); regulation and standards; support for innovation across the innovation chain, from basic research through to the deployment of low-carbon technologies; provision of network infrastructure (public transport systems, smart electricity grids, electric vehicle charging infrastructure, etc.); institutions (such as green investment banks) for overcoming failures in capital markets and thereby promoting the flow of finance for low-carbon investment; labeling on appliances and other methods of facilitating information; and regulation for local health efforts and environmental damage, promoting better agriculture, land, and water management, forest programs, and so on.
- Much of the transition will be driven by private investment, but that investment is threatened by government-induced risk. Policies, governance, and institutions create a risk-return balance on which investors/participants decide to act or not. Government-induced uncertainty all too often stalls, or jeopardizes, investment and innovation. This is particularly important in a transitioning economy, where investors will face

a variety of new situations: e.g., new technologies, new policy environments, new return profiles. Risk and uncertainty will always be present, but governments can and should design and implement policies in a way that attempts to reduce uncertainty. And institutions and policies can indeed be designed and shaped in a way that fosters a low-carbon and energy-efficient transition and brings down risk.

- Technological advances in hydrocarbons are inevitable, and have the potential to make the transition to a low-carbon economy more challenging—for example, by expanding hydrocarbon reserves still further beyond the amount that can safely be burned unabated. Advances in unconventional gas may have some role to play in reducing emissions (relative to coal-fired power generation), but optimistic claims about the extent of this role should be subject to careful scrutiny. In particular, the significance of unconventional gas in reducing emissions will depend strongly on the adequacy of controls to prevent methane leakage, on the acceptability to local communities of the environmental and social impacts of unconventional gas operations, and on future trends in gas prices.

There is no single policy that can deliver the emissions reductions necessary—there are multiple objectives and market failures that policy must tackle. However, we can already see the appropriate combinations to begin the acceleration of change that is necessary. We have much more to learn, but we understand enough to put in place the policies that can drive the transition.

Why Are We Waiting?

The Logic, Urgency, and Promise of Tackling Climate Change

By: Nicholas Stern

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