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Potential Climate Risks in Financial Markets: Report from a workshop, January 20, 2016

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Potential Climate Risks in Financial Markets: Report from a workshop, January 20, 2016

Ingrid Hjort*

February 1, 2016

Abstract

Climate change has the potential to affect the global economy through physical impacts, but may also initiate regulations, policies, as well as technological innovation. Over time climate science and environmental economics have developed a better understanding of the potential impact over a variety of scenarios. The economic impacts on sector, industries and market are still uncertain, making the timing and the extent of impact difficult to predict in detail. As climate change might affect the global economy, risks in financial markets increase. The academic literature on financial economics of climate change is limited. The implications for financial markets of climate change seem not to have been addressed extensively in the literature. The workshop on *Potential climate risks in financial markets* gathered a selected group of scholars from finance, macroeconomics, microeconomics and resource & environmental economics, to explore and discuss the potential financial impacts from climate change.

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Preface

The workshop *Potential climate risks in financial markets* was organized by the University of Oslo, Department of Economics, supported by NBIM (Norwegian Bank Investment Management) and held at Norges Bank on January 20, 2016. There were 30 participants from Norwegian academic institutes (UiO, NHH, NTNU, BI and Cicero) together with NBIM and the Norwegian Ministry of Finance, as well as the speakers.

These were Robert Stavins (Harvard), Rick van der Ploeg (Oxford), Patric Bolton (Columbia), Luc Renneboog (Tilburg), Karin Thorburn (NHH) and John Hassler (Stockholm). The speakers are presented following the order of the programme.

The six selected speakers represent different aspects and approaches to how climate change may affect the financial markets. There was a variety of interpretations of climate related risk elements, leading to fruitful discussions and knowledge exchange. The aim of this workshop was to contribute and bring attention to a new research field connecting financial economics and environmental economics. As part of the project *Potential climate risks in the financial markets*, I was asked to write a literature overview on the same topic, see Hjort (2016)

What follows is a short summary of each speakers' main points and analysis. The author is solely responsible for this summary and any shortcomings.

Robert Stavins

Responding to responses:

The risks of climate change policies in the post-Paris world

The focus of this presentation is how markets may respond to the governmental responses to climate change. Financial impacts of climate policies will likely exceed financial impacts of unabated climate change itself over the next two decades (short term).

The impacts and severe consequences of climate change will be long term. The magnitude of climate change can be moderated by public policies, as well as by exogenous technological change. Economic growth in the developing world works in the opposite direction, increasing world's total emissions and accelerating global warming. However, even with more stringent policy actions today climate change will occur, due to previous emitted greenhouse gases (GHG) already in the atmospheric stock.

The abatement costs of climate change are up front, justifying the focus on short term policy effects. Economists are favoring carbon pricing, e.g., taxes or cap and trade systems, because there are no other feasible approaches that can provide significant emission reductions. These price mechanisms are the least costly both in short and long term, also providing an incentive for technological innovation.

Several countries have already implemented national carbon and energy related taxes. There are also major cap and trade regimes in place both multi-nationally and more regionally. China has announced a national cap and trade system from 2017. However, many jurisdictions will not employ carbon pricing, but will use performance standards or technology standards instead. These mechanisms are less cost effective and can give distorted price signals to the market.

The consequences of carbon pricing will especially affect coal, relative to natural gas and oil. Coal has a high carbon content and repricing will have immediate effects on electricity dispatch. Natural gas has lower carbon content, and the demand may increase in the short term due to substitution for coal.

This result applies especially to the US where natural gas prices have decreased after improvements in extraction technology. The oil sector will experience less impacts from carbon pricing, since there are currently limited substitutes for liquid fuels in the transportation sector. The oil market may be affected by suppressed demand due to investments in energy efficiency.

A recent catalyst of climate policies is the Paris agreement from December 2015. The aspiration of the agreement is to limit global warming to 2°C or even 1.5°C. This target is political, and not based directly on scientific or economic modeling. The most important difference from the Kyoto protocol is the broad scope of participation. The 187 participating countries represent 96% of global emissions, compared to 14% in the Kyoto protocol, and there will be revision for more ambitious contributions every 5 years. The requirements are transparent, stating the same standards for developed and developing countries. Monitoring, verification and reporting will be carried out domestically by each country. The climate agreement binds in the domestic laws of the participating countries. These domestic policies are credible, sending price signals through the market.

The agreement provides for potential linkages among heterogeneous policies and international markets, combining carbon taxes and cap and trade systems Bodansky et al. (2015). This would imply emission reduction outside the countries' borders, reducing overall abatement costs. The agreement does not include any option for liability nor damages to the most vulnerable countries. The agreement will come into force when 55 countries, accounting for at least 55% of global emissions, have approved and deposited their instruments of ratification.

The direct impacts of the Paris agreement will be the persistence of existing policies and the initiation of new regulations. This is, ceteris paribus, bad news for coal and good news for renewables and nuclear. The indirect impacts could be, e.g., increased standards for fuel efficiency affecting investments in the electricity sector. These indirects impacts are the most important for the business sector. In most sectors regulations will increase

costs for energy dependent consumers, and increase demand for energy efficient goods (Stavins, 2015).

The discussion after the presentation by Stavins included the following:

- Regarding liability and lawsuits, how would one consider causality? It is impossible to measure whose emissions are causing what damages.
- If global warming goes beyond 2°C, some low-lying islands in the South Pacific Ocean may disappear; economic models should not translate the loss of eradicated cultures in lost GDP.
- Financial markets want arbitrage and opportunities, not homogeneity. May the financial market help in removing the differences in national climate policies through reallocation?
- The diversity arising in national policies sounds very costly, are there any estimates on how large the regulatory costs would be? One might expect great administrative and transaction costs. The degree of heterogeneity means that the costs are least four times what they would be if everyone was on the same abatement cost. Convergence between the tax system and cap and trade systems are possible. However, a system of linkage is a theoretical finding, will not necessarily lower costs.
- Europe has favored subsidies more than taxes, resulting in dropping energy prices to consumers. Will the new climate policies after Paris end up in subsidies or more stringent taxes? Subsidies are second-best, heavy for the government budget, and tempting for politicians wanting to gain popularity. Subsidies are not marginal and do not hit the target.
- Could multinational companies take advantage of this heterogeneity? Yes, they already do, locating in jurisdictions with favorable taxes and regulations.

Rick van der Ploeg

Portfolio allocation in oil-rich countries: Climate and the risk of stranded assets

The first-best policy response is to impose a gradually rising price of carbon (tax or permits) to depress fossil energy use, or an aggressive renewable subsidy to bring renewable energy quickly into use. These policies would lock up a substantial fraction of fossil fuel reserves, a necessity to curb ongoing global warming. Fossil fuels need to be priced out of the market leaving unused reserves under ground.

Second-best policies are relevant when politicians prefer the carrot to the stick: i.e., put off carbon taxes and subsidize renewable energy instead. Renewable subsidies are, if commitment is feasible, higher than the social benefit of learning. With commitment this gets close to the first best, albeit at expense of some acceleration of global warming. Without commitment, the second-best subsidy equals the social benefit of learning and performs much worse, with a later transition and higher fossil fuel use (van der Ploeg, 2013, 2015).

The optimal carbon tax can be derived with integrated assessment models (IAM), similar to Golosov et al. (2014). IAMs allow for temporary population boom and ongoing technical progress, where temperatures hurt productivity of aggregate production. However, few models are able to derive the economic damage above 4°C warming. The IAM models derive the social cost of carbon (SCC), but the results are very sensitive to the choice of discount rate, due to the long time gap before damages occur. SCC translates the present value of all future damages from burning one tonne of carbon today into monetary values. By 2050 the SCC varies between $57.57 per tonne with a 5% discount rate to $499.45 per tonne with a 3% discount rate (measured in 2007 dollars).

The climate problem is also an issue of intergenerational ethics (Rezai and van der Ploeg, 2015). The first-best price of carbon rises in proportion with world GDP, and the factor increases the lower the discount rate, i.e., the more we value future generations.

High intergenerational inequality aversion gives less climate policies today. On the other hand, for high degree of risk aversion or strong concerns about fat-tailed risk the price of carbon today would be higher. Estimated optimal carbon price is quite low with normal discount rate, but catastrophes justify a much higher price without reducing the discount rate (van der Ploeg, 2014). It is important that the models allow for varying speeds of impact of catastrophes such as Lemoine and Traeger (2015); Lontzek et al. (2015).

It is necessary to leave fossil fuels to keep temperature until 2050 below 2°C. Even if emissions are frozen today, temperature will continue to rise due to the long time lags. Known reserves are 3 ×, and resources are 10 to 11 ×, the carbon budget. Globally we need to keep 1/3 of oil (Canada, Arctic), 1/2 of gas and 4/5 of coal (mainly China, Russia, US) reserves unburnt. According to McGlade and Ekins (2015) 260 billion barrels of oil should not be burned in the Middle East. There is a risk of stranded assets for oil and gas producers if we are meeting the 2 degree target (Allen et al., 2009; IPCC, 2014; McGlade and Ekins, 2015).

Pricing carbon and subsidizing renewables will put many fossil fuel producers out of business. However, there is also a risk of oil and gas consumer-prices staying low due to expansion of shale gas and unconventional oil, and a risk of new and cheap fossil fuel substitutes arriving driven by technical progress. Renewables are fossil fuel substitutes, and they become cheaper as more is invested in research and development. The costs will decrease even more when considering learning-by-doing effects and subsidies.

How to manage sovereign wealth? An intergenerational fund should smooth welfare across generations even if windfall was deterministic but temporary. A liquidity fund acts as precautionary saving buffer against volatility of oil prices, but how does one know that prices are temporarily low? More generally one should follow the Hartwick rule, and convert below-ground assets into above-ground assets. Many oil-rich countries without sovereign wealth funds (SWF) are in a more dire situation. But oil-rich countries with a SWF need to think of decarbonization strategies, taking into account their large stocks

of below-ground oil and gas reserves. They should divest, or develop better dynamic and transparent hedging strategies against the risk of a dramatic and prolonged fall in oil prices (van den Bremer et al., 2015).

The discussion after the presentation by van der Ploeg included the following:

- Consider the scenario where one needs to look at liabilities for future pensions just as the last oil is running out. Is the investment strategy or the assets under ground taking this into account? The extraction rate is geologically determined, what one can determine (the policy variable) is how many wells to open, and this should theoretically follow the Hotelling rule. Uncertainty about future oil prices makes the extraction rate more aggressive. However, patience would allow accumulation of more knowledge about the undiscovered oil reserves.

- The diversification decision: the underlying advice seems to be that the fund should not be considered in isolation, but rather the Norwegian economic wealth as a total. The Norwegian national wealth consists of much more than oil and gas reserves. If one restricts oneself to the current fund and the oil and gas reserves there could be a problem to design how to manage diversification.

- The Norwegian economy needs to transform assets below the ground (oil reserves) into assets above the ground. This transaction is highly dependent on the oil price. To avoid any Dutch disease, oil rich countries should invest in the international market, and not in national infrastructure. It seems like Norway is investing a lot in human capital.

- The fund should consider liabilities together with the climate risk, thus protecting future generations' pensions.

- The perfect hedge is the Norwegian currency. When the oil price dives, the Norwegian krone depreciates. This currency effect is large, helping other export industries.

Patrick Bolton

Hedging climate risk with decarbonized indices

The work by Andersson et al. (2016) tries to contribute to the intersection between finance and environmental economics, and specifically climate change. The debate has shifted from seeing climate change as a threat to society to being a risk to investors. This awareness of investors of a potential risk has developed very fast and was not an issue just five years ago. Many investors want to act in a socially responsible way to influence the outcome of climate change, but they also want to manage risk. This study explore one approach to integrating climate change as a risk factor.

Climate risk is something you cannot ignore if you are a long term investor. Indeed, climate change has been identified as a global risk for investors, ranked among the top five by the World Economic Forum. It is high on both the likelihood scale and the impact scale. How should investors engage with this risk? There are three possibilities; either divestment, engagement or what the authors refer to as decarbonization of indexes. Full divestment is not suitable for mainstream institutional investors and large asset managers that are primarily focused on generating financial returns. Divestment is a bet on renewables and might increase the overall portfolio risk. A decarbonized index is a compromise, it reduces exposure to carbon risk without changing other risk exposures.

The design of decarbonized indices has good properties of risk management. One of the risks of climate change for investors is the risk of timing of climate mitigation policies. Investors do not know when these policies will be introduced. A decarbonized index maximizes the carbon footprint reduction subject to maintaining a minimum tracking error with respect to a benchmark index. The main idea is to reduce exposure to the unpriced carbon risk while otherwise maintaining exposures to other priced risk factors.

The underlying premise is that the climate risk is currently not adequately rewarded nor properly assessed by the market . As long as carbon risk remains unpriced or underpriced, the decarbonized index will produce the same returns as the benchmark index. At

the point when the carbon risk is priced by the market the decarbonized index will outperform the benchmark. At that point, decarbonization will translate into superior financial returns. The decarbonized portfolio replicates market returns until GHG emissions start being priced.

One of the main leaders of carbon footprint data provision is MSCI, which currently offers a family of low carbon indexes based on its benchmark market indexes. Thus, for example, the MSCI Europe Low Carbon leaders index eliminates some constituent stocks that have particularly high carbon footprint. The remaining constituent stocks are rebalanced in order to minimize the tracking error relative to the MSCI Europe. See the details in Andersson et al. (2016).

Based on back-testing from 2012 to November 2014, and on actual market performance since the introduction of the MSCI Europe Low Carbon Leaders Index in November 2014, the design works, meaning that the decarbonized index does have a low tracking error. What is more, it has so far outperformed the benchmark index. It gives substantial carbon reduction, low tracking error and superior returns. At this moment the market is not pricing carbon risks fast enough creating a window of opportunity for superior returns. The outperformance between November 2014 until December 2015 was 200 basis points. However, some of these benefits may come from the collapse in energy prices although the back-testing was done also when commodity prices were high.

The design of the decarbonized index also protects the investor against possible energy price increase due to the minimized tracking error. As more asset owners join the decarbonized investment strategy and climate change mitigation policies take effect, the abnormal return should disappear as carbon will start being priced.

In a bigger perspective the index has good incentive properties and gives precise signals to those firms excluded from the index. This allows the investors, in effect, to combine engagement and exclusion. Financial markets may act as an accelerator, bringing forward the effects of future expected climate change mitigation policies by pricing carbon already

today, although the climate policies are implemented gradually.

The discussion after the presentation by Bolton included the following:

- Right now the market has not fully integrated the climate risk, therefore one will make a return until the risk is properly incorporated.
- CO_2 and GHG emissions are a global externality and therefore need global policies. However, the implementation of a global policy takes long time and allows for arbitrage in the market.
- There is very little awareness of climate risks by professional asset managers in the US, compared to Europe. For a climate skeptic the carbon risk does not exist. Investors uncertain about who's right, should follow the low carbon index because one doesn't lose any financial return. Investors should grab the return opportunities if they are there, it is not rational to leave money on the table.
- Why is there money on the table especially for carbon? It is a long term issue, not well understood in the US - but there could be many other types of assets that experience this. Could one do this with other criteria, e.g., developing an efficient water use index? No one has made this yet, but someone has for carbon.
- One mechanism: Money on the table, hence the market does not work. Another mechanism: People with different perceptions have different portfolios, this does not imply any market failure. Is there a combination of these two mechanisms, or is one of them dominating?
- The climate risk may be outside of the traditional time horizon of asset managers.
- An interesting analysis would be to find the market failure that let money on the table, maybe it is geographical or connected to time. Are there any other known

market failures that could explain mispricing at this scale; might it be the time horizon?

- Concerning the tests presented in the paper: Could the results be related to the time period? How much is driven by falling commodity prices? The back-testing of the model was done also when commodity prices were huge.

- What if there is a technological breakthrough tomorrow, in, e.g., CCS? This is the risk of holding a decarbonized index. But at the moment, the probability for such breakthroughs is very low.

Luc Renneboog

Socially responsible firms - a financial perspective

There are two views in the literature on Corporate Social Responsibility (CSR), either the agency cost view where CSR is a diversion of shareholder value maximization and waste of time, or the superior governance view saying that socially responsible firms are also well governed. There are two ex ante mechanisms that may induce incentives to corporate responsibility; (i) the free cash flow hypothesis where excess cash induces the agency problem or (ii) the executive pay for performance mechanism reducing incentives to responsible investments and the increasing risk of lost returns.

Ferrell et al. (2016) investigate the issue of shareholder and stakeholder tradeoff. The discussion of CSR concerns whether firms should be accountable only for shareholders or for the society in which the corporation operates. CSR therefore becomes an agency problem of cash diversion, focusing on stakeholders additional to shareholders. Ferrell et al. (2016) use cross country data and an instrumental variable approach to investigate whether firms that incorporate the climate problem are maximizing shareholder value. They look at both corporate compliance and voluntary aspects of CSR to investigate the value-enhancing view of CSR. They investigate whether these effects are different depending on the strength of a country's legal protection of shareholders. Their empirical results

support that countries with strong legal protection cause high corporate responsibility among firms. CRS is generating returns rather than increasing costs, enhancing firm value and shareholder wealth (Ferrell et al., 2016).

Why do we observe large differences in corporate social responsibility within countries and across countries? What fundamental country specific forces steer companies to behave as good citizens rather than as pure profit maximizers? There exist different views on the linkage between law and finance. Either common law is superior for shareholder protection and a spur to financial development, accomplishing efficient resource allocation that maximize social welfare. Or civil laws are superior for stakeholder protection by reducing market externalities and increase social welfare.

Liang and Renneboog (2013) use a quasi-experiment and a diff-in-diff approach finding that corporations in countries with English legal origins underperform relative to those located in countries with civil law origins. Legal origins are the only consistent predictors of CSR and sustainability, and civil law firms outperform common law firms in CSR issues. And, noteworthy, Scandinavian firms outperform the rest of the world in CSR, especially concerning environmental issues.

Renneboog et al. (2011) study the behavior of *ethical investors*, referring to those that invest in socially responsible investment (SRI) funds. They investigate whether flows into and out of socially responsible investment (SRI) funds respond to past returns of these funds, and compare this to similar responses in other funds. They find that flows into SRI funds respond less to past negative returns than flows into other funds. Apart from this, responses vary both geographically and between categories of SRI, i.e., anti-sin, ethical, social, and environmental funds. The results indicate heterogeneity between investors in these dimensions. Environmental SRI fund flows are more sensitive to positive past returns, while the other categories have lower sensitivities.

The discussion after the presentation by Renneboog included the following:

- Another potential characteristic of the firm that may explain SCR behavior is monopoly status, to what extent the company can pass on costs to the consumers and engage in costly activity such as CSR and sometimes go beyond full compliance in emission reduction.

- The index is supposed to measure the output of CSR, the quality, then one possible interpretation of these results is that firms with tight constraints do not necessary spend more on CSR but spend it more wisely.

- Does the hypothesis imply that investing in CSR is a way of buying political influence?

Karin Thorburn

What can financial market data tell us about future risks from climate policy?

Environmentally responsible investments may increase firm value, but they require costly investments. Possible positive market effects could be reduced risk of future environmental related liabilities and law suits, reduced production costs, improved efficiency, product differentiation by signaling 'green goodwill' or reduced cost of capital. However, managing reduction in emissions for heavy polluting firms require costly investments and new expensive technology.

Fisher-Vanden and Thorburn (2011) analyze the effect on shareholder value by the announcement of voluntary participation in corporate environmental initiatives, distinguishing between concrete targets of emission reduction (The Climate Leaders) and more general environmental commitments (Ceres). The analysis found that it is considered costly to commit to GHG reduction by the financial markets.

Partnership in the United States Environmental Protection Agency's (EPA) Climate Leaders program is voluntary and involves reports of inventory data and mitigation goals.

On the contrary, a voluntary membership to Ceres signals environmental awareness but does not require any specific preventative actions by the firm. Ceres is a non-profit network of companies and investors promoting sustainable business and founder of the Investor Network on Climate Risk (INCR).

Fisher-Vanden and Thorburn (2011) find a significant negative stock market return at the time of announcement of participation in EPA's reduction program, concluding that commitments to reduce emissions conflict with firm value maximization. The negative effect was greatest for high growth firms. Firms in the carbon intensive industry had a less negative reaction, possibly reflecting partial anticipation of upcoming policy regulations. Firms in competitive sectors also had less negative effects, maybe because unprofitable green behavior is limited for corporations that are unable to shift costs over to the consumers. However, the result is not significant for announcement of the more vague environmental commitments, such as Ceres. This is not that surprising since such commitments don't have any direct influence on the cost structure of firms.

What does the stock market reaction tell us? The cost of cuts in emissions may exceed future benefits. It might, however, be that investors underestimate future benefits, due to lack of understanding of the long term climate risk. The results point out that if society wants firms to reduce their emission, they cannot expect that firms will do this voluntarily. The market is dependent on regulations to push the transition.

What do these results imply for an investment strategy? Stock prices reflect investors' aggregated expectations, everything that is anticipated is already reflected in the prices. Only surprises may change stock prices. The question is then to what extent do stock markets already incorporate costs of future policy regulation? Similar to clean energy stocks that have been underperforming the last years, the reason lies in investors' beliefs. Either the product market has failed to meet investors expectations, or the decline in subsidies was unexpected. Regarding the pricing of the climate risk it depends on whether investors have overlooked the issue of climate change.

The discussion after the presentation by Thorburn included the following:

- Maybe firms announced GHG reduction since there were no growth opportunities left, and this was what the market actually reacted to.
- When some firms are joining these programs the investors become aware of the risk out there, that might be harmful to profits, therefore the share prices drop. But then the rival's share prices should drop too? However, the analysis looked at rivals, and there was no reaction at the time of announcement.
- This study looks at the announcement return when the firms are entering the program, not when the program was established.
- The data stops in 2007, maybe the climate risk is treated differently today, due to greater awareness and also because the climate policy risk has become much more present today. Maybe the negative effect from GHG emissions would be lower today, and the climate risk would be incorporated in the stock prices.
- Is this a message about CSR or governmental policies? The take away is that if one wants significant reduction in GHG emissions, one needs to regulate instead of anticipating voluntary reactions.
- Maybe stock prices were falling because investors did not understand the long term benefits from emissions reduction. The cost of reducing emissions is present, but the benefits arrive in the future and are contingent on many uncertain factors.
- Isn't the investor reaction fully rational if they behave according to short-termism? If one looks at the market reaction to R&D expenditures, it is often positive. Clearly the market is not only looking at cash flows, they take into account the expected future return.

- Is there a country risk? Some countries are especially vulnerable to climate damages. Should one from the financial perspective avoid these countries, are there any signs of this? This depends whether the market understands this risk, then it is incorporated in the price. There is no sign of this systematic risk on countries today, connected to climate. The political risk is much bigger than the climate risk.

- Possible benefits from investing in CSR is to be better prepared when the business or sector enters a crisis. The responsible firms may be punished by the market to a lower extent, share prices do not drop that much. Does this complicate the analysis of measuring the benefits from CSR? This scenario sounds like it should affect expected cash flows and not the systematic risk. So it should not affect expected return, but rather ex post return.

- One can't know whether types of risks are correctly priced by the markets, just because there is no distinct market reaction.

- Shares in Renault tumbled more than 20% as investors feared that the French manufacturer could be drawn into the VW diesel emissions scandal. One might suppose that the stock price drop is equal to the expected size of the penalty.

John Hassler

Climate damage heterogeneity

The damage from climate change will have dispersed and uneven regionally distributed effects. This can be linked to the premise of financial markets. Financial markets and insurance are based on heterogeneity. In a world of homogeneous agents there is no need, nor possibility, for financial transactions and insurance.

The economic consequences of climate change are highly uncertain. Economists have used different approaches to investigate climate change impacts, looking at bottom-up analysis to understand the mechanism, reduced form analysis to look at causality, and

cross-section data which has the advantage that it takes into account long run adaptation to climate change.

The unit of this analysis (based on work in progress by Krusell and Smith (2015)) is a $1^\circ \times 1^\circ$ global grid, dividing the globe into 19,000 cell regions that map the world. The analysis adopts the Nordhaus G-Econ database providing GDP and population for all cells in 1990, 1995, 2000 and 2005. This is combined with temperature data on the same $1^\circ \times 1^\circ$ grids. The underlying assumption is that temperature and GDP per cell are not purely random but reflect a causal relationship, this assesses consequences of temperature changes.

GDP as a function of yearly mean temperature produces a hump-shaped graph with a maximum around 11°C. Comparing this to a graph where global population is a function of temperatures shows that the areas with high temperatures are also the highest populated. Most of the world population live in the areas that are most vulnerable to climate change, with low GDP.

The hump-shaped relationship can be modeled by a U-shaped damage function. By applying this damage function one can derive the causal relationship between economic damages from temperature changes relative to the global average. The analysis shows the distribution of damages where climate change affects regions very differently. 45% of the regions are benefiting from climate change, 55% are hurt. The analysis says nothing about the aggregate. Note also that this does not say anything about loss of biodiversity affecting everyone, or about how many people live in each region, i.e., how many that will experience these losses or opportunities. The graph shows that the big winners, under Laissez-faire, in 2200 are, among other, Alaska and Siberia. From this result we can predict strong migration pressure from climate change.

What policy implications does this diversity imply? Following Golosov et al. (2014) the optimal global carbon tax has a simple structure of three components; the damage elasticity, atmospheric carbon duration and global GDP. With transfers, or other insur-

ance mechanisms, GDP maximization becomes welfare maximization. However, without transfers taxes become much higher (Hassler and Krusell, 2012), but will vary between regions proportionally to regional GDP per capita (unpublished work by Hassler, Krusell and Smith). This result contradicts the efficiency criterion of an equal global tax. Heterogeneity implies a problem on top of the free-rider problem, and this issue may be underestimated by researchers.

This would have implications on investments in the fossil fuel industry, depending on the supply conditions. Oil is almost costless to extract and supplies are limited making the price equal its scarcity rent. On the contrary, coal is almost unlimited and costly to extract making the price equal its extraction cost. The tax on oil will therefore fall on suppliers and have no effect on production. Reasonable estimates of conventional oil and climate damages imply that all oil will and should be extracted. For coal, on the other hand, taxes will reduce production. This supports the policy recommendation that coal production must be made unprofitable. McGlade and Ekins (2015) derive a more detailed description of further fossil fuel use consistent with 2 degrees warning.

The discussion after the presentation by Hassler included the following:

- Regarding damage elasticity: The quadratic and convex Nordhaus damage function cancels out the concavity of the logarithmic carbon cycle, thus gives a constant damage elasticity.

- If one relies on subsidies instead of tax: Electric cars in Norway decrease oil demand, but energy is in many countries produced by coal. Has one considered the scenario where subsidies of electric cars may increase coal demand?

- Would Sea level rise change the picture of damages and benefits in the world in the analysis? The coastal areas have high GDP and are financial centres but the island produce close to nothing so what is loss of drowning? How does one compensate

those that have lost their home country?

- In analyzing the distribution of damages, the model does not look at migration. The problem with endogenous migration is the lack of knowledge about the cost of moving in the aggregate.

- Would it be possible to include migration and dynamic effects? This model represents a static picture, and does not say anything about dynamics.

- Institutions complicate the analysis of migration. The linkage between temperatures and GDP should also be a link to institutions. The benefits from climate change assume that the Scandinavian institution design follows.

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