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Abstract

The Nordic countries have engaged in ambitious policies to reduce greenhouse gas emissions. This might convince other countries to be more ambitious. We explore mechanisms by which small countries can affect emission reduction programs in other countries. Development of improved clean technologies seems to be the most viable of these mechanisms. Inspired by the philosopher Kant, the Nordic countries may also follow an ambitious climate policy because they want to do their share of a global effort to halt climate change. They should then consider whether they want other countries to follow their choice of policies.

Keywords: climate policy, climate-friendly technology, green business, reciprocity, Kantian preferences, moral obligation.

JEL codes: O38, Q54, Q55, Q58.

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1. Introduction

In the fall of 2018, the Intergovernmental Panel on Climate Change (IPCC 2018) issued their latest report on the impacts of global warming of 1.5°C above pre-industrial level and global greenhouse gas emissions pathways in line with this target. The report stresses the difference in climate-related costs to societies between a warming of 1.5°C and 2.0°C. Biodiversity loss is expected to be strikingly more severe, the number of extreme weather events significantly more numerous, the expected sea level rise higher, etc. The report also makes it clear that it will be very difficult not to exceed 1.5°C average global warming. Even if countries comply with their emission reduction pledges in the Paris Agreement, the world is on a course to 3°C warming or more.

The Nordic countries have all adopted the target of maximum 2.0°C global warming and committed to work towards maximum 1.5°C global warming. This is not only 'cheap talk' by Nordic governments. The targets manifest themselves in ambitious climate policies in all the five Nordic countries, the most obvious examples being:

- The promised total greenhouse gas emission (GHG) reductions exceed those of other comparable industrialized countries.
- Taxing of energy and/or greenhouse gas emission-related activities are higher than in other comparable countries.
- The countries have introduced a range of technology and sector-specific climate policy measures.

For instance, in the Paris Agreement the Nordic countries, together with the EU, have set more ambitious targets for emission reductions than other industrialized countries such as Australia, Canada, Japan and the US.[4] Another example could be gasoline prices, assuming that they reflect country-specific energy and emission taxation. If we compare OECD countries with respect to gasoline prices, we find that the Nordic countries on average have more than 20 percent higher prices than the average of the other countries.[5]

Finally, with respect to technology-related climate policy measures, there are ample examples of greenhouse gas abatement subsidies to industries that participate in the

[4] Measured as percentage reduction in GHG from a historical year. See Table A1 in Appendix A1. The US has decided to withdraw from the agreement (in 2020 or later).
[5] The data are for an arbitrary day in 2018 (see Figure A1 in Appendix A2).

European Emission Trading System (ETS). The cost of these measures indicates that it would be less expensive to reduce emissions by buying ETS permits.[6] There are also a range of subsidies and performance standards for sectors outside the EU ETS.

The total emissions from the Nordic countries only constitute a tiny share (less than 0.5 percent) of global emissions. Hence, the direct effect of Nordic countries reducing their emissions on global temperatures is miniscule. One way to rationalize ambitious climate policies in the Nordic countries is that these policies motivate other countries also to follow more ambitious policies. In this way, the ambitious climate policies in the Nordics may have a larger effect. The Nordic countries could also pursue ambitious climate policies out of a moral obligation; *'we should do the Nordic countries' share of a global effort to halt climate change'*. Acting according to a moral obligation will also have implications for global emissions, and there could be a conflict between 'doing the right thing' from a national perspective and 'doing the right thing' from a global perspective.

In general, outlining the global consequences of different ambitious Nordic climate policies is, regardless of the motivation for the action, worth analysing. Our main aim is thus to uncover potential global effects of an ambitious climate policy in a small country. We do not aim to explain why Nordic politicians have chosen the climate policies we currently observe. Instead, we will evaluate to what extent the current Nordic mix of climate policies is likely to have desirable global effects. For instance, we conjecture that no Nordic country would like its policy to increase greenhouse gas emissions in other countries, and certainly not to increase global emissions in spite of domestic emissions declining.

The rest of the article proceeds as follows. Section 2 examines current Nordic climate policies in more detail. Interestingly, we find that the policies are not well aligned. For instance, with respect to road transport, Norway pursues a proactive electric vehicle policy, while Sweden and Finland rely more on biofuels substitution. Moreover, Norway seems to be alone aiming to develop carbon capture and storage technologies.

Section 3 provides an overview of potential mechanisms that a small country may pursue to make ambitious climate policies worthwhile. We divide the explanations into two over-arching theory choices. On the one hand, we have explanations relying on modelling countries as only maximizing their own welfare, see Section 4. On the other hand, we discuss

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[6] See, however, note 7 below.

theories that let countries in one way or the other consider the welfare of other countries when making their choices, see Section 5.

In Section 6, we contrast current climate policies in the Nordic countries with our analysis of potential global effects of Nordic policies. We only discuss climate policies with point of departure in the 2030 targets, and we take the common EU GHG emission reduction targets for 2030 as given. For example, if the purpose of Nordic politicians is to motivate other countries to set more ambitious emission reduction targets, policies should focus on clean technology development. Moreover, research and development (R&D) should be directed at clean technologies that have a market outside the Nordics. Finally, the global impact could possibly be larger if Nordic R&D policies for clean technologies were better coordinated.

Having a technological focus does not run into conflict with a moral duty to *'do the Nordic countries' share of a global effort to halt climate change'*. In our opinion, this duty can be understood as Kant's categorical imperative to act 'as if the maxim of your action were to become through your will a general natural law'. Nordic countries should thus ask to what extent their climate policies constitute examples that they would want other countries to follow. In our opinion, not all types of Nordic climate policies pass this test. For instance, would Nordic countries like other countries to copy their ambitious biofuels policies given all the uncertainty surrounding the climate effects of biofuels? Moreover, does it makes sense from a global point of view to restrict a majority of the emission reductions to be carried out within the jurisdiction of a country instead of utilizing the potential costs savings from emission trading?

2. Climate policy in the Nordic Countries

2.1 Emission reduction targets

In December 2015, all the Nordic countries together with nearly all nations of the world stated their commitment to the Paris Agreement on climate change. As a part of the treaty, all countries should submit their planned greenhouse gas (GHG) emission reduction, which the treaty refers to as Nationally Determined Contributions (NDCs). The EU submitted a common NDC, and Iceland and Norway teamed up with the EU, and stated that they aimed to fulfil their NDCs together with the EU.

The EU, together with Iceland and Norway, committed to reduce emissions by 40 percent compared to 1990 levels. This is significantly more than the emission reductions promised by Australia, Canada, Japan and the US. Pursuant to EU's NDC, the EU has set one target for the emission sources covered by the EU Emission Trading System (ETS) and another target for the sources outside of the ETS, the so-called Effort Sharing Regulation (ESR) sector. For the ETS, the EU member states have a joint responsibility to reduce emissions by 43 percent compared to 2005 levels. Since the ETS facilitates trading in emissions permits between firms across the EU states, additional climate measures directed at ETS firms in the Nordic countries will to a large extent only relocate emissions to other EU countries, and only under certain circumstances reduce total emissions from the ETS.[7] This apparently does not stop Nordic countries from having additional policies for ETS firms, as we elaborate on later.

For the ESR sector, the EU has committed to reduce emissions by 30 percent compared to 2005 levels.[8] Moreover, the Nordic EU countries have agreed to do more than the average emission reductions: Sweden must reduce non-ETS emissions by 40 percent, and Finland and Denmark by 39 percent, more than any other EU country. While Sweden, Denmark and Finland are EU members, Norway and Iceland are only affiliated with the EU through the European Economic Area agreement. As mentioned, both countries aim to participate fully in EU's climate policy, and we can thus treat them as EU members in our analysis. Furthermore, like the Nordic EU countries, Norway and Iceland will likely have to reduce their non-ETS emissions by 40 percent or slightly less.

Except for Iceland, all Nordic countries have ratified a climate change act. All these acts state that the country should become a low-emission society before 2050 (2045 in Sweden). In Denmark, the political parties in the parliament have now agreed that Denmark should be 'climate gas neutral' by 2050.[9] Finland does not explicitly define what they imply by a low emission society, while Sweden states that it will reduce emissions from Swedish territory by 85 percent by 2045 compared to 1990 levels. Norway's goal for 2050 is similar to Sweden's: an 80-95 percent reduction of emissions compared to the 1990 level. However,

[7] Recent changes made to the EU ETS suggest that additional emission reductions taken on by an EU ETS firm may reduce the total available amount of emission permits, and thus that there is not 100 percent leakage as usually assumed (see Perino 2018 and Silbye and Sørensen 2019).

[8] Together, 43 percent reduction for the ETS and 30 percent reduction for the Non-ETS compared to 2005 levels, should yield a total reduction of 40 percent compared to the 1990 level.

[9] See Danish Ministry of Energy, Utilities and Climate (2018).

according to the Norwegian climate change act, Norway may attain some of these reductions through the ETS. All Nordic countries except Iceland communicated these goals as NDCs to the Paris Agreement.

Concerning emission reduction targets for 2030, the Nordic climate change acts restate the common EU contribution to the Paris Agreement: a 40 percent reduction compared to the 1990 level. Furthermore, since the 30 percent reduction target for the ESR sector has been broken down to individual EU country levels, the acts deal in more detail with how the Nordic countries will reach their ESR targets. All Nordic countries seem determined to do a large share of emissions reduction in the ESR sector within their borders. They have signalled that they will only make limited use of the flexible mechanism the EU will introduce for the ESR sector. For instance, the Nordic countries have sectoral policies for ESR emission reductions like biofuels blending mandates for transport fuel, targets for number of electric vehicles sold, plans for emission reductions from agriculture, etc.

We find it strange that the Nordic politicians seem to downplay the flexible mechanism for the ESR sector. First, the Nordic countries may use a limited amount of ETS credits to fulfil their 2030 ESR target. Second, also up to a limit, they may use carbon sequestration by land and forests. Finally, there will be a scheme for trading in ESR emission allowances among EU countries. For example, a country that over-complies with its ESR target may sell allowances to other countries. There is clearly some uncertainty as to how the ESR trading is going to function; to date the EU has not established any institutions to organize and monitor this trading. Moreover, no one knows what the prices will be for an ESR emission allowance. Analyses by, for instance, Aune et al. (2015), and Aune and Fæhn (2016) suggest that these prices may turn out to be considerably higher than the permit prices in the ETS. On the other hand, according to the EU the 43 and 30 percent targets were set such that marginal GHG abatement costs approximately should be equalized between the ETS and the ESR sector.[10]

2.2 Examples of additional policy measures in the ETS sectors

The ETS regulates all emission from the ETS sectors in the Nordic countries. Due to the gradual reduction of the amount of emission permits administered from the EU, no Nordic

[10] See European Commission (2018).

country needs any additional policies to reach the emission reduction target of 43 percent compared to the 2005 level. In spite of this, there are a number of additional policies in the Nordic countries for the ETS sectors:

- In Sweden, there is a subsidy program called *Industriklivet* (the "Industry Leap") which donates up to 300 million SEK per year to emission reduction projects within process industries. Norway has a similar program named *Enova*, which has a total budget of 2.5 billion NOK. A large part of this support goes to the maritime transport sector in Norway.
- Denmark has a range of subsidies to renewable energy. The subsidy scheme differentiates between (i) technology, e.g. on-shore wind, off-shore wind, solar, bio, etc., (ii) scale, e.g. home installations versus power plant size installations, and (iii) area of application, e.g. electricity production, heat production, process industry, etc. Finland also has subsidies to renewable energy.
- Sweden and Norway have a common green certificate system subsidizing wind, solar and new waterpower installations.
- Norway has a separate carbon capture and storage (CCS) program, which currently is considering two projects: a cement factory and a waste-burning facility; the first project is covered by the ETS.
- Finland will ban all use of coal for power production by 2030.
- Norway is the first country in the world to introduce a blending mandate for biofuels in aviation (aviation within EU territory is covered by the ETS). Norway also has a carbon tax on fuel for domestic flights.

2.3 Examples of policy measures in the ESR sector

The main policy measure in the Nordic countries for the ESR sector is taxation of fossil fuels. As mentioned, gasoline is heavily taxed in the Nordics with prices on gasoline being more than 20 percent higher than in other OECD countries. Furthermore, all Nordic countries have a number of sector-specific policies for ESR emissions:

- Promotion of biofuels, both by encouraging domestic production and by increasing blending mandates, are essential ingredients of both the Finnish and Swedish policies. Both countries have a large forestry sector, and producing biofuels from forests material seems to be in focus. Sweden aims to reduce emissions from domestic transport by 70 percent before 2030, which seems hard without a massive substitution of fossil fuels with biofuels. Finland wants to have 30 percent blending of biofuels by 2030.

- Norway has a proactive policy with respect to electric vehicles. These vehicles are exempted from both value added tax and vehicle registration tax, which for some of the more expensive brands can make up more than 50 percent of their sales price. Electric vehicles also enjoy cheaper access to toll roads, cheaper parking and access to bus lines. There exist several studies of the cost of reducing CO_2 emissions by switching from fossil cars to electric vehicles (see e.g. Holtsmark and Skonhoft (2014) and the Norwegian Environmental Agency 2016). All studies show that electric vehicle abatement costs exceed the current permit prices in the EU ETS by a large margin.
- Finland will band all use of coal for district heating by 2030. Finland also has a subsidy to electric vehicles, although with €2000 per vehicle it falls short of the Norwegian subsidies.
- In Sweden there is a program called *Klimatklivet* (the "Climate Leap"), which sponsors GHG abatement projects for the ESR sector. Examples are zero-emission construction machines, production of biogas, charging stations for electric vehicles etc.
- Norway and Iceland sponsor electric ferry connections. The Norwegian road authorities offer concessions on certain routes to ferry companies that supply zero-emission connections. The goal is to have 50 ferries in operation by 2020. Iceland will soon have its first electric ferry operating between the Westman Islands and the mainland.
- Iceland aims to phase out fossil fuels in transport. From 2030, new registrations of gasoline and diesel cars will not be accepted. Moreover, Iceland is considering a rebate system for existing gasoline and diesel cars to speed up their replacement with zero-emission cars.[11]

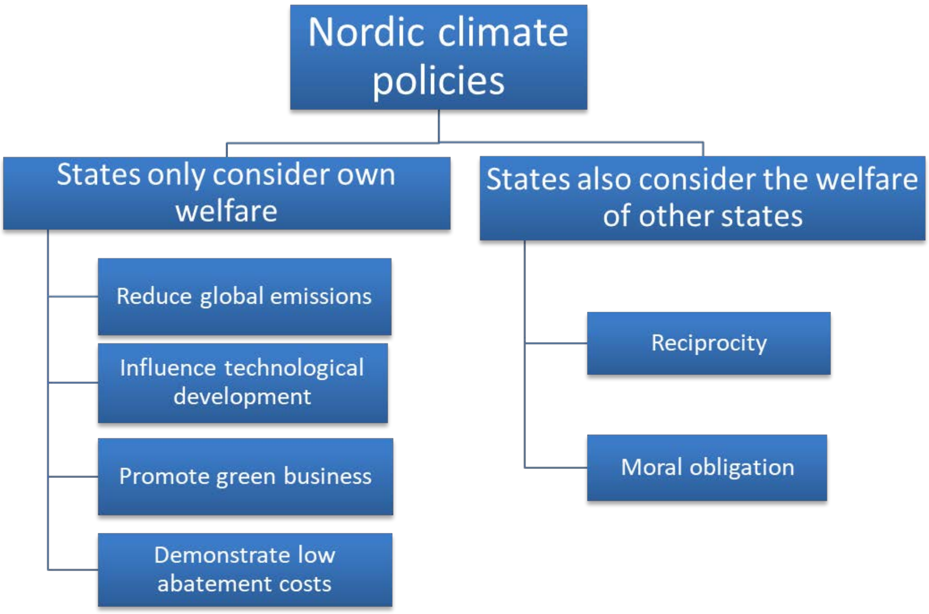
[11] See Government Offices of Iceland (2018).

3. Rationales for ambitious climate policies

In economic models of international climate policy, it is regularly assumed that states act as a monolithic entity that maximizes the welfare of a representative citizen. To know the global effects of ambitious Nordic climate policies, we must make assumptions about the preferences of the representative citizen in other countries – not only the Nordics. Here we will follow two routes as pictured in Figure 1 below.

Along the left branch of the figure, we will explore different rationales assuming that the representative citizen only cares about herself, that is, not citizens in other countries. The state is then acting only in its own self-interest. In the right branch of the figure, we change the strong assumption that the representative citizen only cares about herself. Instead, the citizen could be concerned with the welfare of others, or she could be wanting to 'do the right thing' independent of own welfare. In the case corresponding to the right branch, states will consider also the welfare of other states in some way.

Figure 1 Rationales for ambitious climate policies



The representative-citizen assumption is clearly a large simplification. The Nordic countries are all democracies with political parties catering to different sub-groups of society. Not all citizens of the Nordic countries stand to lose on an excessive climate policy, although the country as a whole might lose. For instance, forest owners and the paper and pulp industries in Sweden, Finland and Norway may benefit from these countries' biofuel policies. Moreover, large parts of the population may be equally well off; city dwellers working for the public sector will have less local pollution, and in exchange for higher energy prices they may benefit from a richer state (due to higher carbon taxes). A ruling party may win the election based on these groups, and hence enact policies that reduce overall welfare, while a political minority bears the losses. But since we do not aim to explain why Nordic politicians have chosen the climate policies we currently observe, we will not explore political-economy models further in this paper. Below we will keep the assumption that the state acts in the interest of a representative citizen, who might or might not have preferences covering more than only her own individual welfare.

4. States act only in their own self interest

In Paris, all countries agreed to limit the temperature increase to well below 2.0°C. On the other hand, even if all countries live up to their NDCs, the temperature increase by 2100 will be 3-4°C (United Nations 2017). The Nordic countries may hope to decrease this gap by increasing their GHG abatement. However, looking at the current and future composition of GHG emissions among countries, it seems naive to expect that extra emission reductions in the Nordics should have any direct significant impact on global temperature levels.

First, the industrialized countries as a whole make up a shrinking share of world emissions. Even if all OECD countries and China should take prudent action, climate change seems impossible to halt without engaging the developing countries (Hoel and Holtsmark 2012).

Second, additional GHG emission reductions in one country could result in increased GHG emissions in other countries through so-called carbon leakage. Bohm (1993) was one of the first to point out that if some countries reduce their consumption of fossil fuels in order to reduce GHG emissions, the price on fossil fuels will go down, leading other countries to use more fossil fuels. This is further elaborated on in Hoel (1994) and Calmfors et al. (2008). The latter analysis suggests that extra emission reductions in the Nordics could be totally offset by emission increases elsewhere. Furthermore, a more stringent climate policy in a region could induce emission-intensive firms to relocate to regions with laxer climate policies, as suggested by Mæstad (2001).

Finally, other countries may also actively change their climate policies as a response to a more ambitious policy in the Nordics. Since a warming climate likely affects every state negatively in one way or the other, every state has a private incentive to reduce emissions. Thus, even in the situation without a climate treaty, we would observe that states set GHG emission reduction goals. In the economic literature, the Nash equilibrium[12] in emission reduction goals in this kind of non-cooperative game has been extensively studied.

First, it is straightforward to show that in such a situation the sum of the individual countries' emission reductions falls short of the globally optimal level of emission reduction. This sub-optimal outcome reflects a *prisoner's dilemma* situation. Second, Hoel (1992) finds

[12] A Nash equilibrium is a situation in which every agent has chosen her best action given the choice of actions of all the other agents.

that if one state becomes more ambitious, the other states likely respond with less ambitious emission reduction goals. This is clearly not what Nordic politicians hope to achieve by promoting an ambitious domestic climate policy. Setting ambitious emission reduction goals may however spur more technological development, and as we discuss below, this can affect other countries in a more desirable direction.

4.1 Influence technological development through R&D policy

R&D entails (at least) two types of market failures. First, production of new knowledge not only benefits the ones conducting the research, but diffuses in various ways through the research community and may benefit all other researchers in the same field. This is often called the 'standing-on-shoulders' effect. It is explicitly modelled in the economic growth literature by allowing past research to make current research more efficient (see for instance Romer 1990). Second, successful research often leads to a patent, which allows the researcher to act as a monopoly for a limited period. In spite of the monopoly rights, the patent owner is still not able to appropriate the full social surplus from her innovation (see Arrow 1962). Both effects imply that the private incentives to innovate may be insufficient, and that the government can improve welfare by supporting innovation in various ways.

Economists tend to stress that innovation support should be neutral. For instance, all innovation projects should receive the same subsidy independent of whether it is a new medicine, a new way of drilling for oil or an improvement in the batteries used for electric cars. Recent research has challenged this view. Acemoglu et al. (2012) consider an economy with two sorts of inputs: dirty and clean. The dirty input leads to the build-up of a stock of pollution, which eventually will cause an environmental disaster. The clean input has no such external effect, but is initially more costly than the dirty input because historically fewer researchers have been developing the clean input production technology. Acemoglu et al. show that under certain conditions the regulator would benefit from both an emission tax and a directed research subsidy to clean research. The reason, as shown by Greaker et al. (2018), is that the external knowledge spillovers in dirty research have lower social value than the external knowledge spillovers in clean research. To avoid an environmental disaster, the economy must stop using dirty inputs in the future, and hence, knowledge that helps improve this technology is of less value.

Most researchers agree that in order to limit global temperature increase to 2°C , the world needs to develop new clean technologies. The Nordic countries, together with the EU, seem to have as their objective to redirect research funds into clean technologies.[13] The crucial mechanism in Acemoglu et al. (2012) is that, as long as the current state of knowledge is largest for dirty technologies, research will continue within these technologies due to the standing-on-shoulder effect. If the state of knowledge within clean technologies can be brought up to the level of the dirty technologies, the process of clean inputs taking over for the dirty inputs can start to happen by itself. Clean technologies may then displace dirty technologies even without an environmental policy. Hence, technology policy could achieve what environmental policy so far has not achieved: to curb carbon emissions.

One crucial assumption in this literature is that clean and dirty technologies belong to different knowledge bases. Greaker et al. (2018) relax this assumption, and demonstrate that a technology policy directed towards clean technologies then loses much of its appeal. On the one hand, the recent empirical literature seems to confirm that there exist separate knowledge bases for clean and dirty technologies.[14] On the other hand, there exists anecdotal evidence of the opposite such as floating windmills based on offshore oil-exploration technology.

Another crucial assumption is that clean and dirty technologies can readily substitute each other. To the extent that clean and dirty technologies can serve the same purposes, clean technologies will displace dirty technologies (almost) completely once they become competitive, and directed technology policy alone can curb carbon emissions. On the other hand, if for many purposes clean technologies cannot easily substitute dirty technologies, it becomes difficult for technology policy alone to curb emissions.[15]

There are studies indicating a low level of substitutability between dirty and clean technologies. Ambec and Crampe (2012) consider deployment of intermittent renewable power technologies, e.g. wind and solar, in the electricity market. They find that due to intermittency problem, wind and solar may become complementary to fossil technologies, such as gas power, at high levels of deployment. On the other hand, the degree of substitutability may also be affected by innovation. Lazkano et al. (2017) study development

[13] One exception is Norway, which also sponsors research in oil and gas extraction.
[14] See Aghion et al. (2016) for a study of innovations in the car industry and Dechezleprêtre et al. (2013) for more examples of clean technologies.
[15] Acemoglu et al. (2012) use a CES production function in which clean and dirty intermediates are combined to produce a final product. With a CES elasticity of substitution higher than 1, technology policy alone can curb emissions, although it becomes economically inefficient to use only a technology policy if the CES elasticity is close to 1. With a CES elasticity lower than 1, technology policy must be supplemented by an emission tax in order to reduce emissions.

of electricity storage technologies, and argue that they increase substitutability between clean and dirty technologies.

Finally, Acemoglu et al. (2012) do not define ‘clean technologies’. Greaker et al. (2018) discuss whether electricity production technologies, such as solar cells, wind batteries and electric engines for mobility, could constitute a separate knowledge base. Moreover, they speculate whether petroleum and coal extraction, and the internal combustion engine, make up the dirty knowledge base.[16]. Clearly, there exist intermediate cases: carbon capture and storage is based on the dirty knowledge platform, but could all the same reduce emissions. Biofuel is likewise based on the internal combustion engine and industrial processing similar to an oil refinery. If we were to follow the policy recommendations from Acemoglu et al., governments should abstain from supporting R&D in these technologies. On the other hand, in their model all dirty technologies produce intermediates that are bound to cause emissions.

Bijgaart (2017) extends the model of Acemoglu et al. (2012) by introducing two regions. She shows that if a region contains the majority of researchers, this region can possibly redirect technical change from dirty to clean technologies. The mechanism is that a critical mass of countries does so much clean research that the knowledge base in this technology overtakes that_of the dirty technology. Researchers from the rest of the world would then also move to clean innovation, and clean technologies would increase their competitiveness towards dirty technologies forever after. A consorted effort by the Nordic countries, the rest of the EU and a set of US states (like California) could possibly achieve such a tipping effect. According to Bijgaart, the EU including the Nordic countries are too small to tip the balance alone. However, another branch of the literature explicitly studies strategic technology policy, which allows small countries to influence emissions abroad through the right type of clean R&D.

4.2 R&D as a strategic investment

The Paris Agreement is based on voluntary GHG emissions reduction contributions by the individual countries, so-called Nationally Determined Contributions (NDCs). Industrialized countries may therefore use technology policy strategically to influence future NDCs of

[16] This is in accordance with the empirical study by Dechezleprêtre et al. (2013).

other countries. Buchholz and Konrad (1994) and Stranlund (1996) were two of the first contributions studying such uses of technology policy.

Both contributions distinguish between an industrialized country and a developing country. The industrialized country can invest in R&D that lowers its own cost of abatement or in R&D that lowers cost of abatement in the developing country. Hence, the technology that lowers cost of abatement differs between the industrialized and the developing country. The developing country is assumed not to be able to invest in R&D due to lack of either competence or funding.

Each country decides on its level of abatement. Let A_1 be of the level of abatement in the industrialized country, henceforth referred to as Country 1, and let A_2 be the level of abatement in the developing country, which is henceforth referred to as Country 2. Consider first the case prior to investment in R&D. For each hypothetical level of abatement in one country, say, Country 1, there is a level of abatement in Country 2 that maximizes the welfare of the latter country. This relationship is referred to as the optimal reaction curve of Country 2. Similarly, Country 1 has an optimal reaction curve that for each level of abatement of Country 2, assigns the level of abatement of Country 1 that maximizes the welfare of the latter country.

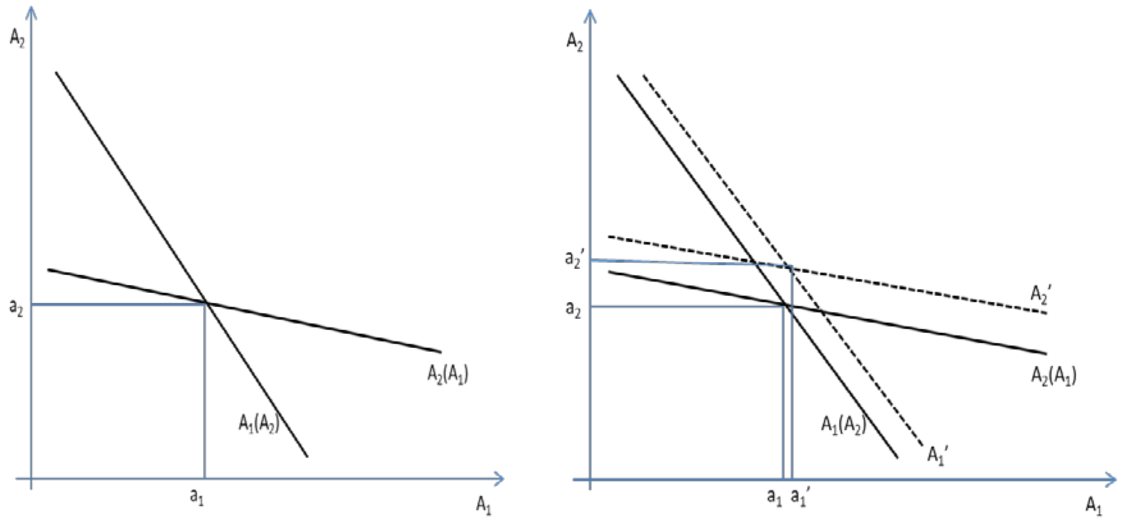
If the level of abatement in one country increases, total abatement also increases (that is, total emissions decrease). This reduces costs of carbon emissions of the second country. Under standard assumptions, it is then optimal for the second country to decrease its own level of abatement. Hence, the higher the abatement of the one country, the lower is abatement in the other country. This situation is depicted in Figure 2, panel (a). Here, $A_2(A_1)$ is the (downward sloping) reaction curve of Country 2, whereas $A_1(A_2)$ is the (downward sloping) reaction curve of Country 1.

The outcome of the game (prior to R&D investment) is given by the point (a_1,a_2), that is, the industrialized country chooses a_1 as its level of abatement, whereas the developing country chooses a_2. Graphically, the point (a_1,a_2) is found where the two reaction curves intersect. In this point both countries are on their (optimal) reaction curves. Therefore, given the choice of abatement of the other country, the country considered cannot make a better choice than the one chosen. This means that (a_1,a_2) is a Nash equilibrium.

Figure 2 Strategic investments in abatement technology

(a: No R&D investment.

(b) Optimal strategic R&D investments in the industrialized country.



Recall that the industrialized country, that is, Country 1, can invest in two types of R&D: one that lowers its own cost of abatement, and another that lowers cost of abatement in the developing country. Further, assume that R&D is determined prior to abatement. If the industrialized country invests in R&D that lowers its own cost of abatement, then for any given level of abatement in the developing country, it is now optimal to choose a higher level of own abatement than prior to the investment. Therefore, the reaction curve of Country 1 shifts outwards in the diagram; this is depicted by the curve A_1' in panel (b). As can be seen, investment in R&D that lowers the own cost of abatement changes the Nash equilibrium (the intersection of the two reaction curves) so that the industrialized country now abates more , whereas the developing country abates less.

If, alternatively, the industrialized country invests (only) in R&D that lowers cost of abatement in the developing country, the reaction curve of the developing country shifts outwards (A_2' is the new reaction curve of Country 2). In the Nash equilibrium in this case, abatement in the developing country has increased (reflecting that abatement has become cheaper there), whereas abatement in the industrialized country has been lowered (reflecting that once the developing country increases its abatement, it is beneficial for the industrialized country to respond by less abatement).

The industrialized country is aware of how investment in the two types of R&D shifts the reaction curves. Under standard assumptions, it is optimal for the industrialized country to invest in both types of R&D. Typically, the outcome is that both countries choose more abatement than in the hypothetical case of no R&D investment. This is shown in panel (b) of the diagram by the intersection of the two dashed reaction curves resulting in the abatement levels a_1' and a_2'. In fact, since by assumption R&D investments reduce abatement costs, both countries benefit from the investments.

A similar mechanism is studied by Golombek and Hoel (2004). In their paper, industrialized countries' R&D spur abatement in other countries through technology spillovers, that is, there is a positive externality. In Golombek and Hoel, an industrialized country invests in R&D to reduce its own cost, and as a by-product developing countries' costs are also reduced. This would lead industrialized countries to invest heavily in R&D, thereby increasing abatement in all countries.

Greaker and Hagem (2013) introduce permit trade between industrialized and developing countries to the game depicted in Figure 2. In this case, investment in both types of R&D also has an effect on the future permit price, and not only on the emission reduction targets of the two players. For instance, investments in the type of R&D that reduces industrialized countries' abatement costs will also reduce industrialized countries' future payments for emission permits to the extent that they will become net permit buyers. This provides an additional incentive for industrialized countries to invest in R&D. However, due to the complexity of the model, the authors do not obtain unambiguous theoretical results with respect to strategic investment in abatement technologies. Instead, they run several numerical simulations and find in these that industrialized countries invest heavily in both types of technologies.

So far, we have discussed strategic investment in R&D assuming that there exists no climate treaty that obliges countries to abate more than they do in the Nash equilibrium. There exists a large literature analysing the prospects for self-enforcing climate treaties that involve higher levels of abatement than in the Nash equilibrium. Barrett (1994), who found that a self-enforcing climate treaty would only attract a small sub-set of countries, and thus achieve little with respect to reducing global emissions beyond the Nash equilibrium levels, pioneered this literature. A treaty is self-enforcing when no country wants neither to leave, nor to enter, the treaty. There is a strong incentive to leave a treaty, especially when the treaty has many members. A treaty with many member countries will set ambitious emission reduction targets since the externalities countries impose on each other by their emissions largely become internalized. Thus, if a country leaves, it can save large abatement costs, and at the same time free-ride on the remaining members' ambitious reduction targets. Due to this effect, the self-enforcing treaty will consist of only few member countries, who will set only modest emission reduction targets. Since Barrett's (1994) contribution this main result has been modified in many ways. For instance, McGinty (2007) studies asymmetric countries that can promise side payments to attract members to the treaty, and Harstad et al. (2018) examines treaty formation as a dynamic game with technology investments that reduce the incentive to free-ride. Here we will focus on the effect of technology investment, but in a simpler way than in Harstad et al. (2018).

The key parameters in the Barrett model are the individual country's benefit and cost of GHG abatement. If the cost is relatively large compared to the benefit, the Nash equilibrium emission reduction levels will be very modest, and there will be a lot to gain from a climate treaty enforcing all countries to abate more. However, as already explained, such a treaty is not self-enforcing (in the Barrett set-up). Beisland (2013) studies the incentives for a single country to conduct R&D that lowers the cost of abatement for all countries. If the country acts non-strategically, and only minimizes its own abatement cost, the level of R&D may be modest since no country is particularly ambitious with respect to emission reductions. If, on the other hand, the country acts strategically, investment will be a lot higher. The reason is that lower abatement costs will not only increase future abatement by both signatories and non-signatories, but also increase the number of member countries in the treaty. Thus, R&D investments can be used as a tool to increase both the breadth and depth of future climate treaties.[17]

The contributions of Buchholz and Konrad (1994), Stranlund (1996), Golombek and Hoel (2004) and Beisland (2013) all have one thing in common: The R&D investment must reduce the GHG abatement costs of other countries, thereby giving them an incentive to reduce their emissions.

4.3 Technology policies which spur the adoption of new technologies

[17] Other contributions also looking into this are Urpelainen (2011, 2013) and Hoel and de Zeuve (2014). The conclusions are in line with those of Beisland (2013).

So far, we have discussed R&D and the market failures connected to R&D. There may also be positive externalities in the diffusion of a new technology. There is ample evidence, among others from windmills, electric vehicle batteries and solar cells, that the unit cost falls as production of the technology accumulates (e.g. International Energy Agency 2000). Researchers illustrate the relationship between the unit cost and accumulated production by so-called learning- or experience curves, the names referring to the process by which the unit cost falls. The cost reduction is often assumed to be a constant fraction per doubling of accumulated production.

Clearly, if a private firm cannot appropriate all of its experience with a new technology, and this experience benefits other similar firms, we have a positive externality. It may then be welfare-improving for governments to support the initial diffusion phase of a new technology. Rosendahl (2004) studies the implications for climate policy when abatement costs are declining in accumulated abatement. There are two regions; an industrialized one, in which experience accumulation takes place, and a developing one, which passively reaps the benefits of a low-cost abatement technology. The paper shows that climate policy, represented by a carbon tax, should be more ambitious in the industrialized than in the developing region. The result follows from the positive experience externalities, that is, every extra use of abatement in the industrialized region today decreases future costs of abatement in both regions.

Learning curves have an intuitive appeal: Anecdotal evidence suggests that experience reduces costs. However, regressing unit costs on accumulated sales seems too simple to be used as a basis for policy. As sales of a product picks up, several parallel processes likely contribute to the decline in costs. R&D to lower the cost of production of the new product is not put to a halt because the product is brought to market; rather, it may be intensified. A larger market may allow for economies of scale, also reducing unit costs, but here there are no positive knowledge externalities. Furthermore, the technology may benefit from R&D in other closely related fields. Nordhaus (2009) points to some of these effects, and conjectures that the estimated learning rates are exaggerated.

Network externalities may also halt the diffusion of a new technology. According to Farrell and Klemperer (2007), the consumption of a good has positive network effects if one agent's purchase of the good increases the incentive of other agents to purchase the good. Recent research suggests that electric cars satisfy this condition. The network externality is indirect, as it mainly results from a wider range of complementary goods and services. For example, Zhang et al. (2016) find, based on data from Norway, that access to charging stations has a strong positive effect on willingness to pay for an electric vehicle. Moreover, Li et al. (2017) use data from the US and estimate a model that combines electric vehicle sales with the number of charging stations. They find that a ten percent increase in the number of charging stations increases electric vehicle demand by eight percent. Even if current climate policy has fully internalized the pollution externality of gasoline cars, the network externality could warrant subsidies to electric vehicles and/or charging stations (see Greaker and Midttømme 2016).

While network externalities to some extent are mainly a national problem, experience effects are international. That is, if network effects are important for the adoption of electric vehicles, a nation may find it worthwhile to subsidize electric vehicles temporarily, independent of any international effects. Accumulated experience, on the other hand, depends on global accumulated sales of a technology. For a single, small nation, or even for the Nordic countries taken together, building up the accumulated experience with a technology, such that costs are significantly decreased, is harder to accomplish. Nevertheless, for some carefully chosen technologies, the effort of a single country may matter. For example, the high electric vehicle sales in Norway may have contributed significantly to the decline in electric vehicle battery cost. Furthermore, the success of the Tesla brand, which has had a large share of its sales in Norway, seems to have spurred incumbent car companies to develop their own high-quality electric vehicles.

4.4 Promote green business

We have shown that the Nordic states could possibly benefit from subsidizing clean technology development such that other states can get access to cheaper abatement options. However, they also want Nordic firms to control these technologies through secrecy or patents, that is, to promote profitable export firms. Greaker and Rosendahl (2008) and Greaker et al. (2016) examine green export promotion. There are in principle two ways in which a country could promote development of green technologies. First, the country could set tough emission standards and/or subsidize GHG abatement to create a larger home market for green technologies. Second, the country could support domestic green-technology firms either indirectly through R&D funding or directly through production subsidies.

Setting ambitious emission standards to create a larger home market is analysed in Greaker and Rosendahl (2008). Such a strategy would spur domestic R&D, but as long as trade barriers are moderate, it will also trigger more R&D by foreign green-technology suppliers. Consequently, the domestic green industry does not get a first-mover advantage by this policy. On the other hand, the policy may lead to more intense competition between abatement technology suppliers, thereby improving welfare. Greaker and Rosendahl also analyse subsidies to domestic firms' green R&D. They find that such subsidies should always accompany the efforts to create a larger home market for green technologies.

Fischer et al. (2017) develop these ideas further, and compare policies directed at the downstream polluting industries with policies directed at the upstream abatement technology suppliers. One conclusion is that policies directed at the upstream abatement technology firms are more robust both with respect to reducing global emissions and to promote new green businesses. The contributions by Greaker and Rosendahl (2008) and Fischer et al. (2017) can thus be seen as more detailed analyses of strategic technology policy.

4.5 Technology policy to demonstrate low abatement costs

Heal and Kunreuther (2017) discuss the concept of *tipping*, *cascading* and *entrapment*. Their point of departure is that a game involving many countries negotiating a climate treaty may have many equilibria. One equilibrium may be no treaty, while other equilibria could imply broad cooperation and deep emission cuts. The equilibrium with no treaty is an example of an *entrapment*. In such a situation, a small number of players may be able to tip the equilibrium into one of the more desirable equilibria. With *tipping*, all other players follow suit, while with *cascading*, other players follow one by one, each incentivizing the next player to change strategy. Heal and Kunreuther view clean technological development, promoted by a group of technologically advanced countries, as a strategy that could trigger cascading. This is in line with the ideas we have discussed above.

It is also possible to think of another cascading mechanism. No country can currently know what it will cost to become a 'low-emissions society'. For instance, it is hard to predict future cost reductions for renewable power, batteries and hydrogen-based solutions. Moreover, it is hard to say how easily consumers will adapt to eating less meat, flying less, etc. In a situation in which no country knows the true costs of drastically cutting GHG emission, the country with the most optimistic belief about costs could find it worthwhile to reduce emissions drastically if that makes other countries update their believes about costs.

In Appendix A.3, we sketch a model with cascading based on imperfect information and updating of beliefs. We show that it may be optimal for a country to cut emissions drastically as long as there is a significant probability that other countries will follow. They will only follow as long as it is privately optimal for them. In our opinion, this likely requires the true GHG abatement costs to be much lower than widely believed. We suspect that the world is not yet there despite the large advances in GHG abatement costs in recent years. This reinforces our argument that more technological development is needed.

Large national co-benefits of GHG mitigation, such as reduced local pollution and less oil dependence, will also make it more probable that other countries will follow if first-mover countries can demonstrate that the true GHG abatement costs are lower than expected. This suggests looking for technologies with significant co-benefits for developing countries.

5. States also consider the welfare of other states

In economic models of international cooperation on climate change, researchers mostly assume that nations act in pure self-interest. If we further assume that political decision makers act in the interest of their citizens, it follows that citizens also must be motivated by pure self-interest. This is not in accordance with ample evidence from lab and field experiments that show that people also consider the well-being of others when making choices. It is, however, hard to disentangle exactly what is driving such behaviour.

5.1 Reciprocity and warm glow

Andreoni (1990) introduced the concept of *warm glow*. It implies that consumers' utility increase both from contributing to a public good and from the public good in itself. Framed in this manner, warm glow can explain observed attitudes towards the environment, recycling of garbage, voluntary acquisition of GHG emission permits when flying, participating in organized beach tidying, etc. On the other hand, we find it hard to argue for ambitious climate policy measures based on warm glow. First, it is not clear whether warm glow is something you get only if you contribute to a public good by your own actions, or if the state can act on behalf of you. Second, we lack a deeper understanding of the correspondence between type of actions and the amount of warm glow. Whereas Andreoni simply postulated the 'warm glow' effect, it is still not completely clear to what extent an underlying mechanism explains the effect. One possibility is that warm glow could be an evolutionary inherited trait that leads to better outcomes for a group as a whole. This leads us to the recent literature on Kantian preferences, with contributions from (among others) Alger and Weibull (2016a, 2016b), which is discussed below.

Another mechanism that could lead to better outcomes for a group as a whole is *reciprocity*. Reciprocity refers to the mechanism that if one actor gives something to another actor, she will get something in return at a later point in time. Reciprocity has been extensively studied in the experimental economics literature. One example is the trust game: A player receives an amount of money. The player decides the share she wants to keep; the remaining share is given to the second player. The amount she gives to the second player is multiplied by some factor, and the second player decides how much to give back to the first player. If the first player believes that the second player is egoistic, the first player will not give anything to the second player as this player is expected to keep all the gain herself. The predicted equilibrium outcome of this game is thus that the first player keeps all money to herself, while the socially optimal action is to give the whole amount to the second player. The literature shows that the predicted equilibrium actions are rarely played. The first player regularly sends away some amount, and is also receiving an amount back. For example, Croson and Buchan (1999) find that 85 percent of the second players return more money than was originally sent. Moreover, there is a clear sign of reciprocity: the higher share the first player gives to the second player, the higher share the second player returns to the first player.

Another type of experiment that can throw light on the reciprocity mechanisms is the ultimatum game. In the ultimatum game, a player receives a sum of money and proposes a sharing rule to the other player. The other player can either approve the sharing rule or reject it. In the case of approval, the sharing goes through, while in the case of rejection, none of the players gets anything. The equilibrium in this game is also that the first player keeps all the money; the second player might as well accept the offer from the first player as he will not get anything if he rejects the offer. Again, the literature shows that the predicted equilibrium actions are rarely played. The first player typically proposes to share more than 20 percent to the other player, and the other player often rejects offers of less than 20 percent. The observation that the second player rejects small offers is seen as examples of negative reciprocity, that is, players are willing to punish players with 'unfair offers' even if they are hurt themselves.

There is of course a question of whether the reciprocity mechanism is valid for countries trying to cooperate on limiting climate change. The experiments are carried out in stylized settings with players that act as individuals. Thus, transferring the results to countries, acting in complicated, multi-dimensional international settings may seem naive. Experiments with groups of agents instead of individuals have been run. This could increase the external validity vis-a-vis an international climate policy setting. Bornstein and Yaniv (1998) and Cox (2002) both find that groups give less than individuals in the trust game. However, Cason and Mui (1997) find that when groups play the ultimatum game, the most generous member of a group tends to end up deciding how much should be offered to the other group. This indicates that it is difficult to predict the behaviour of countries based on experiments with individuals. Moreover, a group in an experiment is far from a nation with a representative democracy or a nation with a ruling party.

It is also important to understand the underlying cause for the observed reciprocity mechanism Some, among others Fehr and Schmidt (1999), have proposed that *inequality aversion* is driving the results, that is, agents experience a loss in utility from an unjust distribution of wealth. If this is the case, it seems unlikely that other countries will reciprocate an ambitious climate policy in the Nordic countries. Ambitious climate policies set by a small country will only in the very long run, and only to a very limited extent, increase the welfare of other countries. Other countries will therefore not necessary feel obliged to reciprocate.

Another possible explanation for the observed behaviour is that the players act *as if* they are playing a repeated game. In a repeated game, contributing to a public good may be an equilibrium strategy. Initiating an ambitious climate policy may be a way of trying to establish an equilibrium in which all countries have more ambitious climate policies. However, countries must in this case also be ready to punish those countries that defect, e.g. do not initiate policies that are more ambitious. As far as we can see, such a tit-for-tat strategy has no role in the Nordic climate policies.

Finally, reciprocity may be an inherited trait: we punish those who treat us unjust although we lose from it, and we reward those who give us favours. It can be discussed to what extent ambitious climate policies in the Nordic countries are viewed as 'favours' by other countries. The developing countries are demanding that industrialized countries should do more towards climate change. Thus, in their opinion, the Nordic countries are just doing what they at least ought to be doing. If so, 'ambitious' Nordic climate policies will not trigger more ambitious climate policies in the developing world.

In our opinion, there may be reasons for considering other countries utility when a country decides its own climate policy. This should, however, not be based on what the country might get back from other countries, but rather on the moral obligation of the country vis-a-vis climate change.

5.2 Moral obligation

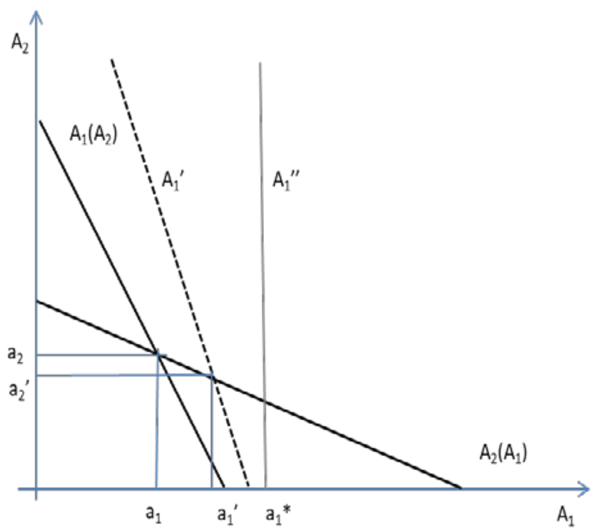
Another mechanism that could lead a state to consider other states' welfare is so-called Kantian optimization. According to Kant (1785) you should "always act in such a way that you can also will that the maxim of your action should become a universal law". Grafton et al. (2017) and Alger and Weibull (2016a) study the actions of people who have a degree of so-called Kantian preferences.

A person who has moral preferences values every action assuming that all other persons make the same action. This can easily be defined for pairwise interactions. Following Alger and Weibull (2016a), let $\pi(x, y)$ denote the payoff to a consumer who plays strategy x when the other consumer plays strategy y. A consumer with Kantian preferences will then maximize:

$$U(x, y) = (1 - \gamma)\pi(x, y) + \gamma\pi(x, x),$$

where γ is the individual's degree of Kantian preferences. The first term in the expression for $U(x, y)$ is a normal utility term; with $\gamma = 0$, the agent maximizes this expression *given* the action of the other consumer. As already explained, in a game where each country sets its emission reduction goal individually, the Nash equilibrium is not socially optimal, that is, the emission reductions are too low. The second term is the agent's utility in the *hypothetical situation* in which the other agent was to follow the action of the first agent. With $\gamma = 1$, the agent has pure Kantian preferences and values every action by considering what would happen to own material well-being if every other agent were to follow this action. If people have Kantian preferences, they may vote for politicians that want to take stronger actions towards climate change. This would have the following implications for panel (a) in Figure 2:

Figure 3 GHG abatement game with Kantian preferences



The solid lines are the original reaction curves from panel (a) in Figure 2 (without R&D investments). We then introduce Kantian preferences to Country 1. This shifts and pivots Country 1's reaction curve outwards, that is, from A_1 to A_1' (or all the way to the vertical A_1'', which appears when $\gamma = 1$). The reason is that Country 1 now considers its welfare if Country 2 were to follow the actions of Country 1. Hence, Country 1 will now do more abatement for every level of abatement in Country 2 since the country benefits from more abatement by Country 2. Country 1 also becomes less sensitive to changes in abatement levels in Country 2.

At the extreme, when $\gamma = 1$, the country does its part of a globally optimal climate agreement a_1* independent of what Country 2 does. Furthermore, if both countries have $\gamma = 1$, they would both do their part of a globally optimal climate agreement. In the original equilibrium (a_1, a_2), both countries optimize their welfare taking the action of the other country as given. On the other hand, with pure Kantian preferences ($\gamma = 1$), both countries optimize their welfare taking as given that the other country will follow their actions. In this way they escape the prisoner's dilemma situation completely.[18]

Alger and Weibull (2016b) use the Kantian preference structure to analyse a dynamic game in which people frequently meet in groups to play a public good game.[19] They show that preferences of the type described above with $\gamma > 0$ will emerge from an evolutionary process in which agents inherit beneficial traits. The authors therefore predict that Kantian preferences may be more widespread than what we tend to think. This implies that other countries also may act as if their citizens had (partly) Kantian preferences. Other countries would then be less sensitive to changes in the abatement level of the Nordic countries. For instance, the reduction in abatement from a_2 to a_2' would be smaller than shown in Figure 3.

Grafton et al. (2017) study the interaction between pure Kantian agents (with $\gamma = 1$) and pure selfish agents in a game inspired by climate change. It is shown that increased occurrence of Kantian players improves the welfare of both Kantian and selfish players.

Greaker et al. (2013) explore the implication of Kantian preferences further, albeit in a different setting. They ask how one should evaluate national climate policies. The authors argue that as long as current climate treaties are insufficient to reach the agreed upon goals

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[18] As briefly explained in the beginning of Section 4, a prisoner's dilemma is a situation in which every agent does her best (given the actions of the others), but the outcome for the group as a whole is inferior to other possible outcomes.

[19] For example, a game like the trust game described in the previous section.

of limiting global warming, the criterion should be to what extent the country complies with a hypothetical *sufficient treaty*. The authors further operationalize this concept along three dimensions. First, current carbon prices in a country should be compared to carbon prices that would limit the global temperature increase to well below 2.0°C. Second, current emission levels minus emission reductions carried out abroad should be consistent with *a fair allocation* of the remaining global carbon budget.[20] Thus, national emission levels in itself are not a criterion. On the other hand, it is not straightforward to say what constitutes a *fair* allocation of the global carbon budget.[21] Finally, the country should actively direct R&D funds to clean technology development. The rationale is that if *a sufficient climate treaty were in place*, the private incentives for conducting clean R&D would be higher. In particular, the incentives would be higher for those technologies that have a worldwide application.[22]

Citizens in the Nordic countries may have voted for politicians that choose climate policies inspired by Kant's categorical imperative. In our opinion, it is then the responsibility of politicians to enact a Kantian climate policy that minimizes any potential conflicts between 'doing the right thing' in a moral sense and 'doing the optimal thing' with respect to limiting climate change. The problem arises because the argument "it is a moral duty" can be used to advocate a wide range of climate-related actions. For instance, one potential pitfall is to focus on national emission reduction targets that cannot be met without introducing technology standards with questionable global emission effects. Another potential pitfall is to introduce policies that conflict with other international obligations such as, for instance, the rules imposed by WTO membership or EU membership. An example of the latter could be to subsidize extensively Nordic firms' investments in GHG abatement equipment, which could be seen as muddling with the EU ETS. Nordic politicians should therefore always ask to what extent their climate policies constitute examples that the Nordic countries would like other countries to copy (precisely as in the model of Alger and Weibull 2016b).

A question of special interest for Norway is whether Norway should avoid developing oil and gas fields that would not have been profitable if a *sufficient* climate treaty were in place. On one hand, it could be argued that a sufficient climate treaty would leave it

[20] The global carbon budget is the amount of carbon dioxide emissions we can emit while still having a fair chance of limiting global temperature rise to 2.0°C above pre-industrial level.
[21] See Greaker et al. (2013) for a discussion of various allocation principles for the global carbon budget.
[22] The authors argue that a high carbon price at home is an insufficient incentive for clean technology R&D since the patents from this would have had a market abroad also if a sufficient treaty were in place.

up to each sovereign state to reduce emissions from their territory, and hence emissions from the use of Norwegian oil and gas in other countries cannot be the responsibility of Norway. On the other hand, it is not yet clear whether a future climate treaty will involve some restrictions on coal, oil and gas exports. Moreover, as pointed out by Leroux and Spiro (2018), arctic oil exploration by Norway will lead to further technology development, which will benefit Russian arctic oil exploration in the future.[23]

Finally, in our opinion, spurring the development of clean technologies would fit with a Kantian climate policy. Note that we can deduct from Figure 3 that the effect of technology investments would be similar in Figure 2 (panel b). Hence, R&D investment in technologies with a global application would still have desirable global effects.

6. Discussion

In Section 2 we discussed Nordic climate policies and concluded that they are ambitious compared to those in other OECD countries, in particular countries outside the EU. Then in Sections 3-5 we explored various rationales for ambitious climate policies in small, open economies like the Nordics. Of these mechanisms, we found clean technology development most likely to induce global emission reductions.

In our opinion, the Nordic countries could take two routes with respect to technological development. One route seeks to develop the state of knowledge of the large category of clean technologies. Such development could include deployment of emerging clean technologies that promotes cost reductions from learning by doing. However, to succeed it may be decisive to cooperate within a larger unit such as the EU, and preferably, even larger units including US states like California and countries like Canada, Japan, etc.

The second route would be to focus on areas in which the Nordic countries have expertise, and consider which innovations can be expected to have a global market. This is not completely unrealistic; Norwegian offshore oil and gas technology is used over the whole world, and Denmark is a world-leading windmill producer. In the near future, a further expansion of windmills may happen off-shore, and therefore windmills may be a promising area for increased Nordic cooperation. However, to determine R&D budgets in this way

[23] See Holtsmark (2019) for a further discussion of this topic.

requires Nordic governments to ‘pick winners’. We acknowledge that this is difficult, and that government bodies often lack detailed information about markets that is necessary to make well-founded decisions. On the other hand, as already discussed, innovation creates spillovers that the innovator does not fully capture or profit from. As a society, we therefore want to promote innovation, but due to financial restrictions, we cannot promote all innovations. Hence, innovation policies are already largely geared at picking winners, e.g., the best ideas with the largest spillovers. What we propose is to shrink the set of potential research and/or demonstration projects that get innovation support somewhat more, that is, focus on clean technologies with a global market potential.

To learn more about the market potential for different clean technologies, a start could be to draw on the various technology-specific studies that examine GHG mitigation scenarios. Two examples are International Energy Association’s (2017) and Luderer at al. (2012); the latter collects results from several independent model studies.

Note that some of the GHG mitigation scenarios also include endogenous R&D investments. For instance, Bosetti et al. (2009) find that increased R&D investments in currently known electricity technologies, such as solar, nuclear and CCS, are highly desirable. Other studies examine the potential for cost reductions from R&D in GHG mitigation technologies. One example is Baker et al. (2015); they compare and aggregate expert elicitation data about energy technology in order to identify technologies which may benefit the most from increased R&D spending. When combining all data, CCS and nuclear turn out to have the largest prospects for advancement with solar following next. One take-away from this literature is that CCS seems to be important. Still, Norway is the only Nordic country that seeks to develop this technology.

Can we hope to sell these technologies to developing countries? It is a well-known fact that the Nordic countries mostly trade with each other and the rest of the EU. The United Nations Framework Convention on Climate Change has created its own body to promote technology transfer to developing countries – the UNFCCC Technology Mechanism.[24] This UN organization has organized technology-need assessments in more than 80 developing countries.[25] However, its main activity is to facilitate project-related clean technology deployment in developing countries. The Nordic states are already engaged in the UNFCCC Technology Mechanism. An ambitious climate policy that is more geared towards

[24] See UNFCCC (2018a).
[25] See UNFCCC (2018b).

technology development for the world might imply that the Nordic countries should step up their engagement in technology transfer further. There is empirical evidence indicating that technology transfer may be spurred by state involvement. For instance, Ferguson and Forslid (2018) show that embassies can have significant effect on export promotion.

Clearly, there could be a potential conflict between developing technology for which Nordic countries have comparative advantages, and developing clean technologies for foreign markets. We tend to think that the Nordic countries can help reduce foreign GHG abatement cost without being forced to venture into technologies for which they have no (or tiny) prior knowledge. To us there seems to be some promising areas like CCS, floating windmills and maritime electric propulsion. We suggest a broadly composed Nordic commission should study this thoroughly before current R&D policies are changed.

7. Conclusion

Based on the review of current climate policies in the Nordic countries, we propose two alternative Nordic views on climate policy: country focus or global focus. These two views are characterized in Table 1.

Our conjecture is that Nordic climate policies still have too much of a country focus:

- Emission reduction targets for the ESR sector in the Nordic countries should not be absolute with respect to the amount of emission reductions carried out at home. The Nordic countries should fully take advantage of the flexible EU mechanisms. By applying absolute targets, the Nordic countries risk promoting technologies that are dead ends.
- Sweden aims to reduce emissions from domestic transport by 70 percent before 2030, which seems hard without a massive substitution of fossil fuels with biofuels. Finland wants to have 30 percent blending of biofuels by 2030. We suspect both policies to be dependent on imports of first-generation biofuels from developing countries. Imports of biofuels could induce emissions from land use change in the exporting

countries that off-set all, or more than, the emission reductions in the importing countries.[26]

- In Finland, Sweden and Norway, there are multiple plans for building biofuels factories based on forestry residues. The countries' motivation for subsidizing the plants seems to be the planned emission reductions in transport (see above). Nordic governments should ensure that the chosen bio-refining processes contribute to technological development for advanced biofuels, and that the chosen processes are relevant for other kinds of cellulosic feedstock.
- The Norwegian state recently supported a large Norwegian aluminium manufacturer with 1.6 billion NOK in order to develop a more energy- and GHG-efficient aluminium-melting production line. According to press statements, the company will not seek to patent the innovation, but keep the innovation secret out of fear that other firms will copy the new technological solutions.[27] This conflicts with the idea that the Nordic countries should develop technologies that other countries could make use of to reduce their emissions at less costs.

Table 1 Two climate policy views

Country focus	Global focus
- Each Nordic country focuses on their own emission targets, even counting national emissions in the ETS sector- - For the ESR sector, the Nordic countries restrict trading with EU countries to 'show a good example' and consider technology mandates that have dubious global effects.	- Acknowledge that the EU has set ambitious climate policies, and work together with the EU to reach the EU targets. - Excess ambitions are channelled to technological development in the form of R&D subsidies and demonstration projects, and sometimes wider roll-outs to promote learning.

[26] See e.g. Valin (2015) for a study of EUs biofuels policies.

[27] See Malkenes Hovland (2017)

- Technology policy is driven by the need to reduce national emissions, and may thus have different focuses in the Nordic countries.	- Clean technological development focuses on technologies that also can be applied in other countries, in particular developing countries.

There are also signs of a ‘world view’:

- Electricity storage and mobility solutions seem to be crucial ingredients of a low-emission society, and thus such technologies likely have a large potential for application in other countries than in the Nordics. In Sweden, there are two initiatives in this direction; two battery factories are planned in Trollhättan and in Skellefteå.[28] The Norwegian electric vehicle policy and the electric ferry initiative should also be studied closer in order to uncover to what extent they have positive global effects.
- Some renewable development may also be promising, for example, the floating windmills development project lead by the Norwegian company Equinor (former Statoil). This technology may have a large potential abroad, and draws on the offshore oil production expertise of Equinor.
- Norway has a separate carbon capture and storage (CCS) program which currently is considering two different projects: a cement factory and a waste-burning facility. The official object of this program is to promote CCS technology in the rest of the world. We believe that there is scope for much greater Nordic cooperation on CCS. According to our understanding, the planned carbon dioxide storage site on the Norwegian continental shelf has a large capacity. It can store carbon dioxide from multiple Nordic sources.

As discussed above, Kantian preferences may motivate climate policies in the Nordics. If so, we recommend Nordic politicians to refine what it implies for the Nordic countries to do their part of *a sufficient climate treaty*. First, Nordic governments should communicate that the EU already has an ambitious climate policy. One could argue that if the EU fulfils its Paris commitment (NDC), the Nordic countries are in fact doing their part of a sufficient climate treaty together with the EU.

[28] See Valle (2018).

The Nordic countries may still aim to be even more ambitious. In this case, the Nordic countries' choice of climate policies should take into account to what extent their climate policies constitute examples that they would want other countries to follow. In our opinion, advancing clean technologies is the key also here. The Nordic countries should also consider coordinating their technology policies better in order to maximize their global impact.

In our opinion, the major uncertainty is whether the EU will succeed to reduce emissions in the ESR sector by 30 percent by 2030. This could require a very ambitious climate policy in the Nordic countries for the ESR sectors, even if full use is made of the flexible EU mechanisms. The centrepiece of this ambitious policy should be to price emissions sufficiently high in all sectors – also agriculture and fisheries, which are now exempted from emission pricing. We tend to think that this would set an example the Nordic countries would want other countries to follow.

References

Acemoglu, D., Aghion, P., Bursztyn, L. and Hemous, D. (2012), The Environment and Directed Technical Change, *American Economic Review*, 102(1), 131-166.

Aghion, P., Dechezleprêtre, A., Hémous, D., Martin, R. and van Reenen, J. (2016), Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry, *Journal of Political Economy*, 124(1), 1-51.

Alger, I. and Weibull, J. (2016a), Morality – Evolutionary Foundations and Policy Implications. Manuscript prepared for the conference 'The State of Economics, The State of the World', World Bank, Washington DC.

Alger, I. and Weibull, J. (2016b), Evolution and Kantian Morality, *Games and Economic Behavior*, 98, 56-67.

Ambec, S. and Crampes, C. (2012), Electricity Provision with Intermittent Sources of Energy, *Resource and Energy Economics*, 34(3), 319-336.

Andreoni, J. (1990), Impure Altruism and Donations to the Public Good: A Theory of Warm Glow Giving, *The Economic Journal*, 100(4), 464-477.

Arrow, K. (1962), Economic Welfare and the Allocation of Resources for Invention, in Nelson, R. (ed.), *The Rate of Direction of Inventive Activity*, Princeton, NJ: Princeton University Press.

Aune, F. R. and Fæhn, T. (2016), Makroøkonomisk analyse for Norge av EUs og Norges klimapolitikk mot 2030 [eng: Macroeconomic Analysis for Norway of the EU's and Norway's Climate Policy Towards 2030], Report 2016/25, Statistics Norway.

Aune, F. R., Golombek R. and le Tissier, H. H. (2015), Phasing Out Nuclear Power in Europe, CREE Working Paper 5/2015, CREE Center.

Baker, E., Bosetti, V., Anadon, L. D., Henrion, M. and Reis, L. A. (2015), Future Costs of Key Low-Carbon Energy Technologies: Harmonization and Aggregation of Energy Technology Expert Elicitation Data, *Energy Policy,* 80, 219-232.

Barrett, S. (1994), Self-enforcing International Environmental Agreements, *Oxford Economic Papers*, 46, 878-894.

Beisland, C. (2013), From Targets to Timetables to Technology Investments, CREE working paper 12/2013, CREE Center.

Bijgaart, I. (2017), The Unilateral Implementation of a Sustainable Growth Path with Directed Technical Change, *European Economic Review*, 91, 305-327.

Bohm, P. (1993), Incomplete International Cooperation to Reduce CO2 Emissions: Alternative Policies, *Journal of Environmental Economics and Management*, 24(3), 258-271.

Bornstein, G. and Yaniv, I. (1998), Individual and Group Behavior in the Ultimatum Game: Are Groups More ‘Rational’ Players?, *Experimental Economics*, 1(1), 101-108.

Bosetti, V., Carraro, C., Massetti, E., Sgobbi, A. and Tavoni, M. (2009), Optimal Energy Investment and R&D Strategies to Stabilize Atmospheric Greenhouse Gas Concentrations, *Resource and Energy Economics*, 31(2), 123-137.

Buchholz, W. and Konrad, K. A. (1994), Global Environmental Problems and the Strategic Choice of Technology, *Journal of Economics*, 60(3), 299-321.

Calmfors, L., Corsetti, G., Devereux, M. P., Saint-Paul, G., Sinn, H-W., Sturm, J-E. and Vives, X. (2008), Chapter 5: Global Warming: The Neglected Supply Side, in *EEAG Report on the European Economy 2008*, Munich: CESifo Group Munich.

Cason, T. N. and Mui, V. L. (1997), A Laboratory Study in Group Polarization in the Team Dictator Game, *The Economic Journal*, 107(444), 1465-1483.

Cox, J. C. (2002), Trust, Reciprocity, and Other Regarding Preferences: Groups vs. Individuals and Males vs. Females, in Zwick, R. and Rapoport, A. (eds.), *Experimental Business Research*, Boston, MA: Springer.

Croson, R. and Buchan, N. (1999), Gender and Culture: International Experimental Evidence from Trust Games, *American Economic Review*, 89(2), 386-391.

Danish Ministry of Energy, Utilities and Climate (2018), Energy Agreement of 29 June 2018, Retrieved December 19, 2018, from https://en.efkm.dk/media/12307/energy-agreement-2018.pdf.

Dechezleprêtre, A., Martin, R. and Mohnen, M. (2013), Knowledge Spillovers from Clean and Dirty Technologies: A Patent Citation Analysis, Working Paper 135, Grantham Research Institute on Climate Change and the Environment.

European Commission (2018), Climate Strategies & Targets: Economic Analysis, Retrieved December 19, 2018, from https://ec.europa.eu/clima/policies/strategies/analysis_en.

Farrell, J. and Klemperer, P. (2007), Coordination and Lock-in: Competition with Switching Costs and Network Effects, in Armstrong, M. and Porter, R. (eds.), *Handbook of Industrial Organization, Volume 3*, New York City, NY: Elservier.

Fehr, E. and Schmidt, K. (1999), A Theory of Fairness, Competition, and Cooperation, *Quarterly Journal of Economics*, 114(3), 817-868.

Ferguson, S. and Forslid, R. (2018), Sizing Up the Impact of Embassies on Exports, *Scandinavian Journal of Economics,* doi: 10.1111/sjoe.12260.

Fischer, C., Greaker, M. and Rosendahl, K. E. (2017), Robust Policies against Emission Leakage: The Case for Upstream Subsidies, *Journal of Environmental Economics and Management*, 84, 44-61.

Golombek, R. and Hoel, M. (2004), Unilateral Emission Reductions and Cross-Country Technology Spillovers, *Advances in Economic Analysis & Policy*, 4(2), 1-27.

Government Offices of Iceland (2018), Iceland's Climate Action Plan for 2018-2030: Summary, Retrieved December 31, 2018, from https://www.government.is/library/Files/Icelands%20new%20Climate%20Action%20Plan%20for%202018%202030.pdf.

Grafton, Q. R., Kompas, T. and van Long, N. (2017), A Brave New World? Kantian-Nash Interaction and the Dynamics of Global Climate Change Mitigation, *European Economic Review*, 99(C), 31-42.

Greaker, M. and Rosendahl, K. E. (2008), Environmental Policy with Upstream Pollution Abatement Firms, *Journal of Environmental Economics and Management*, 56(3), 246-59.

Greaker, M. and Hagem, C. (2013), Strategic Investment in Climate Friendly Technologies: The Impact of Permit Trade, *Environmental and Resource Economics*, 59(1), 65-85.

Greaker, M. and Midttømme, K. (2016), Network effects and environmental externalities: Do clean technologies suffer from excess inertia? *Journal of Public Economics,* 143, 27-38.

Greaker, M., Stoknes, P. E., Alfsen, K. H. and Ericson, T. (2013), A Kantian Approach to Sustainable Development Indicators for Climate Change, *Ecological Economics*, 90, 10-18.

Greaker, M., Heggedal, T. R. and Rosendahl, K. E. (2018), Environmental Policy and the Direction of Technical Change, *Scandinavian Journal of Economics*, 120(4), 1100-1138.

Harstad, B., Lancia, F. and Russo, A. (2018), Compliance Technologies and Self-enforcing Agreements, *Journal of European Economic Association,* forthcoming.

Heal G. and Kunreuther, H. (2017), An Alternative Framework for Negotiating Climate Policies, *Climatic Change*, 144(1), 29-39.

Hoel, M. (1992), International Environmental Conventions: The Case of Uniform Reductions of Emissions, *Environmental & Resource Economics*, 2(2), 141-159.

Hoel, M. (1994), Efficient Climate Policy in the Presence of Free Riders, *Journal of Environmental Economics and Management*, 27(3), 259-274.

Hoel, M. and Holtsmark, B. (2012), Haavelmo on the Climate Issue, *Nordic Journal of Political Economy*, 37, 1-22.

Hoel, M. and de Zeeuw, A. (2014), Technology Agreements with Heterogeneous Countries, in Todd L. C., Hovi, J. and McEvoy, D. (eds.), *Toward a New Climate Agreement: Conflict, Resolution and Governance*, Abingdon: Routledge**.**

Holtsmark, K. (2019), Supply-side climate policy in Norway, *Nordic Economic Policy Review* (this issue).

Holtsmark, B. and Skonhoft, A. (2014), The Norwegian Support and Subsidy Policy for Electric Cars. Should it be Adopted by Other Countries?, *Environmental Science & Policy*, 42, 160-168.

International Energy Agency (2000), *Experience Curves for Energy Technology Policy*, Paris: OECD/IEA.

International Energy Agency (2017), *Energy Technology Perspectives*, Paris: OECD/IEA.

IPCC (2018), Summary for Policymakers, in Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. (eds.), *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, Geneva: World Meteorological Organization.

Kant, I. (1785), *Grounding for the Metaphysics of Morals*, Introduction, page 8, translated by Ellington, J. W., Indianapolis: Hackett Publishing Company.

Lazkano, I., Nøstbakken, L. and Pelli, M. (2017), From Fossil Fuels to Renewables: The Role of Electricity Storage, *European Economic Review*, 99, 113-129.

Leroux, J. and Spiro, D. (2018), Leading the Unwilling: Unilateral Strategies to Prevent Arctic Oil Exploration, *Resource and Energy Economics*, 54, 125-149.

Li, S., Tiong, L., Xing, J. and Zhou, Y. (2017), The Market for Electric Vehicles: Indirect Network Effects and Policy Design, *Journal of the Association of Environmental and Resource Economists*, 4(1), 89-133.

Luderer, G., Bosetti, V., Jacob, M., Leimbach, M., Steckel, J. C., Waisman, H. and

Edenhofer, O. (2012), The Economics of Decarbonizing the Energy System - Results and Insights from the RECIPE Model Intercomparison, *Climatic Change*, 114(1), 9-37.

Malkenes Hovland, K. (2017, July 26), Hydro åpner milliardanlegg i august: Tør ikke patentere teknologien [eng: Hydro Opens Billion-NRK Facility in August: Do Not Dare Patent Technology], *E24*, Retrieved December 19, 2018, from https://e24.no/naeringsliv/norsk-hydro/hydro-aapner-milliardanlegg-i-august-toer-ikke-patentere-teknologien/24104047.

McGinty, M. (2007), International Environmental Agreements Among Asymmetric Nations, *Oxford Economic Papers*, 59(1), 45-62.

Mæstad, O. (2001), Efficient Climate Policy with Internationally Mobile Firms, *Environmental and Resource Economics*, 19(1), 267-284.

Nordhaus, W. D. (2009), The Perils of the Learning Model for Modeling Endogenous Technological Change, NBER Working Paper No. 14638, National Bureau of Economic Research.

Norwegian Environment Agency (2016), Tiltakskostnader for elbil. Samfunnsøkonomiske kostnader ved innfasing av elbiler i personbilparken [eng: Abatement cost for electrical vehicles. Economics costs of phasing in electrical vehicles in the fleet of private cars], Report M-620, Norwegian Environment Agency.

Perino, G. (2018), New EU ETS Phase 4 Rules Temporarily Puncture Waterbed, *Nature Climate Change*, 8, 262-264.

Romer, P. M. (1990), Endogenous Technological Change, *Journal of Political Economy*, 98(5), S71-S102.

Rosendahl, K. E. (2004), Cost-effective Environmental Policy: Implications of Induced Technological Change, *Journal of Environmental Economics and Management*, 48(3), 1099-1121.

Silbye, F. and Sørensen, P. B. (2019), Towards a more Efficient European Carbon Market, *Nordic Economic Policy Review* (this issue).

Stranlund, J. K. (1996), On the Strategic Potential of Technological Aid in International Environmental Relations, *Journal of Economics*, 64(1), 1-22.

Urpelainen, J. (2011), Can Unilateral Leadership Promote International Environmental Cooperation, *International Interactions*, 37(3), 320-339.

Urpelainen, J. (2013), Can Strategic Choice of Technology Development Improve Climate Cooperation? A Game Theoretic Analysis, *Mitigation and Adaptation Strategies for Global Change*, 18(6), 785-800.

UNFCCC (2018a), Support: Technology Mechanism, Retrieved December 19, 2018, from http://unfccc.int/ttclear/support/technology-mechanism.html.

UNFCCC (2018b), Technology Needs Assessment: Overview, Retrieved December 19, 2018, from http://unfccc.int/ttclear/tna.

United Nations (2017), The Emission Gap Report, Retrieved December 31, 2019, from https://news.un.org/en/story/2017/10/569672-un-sees-worrying-gap-between-paris-climate-pledges-and-emissions-cuts-needed.

Valin, H., Peters, D., van den Berg, M., Frank, S., Havlik, P., Forsell, N. and Hamelinck, C. (2015), The Land Use Change Impact of Biofuels Consumed in the EU - Quantification of Area and Greenhouse Gas Impacts. IIASA Report, Retrieved January 19, 2019, from https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf

Valle, M. (2018) , Nå er det klart: En av verdens største batterifabrikker bygges i Sverige [eng: It’s Clear Now: One of the Largest Battery Factories in the World to be Built in Sweden], *Teknisk Ukeblad*, March 15, Retrieved December 19, 2018, from https://www.tu.no/artikler/na-er-det-klart-en-av-verdens-storste-batterifabrikker-bygges-i-sverige/432817.

Zhang, Y., Qian, Z., Sprei, F. and Li, B. (2016), The Impact of Car Specializations, Prices and Incentives for Battery Electric Vehicles in Norway: Choices of Heterogeneous Consumers, *Transportation Research Part C*, 69, 386-401.

Appendices

A1. Industrial countries' NDCs under the Paris treaty

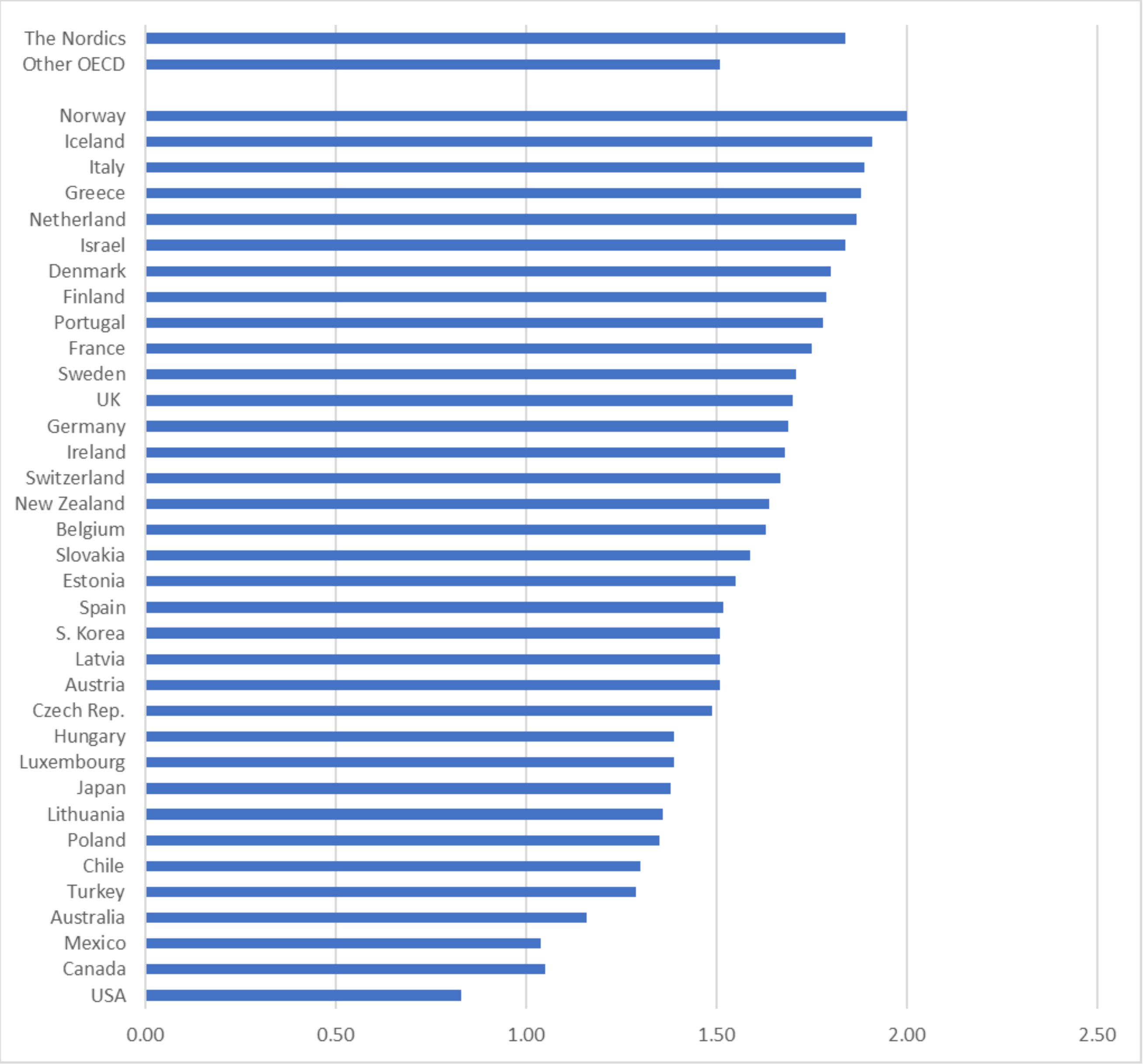
Table A1 Industrial countries NDCs

Country	NDC*
Europe	
EU ETS	43% below 2005 level
EU Non-ETS	30% below 2005 level
Denmark	39% below 2005 level
Finland	39% below 2005 level
Iceland	40% below 2005 level**
Norway	40% below 2005 level**
Sweden	40% below 2005 level
Rest of EU	<30% below 2005 level
Non-Europe	
Australia	26-28% below 2005 level
Canada	30% below 2005 level
Japan	25.4% below 2005 level
New Zealand	30% below 2005 level
Russia	25% below 2005 level
US***	26-28% below 2005 level

* GHG emission-reduction targets for 2030 reported as NDC to the UNFCCC.
** Under negotiation; probably 39% or 40%.
*** The US has announced its intention to withdraw once it becomes legally possible.

A2. Gasoline prices

Figure A1 Gasoline prices in OCED countries (2018 US $/litre)



Source: The data are for an arbitrary day in November 2018, and have been retrieved from https://www.globalpetrolprices.com/gasoline_prices/.

A3. Model with demonstration of low abatement costs

The following model illustrates what we mean by showing 'a good example': Assume that there are two countries only, and that they have a binary choice: choose to either become a 'low-emission society' or comply with a weak international environmental agreement (IEA) at lowest possible costs. The additional cost of becoming a low-emission society is unknown to both countries. For Country 1, we assume that with probability p_1 the cost is c^l, and with probability $(1- p_1)$ the cost is c^h. For Country 2 the costs are identical, but the probability of a low cost c^l is p_2 with $p_2 < p_1$. Further, if both countries become low-emission societies, they will both receive a climate benefit of B, while if only one country makes this choice, the climate benefit is $B/2$ to both countries. Each country i also has a private benefit b_i of becoming a low-emission society. This could for instance be less local pollution, less dependency on oil import, etc. Finally, we normalize country welfare to zero when both countries only comply with existing treaties at minimum costs.

The game has the following normal form:

		Country 2: Low emission society	Country 2: Comply with IEA
Country 1	Low emission society	$B + b_1 - p_1c^l - (1 - p_1)c^h$, $B + b_2 - p_2c^l - (1 - p_2)c^h$	$B/2 + b_1 - p_1c^l - (1 - p_1)c^h$, $B/2$
	Comply with IEA	$B/2$, $B/2 + b_2 - p_2c^l - (1 - p_2)c^h$	0

The two following conditions on the parameters will then yield the classic prisoner's dilemma in the simultaneous-move game:

$$B + b_i - p_ic^l - (1 - p_i)c^h > 0, i = 1,2 \qquad \text{(A1)}$$

$$\frac{B}{2} > B + b_i - p_ic^l - (1 - p_i)c^h, i = 1,2 \qquad \text{(A2)}$$

Although both countries would gain if both countries become a low-emission society (A1), it is privately beneficial for each country to free-ride (A2).

Consider then the following two-stage game: Country 1 chooses strategy first. If Country 1 chooses to become a low-emission society, Country 2 will update its belief about the costs of becoming a low-emission society before it chooses whether to become one. To fix ideas, assume that if Country 1 decides to become a low-emission society and the implied cost turns out to be c^l, Country 2 will update its probability of c^l from p_2 to p_2' with $p_2 < p_2'$ (while if costs turns out to be c^h, Country 2 will update to p_2'' with $p_2 > p_2''$).

The following two conditions will then make it worthwhile for Country 1 to choose to become a low emission society:

$$\frac{B}{2} + b_2 - p_2'^{c^l} - (1 - p_2')c^h > 0 \qquad \text{(A3)}$$

$$\frac{B}{2} + p_1\frac{B}{2} + b_1 - p_1c^l - (1 - p_1)c^h > 0 \qquad \text{(A4)}$$

A3 says that if Country 2 updates its probability of low costs to p_2', it would follow Country 1 and become a low-emission society. A4 denotes the expected welfare of Country 1 taking into consideration that if it successfully becomes a low-emission society – the probability of this event is p_1 – then Country 2 will follow suit.

For a large p_1, A4 may clearly hold. On the other hand, how probable is it that A3 holds? A necessary condition is of course that $\frac{B}{2} + b_2 - c^l > 0$, that is, 'the lowest possible abatement costs' must be so low that it is privately optimal to act. We suspect that the world is not yet there despite the large advances in GHG abatement costs in recent years. This reinforces our argument that more technological development is needed.

This game could be extended to *n* countries, which were ranked by their *a priori* belief about the probability of becoming a low-emission society at low costs. Depending on the mechanism by which beliefs are updated, one country could set off a cascading effect. On the other hand, one may argue that the Nordic countries are 'too special' to influence other countries' beliefs about their costs of becoming a low-emission society.