



The Role of Economic Policy in Climate Change Adaptation

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Abstract

This paper assesses the role of the public sector in adaptation to climate change. We first offer a definition and categorisation of climate change adaptation. We then consider the primary economic principles that can guide the assignment of adaptation tasks to either the private or the public sector, as well as those guiding assignment within the public sector itself. We find that the role of the state in adaptation policy is limited. We identify information policy, the provision of a suitable regulatory framework in some markets, the formation of human capital and policies that foster economic growth and technological and medical knowledge as the main areas in which the public sector has a role in climate change adaptation.

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1. Introduction

Global warming and its implications are considered among the largest and most important threats to mankind in the 21st century. The topic rightly receives considerable attention by the media, politicians, academics and researchers, and it is the focus of institutions such as the Intergovernmental Panel on Climate Change (IPCC). Periodic International Climate Summits have also been established to study the problem and to discuss solutions.

Much of the debate has centred on questions such as whether climate change is already on its way, whether climate change is manmade, what the likely consequences of climate change are and whether climate change can be avoided by a reduction in greenhouse gas emissions. Although the debate has focused on the topic of abatement (mitigation), abatement is only one way to address climate change. A second tool to address climate change is to take adaptation measures. Economists have long emphasised that an economic approach to climate policy must compare the entire set of measures to choose a portfolio of cost-effective measures. Adaptation is now also on the radar of national and international political institutions such as the OECD (2008, 2010, 2011) and the European Commission (2009).

Here, we explore the role of the government in climate change adaptation, asking to what extent adaptation can occur in private markets and which tasks should be performed by the local or by a more centralised tier of government. For this purpose, we outline the economic principles that guide this assignment question, which we subsequently apply to derive conclusions regarding the assignment of different adaptation tasks. Prior to this analysis, we characterise and categorise climate change adaptation measures.

1.1 Adaptation – what is it?

The term “adaptation” shall encompass a broad range of policy measures that change the cost or benefit of climate change for mankind.¹ Some straightforward examples include building dikes that protect the landscape from an increase in sea level or from floods due heavy rainfall; developing vaccines or other means to protect the population from diseases that may spread due to the change in the climate; improving general health conditions to allow the population to cope with extreme weather conditions; changing urban architecture or building standards, which improve living conditions in areas with hot climate and may help to accommodate the costs incurred by an increase in average temperature in summer; pushing farmers to re-optimize their portfolio of inputs, the variety of their products and their production technologies more generally as a reaction to changes in temperature and in the quantity or timing of rainfall. Human capital investment and improvements in farming technology may facilitate such adjustment processes. Research and development on seeds and plants may help provide a wider range of adjustment alternatives. The OECD (2008 p. 90-93) systematically lists the areas affected by climate change², adaptation options and potential policy instruments. A short, adapted version of the list reads as follows:

Coastal zones: Possible implications of climate change include inundation, flood and storm damage through sea surges and backwater effects; wetland loss; erosion;

¹ For a discussion of the term and more or less narrow definitions, see Pielke *et al.* (2007) and Smit *et al.* (2000).

² It is evident from this list that Europe is less affected by the effects of climate change than other parts of the world (OECD 2011, pp. 10-11). The agricultural sector, which is particularly exposed to climate change, constitutes only a very minor share of overall production inside the European Union.

saltwater intrusion in surface and ground waters; rising water tables and impeded drainage. Measures of adaptation discussed are coastal defences/sea walls; surge barriers; upgrade of drainage systems, saltwater intrusion barriers, sediment management; beach nourishment; habitat protection (e.g., wetlands and mangroves) and changes in land use, including the option of relocating economic activity.

Health: Climate change may, for instance, change heat-related and cold-weather-related mortality or may provide conditions for the spread of vector-borne diseases (e.g., malaria and dengue fever). The measures of adaptation include changes in living conditions (air conditioning, construction of climate-controlled buildings), improvements in general health conditions that increase resilience to these challenges, disease eradication programs, medical and biological research and innovation (vaccination, treatment) and providing information about self-protection measures.

Water resources: Climate change may increase or decrease the volume, timing and quality of water flows in different areas, causing severe water shortage or floods with changed probability. The possible adaptation measures include improved infrastructure and technology of water management, including improved markets for water in which water prices reflect on-going scarcity, as well as regulatory interventions and investment programmes with the aim of infrastructure improvement.

Ecosystems: Climate change may occur too rapidly for certain species to adapt to this change, threatening these species with extinction. In addition, climate change may cause changes in the behaviour of species that, in turn, may affect the well-being of mankind. Adaptation measures include a general increase in ecosystem resilience, the reduction in the use-intensity of the natural environment or the protection of habitats for endangered species (both measures would make it easier for species to bear the burden of change). Possible adaptation measures also include facilitating the migration of endangered species and research about the relevant causalities.

Settlements and economic activity: Existing public and private infrastructure in certain areas may be ill-suited for optimal location and type of economic activity once climate change has taken place. This issue is particularly relevant, for instance, in the case of tourism or the varying seasonal dynamics of energy demand. Adaptation measures include insurance, changes in private and public infrastructure, including housing stock and possible relocation.

Agriculture: Climate change may affect the yields of crops and affect farm animals due to changes in temperature, precipitation and other climate conditions, including changes in CO₂ concentration. Possible adaptation measures include changes in crop insurance, investment in new equipment and technology and the introduction of more suitable crops and farm animals.

Recurring elements of adaptation strategies can be identified in these areas. First, adaptation strategies prominently include aspects of risk transformation and risk pooling through changes in economic activity (self-insurance and self-protection) and instruments of private or public insurance. Second, public policy that provides “price signals” appears in almost all categories identified by the OECD. Such policy interventions may aim at removing obstacles, which prevents the functioning of existing markets, or at correcting malfunctioning markets, which is caused by externalities or by existing regulatory intervention. Third, public policy encouraging research and innovation is also a pervasive theme in the OECD list.

Applying economic principles to climate policy suggests that the set of policy tools should be used efficiently.³ In general, this assumption implies that the last Euro spent on climate policy should generate the same improvement for each and every activity, which holds in the context of abatement policies but can also be applied to adaptation measures and the trade-off between mitigation and adaptation.

In this report, we will discuss neither mitigation policy nor the trade-off between resources expended on mitigation versus adaptation. In addition, we will abstain from the discussion of intergenerational and international distribution, which is a key issue in the climate policy debate (see, for example, Hepburn and Stern 2008; Iglesias *et al.* 2011). Instead, our starting point is a world in which climate change is to occur, either because global mitigation policy has largely failed or is likely to fail in the near future or because some part of climate change occurs for reasons other than greenhouse gas emissions. In this setting, we focus on adaptation issues. In particular, we ask what role the government should play in adaptation and which level of government should be involved. We will also explore the question of who should provide the actual adaptation effort. To answer these questions, we apply standard principles of economic reasoning.

1.2 *Categorising adaptation measures*

To address these questions, it will be important to highlight several dimensions by which adaptation policy can be categorised.

Pro-active and reactive adaptation measures. A distinction is typically made between adaptation measures taken much prior to the occurrence of climate change and its impacts and measures that are taken as a reaction to on-going climate change. A key aspect of pro-active measures is that they are taken when there is typically a considerable amount of uncertainty regarding whether climate change will emerge. For instance, building restrictions in areas that may become threatened by floods are pro-active measures that have to be taken in the decades prior to a possible change in precipitation or other weather conditions that may cause future flooding.

Stocks and flows of adaptation effort. A second distinction that is often related to the first one is between stocks and flows of adaptation efforts. In the first case, adaptation expenditures build up a capital good and yield a benefit flow as a function of the size of the stock. In the second case, the adaptation expenditures yield a flow of benefits simultaneously with the flow of expenditures. Installing an air conditioning system is an investment in a capital stock, whereas immediate behavioural reaction to hot climate conditions is a flow. Stock investments will also often precede actual climate change, in which case such investments are also pro-active. However, such investments in adaptation capital may also occur when the change in climate conditions has already materialised.

Adaptation and adaptive capacity. Some measures of adaptation address particular, anticipated or materialised implications of climate change. For example, air conditioning is an adaptive measure to cope with heat, providing suitable conditions for work or life and reducing medical risks.⁴ In contrast, measures that improve the

³ See, for instance, Brennan (2010), Kane and Shogren (2000), and Shalizi and Lecocq (2009) for discussions of the relationship between mitigation and adaptation as policy tools. See also Buob and Stephan (2011) and Zehaie (2009), who discuss some strategic aspects of the substitutability between mitigation and adaptation in a strategic international context. We will touch upon similar issues further below.

⁴ Evidence suggests that heat waves with temperature increases above a certain threshold level lead to an increase in emergency situations involving patients with respiratory problems, whereas there was no significant increase in patients with cardiovascular

general health condition of the population are a means of making the population less vulnerable to extreme temperature events. Such measures increase the adaptive capacity of the society.⁵

Adaptation as a private good or as a public good. The final and most important distinction focuses on the impact zone of adaptation measures. Some measures of adaptation, such as installing air conditioning in a private home, are fully private goods. They are paid by the user and the impact zone of the benefits is essentially limited to the user. Other adaptation measures have a much larger, regional, national or even global impact zone. For instance, the benefits of medical research and innovation, which help to cure climate change-induced diseases, are typically non-rival and non-exclusive: Once a treatment method has been invented and innovated, it can be applied to many patients, and applying it to an additional patient typically does not reduce the benefits received from this treatment by other patients.

2. Economic principles applied to adaptation

We now discuss some general economic principles to lay the foundation for a more detailed discussion surrounding the role of the public sector in the context of adaptation measures.

2.1 *The correspondence principle and subsidiarity*

The subsidiarity principle suggests that decisions about economic activity should preferably be taken by the decision unit at the lowest level of aggregation at which these decisions do not generate major externalities for other decision units. In this Section, we argue that adaptation policy should not only “respect the principle of subsidiarity” as is stated in the White Book of the EC on adaptation (see European Commission 2009, p. 7), but that subsidiarity, based on an application of the more fundamental correspondence principle, should also be the most important guide to the problem of how to assign adaptation tasks to the private sector, to local or regional levels or to higher levels of government as a function of the ‘public good properties’ of the respective adaptation task.

A key economic principle that generally applies to how economic decision rights, payment burden and the cost or return of economic activities should be assigned is the *correspondence principle* introduced by Oates (1972). According to this theory, “perfect correspondence” (1972, p. 34) applies if the set of beneficiaries of a particular type of good is congruent with the set of individuals who decide and pay for this good. Applied to adaptation, the correspondence principle suggests that the set of economic players who bear the cost of some adaptation measure, the set of players who earn the economic benefits of this measure and the set of players who decide on this measure should coincide. Deviations from this principle are likely to generate inappropriate incentives and cause economically harmful decisions. Therefore, the responsibility for adaptation should be with the individual rather than with the state wherever the adaptation measure is a private good with respect to the implementation of the measure and with respect to the benefits it creates. If the adaptation activity affects a whole group of economic players, the adaptation decisions should typically be made by this group. For many adaptation measures, this group is locally or regionally

diseases (Michelozzi *et al.* 2009). Gabriel and Endlicher (2011) found increased mortality risks from heat waves in urban areas in Germany.

⁵ Engle (2011) extensively discusses various concepts of adaptive capacity.

distinct. Goods such as parks, dikes and sewer systems naturally have a local impact zone. Decision making and implementation via the local government is then the appropriate procedure.

The subsidiarity principle, which is a major principle of policy task assignment in the European Union, can be seen as an application of the correspondence principle. In the context of adaptation policies, the subsidiarity principle provides an important guideline. It suggests that the assignment of specific adaptation measures to the private or public sphere depends on the impact zone of the respective adaptation measures (*i.e.*, whether the adaptation measure is limited to single private decision makers, localities, regions or countries). Many adaptation activities generate a *private good*, according to the categorisation in Section 1.2. For instance, fixing the roof tiles reduces the respective homeowner's potential damages from windstorms. Superior insulation shields the occupants of a building from extreme temperatures during cold winters and hot summers. Efficient air conditioning on the factory floor may help to avoid closing down production during heat waves and benefits the shareholders of the company that own the respective factory. Securing the water supply via secondary sources insures the factory against falling ground water levels during dry periods. All of these examples illustrate why and how private investment in these adaptation measures causes a private cost and creates private benefits to the same economic actor. The investor bears the full cost but also appropriates the full benefits of being adapted to climate changes. Because there are no significant externalities involved in these decisions, private consumers, investors, company owners or entrepreneurs will choose the efficient level of these types of adaptation measures. The correspondence principle suggests that these activities are chosen appropriately and efficiently when they are chosen by the individual private sector decision maker, and the subsidiarity principle rightly suggests that these activities should be performed by the respective private decision makers – the most decentralised level of decision making for which there are no major externalities between the decision makers.

Such a purely private solution will not be efficient if (local or regional) *public goods* are involved. Building a dike for flood prevention protects the entire population living behind the dike. Accordingly, if a single private resident who is threatened by possible floods is left with the decision of whether to build this dike, his decision has an externality for other private residents who would also be protected by the dike. Similarly, creating green spaces in a city reduces the temperature and therefore improves living conditions for all inhabitants. Leaving the creation of green spaces to private initiative will typically fail to generate efficiency. In these examples, adaptation consists of the provision of (regional or local) public goods. Relying on the most decentralised, private solution would create the well-known free rider problem. Individual providers would bear the cost, but all households in the region would benefit. Such adaptation measures would be carried out on an inefficiently small scale. The subsidiarity principle suggests that the provision of regional public goods has to be assigned to more centralised institutions such as the government of the respective region. Finally, public goods with an even larger impact zone, such as basic research or medical research that yields new treatment methods that are applicable worldwide, should be implemented by an even higher level of government.

Stated differently, the *subsidiarity* principle suggests that decisions should be made by the most decentralised unit that can handle matters efficiently. Apart from the externalities argument, one of the most salient arguments in favour of a decentralised solution relies on the availability of information. The government might generally be better informed about climate change and its impact and may play an important role in

providing this information, whereas the individual homeowner will be better informed than the government about the specific exposure of his house to windstorms, heavy rain or heat waves and about the most suitable, customised adaptation measure (Naess *et al.* 2005, Olsson and Folke 2001).

The assignment, when combined with the subsidiarity principle, can help avoid free-riding but simultaneously allow benefits from local or group specific information. Considering the types of adaptation measures listed by the OECD (2008), a preliminary assessment suggests that a very limited number of adaptation decisions need to be made at the level of the central government. Many decisions need to be made at the local level or at the level of individual decision makers – although one important exception is discussed in the next Section.

2.2 *Information – the ultimate global public good*

We next take note of specific properties of information regarding climate change, its implications and the technologies allowing adaptation to climate change. As has been frequently stressed, the ability to react to climate change is a function of the availability of resources, information and technology, all three of which are generally increasing in national income. The development of adaptive technology is largely a function of the resources that have been invested in research and development.

Even though adaptation to different climate conditions has always been one of the key abilities of mankind, there is relatively little knowledge regarding how to adapt to a rapidly changing climate. The systematic analysis of how to adapt, for instance, to more extreme weather events is a very recent strategy to cope with climate change. Information about climate change and the impact of climate change, in addition to information about which sets of instruments and technical adaptations to these changes currently exist (see also Hallegatte *et al.* 2011), are typical public goods: the cost of generating the information has to be incurred once by the generator of this information, whereas the marginal costs of using the information are zero for additional users of it.

Information about the impact of climate change and the choice of effective adaptation measures is typically not readily available and has to be generated. Research and development increases our knowledge about the consequences of climate change, about the costs and benefits of adaptation technologies and about the effectiveness for different types of climate change. Therefore, financing basic research in this area is also one of the fundamental tasks of government. Because most information is equally useful for many jurisdictions, financing research, as well as collecting and disseminating knowledge about adaptation, are key tasks for a central government.

Because the consequences of climate change can vary widely at the regional level, each region will be required to generate information on how to “adapt adaptation measures” to its own needs.⁶ For instance, the increase in heavy rainfall will differ across regions within a country, and even in a region with the same amount of heavy rainfall, the necessary adaptation measures may vary depending on whether a region expects landslides, floods or rising ground waters.

⁶ Several national governments have initiated research programs to generate more information about suitable local adaptation measures. See, for instance, KLIMZUG (<http://www.klimzug.de/>) by the German Federal Ministry of Education and Research, the “Aktionsplan Anpassung der Deutschen Anpassungsstrategie an den Klimawandel” (Bundesregierung 2011), “Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future” (Royal Academy of Engineering 2011) and Preston *et al.* (2011) for a review of adaptation planning in a large set of studies. This issue also figures prominently in the list of adaptation measures listed in the OECD (2008) list that we reproduced in Section 1.

2.3 *Uncertainty and insurance*

We now consider the role of exogenous uncertainty regarding both climate change and the effectiveness of adaptation measures, for instance, due to technological uncertainty. Uncertainty is one of the most salient aspects of the climate change debate.⁷ We discuss whether and how exogenous uncertainty affects the task assignment that was derived in the first step.

Uncertainty is often mentioned as an argument for state intervention. However, in general, these cases are not clear-cut and uncertainty in itself is not a good reason for government intervention. The government may be given authority if the government has an informational advantage that is not easily transferable to the private sector. However, it is unclear why the government should generally be better informed than the individual decision maker with regard to the specific choice of adaptation measures. The government often knows even less about the specific situation of individual decision makers than the decision makers themselves. There is clearly uncertainty regarding the future impact of climate change on a specific region; the frequency and timing of extreme weather events is largely uncertain and the investment in new adaptation technologies is highly risky. The government may have an information advantage about expected regional climate change (see 2.2), but the government is often no less uncertain regarding what this implies for a specific actor. Therefore, it is not ideal for the government to choose the appropriate measures of adaptation on behalf of private sector decision makers.

Preventive measures are only one way of dealing with risk and uncertainty. A second, equally important measure is risk pooling and diversification. Excellent institutions in the private sector have been developed to deal with these risks. Private insurance markets can diversify the risk of suffering large losses from extreme weather events and transform the small risk of a large loss by a single private decision maker into the payment of a riskless insurance premium.⁸ Moreover, the insurance and re-insurance sector can spread these risks across many companies within a global industry, making use of the fact that damages from extreme weather conditions are stochastically independent between continents. In addition, damages from extreme weather conditions are, for the most part, not strongly correlated with economic risks, which further reduces the economic cost of risk bearing if these risks are spread even further among investors. Government-provided insurance or national disaster relief programs do not have the same advantage of international diversification. This difference becomes important in the context of large natural disasters that systematically affect a whole region.

The optimal adaptation policy of private decision makers in the presence of insurance markets will entail a mix of preventive adaptation measures and market insurance.⁹ The optimal mix of insurance for a decision taker requires that the marginal cost per unit of risk reduction is the same across the two policy instruments if both are in use.¹⁰ Some simple and inexpensive adaptive measures may, for instance, greatly reduce the financial or health risks from extreme weather events. Here, self-insurance is a highly effective means of reducing risk and may occasionally make market insurance

⁷ For meta-analyses on estimates, see, for example, Tol (2002a, 2002b, 2009).

⁸ On the insurability of damages from climate change, see Kunreuther and Michel-Kerjan (2007). Botzen and van den Bergh (2009), Botzen *et al.* (2010a) discuss the role of insurance markets for flood risks, windstorm risks and hailstorm damage risks.

⁹ In a risky environment, preventive adaptation measures act as devices of self-insurance and self-protection (Ehrlich and Becker 1972).

¹⁰ For an analysis of the interaction between market insurance and self-insurance, see Lohse *et al.* (2012).

unnecessary. However, in other instances, complicated and expensive preventive measures may be required to reduce exposure to possible loss. In these cases, it is best to insure the remaining risks in competitive insurance markets. This scenario suggests that there is a trade-off between activity that reduces risk exposure and the purchase of additional market insurance. The optimal combination of activities can typically be decided by the individual private decision maker without government intervention.¹¹

Where there is a problem of information about suitable measures of self-protection, the private insurance companies have an incentive to provide this information to their customers and to promote an efficient mix of the different adaptation measures: self-insurance, self-protection and market insurance. If an insurance company makes its contracts contingent on inexpensive self-insurance efforts, it can offer more attractive insurance contracts (Botzen *et al.* 2010b), creating a strong incentive for insurance firms to provide information on possible adaptation measures. Therefore, uncertainty about potential damages from extreme weather events brings the insurance industry into play and this sector even takes over some of the government responsibilities of providing information to the public (Ward *et al.* 2008).

More sophisticated arguments are needed to justify government intervention on the basis of uncertainty. These arguments are related to problems of asymmetric information (hidden action and hidden information) and consistency problems resulting from the dynamic revelation of information. We discuss these three arguments sequentially.¹²

First, purchasing insurance changes the incentives of the insurance customer to take preventive measures against damage risks or to reduce the exposure to possible damages. If the insurance company can observe these preventive measures and adjust the individual premium paid by an insured individual according to the preventive measures he takes, then a private market with a competitive insurance market will bring about an efficient outcome. If insurance companies cannot clearly observe these private activities of self-insurance or self-protection (hidden action) and cannot adjust the size of the premium to the preventive measures taken by an insured individual, then it is likely that the amount of preventive measures taken is too low from the perspective of efficiency: The insured is not awarded for his own preventive measures by a reduction in premium. The individual pays a premium that is calculated on the basis of the average level of preventive measures taken by the collective customers of the insurance company; accordingly, the individual has to bear all of the cost of self-protection but receives only a small share of the benefits. This moral hazard problem typically leads to inefficiently low preventive measures and to insurance contracts that do not fully insure the customers but provide only partial coverage in the state of loss.¹³ Although this is a potentially serious problem for insurance markets, there is little that the government can do to improve the quality of the insurance market. Publicly provided insurance suffers from the same information limitations. One possible means of intervention is a subsidy on items that are predominantly used for self-insurance and self-protection. A problem with this policy is that it may be difficult to adequately target such subsidies. If there are multiple prevention activities and only

¹¹ In Section 2.4, we will discuss why government intervention can even destroy the incentives for an efficient choice between self insurance and market insurance.

¹² A fourth type of market failure will arise from market power, leading to non-competitive insurance premiums. As this is a general issue for competition policy, we do not further discuss the necessary regulation of insurance markets. In thin and highly specialized insurance markets, it might be difficult to maintain competitive pressure.

¹³ This type of ex-ante moral hazard is well known and is studied and formalized in most textbooks of insurance or microeconomics. One of the classic references is Shavell (1979).

some are subsidised, then the prevention decisions are distorted. If some subsidised items can be used for purposes other than prevention, then this subsidy may become expensive and may even distort production or consumption in other areas of economic activity.

A second problem is asymmetric information about individual insurance customers' exposure to risk.¹⁴ This issue is particularly relevant if the insurance holder has more accurate information compared to the insurer (hidden information). A homeowner may be better informed about potential damages to his building from windstorms or heavy rainfall than the owner's insurance company. The insurance company only has data on the regional climate and lacks information about the potential damages to individual buildings. This is a typical scenario under which adverse selection occurs. Homeowners with risks far below average are unwilling to purchase insurance at the price of a community rating. This situation in turn requires higher community ratings on existing contracts in order for the insurance company to break even and this premium increase makes further customers abstain from purchasing insurance. At equilibrium, only homeowners with very high risk exposure will purchase market insurance at a high equilibrium premium. The mix of market insurance and self-insurance will be distorted toward excessive risk bearing and excessive preventive adaptation efforts by individuals who abstain from purchasing insurance. If the market suffers from this type of adverse selection, the government may be able to improve the allocation (*e.g.*, by making insurance mandatory).

The third problem is the time inconsistency of insurance contracts in a multi-period context. When insurer and insured have the same information but learn over time about individual risks, long-term insurance contracts may not be viable. Suppose that homeowners want to insure against damages from extreme weather events. As we are currently uncertain about the specific consequences of climate change, a long-term insurance contract will provide two types of benefits. First, it will insure against damages from extreme weather events in a given period. Second, it will shield the insured against "bad news" (*i.e.*, the risk that his home is located in a region that is particularly vulnerable to climate change). The second benefit emerges from the long-term nature of insurance contracts. These contracts are concluded *ex ante* before it is known whether the insured object is a good or a bad risk. *Ex post*, this pooling of risks appears as a transfer from good to bad risks. Even though most homeowners would like to benefit from such a comprehensive insurance scheme, these long-term contracts are not temporally consistent. Homeowners that turn out to be good risks will want to cancel the (unfavourable) insurance contract. The insurance companies, in turn, will try to remove the bad risks. Because of the time consistency problem, the efficient long-term insurance contracts will vanish and only spot market insurance contracts will remain. As in the case of adverse selection, the government can overcome this inefficiency by making long-term insurance mandatory. Alternatively, a scheme of severance payments may eliminate the inefficiency (see Cochrane (1995) for an application to health insurance).

Insurance markets are useful for allocating risks but are also far from being perfect. Moral hazard, adverse selection and time inconsistency may lead to deviations from the ideal of a full-information first-best allocation of risks. This ideal, however, is a misleading benchmark. It has to be shown that the government can achieve better

¹⁴ The formal theory is typically covered in most textbooks on insurance. Classic seminal references on this problem are Akerlof (1970) and Rothschild and Stiglitz (1976).

allocations than the private sector. The government typically suffers from informational problems similar to the insurance industry. Rather than replacing market insurance through government intervention (*e.g.*, subsidising insurance premia), the government should focus on the cases where the regulation of mandatory insurance is necessary.¹⁵

2.4 *Governmentally induced market failure*

Markets for adaptive measures may fail even if the adaptation measures taken are generically fully private goods. The government itself plays a key role in this context because it also faces problems of time consistency, which are related to Buchanan's (1975) Samaritan's dilemma.¹⁶ In case of a major disaster (a flood, hurricane or other extreme weather events, or an outbreak of a disease) that threatens the economic existence or survival of a population group, the government will typically provide help to all those who have not taken preventive measures in terms of appropriate insurance provisions. This provision of help can be anticipated by the individuals in a region that is exposed to certain types of disaster risks. They may also anticipate that, in case of incurring damage, their purchases of disaster relief insurance and their investments in self-insurance crowd out help to be received from the government. Why should they pay the premium for private insurance or invest in self-insurance or self-protection measures if they enjoy a similar amount of free protection from the government?¹⁷

One might argue that the negligence of insurance opportunities is simply a distributive issue. Those who forego market insurance are compensated by the tax payer rather than by the collective of insured. This appears to be a problem of redistribution – from the tax payer to the uninsured – rather than a problem of efficiency. If all individuals remain uninsured, then the government replaces the insurance sector, charging a tax rather than an insurance premium to finance disaster relief. However, this view is flawed as it disregards important incentive effects. Individuals may systematically make choices that invoke large expected disaster costs. For example, the construction of private homes in areas that are exposed to a high risk of flooding or other extreme climate events is not sufficiently discouraged if the owners of these homes can rely on disaster relief payments from the government. It is difficult to deal with this incentive problem. One of the few remedies of this problem is mandatory insurance and this argument provides the primary reason why disaster relief insurance may be imposed as a mandatory requirement by the government. In addition to the incentive problem, governmental provision of disaster relief is a 'one-size-fits-all' insurance program. It does not, and cannot, adequately account for differences in risk attitudes, uninsurable background risk that individuals may have, or many other idiosyncratic characteristics of individuals that cause their optimal insurance demands to vary widely.

The Samaritan's dilemma could, in principle, be resolved by the Samaritan's commitment not to help in case of a disaster. Practically, this will be difficult and may have undesired side effects.¹⁸ High public debt at the level of the municipality or the regional government may yield such commitment, but it is undesirable for other reasons. Therefore, the prototypical solution for the problem is some amount of mandatory insurance. Full insurance is typically not required. The amount of mandatory insurance coverage is sufficiently comprehensive if it removes the strategic

¹⁵ See Rees and Kessner (1999) for a careful assessment.

¹⁶ See also Besley and Coate (1991), Bruce and Waldman (1990) and, in the context of adaptation, Aakre and Rübhelke (2010).

¹⁷ In an empirical study, Botzen, Aerts and van den Bergh (2009) show that this crowding-out effect is statistically significant.

¹⁸ See, for instance, Konrad (1994) for a discussion of the commitment value of tight resource constraints.

incentive to abstain from purchasing the individually optimal amount of insurance. Once a sufficient level of mandatory insurance is reached, the government can leave it to the individuals to decide whether to purchase additional insurance.

Note that mandatory insurance is not the same as governmentally provided insurance. There are many instances in which regulation requires mandatory insurance but in which individuals must purchase this insurance in a private insurance market.¹⁹

Goodspeed and Haughwout (2012) show that the Samaritan's dilemma problem for insurance decisions is not limited to the relationship between private individuals and a government that cares about these individuals' welfare. In addition, regional governments may abstain from taking appropriate protective measures if they know that a higher level of government will intervene and help with federal disaster relief programs if a major disaster occurs. For instance, the incentives of municipalities or regions to enforce suitable zoning restrictions are insufficient. This reasoning provides an argument for a federation to impose rules and to incentivise or prescribe the protection measures on the regional or local level.

Government intervention may not only crowd out private or subnational self-insurance or market insurance activity, but it may also inhibit long-run growth and development. The attempt of the government to shield its population from the consequences of climate change prevents the necessary reallocation of resources. For instance, many African countries may lose some of their current comparative advantage in agricultural production due to climate change (Collier *et al.* 2008). Implicit insurance by the government against weather-induced losses in agriculture keeps more workers in this sector and thus inhibits the necessary structural change in these countries. This problem need not be limited to developing countries.

2.5 *Learning and technology choices*

Technology choices of firms and consumers are sometimes characterised through strong complementarities. If the positive effects from complementarities accrue to third parties, they are often called network externalities.²⁰ These network externalities lead to the government serving a coordination function.

Climate change may be addressed by a set of alternative means of adaptation and these means can be substitutes. For instance, there may be different types of air conditioning systems to stabilise temperature and humidity in a production facility. These different technologies may even be equally efficient *ex ante*. However, each firm that employs a certain type of air conditioning adds knowledge regarding this technology and makes this technology more attractive compared to substitute technologies. *Ex post*, a small number of technologies will turn out to dominate in adaptation due to the stock of experience. As other firms benefit from the enhanced knowledge, each adopting firm creates a positive externality.

Three types of market failures may emerge in situations involving network externalities. First, there might be a lock-in on an inefficient technology (Arthur 1989, Cowan 1990, David 1985). As the dominant technology emerges more or less randomly from early experimentation, the technology chosen by the first adopters can dominate, even though other technologies may prove to be more effective *ex post*.

¹⁹ Note also that the private insurance market can suffer from a number of deficiencies that are not the topic of this paper, which may require governmental regulation or supervision of this market – explaining why there is such supervision in most countries (see also Rees and Kessner 1999).

²⁰ For an application of network externalities to mitigation technologies, see Schalizi and Lecocq (2009).

There is little that governments can do about these (*ex post*) insights into inefficient technology choice as the information possessed by governments is no better than that held by private adopters about the future prospects of different technologies. Second, if the positive externalities emerge from learning-by-doing, the adoption of adaptive measures is too little and too late. Here, the government can partially overcome inefficiently low levels of experimentation by subsidising new technologies. These subsidies should be limited over time to create incentives for early adoption. (There is clearly a time consistency problem, as the government always has an incentive to prolong the subsidies when adoption is deemed insufficient.) Third, firms may find it profitable to invest in a given technology only if they are sufficiently confident that this investment is matched by respective activities of other players in the private sector. Certain technologies may break even only if the number of adopters of this technology is sufficiently large. Even though technologies are available, adoption never takes off because all market participants are waiting for adoption by other players (Barrett 2002). Government need not intervene in this case, but it may play a coordinating role. By making one technology a focal point for all market participants, it can create a decisive break-through.

We mention network externalities as something that may be, but need not be, relevant for adaptation products. It is important to note, however, that we do not currently have any evidence that complementarities or network externalities are more pronounced in the context of adaptation technologies than with other types of goods. As for these other categories of products, the burden of proof for why the government should intervene in these markets is on the side of the government considering such an intervention.

2.6 *Irreversibility, pre-emptive and reactive adaptation*

Climate change is associated with large uncertainties. We still know very little about the likely frequencies of extreme weather events and the occurrence of these events will be highly specific to the region. We are also uncertain about how such events will affect the economy and society, given that we know little about how goods will be produced in 50 or 100 years. In addition, we do not know what technologies will be available in the future to cope with heat waves or floods, and we can only guess about the costs of reactive adaptation to these risks. In Section 2.3, we have already noted the enormous uncertainty associated with climate change; we have documented the role of insurance markets in covering residual risks that can only be avoided at excessive costs. In this Section, we want to stress the trade-off between early action (pro-active) and *ex post* (reactive) adaptation choices in the presence of uncertainty. If future states of nature are uncertain, governments and the private sector will benefit from delaying irreversible choices and from choosing flexible measures of adaptation.²¹

If a government implements adaptation measures that are appropriate for the *expected climate change*, this may initially seem to be cost effective. At closer inspection, however, it will be clear that it is much better to choose those measures that minimise the *expected costs* considering the alternative states of nature. Some measures suitable for expected climate change might be very expensive (or ineffective) in cases with slight deviations from the predicted climate change. Therefore, the distribution of outcomes itself plays an important role in the choice of adaptation measures. Only

²¹ For a simulation model of adaptation and mitigation with learning over time, see Felgenhauer and De Bruin (2009).

with flexible adaptation measures or with measures that are beneficial for a broad range of possible climates can the government properly react to climate change. Flexibility and resilience are highly valuable in a world with large uncertainties.

This consideration also highlights that there might be a positive option value of waiting. Early action is not necessarily the best choice if investments are largely irreversible. Early action has the advantage of allowing long-term adjustments (*e.g.*, the long-run rebuilding of sewer systems or the extension of flood prevention). These investments can typically not be made within short periods of time. In addition, the cost of adaptation to a particular climate change outcome may be lower if accounted for at an early stage. Air conditioning a building is typically less expensive and more energy efficient if measures are taken during the construction process of the building, compared to adding air conditioning in a building that has already been constructed. Early action, however, also has the disadvantage of generating irreversible structures. The amount of air conditioning installed pro-actively may turn out to be excessively small or excessively large. Once the government learns about the ‘true’ problems or the actual dimensions of climate change, pro-active investment may turn out to be useless. Therefore, the government may benefit from delaying decisions and maintaining the option of later (but well-prepared) responses.

2.7 *The international dimension of adaptation*

So far, we have stressed the role of national or subnational governments and of the private sector in adaptation policy. The international dimension was removed from the picture. This position is in stark contrast to issues of mitigation policies, where international coordination is the primary aspect. Due to the nature of mitigation as a global public good, mitigation efforts will fall considerably short of their optimum levels in the absence of a benevolent world government that can enact and enforce efficient policies from a global perspective. The series of world climate summits, each of which failed to reach a binding global treaty for all countries, is evidence of this problem. Given these severe collective action problems, we should not be too confident that an efficient mitigation goal will be achieved at future summits.

Adaptation, in contrast, does not suffer from this problem. The benefits of adaptation measures are typically limited in scope. A dike protects the land behind the dike. To choose the optimal protection policy for dikes, it is sufficient for the region that receives protection to coordinate financing for the dike. Some measures, such as changes in construction materials to make houses more resistant to heat or storm, are even more limited in scope. The beneficiary of such measures is the owner of the building and this owner has the appropriate incentives to make these investments privately, even in the absence of government intervention. Hence, adaptation policy is largely local and requires little international coordination.²²

From a strategic perspective, however, the international dimension plays a vital role in adaptation policy. Effective adaptation shields countries or regions against major disasters from extreme weather events. This advantage can be used strategically to push other countries toward more ambitious mitigation policies (Zehaie 2009). Mitigation efforts contribute to the global public good. From the literature on the

²² A notable exception is the role of international transfers aiming at an improvement of adaptive capacity in developing countries. Rübhelke (2011) argues that the increase in national welfare in the developing country makes it more developed, and because climate is a superior good, it changes the willingness of the country to contribute. However, there is also a counter argument: once adaptation in Bangladesh has taken place, the country is still poor, but it is generally less vulnerable and even less willing to contribute to global mitigation efforts.

private provision of public goods, it is well known that the private provision strongly depends on the income of a country, on its cost of mitigation and, last but not least, on the benefits from reducing climate change. This benefit will be lower for a country if its vulnerability has been reduced via effective adaptation measures inside the country. A country that invests in adaptation reduces its own incentives to contribute to the global public good “mitigation” and forces other countries to provide more of this good (“crowding in”).²³ Hence, a national government can strategically invest in adaptation or subsidise adaptation to shield itself against international pressure on this government’s advances in mitigation policy.²⁴

2.8 *The Schelling Conjecture – the nexus of income and adaptation capacity*

Early in the debate about climate change, Thomas Schelling (1992) formulated what is known as “Schelling’s Conjecture” (Anthoff and Tol 2011). He suggests that highly developed, richer societies are less vulnerable to changes in climate. Highly developed societies have the human capital, the knowledge and the appropriate technologies for an optimal reaction to climate change and they have the financial means to make the investments that may be required. Poor societies with low human capital lack knowledge regarding how to adjust to climate change; additionally, they do not have the financial resources required to implement the appropriate measures.

A considerable body of literature shows that poor societies and population groups with low levels of education have the highest exposure to climate change, whereas richer societies have the means to cope with the implications of climate change. This observation, however, implies that the growth of economic prosperity and investment in technological and medical knowledge are important self-protection measures against the risks of climate change. Sacrifices in growth that are made to slow down climate change therefore increase vulnerability to climate change. Rather than implementing an expensive program with considerable mitigation to slow down climate change, it may be better to prepare strategies to cope with climate change in the future through policies that foster economic growth and development. There is not only a trade-off between mitigation and growth as a means to increase adaptive capacity, but there is also a similar trade-off between expensive pro-active investment in specific adaptation projects, on one hand and fostering economic growth and technological development, on the other. Therefore, the government may play an important role in the context of adaptation by providing favourable conditions for economic development.

The Schelling conjecture regarding the relationship between economic prosperity and adaptive capacity is based on several pieces of evidence. Schelling’s argument is based on an analysis of modern developed societies and a comparison of these developed societies with societies that are currently developing, suggesting that most modern sectors of production are not substantially affected by climate change and that agriculture is the sector most affected by climate change. In addition, the agricultural sector seemingly has the lowest adaptive capacity, where farmers are poorest and least

²³ When risk comes into play, the selfish and strategic behavior of countries may even be globally beneficial, as the total amount of mitigation efforts may be increased (Auerswald *et al.* 2011).

²⁴ Such strategic aspects are key for international mitigation, for the quality of the non-cooperative outcome, for the quality of the cooperative outcome, and for the likelihood of a cooperative outcome (see Beccherle and Tirole 2011, Buchholz and Konrad 1994, Harstad 2007, Hoel 1991, Konrad and Thum 2012). We do not focus on this aspect because mitigation is not the topic of this paper.

educated. In fact, some analyses indicate the importance of education and wealth in the adaptive capacity of the agricultural sector.²⁵

Schelling also stresses that it is difficult to predict the state of production processes and technologies that apply in the year 2100. Suppose our ancestors in the year 1920 had considered climate change in the early 21st century and discussed specific types of pro-active adaptation investments. What would these have been? And would they be adequate *ex post*, given that the sector composition of the current economy was completely unforeseen at that time? *Ex post*, a pro-growth policy was probably the best adaptation investment that they could have made. The idea that additional knowledge, an enlarged set of technological alternatives and increased resources for possible adaptation generally improve the adaptive capacity of a society and its economy has a strong appeal. Practical applications of Schelling's conjecture may emerge in the context of health. As argued by Keim (2008, p. 511), "Community public health and medical institutions can play an active part in reducing human vulnerability to climate-related disasters through promotion of 'healthy people, healthy homes and healthy communities'."

3. Conclusions for the role of government policy

Let us consider the OECD list²⁶ of areas that are potentially affected by climate change and the scope of government intervention mentioned there: water management, coastline protection, soil management, biodiversity, agriculture, forestry, tourism, energy demand, natural resource demand, mobility, industrial production, construction, financial services, health and health care and international migration. The long list of areas affected by climate change by no means implies that the government should be involved in adaptation measures in all of these areas.

3.1 Guidelines for government intervention

Most adaptation measures can easily be implemented by private players. Coming back to the cross-cutting topics discussed in Section 2, we suggest that governments focus on their vital role in adaptation policy:

- *Provide information* about the impact of climate change and about the set of possible responses in adaptation (Section 2.2). Information being a non-rival good, this task should be accomplished by the central government, possibly the European Union.
- *Provide local public goods* to increase adaptive capacity (Section 2.1). As the knowledge about efficient adaptation measures is largely regional, the subsidiarity principle suggests assigning this task to the lowest possible layer of government.
- *Provide the regulatory framework for insurance markets* (Section 2.3 and 2.4). A major market failure can result from a lack of insurance markets due to adverse selection, which can be fixed by making natural disaster insurance mandatory. This regulatory decision can be assigned to national bodies of government and it does not imply public insurance.

The economic analysis in Section 2 has also brought forward some guiding principles for government measures toward adaptation:

²⁵ See Iglesias *et al.* (2011) and Di Falco *et al.* (2011) for a case study on Ethiopia. For a simulation model on the conjecture, see Anthoff and Tol (2011).

²⁶ For an extended list, see Vahrenholt (2011).

- Given the large uncertainty about the (local) impact of climate change, it may be more efficient to *fix damages reactively* rather than to try to prevent all possible damages proactively (Sections 2.3, 2.6 and 2.8). Currently, the policy debate seems largely focused on preventing damages at high costs *ex ante*.
- The large uncertainty also requires choosing measures that are suitable for many different states of the world in the future (Section 2.6). Selecting adaptation measures that are tailored to a very specific scenario can lead to expensive bad investments. The ability to cushion different types of shocks is often referred to as *resilience*. Technological and medical progress can be viewed as measures to increase the adaptive capacity of a society. The government can play a prominent role in building the appropriate regulatory framework for the production of technological and medical knowledge.²⁷
- *Growth and technological development* should not be dismissed as antagonistic to adaptation (Section 2.8). Instead, enhancing growth acts as a self-insurance device against the uncertain future challenges of climate change. The production of basic knowledge, technological development and human capital is likely to be a key driver of economic growth. The government has a strong role in these areas. It is important to note that governmental policy that fosters the production of basic knowledge, technological development and the formation of human capital is also a crucial component of adaptation to climate change.

3.2 *The role of government in sectoral adaptation*

Climate change may have different implications for those sectors of the economy that were mentioned in the above introduction. Although each of these sectors deserves special and detailed consideration, which cannot be provided here, it is evident *prima facie* that climate change is more important for some of these sectors than for others. In addition, the type of government intervention varies widely in these sectors. We discuss several examples to highlight the differences between these sectors and, in particular, the different roles of the government:

- *Water management and coastline protection*, for instance, are classical tasks in which increasing returns and/or public good play important roles, suggesting that government involvement is also important when it comes to adaptation to climate change.
- *Soil management* is not an area of major concern in many central European states because the standards for preventing erosion are already fairly high. However, there are clearly regional differences, as climate change may bring about considerable regional changes in precipitation. Instead of uniform national policies, climate change will require more diversified and locally determined standards.
- *Agriculture and forestry* may undergo major processes of adaptation. Public information policy may be important in this context. In addition, public R&D may enlarge the set of available adaptation measures. The adaptation measures in these areas that are taken by the private sector may require changes in the regulation of the Common Agricultural Policy in the EU. Regulation determines, which

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The role of governmental regulation and other types of government intervention in the process of knowledge generation and in providing an environment that is prone to innovation is a complex issue that cannot be outlined here. It is clear, however, that the role of the government is particularly prominent in the context of financing basic research. In the context of applied research and innovation, the focus of governmental activities should be on providing a suitable regulatory framework.

products are most profitable, and existing regulation and intervention rules may slow desirable adaptation processes.

- The implications of climate change for *tourism* are not fully clear. They likely depend on the level of changes in precipitation and temperature and on how the preferences of tourists and travel technologies will develop in the next fifty years. Looking back fifty years, the changes in the tourism industry are remarkable and are strongly affected by technological changes such as new transportation systems. Although there is large uncertainty, there is little that the government can and should do in this sector. (Even if the government had known that the tourism industry in the Alps would decline because of worsening skiing conditions, it would have had no useful allocative instruments at hand. Preventing structural change could even have been harmful.)
- Climate change may affect *health and the health sector*. As has been argued above, the general health situation of the population is a key parameter determining whether the population can cope with climate change. Extrapolating the development of health care and medical process over another fifty years suggests that climate change will meet a society in Europe which is, technologically and by its health constitution, well prepared for these changes. Of course, one cannot rule out major natural disasters or the appearance of new diseases, meaning that there is a considerable amount of uncertainty. The Schelling conjecture makes particular sense in the context of the relationship between the wealth of a society and its health status.
- Governments seem to be sceptical about the functioning of *insurance markets*. For instance, the OECD (2011, p. 40) writes: “Another critical role of governments is therefore to evaluate whether the level of insurance cover is adequate and risk sharing systems are fair. They also might have to develop publicly funded adaptation measures that bring down risks, or share the most extreme layer of risks with commercial insurance.” A convincing argument for stronger government involvement in the insurance market must show that the private market solution performs poorly and that government involvement can generate an improvement. There is little evidence for either of these points. Even the observation that insurance is not available in some cases or that insurance premiums are not affordable for some customers is not necessarily a sign of market failure. High premiums may simply reflect high risks and, therefore, will be useful market signals. Any attempt to reduce insurance premiums through government intervention can distort the allocative role of insurance markets. As we have demonstrated in Sections 2.3 and 2.4, private insurance markets are generally effective instruments to share the burden of risk internationally. With some exceptions (adverse selection) and with some need for supervision (market power), competitive private insurance markets should achieve the appropriate mix of self-insurance and market coverage. Here, it is often government intervention that creates the distortions.

3.3 *Climate change adaptation in the White Book of the European Commission*

The White Book (European Commission 2009) makes specific recommendations on climate change adaptation. The general assessment in Sections 3.1 and 3.2 on the role of the public sector in climate change adaptation applies to the European Union. One can discuss the specific recommendation in the White Book on the basis of the economic principles outlined in Section 2. We focus on three elements:

- The White Book identifies a number of European tasks: (1) the role of coordinating, integrating and harmonising national, regional or local adaptation measures,²⁸ (2) the fact that adaptation “needs to be mainstreamed in EU politics”. According to the White Book, in “each policy area there should be a review of how policies should be re-focused or amended to facilitate adaptation” [European Commission 2009, p.8], (3) “Adaptation will require solidarity”, referring to Article 2 in the EU Treaty [European Commission 2009, p.6]. None of these three types of activity can be derived from the economic principles that have been extracted in Section 2.
- The White Book advocates that the EU should subsidise adaptation in partner countries as a part of EU foreign policy. It is difficult to see why the EU or the Commission should have superior information about optimal policies for adaptation in partner countries. If it has superior information, the subsidiarity principle suggests that a transfer of this superior information is the better policy tool.
- In line with the White Book recommendations, we see a clear role for the European government in the context of funding basic research and funding medical research and climate impact research. The share of public funding and government involvement should be highest in the area of basic research. Applied research, which yields major economic returns for the private innovator, may also need some support. However, the case for funding applied research is much weaker than the case for basic research. A second role of the government is the transmission of relevant information. The government has a major role in providing the private sector with state-of-the-art information about available technology and available facts about the impact of climate change.

4. Conclusions

Climate change adaptation is an important tool in coping with the challenge of climate change. Applying basic economic principles to guide the assignment of adaptation tasks between the private and the public sector, we find that a large portion of adaptation can be expected to take place in the private sector, voluntarily, and in private markets, as a reaction to climate change and with little governmental involvement. We also identified areas in which government involvement is desirable. This is the case if certain adaptation measures have characteristics of local, regional or global public goods. The production of knowledge about climate change has been identified as a major good with this property. Given the high uncertainty about the likely impact of climate change and about the economic environment in which climate change will occur decades in the future, adaptive capacity may be more important than pro-active investment in specific adaptation measures. In line with Schelling’s conjecture, adaptive capacity is likely to be high for economies that are well endowed with financial resources, human capital and technological and medical skills. Accordingly, a major task of the government is to provide a framework that fosters economic growth, investment in human capital and the production of technological and medical knowledge.

²⁸ The White Book advocates, for instance, “harmonised standards for construction with (...) a possible widening or extension of the existing Eurocodes” (European Commission 2009, p. 12). Given the diversity of climate conditions, the building standards in Greece and in the northern parts of Sweden may and probably should differ widely. Global warming will shift existing climate zones further towards north, and it is not unlikely that it will generate even more heterogeneity in the European climate. Harmonization of the norms of construction of private homes will not be the appropriate policy response to these changes.

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