Global warming from an economic perspective

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A global climate policy is necessary to reduce global warming sufficiently. With a smart and cost-efficient climate policy, it would not be expensive to limit increases in temperature to 2 degrees by the year 2100. Economists have important knowledge and tools in this area to evaluate which instruments that can be expected to be effective for this purpose. The most cost-efficient measure would be a carbon tax that is the same in every country. In addition, an ambitious climate policy would be a cheap form of insurance against future high and uncertain expenses, but only if it is cost-efficient. Otherwise, an ambitious policy would risk being very expensive and, in a worst-case scenario, also ineffective. The most important way of reducing warming is to reduce the use of coal. Measures that do not contribute to this will be ineffective.

1 Introduction

In this article, I discuss how economic theory can be used to understand the interaction between human activity and the climate, why global political measures are necessary, and which political measures can be expected to be effective and which cannot. I formulate important results in a number of insights.

An initial question may be what economists have to say about a scientific problem such as global warming. When you think about it, it is actually obvious that the greenhouse gases emitted by people are a result of economic activity – of consumption, production and investment – and are affected by factors such as technological development, economic growth, natural resources and institutions. All of these things are exactly what economists have been studying and attempting to understand for a very long time.

But economists also study how economic instruments can counteract so-called market failures.[1] The Stern Review from 2007 described global warming as the greatest market failure in history.[2] To manage climate change, it is then necessary to make sure that households have economic incentives to take decisions that are less harmful to the climate and that companies have economic incentives to develop new technologies that can replace the need for fossil fuels.

There is no shortage of suggestions in the general debate for how we should manage global warming. These include everything from taking shorter showers, stopping travelling or stopping having children to, investing in sustainable companies and subsidising green energy. But how effective are these suggestions in actually reducing global warming? An economic analysis is also valuable here to evaluate which measures are good and which are too expensive, ineffective or both.

The proposals I discuss in this article include both policies such as taxes and the quantity regulation of carbon emissions, and measures such as subsidies for green energy, sustainable financing and green bonds. The conclusions and reasoning are based entirely on economic

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The interpretations in the essay are the author's own and shall not be perceived as the views or stances of the Riksbank.

1 A market failure occurs when free markets cannot be expected to allocate resources in an efficient manner.

2 See Stern (2007), p. viii.

research. The article also builds further on and deepens some of the reasoning I previously expressed in Olovsson (2018).

2 The economy and the climate affect each other

Before I start discussing various measures to reduce global warming, it is necessary to provide a short description of how the climate interacts with our economies. I have, however, kept this section brief, as several of these aspects are complex and could each be dealt with in its own paper.

2.1 The human impact on the climate

The Earth's temperature varies naturally for many reasons that are not connected with human behaviour. For example, the Earth's orbit around the sun varies according to a cyclical pattern. There are also variations in the tilt of the Earth's axis (known as Milankovitch cycles). These and other phenomena affect the Earth's climate entirely without the help of people. However, humans can also affect the climate, among other means by releasing greenhouse gases. Carbon dioxide is the dominant greenhouse gas with a human source and is responsible for about 75 per cent of total emissions.[3] Carbon dioxide is primarily emitted as a by-product from the burning of fossil fuels coal, oil and natural gas.

How the greenhouse effect works

For over 100 years, we have known that the amount of carbon dioxide in the atmosphere affects the Earth's energy budget, which is to say the difference between incoming energy – in the form of solar radiation – and outgoing energy – among other things, in the form of thermal radiation. This happens because carbon dioxide does not affect the incoming solar radiation, which goes straight through the carbon dioxide, at the same time as the carbon dioxide makes it more difficult for heat to radiate back into outer space. If the system is initially in balance, an increase in the amount of carbon dioxide in the atmosphere leads to a surplus in the energy budget, meaning that the temperature will rise until a balance is again reached. This is known as the *greenhouse effect*.

It is called this because it acts exactly like a greenhouse, where the sun's rays go straight through the greenhouse's glass, which simultaneously keeps the warmth in. This warms the greenhouse up. The greenhouse effect is not only a bad thing. Without greenhouse gases in the atmosphere, the Earth would be covered with ice and would have an average temperature of around −20 degrees instead of the approximately 15 degrees we have at present.

Carbon circulates in the form of carbon dioxide, among other things, in a constant flow between ground, air and sea in a process called the *carbon cycle*. What makes carbon dioxide particularly problematic is that it stays in the atmosphere significantly longer than other greenhouse gases. About 20–25 per cent of all carbon dioxide emitted stays in the atmosphere for a very long time – up to over a thousand years. About 50 per cent disappears in a few decades. The rest takes a few centuries to circulate onwards to the oceans, where it contributes to acidification. This means that the carbon dioxide emitted today will contribute towards global warming for a very long time to come. In comparison, methane stays in the atmosphere for about a decade, even if it is a stronger greenhouse gas while it is there.

The Swedish chemist and physicist Svante Arrhenius was the first to demonstrate, in 1896, that carbon dioxide in the atmosphere contributes to the increase of global temperatures. The *direct* effect is not controversial and can be replicated in simple laboratory experiments. However, the *total* effect of a change in the carbon dioxide content of the

3 However, by far the most important cause of the greenhouse effect is water vapour, but water vapour does not derive directly from human activity.

atmosphere is significantly less certain. This is due to the large number of feedback effects, such as how water vapour, cloud formation and the reflective ability of the Earth's surface will be affected as the Earth warms up. These feedback effects could either strengthen (positive mechanisms) or weaken (negative mechanisms) the direct effect. At present, most indications are that the feedback effects will strengthen the direct effects and contribute towards more warming (IPCC 2013).

Unclear how great the Earth's climate sensitivity is

Due to the uncertainty about how great the total effect will be when the carbon dioxide content of the atmosphere changes, the UN Intergovernmental Panel on Climate Change (IPCC) has specified an interval for what is known as *climate sensitivity*, which specifies how much the average global temperature will rise in the event of a *doubling* of the carbon dioxide content of the atmosphere. From international research results, the IPCC concludes that climate sensitivity is between 1.5 and 4.5 degrees. This is a relatively broad interval. In plain language, this also means that it is very uncertain how serious the problem with global warming actually is.

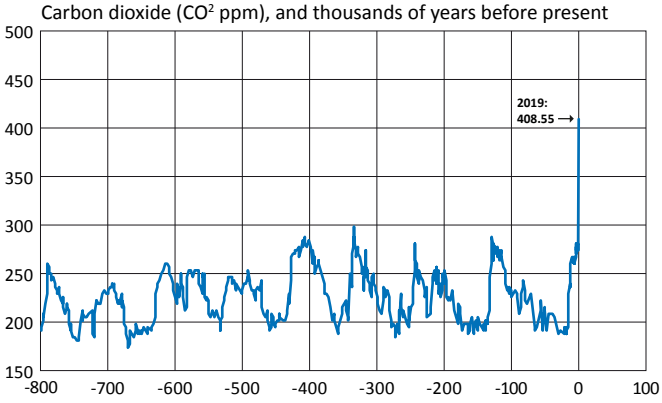
The fact is that, if climate sensitivity were to turn out to be in the lower part of the interval given by the IPCC, global warming would not be a particularly great problem. So far, we have increased the carbon dioxide content of the atmosphere by just below 50 per cent and could therefore increase it by as much again and still meet the target of 1.5 degrees. On the other hand, if the climate sensitivity turns out to be in the middle or upper part of the interval, we are facing potentially very great challenges. The uncertainty regarding the climate sensitivity has not decreased over time either. About equal numbers of studies being published today find that climate sensitivity is in the lower interval as find that it is in the upper interval.[4] The fact is that the IPCC has even widened the interval recently.[5]

Greater carbon dioxide emissions and higher temperatures over the last century

During the Industrial Revolution of the 19th Century, fossil fuels started to be used on a large scale. Since then, the concentration of carbon dioxide in the atmosphere has increased by almost 50 per cent. This means that the carbon dioxide content is completely unprecedented over the last 800,000 years, as Figure 1 illustrates.

Figure 1. Carbon dioxide concentrations in the atmosphere over the last 800,000 years

Carbon dioxide (CO^2 ppm), and thousands of years before present



Sources: NOAA Climate.gov and CO2.earth

4 See, for example, 'Explainer: How scientists estimate "climate sensitivity'' ', https://www.carbonbrief.org/explainer-how-scientists-estimate-climate-sensitivity.

5 IPCC (2007) states that climate sensitivity is ''likely' to lie in the range 2–4.5°C, and is 'very likely' to be above 1.5°C'. IPCC (2013) writes instead that climate sensitivity 'is likely in the range 1.5°C to 4.5°C (high confidence), extremely unlikely less than 1°C (high confidence), and very unlikely greater than 6°C'.

Even though a small number of countries are responsible for a relatively large share of emissions, their share of total emissions is nevertheless limited. For example, as can be seen in Table 1, the United States, China and the EU together are responsible for about 50 per cent of the world's emissions. The rest of the countries in the world are typically responsible for less than half of one per cent of total emissions. For example, Sweden is only responsible for a modest 0.15 per cent. This means that it will not be possible to solve global warming unless all countries – including emerging market economies – reduce their emissions significantly.

Table 1. Greenhouse gas emissions for different regions

Country	Share of global emissions (2012)
China	26.72
United States	13.52
EU28	9.86
India	6.99
Russia	5.04
Africa	3.84
Argentina+Brazil+Chile+Uruguay	3.51
Sweden	0.15

Source: EDGAR (Emission Database for Global Atmospheric Research), European Commission

The carbon dioxide content of the atmosphere has thus increased over the last century. At the same time, according to NASA scientists, the global temperature has increased by about 1 degree since 1880.[6] Climate scientists from the IPCC and other organisations have tried to weigh in all causes for this temperature growth. They have attempted to identify and weigh in the anthropogenic effect coming from human activity alongside all other effects, such as variations in solar radiation, the Earth's movements or volcanic eruptions. One of the conclusions of the fifth IPCC report is that human beings have affected the climate. In its report, IPCC (2013, p.17) states the following:

> *It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together.*

2.2 The effects of the climate on the economy

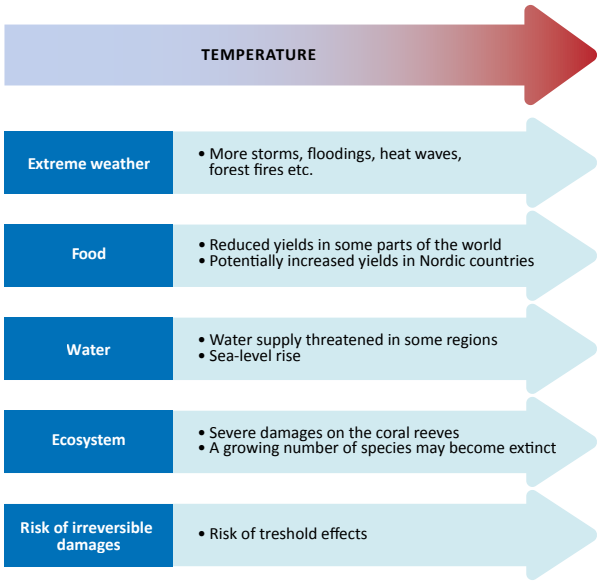
We know with certainty that changes in the climate have affected people and their economies throughout history and that they will continue to do so in the future. However, calculating the total costs of different temperature increases is a complicated task. Some of the most obvious costs of global warming are illustrated in Figure 2.

6 https://earthobservatory.nasa.gov/world-of-change/global-temperatures

Damage from extreme weather

Climate change is expected to lead to extreme weather becoming increasingly common, with more intensive storms, forest fires, rising sea levels and floods, for example. These will destroy property and capital, kill and injure people and may also lead to political unease and economic crises.

Figure 2. Effects of the global temperature on our economies.



Source: IPCC (2013)

Dwindling water resources

Another effect of rising temperatures will be severe water shortages in many regions. Emerging market economies are expected to be hardest hit by this, as such countries tend to be warm already and to be strongly dependent on agriculture. Emerging market economies will probably also find it harder to adapt to climate change due to less efficient institutions and infrastructure and lower technological development. Dwindling water resources are not just something that affects poor countries, however. In recent years, both southern Australia and the western United States have been affected by severe droughts.

Increased migration

Global sea levels are expected to rise by 0.26–0.77 metres by the year 2100 if temperatures rise by 1.5 degrees. This could potentially mean that millions of people will have to move.[7]

Damaged ecosystems

A higher temperature may also have a widespread impact on ecosystems. With increased temperatures of only 1.5 degrees, 70–90 per cent of the world's coral reefs are expected to disappear. Some of these effects may be very long-term or even irrevocable. All of these problems will become worse the more temperatures rise, but we are already noticing more extreme weather and negative effects on ecosystems (IPCC 2018).

Changes may be difficult or impossible to remedy

There is a risk that some of these changes will be irreversible. However, IPCC (2013) points out that there is no evidence of global 'tipping points' or threshold effects where

7 Sea levels are expected to rise by a further 0.1 metres if the temperature increase instead reaches 2 degrees.

temperature increases would start to run out of control. On the other hand, there is evidence of threshold effects for certain specific aspects of the climate, such as ocean currents and ice cover. However, these phenomena act over time horizons of several hundred to a thousand years.

It is relatively simple to list a large number of potential consequences of a higher temperature. But to assess how serious the consequences will be and hold an objective discussion of how economic instruments can be designed, it must also be possible to set prices for all the effects in the figure (as well as all the conceivable effects that I have not listed). This is a complicated task requiring, among other things, a stance to be taken on how future generations are to be valued against those living today, as well as how much saving a human life is worth. Without taking a stance on things like this, we have no figures to compare with the costs of various measures. It would then become impossible to calculate how high a tax on carbon dioxide emissions should be, for example.

Calculating the total costs of various temperature increases is therefore a complicated task characterised by great uncertainty. The IPCC reports that it is reasonable to expect losses of 1 to 5 per cent of global GDP with an increase of global average temperatures of 4 degrees (IPCC 2007). In their study, Nordhaus and Moffat (2017) find that the calculated cost would be 2.04 per cent of global GDP with a temperature rise of 3 degrees Celsius and 8.06 per cent at 6 degrees.[8] However, the estimates from both of these studies are characterised by significant uncertainty. As a comparison, US GDP fell by just over 4 per cent during the financial crisis of 2008–09.

It is, however, important to understand that the costs may be devastating on a local level. For example, when Hurricane Katrina hit the US states of Florida and Louisiana in 2005, it led to costs of around USD 125 billion and more than 1,800 fatalities. However, seen as a proportion of the United States' GDP, this cost corresponded only to around 1 per cent.

3 Global political measures are necessary

So what solutions are there to the problem of global warming? Do we need to regulate or even ban carbon emissions? The obvious starting point when economists are considering whether a market needs to be regulated is the *first fundamental theorem of welfare economics*, which is discussed in the paragraph below.

3.1 Global warming is a market failure

Put very simply, the first theorem of welfare economics says that, if property rights are well-defined and respected, there is a market for all goods, and households and companies can make free choices on markets with perfect competition, then outcomes on the markets will be efficient. This implies that there is no scope for taxes and subsidies to improve the outcome from an *efficiency point of view*. The fact is that, in this case, political measures will only lead to a less efficient outcome.[9] When markets function, it is thus most efficient to let the markets to allocate resources.

However, the theorem rests on a number of assumptions and, when it comes to global warming, it is clear that at least one of these has not been fulfilled: there lacks a market on which greenhouse gas emissions are priced. Since nobody owns the climate or atmosphere, there is nobody to take payment for emissions. It is thus free of charge to emit carbon

8 See also Dell et al. (2012) and Colacito et al. (2018). The first of these studies finds that a temperature increase of 1 degree Celsius would reduce growth in poor countries by 1.3 percentage points. In rich countries, the authors find no effect on growth. The later study instead finds that the forecast temperature increase could also heavily reduce growth in the United States over the coming century.

9 On the other hand, there may be reason to use policies to change the distribution of resources in an economy.

dioxide, even though it generates costs for households and companies around the world.[10] In addition, it does not matter where in the world the carbon dioxide is emitted. One unit of carbon dioxide has the same effect on the global temperature regardless of whether it is emitted in India, China, the United States or Sweden. This is because carbon dioxide rapidly spreads through the atmosphere.

Carbon dioxide emissions are an example of what economists call an *externality*. An externality involves a person or company impacting others without paying any compensation. Externalities can be positive or negative but they always constitute a market failure.[11] This market failure, in turn, implies that the first theorem of welfare economics does not hold. Instead, the conclusion is the opposite: the market cannot allocate the resources efficiently, but political measures are necessary to correct the market failure and allocate the resources. Without political measures, emissions will be far too high as it is, quite simply, too cheap to emit greenhouse gases.

We can summarise the reasoning above in our first insight.

Insight 1: *Global political measures that increase the price of greenhouse gas emissions are necessary if we are seriously to reduce global warming.*

Insight 1 actually contains two messages:

1) Political measures are needed to increase the price of carbon dioxide emissions.
2) These measures must be global.

Raising the price of emissions will work, as it will give households incentives to purchase products that are less harmful to the climate and companies incentives to develop new technologies that can contribute towards reducing emissions.[12]
The implication of the insight is also that it is not realistic to rely on voluntary measures and responsible behaviour when it comes to climate change. This may possibly have worked if only a few actors had been involved, but hardly in a global arena involving millions of companies and billions of people. It is exactly the scale of the problem that led Nicholas Stern to call climate change the greatest market failure in history (see footnote 2).

It will therefore probably not be enough to just appeal to people to do the right thing, change their behaviour and consume less. Neither is it likely a solution to moralise and make people feel guilty. There are, quite simply, too many people who can choose not to change their behaviour.

It is therefore decisive that the price of carbon dioxide emissions be raised worldwide. The problem cannot be solved on an individual level or even on a national level; instead, global warming is a global problem that requires global solutions. This is a direct consequence of no single country being responsible for the emissions. This may sound trivial but, at the same time, it sometimes seems to be overlooked in the general debate.

Today, such a global climate policy is still absent. It is true that the Paris Agreement, signed by 196 countries in 2016, establishes that a long-term goal is to ensure that global temperature increases stabilise well below 2 per cent. But this agreement is entirely based on the countries voluntarily taking measures to reduce their emissions. Nothing forces them to set specific targets. Even if the Paris Agreement can, in some ways, be seen as a diplomatic success, it cannot be expected, on the basis of economic theory and Insight 1, that it will

10 In other words, we pay for the petrol we buy but not for the damage caused by the carbon dioxide released when we then drive our cars.
11 Put simply, this market failure means that the resources could be reallocated in a way that would increase the welfare of at least one person without the welfare of others decreasing.
12 Insight 1 does not imply that the measures must come from price regulations or taxes. For example, a quantity regulation would reduce the supply and thereby increase the price.

reduce global warming sufficiently. It is still far too cheap and tempting to continue to release carbon dioxide.

This forecast also corresponds with what has been observed so far. Most countries with large emissions have, in principle, made no efforts whatsoever. The fact is that carbon dioxide emissions reached a new record and became the highest ever in 2018.

3.2 Measures must be cost-effective

One way of reducing emissions could, quite simply, be to ban fossil fuels immediately. However, this would be far too costly, as it would more or less completely shut down our economies. This would cause a catastrophic global recession and would not be worth it. At the same time, we know that completely free emissions are leading to there being too much carbon dioxide in the atmosphere. This means we have to find a 'balanced' amount of emissions.

Not all suggestions claiming to lead to reduced global warming therefore have to be good suggestions. Some may be far too expensive. Some may also be ineffective and some may perhaps be based on unrealistic assumptions. Distinguishing between good and less good measures needs methods and models to evaluate how effective various measures are and also to estimate how large the costs will be if we fail to take any measures at all. This is referred to as a *cost-income analysis*. In one of these, all future costs of emitting a unit of carbon dioxide are weighted against the benefits associated generated by the emission. The revenues come from the production and consumption for which the fossil fuel is used. The costs are the climate-related damages we discussed above.

Making a cost-income analysis of global warming is a complicated task. It requires an understanding of how both the carbon cycle and the climate work, as well as our economies. We also have to be able to make forecasts for 50 to 100 years ahead, which takes both meticulousness and humility. To make analyses like this, William Nordhaus developed a framework of models, called integrated assessment models, at the start of the 1990s. These models consist of three connected submodels: an economy, a carbon cycle and a representation of the climate. There are many such models today, but most of them are based on Nordhaus's work, which has become standard for the analysis of various scenarios for global warming. In 2018, Nordhaus received the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel for his work in this area.

The point of cost-income analyses is to understand the measures that can best reduce temperature increases for the smallest possible cost. Cost-efficiency is an important goal in itself. Just as we should not squander resources, neither should we undertake unnecessarily expensive measures to reduce warming. Less costly measures will instead free up funds that can instead be used for other important purposes such as reducing poverty and water shortages or reducing the spread of various illnesses.

However, it is probably even more important that the measures be cost-effective if countries with ambitious climate goals, like Sweden, are to convince countries like India and China to reduce their emissions. This means it will be decisive that the measures are not too expensive. As we will see later, it would not be particularly expensive to limit global warming to 2 degrees, but only if we actually use cost-effective measures. Otherwise it will be significantly more expensive.

3.3 Taxes and quantity regulation

The two most obvious political measures to reduce global warming are the introduction either of a carbon dioxide tax or of what is known as quantity regulation for emissions where a limit is set for the quantity that may be emitted.

Carbon tax

As I mentioned above, carbon dioxide emissions are a negative externality and the English economist Arthur Pigou demonstrated 100 years ago that a correctly set tax – a so-called Pigovian tax – can solve the problem of externalities (Pigou 1920). As regards global warming, the tax per emitted unit of carbon dioxide should be set so that it is as large as the climate cost generated by that unit. The price of fossil fuel, including carbon dioxide tax, will then consist of the price charged by the producers plus the climate cost generated by the fuel. This allows the climate costs to be reflected by the price.

The advantages of a carbon dioxide tax are many, but its main strength lies in its simplicity: it is a *market-based* solution that implies that people do not need to think about how their behaviour exactly affects the climate. This effect has already been incorporated into the price, which automatically gives people the right incentive. This is a great advantage as it is very difficult for individual persons to evaluate their own climate impact. Another advantage is of a more technical nature. Efficiency demands that it costs the same to reduce emissions everywhere.[13] A global tax will achieve this directly, unlike, for example, the Paris Agreement, under which all countries decide themselves how much they will reduce their emissions.

A common misapprehension concerning carbon dioxide taxes is that they have to involve large redistributions of tax revenues among countries. This is not at all necessary. All countries can set the same tax and then use the revenue for whatever they like – it does not have to be redistributed internationally if this is not wanted. All that is needed is an agreement that every country will implement a carbon dioxide tax.

Another important thing to point out is that a tax on carbon dioxide is fundamentally different from most other taxes. This is because a tax on employment income, for example, *distorts* the incentive to work, which would normally lead to a welfare loss. A tax on carbon dioxide, in contrast, would *correct* the incentive to emit carbon dioxide, leading to a welfare gain.[14]

Quantity regulation

The second obvious measure to reduce global warming is the introduction of quantity regulation, which restricts how much carbon dioxide may be emitted. Such a system is standard today to reduce global warming and has been used, for example, in the Kyoto Protocol and in the EU Emissions Trading System (ETS). It works by limiting total emissions by sharing or auctioning emission rights to companies and other actors. Those owning the rights can then sell them to other actors. The point of trading emission rights in this manner is to allow some companies to reduce their emissions for a lower cost than others. If it is very expensive for a company to reduce its emissions, it becomes more economically effective for that company to purchase emission rights from companies able to reduce their emissions at a lower cost.

Both approaches have advantages and disadvantages

Taxation and quantity regulation can, theoretically, be completely equivalent, but, in practice, there are a few important differences. One is that they are associated with different kinds of uncertainty (Weitzman 1974). Under a carbon dioxide tax, the emitters know what the price is, but the legislator does not know, with certainty, how large emissions will actually be. Under quantity regulation, the legislator knows exactly how large emissions will be but the price of them is uncertain instead.

13 The tax has to be the same everywhere as climate damage occurs independently of where the carbon dioxide is emitted.
14 This follows directly from the above discussion of the first fundamental theorem of welfare economics. The labour supply is not clearly characterised by a market failure and a tax would then lead to a welfare loss.

Another potentially important difference regards with tax revenues. Like all taxes, a carbon dioxide tax generates greater costs for the private sector and greater revenues for the state. Emission caps and trade are more complicated. If the state auctions emission rights and collects revenues, this certainly acts like a tax. However, it is common for the state to allocate emission rights, in which case there are no tax revenues. Another difference, which is illustrated in Golosov et al. (2014), is that a carbon dioxide tax requires significantly less information to implement than quantity regulation.

Today, many economists are agreed that a global carbon dioxide tax would be the most direct and effective way of reducing global warming. In January 2019, about 40 highly reputable economists – over half of whom had been awarded the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel – signed a petition claiming that a carbon dioxide tax would be the most cost-effective way to reduce emissions fast enough.[15] Since then, more economists have signed the petition. At the time of writing, these economists number over 3,500.

Despite the academic unanimity, there are several problems with a carbon dioxide tax. For example, there is a traditionally strong opposition to taxes in the United States, which makes it difficult to see any tax receiving political support there.

Both taxes and quantity regulations suffer from an inherent free-rider problem: if all countries were to implement a carbon dioxide tax or quantity regulation, but one individual country did not, that country could cut its production costs in relation to everybody else, at the same time as the cost of the extra emissions generated by the country would be shared among all countries around the world. The problem is that all countries have the same incentive to deviate from taxation and quantity regulation. It may therefore be necessary for the countries to monitor one other's emissions and also penalise any countries deviating.

3.4 Coal is a larger problem than oil

Before we say anything about how an efficient policy can be designed to reduce global warming, it is necessary to discuss a few important differences between fossil fuels. Even though coal, oil and natural gas all form carbon dioxide when they are burned, there are still important differences between them.

Conventional oil is a highly efficient fuel and is very cheap to extract. But there is only a relatively small amount left. I am talking here about conventional oil and not oil sands or oil produced through hydraulic fracturing ('fracking').[16] In addition, oil is traded on a world market and there is an infrastructure in place to transport oil anywhere in the world.

The situation is completely different for coal. According to prevailing estimates, coal exists in very large amounts spread over basically the entire world.[17] Coal is also significantly more expensive to produce per unit of supplied energy. Due to the high transportation costs, coal is not traded between countries to any great extent.

These differences are important. The very low marginal cost of producing conventional oil in combination with international trade means that a tax on oil would be almost futile. There are two reasons for this.

The first is so-called carbon leakage. If some countries choose not to purchase oil, for example for climate reasons, the sellers can cut the price without this making it unprofitable. Then they can sell the oil more cheaply to countries that do not take the same consideration of global warming.

The other reason is that a tax will not substantially affect the supply of oil. Even if all countries join forces and introduce a tax on oil, the owners of the oil could just cut the

15 Wall Street Journal, 16 January 2019.

16 Such *unconventional* oil has several similarities with coal in the sense that it is significantly more expensive to extract.

17 See, for example, Rogner (1998), who shows that, with technological development, the total stock of fossil fuel is 5,000 Gigatons of Oil Equivalent (GTOE). Most of these resources are formed of coal. With a global annual consumption of around 10 GTOE, this stock will thus last for about 500 years.

price until it is as low after tax. The profit margin on oil is quite simply too high. A tax would therefore mostly affect the price sellers can charge, not the supply of oil.

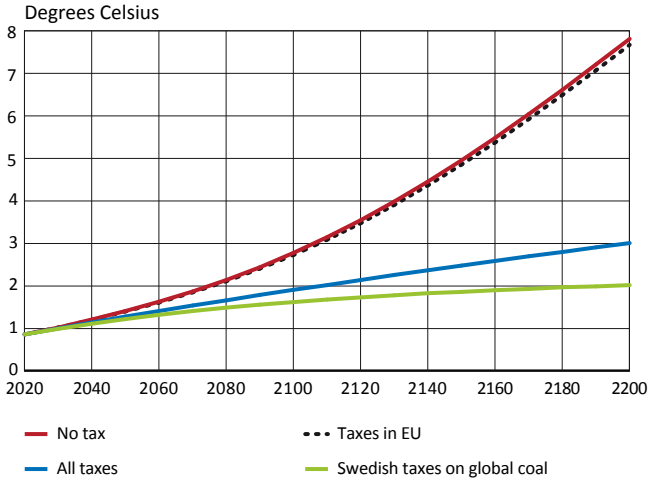
It may seem disheartening to find that a tax on oil would be almost futile, but the good news is that a carbon dioxide tax would be significantly more effective in reducing the production of coal. Even a relatively low tax would be enough to make a large part of the production of coal unprofitable. As we will see in the next section, the most important initiative that can be taken to reduce global warming is to reduce the production of coal.

3.5 How much would it cost to limit global warming?

Limiting the future costs of global warming means that we must take measures today. The most expensive scenario would be to ignore it completely. The problem is that there is an inherent conflict between the present and the future. Taking measures today will cost us today, but we will not be able to see the benefits – in the form of less warming – until the future. This means that the current generations must make sacrifices so that future generations can have better lives.

Hassler et al. (2020) analyses which temperature increases we will experience, depending on which policies we implement, above all various taxes. Among other things, they investigate what the temperature will be if we apply no taxation at all on greenhouse gases, and if only certain regions do so. The results show that, without political measures, we are facing comprehensive global warming.[18] The temperature will then rise by about 3 degrees during the current century, to increase by 9 degrees by 2200.[19] This is illustrated by the red line in Figure 3. Without saying exactly what costs such a scenario would entail, it is fairly obvious that, according to all reasonable calculations, they would be significant.

Figure 3. Scenarios for the global temperature
Degrees Celsius



Source: Hassler et al. (2020)

On the other hand, a relatively low global tax of USD 25 per ton of carbon dioxide, corresponding to roughly USD 0.25 per gallon gasoline, would be an effective way of holding the temperature increase below 2 degrees for the rest of this century. This is illustrated by the blue line in the diagram. However, it is entirely decisive that the tax be implemented globally. If, for example, only the EU were to implement the tax, we would be facing basically the same development of temperatures as we would be if nobody were to tax carbon dioxide, as illustrated by the broken line in the diagram.

18 Climate sensitivity has been set at 3, which is to say in the middle of the interval calculated by the IPCC. Uncertainty over climate sensitivity is considered in the next section.
19 These temperatures are expressed in relation to the temperature prior to the Industrial Revolution.

These results confirm what was stated in Insight 1 – that the price increase must be global. They also show that the EU's ETS system (see the section 'Taxes and quantity regulation') needs to be broadened and to include significantly more countries if the system is to have a chance of making an impact.

Finally, a global tax in line with the Swedish one of about SEK 1150 per ton of carbon dioxide, which corresponds to around USD 1 per gallon of gasoline, is enough to keep the temperature below 2 degrees until 2200, as illustrated by the green line.

The conclusions of these analyses bring us to Insight 2.

Insight 2: *Using a global tax to limit the increase in the global temperature to 2 degrees would not be particularly expensive as long as the tax is introduced on a global level.*

A relatively low tax would be enough for this purpose. Even if many voices in the general debate claim, at times, that a carbon dioxide tax would be completely devastating for the country's production and competitiveness, there is no empirical or theoretical evidence for this. After all, for almost 30 years, Sweden has had a tax about seven times as high as the tax that could limit temperature rises to 2 degrees this century. Sweden has even had better growth than many comparable countries since the tax was introduced. However, this again brings us back to the significance of implementing the tax globally so that competitiveness is not worsened for any particular country.

As coal can be found in such large amounts, it is precisely coal production that forms the greatest threat (see also IPCC 2018). It is coal that will push the temperature increase up to 9 degrees unless we tax it. The analysis in Hassler et al. (2020) also shows that it does not matter whether we tax conventional oil. Such a tax would have basically no effect on the supply of oil.

However, even if the tax is ineffective against oil use, the social costs of continuing to use up oil at the same rate are minor. The reason for this is that conventional oil is so cheap to produce, exists in such small amounts and is such an efficient fuel that it would actually be effective to use up all the oil – despite the negative effects on the climate.[20] This does not apply to unconventional oil such as oil shale, oil sands and the oil derived from fracking. This oil is significantly more like coal in the sense that it is significantly more expensive to produce and exists in very great quantities. Consequently, it should absolutely not be consumed at the same rate.

The difference between coal and oil is so important that it can be formulated as an insight.

Insight 3: *The absolutely most important initiative for reducing global warming is to restrict the use of coal.*

This is interesting considering that the general debate very much focuses on restricting the use of oil. For example, we are supposed to stop flying and driving cars. The current Swedish government has voiced the explicit ambition that Sweden should become fossil-free. As Sweden does not use coal to any major extent, this policy largely means that Sweden is to stop using oil. But, combined with the possibility of selling it to others, the profitability and efficiency of oil mean that such a policy can only be expected to lead to major carbon leakage in which the oil is sold to other countries instead.

20 If the supply of conventional oil had been significantly greater, it is likely that this conclusion would have been changed.

A national climate policy seriously aimed at reducing global warming instead needs to focus on the effects the policy can be expected to have on global emissions. A stance needs to be taken on whether it will actually reduce global emissions or if it will just lead to production being moved abroad.

3.6 Should we take measures even if we are not certain that the climate costs will be high?

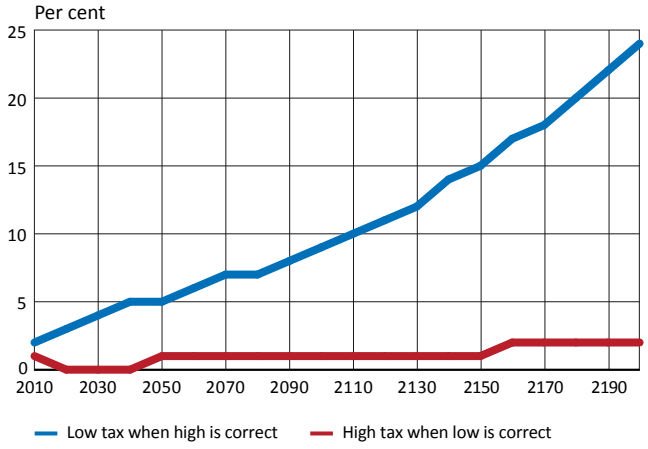
The fact that there is such great uncertainty over both climate sensitivity and the economic costs of climate change has led climate sceptics to argue for a very restrained climate policy, quite simply because there may not be any major effects. This is certainly true. We cannot rule out that the costs of global warming actually may not be so high. However, at the same time, we cannot rule out the possibility that they may be very high.

Climate policies must be designed in light of this great uncertainty.[21] This means that we have to decide what to believe right now and then design our policy to fit. It also means that the policy may be badly designed, for example if it later turns out that climate sensitivity is higher or lower than we had earlier expected.

Hassler et al. (2018) calculate the effects of two different policy errors. The first error concerns designing policy on the basis of low climate sensitivity and low costs that later turn out to be high. The second error is the inverse: assuming that climate sensitivity and costs will be high, but both of these later turning out to be low.

The results can be seen in Figure 4, where the red line shows that it is not at all expensive to overestimate climate change if it should later turn out to be mild. The reason for this is that a carbon dioxide tax is so cost-effective that being extra ambitious is not particularly expensive. In contrast, acting in line with the climate deniers risks being very expensive in the event that climate sensitivity and costs later turn out to be high. The blue line indicates that the costs of underestimating climate change are potentially very high. After 2150, consumption will be more than 15 per cent lower per year than it would be with an optimal policy. As a comparison, global GDP fell by about 15 per cent in the Great Depression between 1929 and 1932.

Figure 4. Loss of GDP relative to optimal policy



Source: Hassler et al. (2018)

An ambitious climate policy would thus be a cheap form of insurance against future high but uncertain expenses. However, this only applies if the policy is cost-efficient, otherwise it may be significantly more expensive. The conclusion of this analysis is that it would be highly

21 See Weitzman (2009) for a discussion of potential problems with analyses of climate policy that can arise against the background of the great uncertainty prevailing over climate change.

justifiable to take out this insurance according to the motto 'hope for the best but prepare for the worst'. It also means that it would not be sensible to commit to a policy that assumes small losses and low costs, even if such a scenario could be realised.

4 Alternative political measures

What alternative measures can we rely on if we fail to introduce a global carbon dioxide tax or a broad regulation of quantity? There are many suggestions. Some examples include subsidising green energy sources, sustainable financing and technology solutions such as carbon capture and storage (CCS).

If alternative measures are to succeed, they must be able to reduce global carbon dioxide emissions significantly. And to do this they must be able to resolve and manage the market failure that has led to emissions being cheap, and which is a fundamental reason for global warming.

Subsidies to green technology

As the problem of global warming stems from coal production, a conceivable strategy would be to subsidise the development of energy sources such as sun, wind and water. They are called 'green', as they do not increase the amount of carbon dioxide in the atmosphere. But although technological advances have a spillover effect between countries, subsidies in an individual country will not have any major effect on global production. Just as for taxes, alternative sources of energy should preferably be subsidised at global level to be effective, even in theory.

I therefore state a point that is in many ways trivial, but which many people tend to miss in Insight 4.

Insight 4: *Green energy is only viable to reduce global warming if it substantially reduces the use of coal.*

This is equally relevant when it comes to so-called sustainable investment and green bonds, which will be discussed further later on.

So how can green subsidies stop coal power? The idea is that the subsidies will lower the price of green energy. So far so good. However, one assumption is that this price cut will then lead to lower demand for fossil fuels. But this is far from evident. It all depends on the *substitutability* of green and fossil energy sources.

If two goods are highly substitutable, it means that the buyers are equally happy with the one as with the other. They therefore tend to buy only one of the two goods, namely the cheapest one. If the two goods are instead complementary, the buyers will want to buy both of them.[22]

If the energy sources have sufficient substitutability, then cheaper green energy could entirely drive out fossil fuels. The subsidies would then lead to a reduction in coal power, at the same time as they resolve the market failure – as all use of fossil fuels will cease. If, on the other hand, the energy sources are more *complementary*, the subsidies will not work. The fact is that green subsidies might then possibly lead to an increase in the use of fossil fuels, as both fossil and non-fossil fuels are used.

Unfortunately, the scientific studies available today do not support the idea of high substitutability between green and fossil energy sources. On the contrary, the relationship appears to be more complementary, at least in the medium term (see Stern 2012). One

22 Examples of substitutable goods are whole litres and half litres of milk, and examples of complementary goods are butter and bread.

reason is that fossil fuels are stable energy sources that function regardless of whether the sun is shining or it is windy. They therefore tend to complement the green energy sources, which are less stable. Consequently, green subsidies cannot be expected to be effective against global warming. This is also verified by Hassler et al. (2020), who analyse how a more rapid technological development of green energy sources affects global warming. They find that subsidies are not effective in significantly reducing global warming. Even if the price of green energy is subsidised so that it falls 2 per cent faster per year than without subsidies, it will have no great effect on the global temperature. Just as in the case without a global tax, the temperature is then raised to 9 degrees in 2200.

One important reason why a lower price for green energy does not have sufficient effect is that there are also technological advances within coal mining. The green energy therefore does not become sufficiently cheaper to be able to knock out coal mining.

If, on the other hand, it were possible to stop technological advances in coal mining completely, the price of coal would rise sufficiently over time to be able to limit global warming to 2 degrees up to the year 2200. The price of coal would then rise because it would become relatively more expensive over time to mine coal, and the price increase would function in roughly the same way as a carbon tax. It would be the same solution as before: it is necessary to raise the price of coal to reduce global warming.[23]

Sustainable financing?

Another measure that is often advocated today is so called *sustainable financing*. The idea is that companies, institutions and private individuals can themselves act in a moral way by refraining from investing in projects that do not meet certain ethical criteria. Specific criteria have been set up for this, so-called *ESG* criteria, where E stands for environmental, S for social, and G for governance. Companies can invest in line with the ESG criteria to signal that they are ethical and that their products contribute to sustainable development.

The ESG categories are very broad and all-inclusive. The E includes large, broad sub-categories such as climate change, greenhouse gases, environmental aspects, emissions, indicators related to land and water use, recycling, refuse and a further 50 factors. The S includes just as much and as many points on, for instance, human rights and issues related to gender and diversity. And finally, the G is at least as broad, and concerns, for instance, how companies treat their employees.

ESG investments have increased substantially over the past 20 years. In the year 2018, a good 12 trillion, that is to say 12 thousand billion dollars was put into so-called sustainable and responsible investment in the United States alone.[24] As the ESG criteria include very many different aspects, ratings institutes and various other methods have been developed to rate how well different companies live up to them.

It is, of course, positive that companies are endeavouring to act in a moral and ethical manner, but as the E includes many climate aspects, one can also ask to what extent ESG investments can help to limit global warming. There are three major problems in particular that mean there is good reason to be sceptical.

The first problem was described in Insight 4: green investment is only effective against global warming if it can stop coal mining. There is neither empirical nor theoretical evidence that this will be the case.

The second problem is that sustainable financing does not resolve the market failure that is an important part of the problem that contributes to global warming. There is no indication that enough people will voluntarily refrain from investing in potentially very profitable projects that are not good for the climate. Even if some companies refrain from a

23 These conclusions could change if the future elasticity proved much greater. It would then need to be at least five times higher than the prevailing empirical estimates.

24 US SIF Foundation (2018).

certain type of investment, it does not mean that these investments will not be made. There is probably a sufficient number of actors, or large enough actors on the financial markets that value the project from a purely financial perspective, rather than an ethical one. This will counteract the investments made from an ethical perspective.

The fact is that if many voluntarily refrain from investing in profitable projects that contribute to global warming, it will only mean that the price of these projects falls. They will therefore become even cheaper and even more profitable.

These types of *general equilibrium effects* are decisive when it comes to global warming. Ethical and moral behaviour by a company or country can be easily neutralised by others, and it is therefore necessary for governments around the world to agree to take political measures simultaneously.

The third problem is that the ESG criteria are so broad and extensive that they in practice mean everything and nothing. Different methods and different rating institutes therefore tend to give the same company completely different rankings. For instance, one rating institute ranked Tesla as the worst car manufacturer in the year 2018 from an ESG perspective, while another ranked it as the best.[25] It is not actually surprising, given that the ranking is based on trying to find the aggregate of a number of completely disparate areas and then distil it into a figure.

In their current form, there is a risk that the ESG criteria largely give a false feeling of security to investors, who do not really understand exactly what lies behind a particular rating, or what it entails in practice.

The Swedish Society for Natural Conservation evaluates in a report published in 2015 to what extent financial products marketed as ethical, green or sustainable can be used by households and asset managers to 'make a difference' and promote a better environment. They base their analysis on both theoretical and empirical studies. Their pessimistic conclusion is summarised in the following paragraph.

> *It is normally very difficult for households and asset managers to act effectively to promote a better environment by avoiding environmentally damaging companies' shares or bonds. This avoidance might possibly have a symbolic effect in the longer run, but it should not be overestimated in this context.*[26]

Green bonds

Green bonds are actually only a specific form of sustainable financing. They are bonds that are earmarked for use in new or existing climate and environmental projects. Within this broad definition of green bonds, there are then many sub-areas, such as energy, transport, waste management, building and construction and land and water use. In the year 2018, green bonds to a value of around USD 180 billion were issued around the world, and this is a market that is expected to expand very rapidly going forward.

Green bonds have many potentially good qualities. Above all, they can help to fund environmental projects that are beneficial to society. But when it comes to their ability to reduce global warming, they unfortunately suffer the same problems as sustainable financing, for instance, that they do not necessarily lead to a reduction in use of carbon.

Another problem is that, as with the ESG criteria, the criteria regarding how green a bond needs to be are not sufficiently strict or clear. There are guidelines – the Green Bond Principles – but these are only guidelines.[27] As there is no global standard for the criteria, it is often unclear exactly how green a bond is. For this reason, one hears about light green bonds, medium green bonds and dark green bonds.

25 See, for instance, the Financial Times, on 6 December 2018: 'Lies, damned lies and ESG rating methodologies.'
26 Swedish Society for Natural Conservation (2015), pp. 5–6.
27 See, for example, ICMA (2018).

A third problem is that it is very unclear what an investment in a green bond actually entails. A financier may, for instance, think that it helps to fund solar panels. But if the issuer of the bond already has resources for these, the investment instead frees up funding for other, potentially non-green activities. It is not possible to rule out this type of effect. These problems mean it is also very difficult to make an empirical evaluation of how effective green bonds are in general.

The conclusion is that even if so-called sustainable investments may have many positive effects, their opportunities to limit global warming must be regarded as small. There is insufficient theoretical and empirical evidence to indicate that they are a possible way forward. The demand for green bonds has increased substantially in recent years, and sometimes there is even talk of a green bubble. There is also an evident risk here of *green washing*, that is, companies and institutions want to hold this type of asset to paint a picture of themselves as being environmentally and climate friendly. This could create a false security, in that we are led to believe we are moving in the right direction, even though this may not actually be the case.

5 Concluding remarks

In this article, I have discussed global warming from an economic perspective. I have summarised the most important results into a number of points I call *insights*.

Insight 1: *Global political measures that increase the price of greenhouse gas emissions are necessary if we are seriously to reduce global warming.*

Insight 2: *Using a global tax to limit the increase in the global temperature to 2 degrees would not be particularly expensive as long as the tax is introduced on a global level.*

Insight 3: *The absolutely most important initiative for reducing global warming is to restrict the use of coal.*

Insight 4: *Green energy is only viable to reduce global warming if it substantially reduces the use of coal.*

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