S. HRG. 110–52

ECONOMICS OF CLIMATE CHANGE

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED TENTH CONGRESS

FIRST SESSION

TO

RECEIVE TESTIMONY ON THE STERN REVIEW OF THE ECONOMICS OF CLIMATE CHANGE, EXAMINING THE ECONOMIC IMPACTS OF CLIMATE CHANGE AND STABILIZING GREENHOUSE GASES IN THE ATMOSPHERE

FEBRUARY 13, 2007

Printed for the use of the
Committee on Energy and Natural Resources

U.S. GOVERNMENT PRINTING OFFICE

35–906 PDF WASHINGTON : 2007

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2250 Mail: Stop SSOP, Washington, DC 20402–0001

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ECONOMICS OF CLIMATE CHANGE

TUESDAY, FEBRUARY 13, 2007

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The committee met, pursuant to notice, at 10:07 a.m., in room SD–106, Dirksen Senate Office Building, Hon. Jeff Bingaman, chairman, presiding.

OPENING STATEMENT OF HON. JEFF BINGAMAN, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. Why don't we go ahead with the hearing? Thank you all for being here.

For the past 6 years the United States has done far too little in my view on the issue of global warming. There are two reasons for this. First, significant numbers of lawmakers have not been persuaded that the threat is real, and the critics have cited too many uncertainties that needed to be resolved before we took significant policy action. The second reason is the concern that economic impacts to the country would be too great and could lead to the United States sacrificing its ability to compete in world markets, and the loss of jobs and other factors that would result.

Earlier this month the latest scientific report from the United Nations, a report by the intergovernmental panel on climate change, did much to lay to rest the debate on the first problem. The problem that there are too many scientific uncertainties the report affirmed with over 90 percent certainty, that most of the warming of the climate system has experienced in the last 50 years is due to human-caused greenhouse gas emissions, and that extreme weather events, heat waves, and heavy precipitation will become more frequent.

The second concern over the impact to our economy has been more difficult to overcome. The debate over what we can and cannot afford has persisted in every discussion on global warming that has occurred here in the Senate. Now we have the release of the report by Sir Nicholas Stern, the Stern Review, on the economics of climate change. Sir Nicholas gave me a copy yesterday. I've read it to make sure there are no mistakes in there.

[Laughter.]

But with the issuance of that report we're beginning to understand and to focus not just on the cost of action, but the cost of inaction. Since release of the Stern Review and the November elections in the United States the ground on this issue has shifted substantially. I believe there's an opportunity for us to move forward

with legislation on global warming this year. My colleague Senator Domenici was just pointing out that this is one of three hearings on this issue this morning here in the Congress so clearly there is great interest and focus on the issue.

The challenge now will be to get a majority of the Congress to agree on specific proposals. There are a number of proposals introduced and circulated already this year. I think it's vital that in trying to craft a proposal that would make good policy sense, we work together and try to get something enacted sooner rather than later. Science tells us that action is needed immediately and that the longer we delay, the more difficult the problem will be.

Let me call on Senator Domenici for his opening statement and then I'll introduce our witnesses.

STATEMENT OF HON. PETE V. DOMENICI, U.S. SENATOR FROM NEW MEXICO

Senator DOMENICI. Well Mr. Chairman, you indicated that there are three hearings today in the U.S. Congress on the issue. I would think that maybe our witnesses would figure that with that many hearings, maybe by this afternoon or maybe the day after tomorrow, we'll be able to solve this problem. But frankly the number of hearings, Mr. Chairman hasn't produced significant proposals that this Senator would be willing to sign on to. Yours comes closest to any, for which I complement you. I don't know where the others will be coming from.

I have a statement. I'd ask you to put it in the record, because I think we want to hear from these witnesses. But I do want to say in my opening remarks that Sir Nicholas Stern accepted a big job, and he produced a big report, but there is no question that it is vulnerable. It is vulnerable in a big way with reference to the way he uses the economic calculations. We can do that by asking him questions—far smarter people than I have said that, so I'm not dreaming it up—and I believe it's understandable what he has done, but I think it's probably not something we're going to take seriously in terms of a bill. That is, the way he calculated, the way he put in the discount, which is a little bit different than most would have used.

I also want to say that I grow more and more fearful with the passage of each month. What's going to happen to this world, to our country if we go out and try to settle this issue here and nothing significant is done with reference to China and India?

I just want to state for the record, because the facts begin to develop and begin to get very frightening, and begin to say to me that somebody in a big leadership role has to get together with the Chinese and the Indians and decide whether they have a stake or not, and if they do, that we try to do something together.

China uses more coal than the United States, Europe and Japan combined. It has increased coal consumption 14 percent in each of the past 2 years and every week to 10 days, another coal-fired power plant opens somewhere in China. That's big enough to serve all the households in Dallas or San Diego. In fact, China's economy continues to grow at 10 percent on an annual basis and it is projected to continue to do so in the near future. We must say at the same time the United States has not built a new power plant. We

have a consortium in Texas that plans to build 11 over a rather long period of time. I'm not sure that they will be able to complete that because we're in such a state of flux, as to whether we want those or don't want them or what we want to do with reference to clean up.

My last observation would be that all the nations of the world—in my opinion including the big two that I just mentioned, and America—must join together and put up large amounts of capital for research efforts, the likes of which we have never seen. If we intend to attack this issue with new technology and sequestration and permanent placement of the CO underground or someplace, we can't do that one alone. Somebody must bring China and India in, and even then when you look at the dimensions of the clean-up we're talking about with new technology, it is rather—just almost defies doing. Sometimes I think that the suggestion that maybe we ought to set up some group to start analyzing how we're going to adapt to this might be in order. Maybe we ought to do that rather quickly, and let them start looking at how we might adapt, because we might just have to. I yield. Thank you very much.

[The prepared statements of Senators Domenici and Sanders follow:]

PREPARED STATEMENT OF HON. PETE V. DOMENICI, U.S. SENATOR FROM NEW MEXICO

I want to add my thanks to our distinguished panel of witnesses for participating in our hearing today.

Last month, this Committee held a hearing to consider an analysis of Chairman Bingaman's draft climate change legislation done by the Energy Information Administration. The EIA report estimated that the effect of the proposal on our national GDP would be perhaps 0.25 percent below baseline projections in 2030.

However, the EIA analysis did not consider whether energy intensive industries might relocate to nations that do not impose costs on carbon—nations such as China and India. I continue to be concerned about the implications for our economy of limiting carbon emissions if other key nations do not impose similar requirements. Some industries would be facing difficult consequences under carbon-limiting legislation, both now and in the long-term.

The projected growth in emissions from India and China is daunting. Even with dramatic cuts in our own greenhouse gas emissions, we will not solve the problem without key developing countries. Limiting our own emissions without the participation of these nations would not only harm our economy, but would also accomplish nothing for the climate.

I do thank Chairman Bingaman for holding a second hearing on the economics of climate change. I believe that economic analysis is crucial to the climate change policy debate. We have to make every effort to know exactly the effects on our citizens of whatever course of action we pursue.

I understand that the Stern Review's methods have been the subject of controversy among economists. Several highly respected economists—including our panelists Professor Jacoby and Professor Yohe—have published papers questioning some of the Review's methods.

For example, both Professors Jacoby and Yohe have questioned the very small "discount rate" used in the Stern Review. The discount rate gives a comparative weight to spending money now, compared to spending money later. This is an important point in an issue like climate change, which took generations to create and would take generations to address.

If we are confident that the world economy will continue to grow, then we can be confident that people living in future decades will be much wealthier than people living today. It only makes sense that some of the costs of our response to climate change should be shared among generations.

Future generations will also have the advantage of improved technologies that will be better able to address climate change. I believe an essential part of today's response to climate change is to increase our commitment to developing new energy technologies. Research and development funding, both public and private, is vital to

addressing many of our nation's energy challenges, and the climate change issue is no exception.

I am interested in learning as much as I can about the Stern Review, and the questions surrounding it.

PREPARED STATEMENT OF HON. BERNARD SANDERS, U.S. SENATOR FROM VERMONT

Chairman Bingaman, Ranking Member Domenici, as you both know, global warming threatens the very future of the planet—its people, its places, and its life-sustaining resources. The world is longing for leadership to address the threat and if I have anything to do with it, the United States will rise to the occasion and send clear signals that we understand the magnitude of the problem.

One of the issues that, up to this point, has stifled progress on addressing global climate change is the question of what it will cost to do so. While I have no doubt that acting with purpose and vision on this most important environmental issue will actually create new jobs and save us money in the long run, I understand that there are those who disagree with me. And that's why I sincerely appreciate the Committee leadership holding today's hearing on the Stern Review of the Economics of Climate Change.

The Stern Review, written by Sir Nicholas Stern, a former chief economist of the World Bank, tells us that it is a lack of bold vision that will financially cost us. In turning the old economic arguments against taking action on climate change on their head, the report suggests that taking aggressive action to combat global warming will, in fact, save industrial nations money and that failing to act to boldly to curb global warming is what will cost us—and he says it won't be cheap. I think his report is groundbreaking and having him testify today helps to highlight the fact that acting on climate change is a pro-growth strategy.

I thank all of the witnesses here today and look forward to their testimony. Their thoughts will surely be referenced time and time again as the Senate moves closer to passing global warming legislation.

The CHAIRMAN. Thank you very much. Let me introduce our witnesses here. First, let me acknowledge—he's not a witness, but has joined us this morning as an observer—is Ambassador David Manning, from the British Embassy. We're very pleased to have you here and thank you for coming.

Sir Nicholas Stern, who is the head of the government economic service and advisor to her majesty's government on the economics of climate change, the author of the Stern Review which I mentioned before, will be our first witness. Accompanying him is Siobhan Peters, who is head of the review team that worked with Nicholas Stern on the development of this Review, and we appreciate her being here as well. Professor Henry Jacoby from MIT is here and we very much appreciate his presence, a very respected economist who has insights on this same issue. Also Gary Yohe, who is a professor at Wesleyan University, is a respected economist as well. So we have three very distinguished witnesses and we look forward to hearing from each of you.

Why don't we just take any written statement that you have, include it in the record and why don't you take whatever time you'd like and summarize the main points that you think this committee should understand. Then, of course, we'll try to ask some questions after that. Let me start with you, Sir Nicholas Stern.

STATEMENT OF SIR NICHOLAS STERN, HEAD OF THE GOVERNMENT ECONOMIC SERVICE, UNITED KINGDOM

Mr. STERN. Thank you very much. Chairman, Senators, it's an honor to be with you today. Thank you for the opportunity to address this committee.

Uncontrolled climate change will transform the physical geography, and thus the human geography, of the world. That means where we live and how we live our lives.

It involves great risks of economic and social disruption, migration and conflict. The recent report that the U.N.'s expert panel of climate scientists to which you referred, Mr. Chairman, confirms that global average temperatures have already risen 0.7 degrees centigrade from pre-industrial levels. If emissions continue to rise, the panel's central estimate that further warming for the end of this century is 4 degrees centigrade. This would also give a greater than 50 percent probability of increases over 5 degrees centigrade. Those of you who like to speak in Fahrenheit, that's 9 degrees Fahrenheit in the next century, so more than 50 percent probability of increases of over 5 degrees Fahrenheit in the next century, if we go on under business as usual.

Their analysis is exactly in line with the analysis presented in the Stern Review last year. Warming on this scale is associated with widespread and serious impacts on the availability of water, on human health, on food production, and the environment. The impacts in the United States are likely to be substantial; for example, an increase in the intensity of hurricanes in the Gulf of Mexico, still greater water stress in California, sea level rise in Florida, and an increased risk of storm surges in New York. We've already seen how long-term shifts in weather patterns interact with other factors to generate movements of people and the conditions for conflict, for example in Darfur and Sudan.

Abrupt regional shocks become more likely as average temperatures rise, including the risk of sudden changes to monsoon rains in densely populated regions in South Asia, or significant reductions in water flow in the river Nile—affecting 10 countries in North and East Africa. To reduce these risks in manageable proportions, we'd have to keep the atmospheric concentration of greenhouse gases below around 550 parts per million, a CO_2 equivalent. Even at this level there are serious risks—indeed there's only a 50 percent chance that the eventual temperature rise would not exceed 3 degrees centigrade.

So how can we reduce the risks? My initial observation is that previous delay in action means that we do not start in a good place. We cannot control the stock of gases already released in the atmosphere but we can, as a world, control the future flows. A global problem requires a global response. And equity demands that rich countries take the lead. It's they who are responsible for the bulk of the problem, and it's the poor countries who will be hit earliest and hardest.

Controlling emissions will not remove all the risks of future climate change, but it can drastically reduce them, and we've shown in the Stern Review that the cost of controlling these flows is much less than the damages that are thereby averted. The case for taking strong action across the world is compelling and actually is urgent. The later we leave it, the greater the risks, and the higher will be the cost of controlling them.

So how much will it cost to reduce the risks? We estimated the cost of the global economy of around 1 percent of GDP, a cost similar to one-off increase in the price of cost index, one-off. The models

give the range of plus or minus 3 percent—a big range here. We're uncertain about these costs, but higher estimates embody rather pessimistic assumptions about progress in technologies. Of course the cost of 1 percent extra is not trivial, but it's similar to the costs we accommodate all the time, for example by changes in exchange rates. That will not slow growth. It is failing to act that will eventually damage growth.

The message from the economics and climate change is clear. We must act strongly and we must act now. The damages that this strategy would avoid can be estimated in various ways, taking account of the more serious risks that are now evident. Simple economic models suggest that the damage is averaged over time and over the range of possible outcomes, or at least 5 percent of global consumption. There are uncertainties, there are technical challenges in the modeling, but there is no case to believe that the economic impacts will be small. Indeed on a number of key dimensions, the models we used underestimated the damages. For example, we excluded irreversibilities and a number of relevant risks.

So what are the key elements in the strategy? First we must ensure that we correct the biggest market failure the world has ever seen. People should pay in the prices they face for the cost of their actions—in this case, cost to the climate. Pricing carbon directly through either tax or carbon trading or implicitly through regulation is fundamental to a policy response. Given the global nature of the market failure and the efficiency that comes from using economic instruments, developing a global price for carbon is crucial. In Europe we've long had strong taxes on fuel. The European Union has established the world's largest emissions trading scheme and is taking steps to ensure that it's long-term, ambitious, and open to trade with others.

I hope that as your committee scrutinizes proposals for U.S. policy, including the range of different suggestions for cap and trade, you will bear in mind not only the potential gains in terms of cost reductions of creating schemes that can link to those in the EU, Australia and elsewhere, but also the value of using carbon finance as one key element in building cooperation on climate change with China and India and other developing countries, as Senator Domenici described.

The United States has shown how regulation and standards can build markets, for example in energy efficient domestic appliances, and tackling other environmental problems, such as lead in gasoline. Leadership in the world's largest markets sets the pace elsewhere. Indeed, the Sudan now uses lead-free gasoline. China and India are taking steps of their own: for example China is implementing a domestic goal of reducing the energy intensity by 20 percent in 5 years, and India, too, is focusing on energy efficiency and increasing renewable energy. But they can and will go further and faster with international support.

The second element of the strategy after the pricing element: we must invest in policy to bring forward low carbon technologies. Spending on public energy research worldwide is halved over the last 20 or 30 years and public and private investment are highly correlated, of course. As a world we must double public R&D spending on energy and we must promote the development of key

technologies, such as renewable energy and carbon capture and storage. Carbon capture and storage is a strategy that will allow us to continue to make use of abundant reserves of coal, vital for energy security without causing unacceptable harm to the environment.

Urgent steps are required to move toward widespread deployment of this technology, as rich and poor countries alike invest in a new generation of coal-fired power generation plants. In transport, new technologies such as plug-in hybrid cars and the use of cellulosic ethanol could go a very long way to reducing emissions without changing our basic mobility. Further, these low carbon technologies will create opportunities: markets for low carbon power generation technologies alone could be worth $500 billion a year by 2050.

The third, final element to the strategy is that we have to recognize there are many ways to reduce emissions now that do not need new technology. Energy efficiency and combating deforestation are very inexpensive ways to reduce emissions, but they require decisions and action on policy and changes in behavior—for example, problems in building regulations in tenant-landlord contracts—can prevent energy efficiency investments being made. In the case of deforestation, solutions should be based on supporting the countries in which the trees stand, to develop their own approaches to this complex problem.

So given this, why would anyone deny this case for action? I've heard three reasons to do so. They are all in my view profoundly mistaken. The first is that the science is incorrect. I need to do no more than to refer to the conclusions at the recent U.N. panel on the science, which you mentioned, Mr. Chairman, which reported so clearly and strongly only 10 days ago.

The second reason for denial is that we can adapt as a human race to any rising temperatures. That in my view is reckless. It ignores the risk of very high temperature increases. Business-as-usual growth in emissions over the next 100 years will be likely to take the next century to a world that will be 5 or 6 degrees centigrade, more than 9 degrees Fahrenheit hotter than today. That's a change which is equivalent to the difference between now and the last ice age 10,000 or 12,000 years ago. It would transform the world, involving massive dislocation and in all probability, conflict.

A third reason for refusing to act is that such risks and their impacts will happen a long way into the future and we, as this current generation, have little interest in what happens in the future. I trust that many of you would find this argument ethically untenable.

Mr. Chairman, Senators, uncontrolled climate change constitutes a risk that as a global community we cannot afford to take. We have an understanding of the scale of action necessary and of the economic policies to deliver this action. Now is the time to act, urgently, strongly and internationally. Strong leadership from the United States of America is of the utmost importance. The decisions made by this committee will be fundamental in creating that leadership. Thank you very much.

[The prepared statement of Mr. Stern follows:]

PREPARED STATEMENT OF SIR NICHOLAS STERN, HEAD OF THE GOVERNMENT ECONOMIC SERVICE, UNITED KINGDOM

THERE IS STILL TIME TO AVOID THE WORST IMPACTS OF CLIMATE CHANGE, IF WE TAKE STRONG ACTION NOW

The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response.

The recent report by the U.N.'s expert panel of climate scientists confirms that global average temperatures have already risen 0.7 degrees C from pre-industrial levels. If emissions continue to rise, the panel's central estimate of further warming for the end of this century is 4 degrees C. This would also give a greater than 50% probability of increases over 5 degrees C in the next century beyond 2100—exactly in line with the analysis presented in the Stern Review last year.

The Stern Review assessed a wide range of evidence on the impacts of climate change and on the economic costs, and has used a number of different techniques to assess costs and risks. From all of these perspectives, the evidence gathered leads to a simple conclusion: the benefits of strong and early action far outweigh the economic costs of not acting.

Warming on the scale implied by allowing emissions to grow on business-as-usual basis is associated with widespread and serious impacts—on the availability of water, on human health, on food production, and the environment. The impacts in the U.S. are likely to be substantial—an increase in the intensity of hurricanes in the Gulf of Mexico, still greater water stress in California, sea level rise in Florida, an increased risk of storm surges in New York.

We have already seen how long-term shifts in weather patterns interact with other factors to generate movements of people and the conditions for conflict—for example in Darfur. Abrupt regional shocks become more likely as average temperatures rise—including the risk of sudden changes to monsoon rains in densely populated regions of South Asia, or significant reductions in water flow in the River Nile affecting 10 countries in North and East Africa.

To reduce these risks to manageable proportions, we would have to keep the atmospheric concentration of greenhouse gases below around 550 ppm CO_2 equivalent. Even at this level there are serious risks: indeed, there is only a 50% chance that the eventual temperature rise would not exceed 3 degrees C.

In contrast, the costs of action—reducing greenhouse gas emissions to avoid the worst impacts of climate change—can be limited to around 1% of global GDP each year. The models give a range of +/3%—but higher estimates embody pessimistic assumptions about progress in technologies and other issues. A cost of 1% is not trivial—but it is similar to a one-off increase in the price index, the kind of cost that we accommodate all the time, for example, through changes in exchange rates. It will not slow growth. It is failing to act that will damage growth. The message from the economics of climate change is clear: we must act strongly and we must act now.

The investment that takes place in the next 10-20 years will have a profound effect on the climate in the second half of this century and in the next. Our actions now and over the coming decades could create risks of major disruption to economic and social activity, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century. And it will be difficult or impossible to reverse these changes.

So prompt and strong action is clearly warranted. Because climate change is a global problem, the response to it must be international. It must be based on a shared vision of long-term goals and mutual understanding that will accelerate action over the next decade. It must build on mutually reinforcing approaches at national, regional and international level.

CLIMATE CHANGE COULD HAVE VERY SERIOUS IMPACTS ON GROWTH AND DEVELOPMENT

If no action is taken to reduce emissions, the concentration of greenhouse gases in the atmosphere could reach double its pre-industrial level as early as 2035, virtually committing us to a global average temperature rise of over 2 degrees C. In the longer term, there would be more than a 50% chance that the temperature rise would exceed 5 degrees C. This rise would be very dangerous indeed; it is equivalent to the change in average temperatures from the last Ice Age to today. Such a radical change in the physical geography of the world must lead to major changes in the human geography—where people live and how they live their lives.

Even at more moderate levels of warming, all the evidence—from detailed studies of regional and sectoral impacts of changing weather patterns through to economic models of the global effects—shows that climate change will have serious impacts on world output, on human life and on the environment.

All countries will be affected. The most vulnerable—the poorest countries and populations—will suffer earliest and most, even though they have contributed least to the causes of climate change. The costs of extreme weather, including floods, droughts and storms, are already rising, including for rich countries.

Adaptation to climate change—that is, taking steps to build resilience and reduce the costs of impacts—is essential. It is no longer possible to prevent the climate change that will take place over the next two to three decades, but it is still possible to protect our societies and economies from its impacts to some extent—for example, by providing better information, improved planning and more climate-resilient infrastructure and crops. Adaptation will cost tens of billions of dollars a year in developing countries alone, and will put still further pressure on already scarce resources. Adaptation efforts, particularly in developing countries, should be accelerated.

THE COSTS OF STABILISING THE CLIMATE ARE SIGNIFICANT BUT MANAGEABLE; DELAY WOULD BE DANGEROUS AND MUCH MORE COSTLY

The risks of the worst impacts of climate change can be substantially reduced if greenhouse gas levels in the atmosphere can be stabilised between 450 and 550ppm CO_2 equivalent (CO_2e). The current level is 430ppm CO_2e today, and it is rising at more than 2ppm each year. Stabilisation in this range would require emissions to be at least 25% below current levels by 2050, and perhaps much more.

Ultimately, stabilisation—at whatever level—requires that annual emissions be brought down to more than 80% below current levels.

This is a major challenge, but sustained long-term action can achieve it at costs that are low in comparison to the risks of inaction. Central estimates of the annual costs of achieving stabilisation between 500 and 550ppm CO_2e are around 1% of global GDP, if we start to take strong action now and follow sound and economically efficient policies.

Costs could be even lower than that if there are major gains in efficiency, or if the strong co-benefits, for example from reduced air pollution, are measured. Costs will be higher if innovation in low-carbon technologies is slower than expected, or if policy-makers fail to make the most of economic instruments that allow emissions to be reduced whenever, wherever and however it is cheapest to do so.

It would already be very difficult and costly to aim to stabilise at 450ppm CO_2e. If we delay, the opportunity to stabilise at 500-550ppm CO_2e may slip away. Business as usual emissions for the next 30 years would already take us well over 500ppm CO_2e.

ACTION ON CLIMATE CHANGE IS REQUIRED ACROSS ALL COUNTRIES, AND IT NEED NOT CAP THE ASPIRATIONS FOR GROWTH OF RICH OR POOR COUNTRIES

The costs of taking action are not evenly distributed across sectors or around the world. Even if the rich world takes on responsibility for absolute cuts in emissions of 60-80% by 2050, developing countries must take significant action too. But developing countries should not be required to bear the full costs of this action alone, and they will not have to. Carbon markets in rich countries are already beginning to deliver flows of finance to support low-carbon development, including through the Clean Development Mechanism. A transformation of these flows is now required to support action on the scale required.

Action on climate change will also create significant business opportunities, as new markets are created in low-carbon energy technologies and other low-carbon goods and services. These markets could grow to be worth hundreds of billions of dollars each year, and employment in these sectors will expand accordingly.

The world does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and in the structure of economies have created opportunities to decouple growth from greenhouse gas emissions. Indeed, ignoring climate change will eventually damage economic growth.

Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries.

A RANGE OF OPTIONS EXISTS TO CUT EMISSIONS; STRONG, DELIBERATE POLICY ACTION IS REQUIRED TO MOTIVATE THEIR TAKE-UP

Emissions can be cut through increased energy efficiency, changes in demand, and through adoption of clean power, heat and transport technologies. The power sector around the world would need to be at least 60% decarbonised by 2050 for atmos-

pheric concentrations to stabilise at or below 550ppm CO_2e, and deep emissions cuts will also be required in the transport sector.

Even with very strong expansion of the use of renewable energy and other low-carbon energy sources, fossil fuels would still probably make up over half of global energy supply in 2050. Natural resources dictate that coal will continue to be important in the energy mix around the world, including in fast-growing economies. If it proves a viable technology as expected, extensive carbon capture and storage will be required to allow the continued use of fossil fuels without damage to the atmosphere.

Cuts in non-energy emissions, such as those resulting from deforestation and from agricultural and industrial processes, are also essential.

With strong, deliberate policy choices, it is possible to reduce emissions in both developed and developing economies on the scale necessary for stabilisation in the required range while continuing to grow.

Climate change is the greatest market failure the world has ever seen, and it interacts with other market imperfections. Three elements of policy are required for an effective global response. The first is the pricing of carbon, implemented through tax, trading or regulation. The second is policy to support innovation and the deployment of low-carbon technologies. And the third is action to remove barriers to energy efficiency, and to inform, educate and persuade individuals about what they can do to respond to climate change.

CLIMATE CHANGE DEMANDS AN INTERNATIONAL RESPONSE, BASED ON A SHARED UNDERSTANDING OF LONG-TERM GOALS AND AGREEMENT ON FRAMEWORKS FOR ACTION

Many countries and regions are taking action already: the EU, California and China are among those with the most ambitious policies that will reduce greenhouse gas emissions. The U.N. Framework Convention on Climate Change and the Kyoto Protocol provide a basis for international co-operation, along with a range of partnerships and other approaches. But more ambitious action is now required around the world.

Countries facing diverse circumstances will use different approaches to make their contribution to tackling climate change, and will use different combinations of policy tools. As far as possible, a common carbon price across different sectors and countries will ensure that reductions are made in the most efficient way around the world. It is essential to create a shared international vision of long-term goals to provide the context for domestic policy, and to build the international frameworks that will help each country to play its part in meeting these common goals.

Key elements of future international frameworks should include:

- *Emissions trading*.—Expanding and linking the growing number of emissions trading schemes around the world is a powerful way to promote cost-effective reductions in emissions and to bring forward action in developing countries: strong targets in rich countries could drive flows amounting to tens of billions of dollars each year to support the transition to low-carbon development paths.
- *Technology cooperation*.—Informal co-ordination as well as formal agreements can boost the effectiveness of investments in innovation around the world. Globally, support for energy R&D should at least double, and support for the deployment of new low-carbon technologies should increase up to five-fold. International cooperation on product standards is a powerful way to boost energy efficiency.
- *Action to reduce deforestation*.—The loss of natural forests around the world contributes more to global emissions each year than the transport sector. Curbing deforestation is a highly cost-effective way to reduce emissions; large-scale international pilot programmes to explore the best ways to do this could get underway very quickly.
- *Adaptation*.—The poorest countries are most vulnerable to climate change. It is essential that climate change be fully integrated into development policy, and that rich countries honour their pledges to increase support through overseas development assistance. International funding should also support improved regional information on climate change impacts, and research into new crop varieties that will be more resilient to drought and flood.

RESPONSES TO THE STERN REVIEW

Since publication, the Review team have travelled widely, presenting the results of the Review and listening to the reactions of policymakers, academics and business leaders, in particular in the EU, China, India, Japan, Africa and the U.S.

In the academic literature, many people have supported the approach taken in the Review, but some have raised questions about particular technical aspects of the

analysis—often based on misconceptions of the approach undertaken in review. We are publishing a detailed paper responding to the critiques this week. In summary, the economic analysis in the Review remains robust. The costs of inaction on climate change are much greater than the likely costs of early action to reduce the risks.

THE ANALYSIS IS BUILT ON THE EXISTING LITERATURE, BUT THE ESTIMATES OF THE COST OF DAMAGES WERE HIGHER FOR THREE REASONS

First, crucial advances of the science in the past few years have allowed estimates to be made of the probabilities of temperature rises associated with increases in the quantity of greenhouse gases in the atmosphere. These estimates point to significant risks of temperature increases above 5 degrees C under a business-as-usual scenario by the early part of the next century. Previous studies have mainly focused on 2-3 degrees C temperature rises and our results for these temperatures are consistent with existing studies.

Second, we have taken account of the impact on wellbeing across the full range of possible outcomes, including worst- and best-case scenarios, and have explicitly built in aversion to risk. Risks and uncertainties are the heart climate change modelling, and risk aversion entails giving more weight to the worse outcomes, as people routinely do in their daily lives, for example, in buying insurance. That, together with the risks of higher temperatures, and an ethically supportable approach to valuing future lives, is what drives our results. These results are supported by a detailed analysis of the economic impacts of climate change at the regional and country level.

The review examines the application of discounting to the particular characteristics of climate change and the ethical issues involved. With higher discount factors, it becomes easy to see why climate change—which results in significant impacts in the future—gets a relatively low ethical weight. For example, a discount rate of 3% would give individuals existing at the end of this century roughly one tenth of the ethical weight of the current generation and only a 1% weight by 2200. Because we know that future generations will exist and that their consumption and welfare will be affected by the climate that they experience, we adopt a low pure time discount rate that gives future generations equal ethical weight. But this is only one element of the discount rate. How much we discount the future depends also on how much richer we expect to be. Risks and uncertainties surrounding climate change imply that strongly divergent paths for future growth are possible, so the use of a single discount rate is inappropriate. The discount rates used in the Review do include the appropriate rate of economic growth for each model run.

Discounting has been the subject of much attention since publication of the Review, and rightly so, since it does drive the results to some extent. We welcome the legitimate debate on the values chosen given the ethical implications of different choices. But the discount rate is not the only factor driving the case for climate change. Our sensitivity analysis demonstrates that the treatment of risk and uncertainty and the extent to which projections of impacts reflect progress in the scientific literature are of roughly equal importance.

Given that the assumptions underlying our model can be shown to be plausible and unbiased, the question is often asked why our results show a higher valuation of the impacts of climate change under business as usual when compared with previous studies? The answer should by this stage be clear:

- Our study takes on the published findings of the latest science including a probabilistic assessment of high climate change impacts.
- We have explicitly accounted for the economics of risk, which has hitherto been mostly ignored.
- We have taken an ethical judgement about the way we value future generations that is time-consistent and allows the Review to be objective with conclusions that do not discriminate on the basis of birth dates.

Having assessed the model properties and characteristics and compared the results with the disaggregated impacts associated with a business as usual emissions path, we remain confident that our estimates are very much in the centre of any plausible range of model projections.

SINCE THE PUBLICATION OF THE REVIEW, MOMENTUM IN NATIONAL AND INTERNATIONAL POLICY-MAKING HAS INCREASED

The messages in the Review have been well received by policymakers and business, and momentum has continued to build towards more effective domestic policies and more effective international links between them.

The development of policy in the EU has accelerated significantly in the last few months. The European Commission rejected several of the draft National Allocation Plans for Phase II of the EU ETS, asking for allocations to be reduced in a number of countries—a move that will increase the credibility of the market for 2008-2012. This has sent a strong signal on the role of carbon markets at the centre of the EU's strategy to deliver deeper emissions cuts. The EU's Strategic Energy Review, published in January 2007, recommends a target for the EU to reduce greenhouse gases by up to 30% by 2020, and proposes other mandatory targets on energy efficiency, renewables and biofuels.

In China and in India, policymakers are also demonstrating a strong interest in moving towards more secure and sustainable energy use. In China, we heard about the wide range of measures that China is beginning to implement towards its domestic target to improve energy intensity by 20% by 2010: energy efficiency audits and major investment projects for manufacturing industry, and tariffs on the export of energy-intensive products including for cement, iron and steel and aluminium. In India, we saw how the Integrated Energy Policy under the 11th Five Year Plan is being taken forward—including changes to energy subsidies, plans for more efficient coal-fired power plant and further development of innovative new technologies for renewable energy.

In Japan, debates between government, industry and civil society on the challenges of designing further domestic and international action are intensifying. There was encouraging news of rapid technological progress—confidence on the role of plug-in hybrid vehicles and imminent breakthroughs in solar technology. There was increasing recognition of the role of trading and investment strategies in creating stronger co-operation with China and India, and interest in sectoral approaches that could mitigate concerns about competitiveness.

In Africa, climate change has risen sharply up the agenda. The decision by the African Union to make climate change one of the key themes for its Summit in January 2007 has drawn the attention of African leaders to the vulnerability of their countries, and to the opportunities for adaptation, sustainable land management and low-carbon development.

The U.S. has shown how regulation and standards can build markets, for example in energy efficient domestic appliances, and in tackling other environmental problems such as lead in gasoline. Leadership in the world's largest markets sets the pace elsewhere—even the Sudan now uses lead-free gasoline. In the 2007 State of the Union President Bush outlined further plans to improve efficiency, reduce emissions and improve energy security particularly in the transport sector.

In the light of these developments, there are clear opportunities to build momentum towards effective international collective action on climate change.

CONCLUSION

Our analysis suggests that uncontrolled climate change constitutes a risk that we cannot afford to take. Three main reasons have been put forward to reject this conclusion. They are all profoundly mistaken. The first is that the science is incorrect. This is not borne out by the conclusions of the recent U.N. panel on the science, which reported so clearly and strongly only ten days ago. The second is that we can adapt as a human race to rising temperatures. That is reckless; it ignores the risk of very high temperature increases. Business-as-usual growth in emissions over the next hundred years would be likely to take us to a world that would be 5 or 6 degrees hotter than today—a change which is equivalent to the difference between now and in the last Ice Age. It would transform the physical geography of the world and that would, in turn, transform the human geography. It would involve massive dislocation and in all probability conflict. The final reason for refusing to act is that such risks and their impacts will happen a long way into the future, and we have little interest in what happens in the future. Many would find this argument ethically untenable.

We have an understanding of the case for action, of the scale of action necessary, and of the economic policies to deliver this action. However, the scale of the response will have to increase dramatically in the coming decades. A shared vision of the goals for long-term climate polices will provide an essential reference point for the development of international and national policy.

If we are to stabilise at 550ppm CO_2e or below, reducing the risks of very high temperature increases, global emissions must peak in the next 10-20 years. Now is the time to act: urgently, strongly and internationally. Strong leadership from the U.S. is of the utmost importance in this endeavour.

The full report of the Stern Review on the Economics of Climate Change is published by Cambridge University press and is available to download for free, along with supporting material and more recent papers, at www.sternreview.org.uk.

Also available from this site is the 30 page executive summary, frequently asked questions, papers published since the launch and supporting commissioned research.

STERN REVIEW: THE ECONOMICS OF CLIMATE CHANGE

EXECUTIVE SUMMARY

The scientific evidence is now overwhelming: climate change presents very serious global risks, and it demands an urgent global response.

This independent Review was commissioned by the Chancellor of the Exchequer, reporting to both the Chancellor and to the Prime Minister, as a contribution to assessing the evidence and building understanding of the economics of climate change.

The Review first examines the evidence on the economic impacts of climate change itself, and explores the economics of stabilising greenhouse gases in the atmosphere. The second half of the Review considers the complex policy challenges involved in managing the transition to a low-carbon economy and in ensuring that societies can adapt to the consequences of climate change that can no longer be avoided.

The Review takes an international perspective. Climate change is global in its causes and consequences, and international collective action will be critical in driving an effective, efficient and equitable response on the scale required. This response will require deeper international co-operation in many areas—most notably in creating price signals and markets for carbon, spurring technology research, development and deployment, and promoting adaptation, particularly for developing countries.

Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen. The economic analysis must therefore be global, deal with long time horizons, have the economics of risk and uncertainty at centre stage, and examine the possibility of major, non-marginal change. To meet these requirements, the Review draws on ideas and techniques from most of the important areas of economics, including many recent advances.

The Benefits of Strong, Early Action on Climate Change Outweigh the Costs.

The effects of our actions now on future changes in the climate have long lead times. What we do now can have only a limited effect on the climate over the next 40 or 50 years. On the other hand what we do in the next 10 or 20 years can have a profound effect on the climate in the second half of this century and in the next.

No-one can predict the consequences of climate change with complete certainty; but we now know enough to understand the risks. Mitigation—taking strong action to reduce emissions—must be viewed as an investment, a cost incurred now and in the coming few decades to avoid the risks of very severe consequences in the future. If these investments are made wisely, the costs will be manageable, and there will be a wide range of opportunities for growth and development along the way. For this to work well, policy must promote sound market signals, overcome market failures and have equity and risk mitigation at its core. That essentially is the conceptual framework of this Review.

The Review considers the economic costs of the impacts of climate change, and the costs and benefits of action to reduce the emissions of greenhouse gases (GHGs) that cause it, in three different ways:

- Using disaggregated techniques, in other words considering the physical impacts of climate change on the economy, on human life and on the environment, and examining the resource costs of different technologies and strategies to reduce greenhouse gas emissions;
- Using economic models, including integrated assessment models that estimate the economic impacts of climate change, and macro-economic models that represent the costs and effects of the transition to low-carbon energy systems for the economy as a whole;
- Using comparisons of the current level and future trajectories of the 'social cost of carbon' (the cost of impacts associated with an additional unit of greenhouse gas emissions) with the marginal abatement cost (the costs associated with incremental reductions in units of emissions).

From all of these perspectives, the evidence gathered by the Review leads to a simple conclusion: the benefits of strong, early action considerably outweigh the costs.

The evidence shows that ignoring climate change will eventually damage economic growth. Our actions over the coming few decades could create risks of major disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century. And it will be difficult or impossible to reverse these changes. Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries. The earlier effective action is taken, the less costly it will be.

At the same time, given that climate change is happening, measures to help people adapt to it are essential. And the less mitigation we do now, the greater the difficulty of continuing to adapt in future.

The first half of the Review considers how the evidence on the economic impacts of climate change, and on the costs and benefits of action to reduce greenhouse gas emissions, relates to the conceptual framework described above.

The Scientific Evidence Points to Increasing Risks of Serious, Irreversible Impacts From Climate Change Associated With Business-As-Usual (BAU) Paths for Emissions.

The scientific evidence on the causes and future paths of climate change is strengthening all the time. In particular, scientists are now able to attach probabilities to the temperature outcomes and impacts on the natural environment associated with different levels of stabilisation of greenhouse gases in the atmosphere. Scientists also now understand much more about the potential for dynamic feedbacks that have, in previous times of climate change, strongly amplified the underlying physical processes.

The stocks of greenhouse gases in the atmosphere (including carbon dioxide, methane, nitrous oxides and a number of gases that arise from industrial processes) are rising, as a result of human activity. The sources are summarised in Figure 1 below.*

The current level or stock of greenhouse gases in the atmosphere is equivalent to around 430 parts per million (ppm) CO_2[1], compared with only 280ppm before the Industrial Revolution. These concentrations have already caused the world to warm by more than half a degree Celsius and will lead to at least a further half degree warming over the next few decades, because of the inertia in the climate system.

Even if the annual flow of emissions did not increase beyond today's rate, the stock of greenhouse gases in the atmosphere would reach double pre-industrial levels by 2050—that is 550ppm CO_2e—and would continue growing thereafter. But the annual flow of emissions is accelerating, as fast-growing economies invest in high-carbon infrastructure and as demand for energy and transport increases around the world. The level of 550ppm CO_2e could be reached as early as 2035. At this level there is at least a 77% chance—and perhaps up to a 99% chance, depending on the climate model used—of a global average temperature rise exceeding 2 degrees C.

Under a BAU scenario, the stock of greenhouse gases could more than treble by the end of the century, giving at least a 50% risk of exceeding 5 degrees C global average temperature change during the following decades. This would take humans into unknown territory. An illustration of the scale of such an increase is that we are now only around 5 degrees C warmer than in the last ice age.

Such changes would transform the physical geography of the world. A radical change in the physical geography of the world must have powerful implications for the human geography—where people live, and how they live their lives.

Figure 2* summarises the scientific evidence of the links between concentrations of greenhouse gases in the atmosphere, the probability of different levels of global average temperature change, and the physical impacts expected for each level. The risks of serious, irreversible impacts of climate change increase strongly as concentrations of greenhouse gases in the atmosphere rise.

Climate Change Threatens the Basic Elements of Life for People Around the World—Access to Water, Food Production, Health, and Use of Land and the Environment.

Estimating the economic costs of climate change is challenging, but there is a range of methods or approaches that enable us to assess the likely magnitude of the risks and compare them with the costs. This Review considers three of these approaches.

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* Graphic has been retained in committee files.

[1] Referred to hereafter as CO_2 equivalent, CO_2e.

This Review has first considered in detail the physical impacts on economic activity, on human life and on the environment.

On current trends, average global temperatures will rise by 2-3 degrees C within the next fifty years or so.[2] The Earth will be committed to several degrees more warming if emissions continue to grow.

Warming will have many severe impacts, often mediated through water:

- Melting glaciers will initially increase flood risk and then strongly reduce water supplies, eventually threatening one-sixth of the world's population, predominantly in the Indian sub-continent, parts of China, and the Andes in South America.
- Declining crop yields, especially in Africa, could leave hundreds of millions without the ability to produce or purchase sufficient food. At mid to high latitudes, crop yields may increase for moderate temperature rises (2-3 degrees C), but then decline with greater amounts of warming. At 4 degrees C and above, global food production is likely to be seriously affected.
- In higher latitudes, cold-related deaths will decrease. But climate change will increase worldwide deaths from malnutrition and heat stress. Vector-borne diseases such as malaria and dengue fever could become more widespread if effective control measures are not in place.
- Rising sea levels will result in tens to hundreds of millions more people flooded each year with warming of 3 or 4 degrees C. There will be serious risks and increasing pressures for coastal protection in South East Asia (Bangladesh and Vietnam), small islands in the Caribbean and the Pacific, and large coastal cities, such as Tokyo, New York, Cairo and London. According to one estimate, by the middle of the century, 200 million people may become permanently displaced due to rising sea levels, heavier floods, and more intense droughts.
- Ecosystems will be particularly vulnerable to climate change, with around 15-40% of species potentially facing extinction after only 2 degrees C of warming. And ocean acidification, a direct result of rising carbon dioxide levels, will have major effects on marine ecosystems, with possible adverse consequences on fish stocks.

The Damages From Climate Change Will Accelerate as the World Gets Warmer.

Higher temperatures will increase the chance of triggering abrupt and large-scale changes.

- Warming may induce sudden shifts in regional weather patterns such as the monsoon rains in South Asia or the El Niño phenomenon—changes that would have severe consequences for water availability and flooding in tropical regions and threaten the livelihoods of millions of people.
- A number of studies suggest that the Amazon rainforest could be vulnerable to climate change, with models projecting significant drying in this region. One model, for example, finds that the Amazon rainforest could be significantly, and possibly irrevocably, damaged by a warming of 2-3 degrees C.
- The melting or collapse of ice sheets would eventually threaten land which today is home to 1 in every 20 people.

While there is much to learn about these risks, the temperatures that may result from unabated climate change will take the world outside the range of human experience. This points to the possibility of very damaging consequences.

The Impacts of Climate Change Are Not Evenly Distributed—The Poorest Countries and People Will Suffer Earliest and Most. And If and When The Damages Appear It Will Be Too Late To Reverse the Process. Thus We Are Forced To Look a Long Way Ahead.

Climate change is a grave threat to the developing world and a major obstacle to continued poverty reduction across its many dimensions. First, developing regions are at a geographic disadvantage: they are already warmer, on average, than developed regions, and they also suffer from high rainfall variability. As a result, further warming will bring poor countries high costs and few benefits. Second, developing countries—in particular the poorest—are heavily dependent on agriculture, the most climate-sensitive of all economic sectors, and suffer from inadequate health provision and low-quality public services. Third, their low incomes and vulnerabilities make adaptation to climate change particularly difficult.

Because of these vulnerabilities, climate change is likely to reduce further already low incomes and increase illness and death rates in developing countries. Falling

[2] All changes in global mean temperature are expressed relative to pre-industrial levels (1750-1850).

farm incomes will increase poverty and reduce the ability of households to invest in a better future, forcing them to use up meagre savings just to survive. At a national level, climate change will cut revenues and raise spending needs, worsening public finances.

Many developing countries are already struggling to cope with their current climate. Climatic shocks cause setbacks to economic and social development in developing countries today even with temperature increases of less than 1 degree C. The impacts of unabated climate change—that is, increases of 3 or 4 degrees C and upwards—will be to increase the risks and costs of these events very powerfully.

Impacts on this scale could spill over national borders, exacerbating the damage further. Rising sea levels and other climate-driven changes could drive millions of people to migrate: more than a fifth of Bangladesh could be under water with a 1 m rise in sea levels, which is a possibility by the end of the century. Climate-related shocks have sparked violent conflict in the past, and conflict is a serious risk in areas such as West Africa, the Nile Basin and Central Asia.

Climate Change May Initially Have Small Positive Effects for a Few Developed Countries, but Is Likely To Be Very Damaging for the Much Higher Temperature Increases Expected by Mid- to Late-Century Under BAU Scenarios.

In higher latitude regions, such as Canada, Russia and Scandinavia, climate change may lead to net benefits for temperature increases of 2 or 3 degrees C, through higher agricultural yields, lower winter mortality, lower heating requirements, and a possible boost to tourism. But these regions will also experience the most rapid rates of warming, damaging infrastructure, human health, local livelihoods and biodiversity.

Developed countries in lower latitudes will be more vulnerable—for example, water availability and crop yields in southern Europe are expected to decline by 20% with a 2 degrees C increase in global temperatures. Regions where water is already scarce will face serious difficulties and growing costs.

The increased costs of damage from extreme weather (storms, hurricanes, typhoons, floods, droughts, and heat waves) counteract some early benefits of climate change and will increase rapidly at higher temperatures. Based on simple extrapolations, costs of extreme weather alone could reach 0.5-1% of world GDP per annum by the middle of the century, and will keep rising if the world continues to warm.

- A 5 or 10% increase in hurricane wind speed, linked to rising sea temperatures, is predicted approximately to double annual damage costs, in the U.S.
- In the U.K., annual flood losses alone could increase from 0.1% of GDP today to 0.2-0.4% of GDP once the increase in global average temperatures reaches 3 or 4 degrees C.
- Heat waves like that experienced in 2003 in Europe, when 35,000 people died and agricultural losses reached $15 billion, will be commonplace by the middle of the century.

At higher temperatures, developed economies face a growing risk of large-scale shocks—for example, the rising costs of extreme weather events could affect global financial markets through higher and more volatile costs of insurance.

Integrated Assessment Models Provide A Tool for Estimating the Total Impact on the Economy; Our Estimates Suggest That This Is Likely To Be Higher Than Previously Suggested.

The second approach to examining the risks and costs of climate change adopted in the Review is to use integrated assessment models to provide aggregate monetary estimates.

Formal modelling of the overall impact of climate change in monetary terms is a formidable challenge, and the limitations to modelling the world over two centuries or more demand great caution in interpreting results. However, as we have explained, the lags from action to effect are very long and the quantitative analysis needed to inform action will depend on such long-range modelling exercises. The monetary impacts of climate change are now expected to be more serious than many earlier studies suggested, not least because those studies tended to exclude some of the most uncertain but potentially most damaging impacts. Thanks to recent advances in the science, it is now possible to examine these risks more directly, using probabilities.

Most formal modelling in the past has used as a starting point a scenario of 2-3 degrees C warming. In this temperature range, the cost of climate change could be equivalent to a permanent loss of around 0-3% in global world output compared with what could have been achieved in a world without climate change. Developing countries will suffer even higher costs.

However, those earlier models were too optimistic about warming: more recent evidence indicates that temperature changes resulting from BAU trends in emissions may exceed 2-3 degrees C by the end of this century. This increases the likelihood of a wider range of impacts than previously considered. Many of these impacts, such as abrupt and large-scale climate change, are more difficult to quantify. With 5-6 degrees C warming—which is a real possibility for the next century—existing models that include the risk of abrupt and large-scale climate change estimate an average 5-10% loss in global GDP, with poor countries suffering costs in excess of 10% of GDP. Further, there is some evidence of small but significant risks of temperature rises even above this range. Such temperature increases would take us into territory unknown to human experience and involve radical changes in the world around us.

With such possibilities on the horizon, it was clear that the modelling framework used by this Review had to be built around the economics of risk. Averaging across possibilities conceals risks. The risks of outcomes much worse than expected are very real and they could be catastrophic. Policy on climate change is in large measure about reducing these risks. They cannot be fully eliminated, but they can be substantially reduced. Such a modelling framework has to take into account ethical judgements on the distribution of income and on how to treat future generations.

The analysis should not focus only on narrow measures of income like GDP. The consequences of climate change for health and for the environment are likely to be severe. Overall comparison of different strategies will include evaluation of these consequences too. Again, difficult conceptual, ethical and measurement issues are involved, and the results have to be treated with due circumspection.

The Review uses the results from one particular model, PAGE2002, to illustrate how the estimates derived from these integrated assessment models change in response to updated scientific evidence on the probabilities attached to degrees of temperature rise. The choice of model was guided by our desire to analyse risks explicitly—this is one of the very few models that would allow that exercise. Further, its underlying assumptions span the range of previous studies. We have used this model with one set of data consistent with the climate predictions of the 2001 report of the Intergovernmental Panel on Climate Change, and with one set that includes a small increase in the amplifying feedbacks in the climate system. This increase illustrates one area of the increased risks of climate change that have appeared in the peer-reviewed scientific literature published since 2001.

We have also considered how the application of appropriate discount rates, assumptions about the equity weighting attached to the valuation of impacts in poor countries, and estimates of the impacts on mortality and the environment would increase the estimated economic costs of climate change.

Using this model, and including those elements of the analysis that can be incorporated at the moment, we estimate the total cost over the next two centuries of climate change associated under BAU emissions involves impacts and risks that are equivalent to an average reduction in global per-capita consumption of at least 5%, now and forever. While this cost estimate is already strikingly high, it also leaves out much that is important.

The cost of BAU would increase still further, were the model systematically to take account of three important factors:

- First, including direct impacts on the environment and human health (sometimes called 'non-market' impacts) increases our estimate of the total cost of climate change on this path from 5% to 11% of global per-capita consumption. There are difficult analytical and ethical issues of measurement here. The methods used in this model are fairly conservative in the value they assign to these impacts.
- Second, some recent scientific evidence indicates that the climate system may be more responsive to greenhouse-gas emissions than previously thought, for example because of the existence of amplifying feedbacks such as the release of methane and weakening of carbon sinks. Our estimates, based on modelling a limited increase in this responsiveness, indicate that the potential scale of the climate response could increase the cost of climate change on the BAU path from 5% to 7% of global consumption, or from 11% to 14% if the non-market impacts described above are included.
- Third, a disproportionate share of the climate-change burden falls on poor regions of the world. If we weight this unequal burden appropriately, the estimated global cost of climate change at 5-6 degrees C warming could be more than one-quarter higher than without such weights.

Putting these additional factors together would increase the total cost of BAU climate change to the equivalent of around a 20% reduction in consumption per head, now and into the future.

In summary, analyses that take into account the full ranges of both impacts and possible outcomes—that is, that employ the basic economics of risk—suggest that BAU climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%. Taking account of the increasing scientific evidence of greater risks, of aversion to the possibilities of catastrophe, and of a broader approach to the consequences than implied by narrow output measures, the appropriate estimate is likely to be in the upper part of this range.

Economic forecasting over just a few years is a difficult and imprecise task. The analysis of climate change requires, by its nature, that we look out over 50, 100, 200 years and more. Any such modelling requires caution and humility, and the results are specific to the model and its assumptions. They should not be endowed with a precision and certainty that is simply impossible to achieve. Further, some of the big uncertainties in the science and the economics concern the areas we know least about (for example, the impacts of very high temperatures), and for good reason—this is unknown territory. The main message from these models is that when we try to take due account of the upside risks and uncertainties, the probability-weighted costs look very large. Much (but not all) of the risk can be reduced through a strong mitigation policy, and we argue that this can be achieved at a far lower cost than those calculated for the impacts. In this sense, mitigation is a highly productive investment.

Emissions Have Been, and Continue To Be, Driven by Economic Growth; Yet Stabilisation of Greenhouse-Gas Concentrations in the Atmosphere Is Feasible and Consistent With Continued Growth.

CO_2 emissions per head have been strongly correlated with GDP per head. As a result, since 1850, North America and Europe have produced around 70% of all the CO_2 emissions due to energy production, while developing countries have accounted for less than one quarter. Most future emissions growth will come from today's developing countries, because of their more rapid population and GDP growth and their increasing share of energy-intensive industries.

Yet despite the historical pattern and the BAU projections, the world does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and the structure of economies have reduced the responsiveness of emissions to income growth, particularly in some of the richest countries. With strong, deliberate policy choices, it is possible to 'decarbonise' both developed and developing economies on the scale required for climate stabilisation, while maintaining economic growth in both.

Stabilisation—at whatever level—requires that annual emissions be brought down to the level that balances the Earth's natural capacity to remove greenhouse gases from the atmosphere. The longer emissions remain above this level, the higher the final stabilisation level. In the long term, annual global emissions will need to be reduced to below 5 $GtCO_2e$, the level that the earth can absorb without adding to the concentration of GHGs in the atmosphere. This is more than 80% below the absolute level of current annual emissions.

This Review has focused on the feasibility and costs of stabilisation of greenhouse gas concentrations in the atmosphere in the range of 450-550ppm CO_2e.

Stabilising at or below 550ppm CO_2e would require global emissions to peak in the next 10—20 years, and then fall at a rate of at least 1—3% per year. The range of paths is illustrated in Figure 3.* By 2050, global emissions would need to be around 25% below current levels. These cuts will have to be made in the context of a world economy in 2050 that may be 3—4 times larger than today—so emissions per unit of GDP would need to be just one quarter of current levels by 2050.

To stabilise at 450ppm CO_2e, without overshooting, global emissions would need to peak in the next 10 years and then fall at more than 5% per year, reaching 70% below current levels by 2050.

Theoretically it might be possible to "overshoot" by allowing the atmospheric GHG concentration to peak above the stabilisation level and then fall, but this would be both practically very difficult and very unwise. Overshooting paths involve greater risks, as temperatures will also rise rapidly and peak at a higher level for many decades before falling back down. Also, overshooting requires that emissions subsequently be reduced to extremely low levels, below the level of natural carbon absorption, which may not be feasible. Furthermore, if the high temperatures were to weaken the capacity of the Earth to absorb carbon—as becomes more likely with

* Graphic has been retained in committee files.

overshooting—future emissions would need to be cut even more rapidly to hit any given stabilisation target for atmospheric concentration.

Achieving These Deep Cuts in Emissions Will Have a Cost—The Review Estimates the Annual Costs of Stabilisation at 500-550ppm CO_2e To Be Around 1% of GDP by 2050—A Level That Is Significant but Manageable.

Reversing the historical trend in emissions growth, and achieving cuts of 25% or more against today's levels is a major challenge. Costs will be incurred as the world shifts from a high-carbon to a low-carbon trajectory. But there will also be business opportunities as the markets for low-carbon, high-efficiency goods and services expand.

Greenhouse-gas emissions can be cut in four ways. Costs will differ considerably depending on which combination of these methods is used, and in which sector:

- Reducing demand for emissions-intensive goods and services;
- Increased efficiency, which can save both money and emissions;
- Action on non-energy emissions, such as avoiding deforestation;
- Switching to lower-carbon technologies for power, heat and transport.

Estimating the costs of these changes can be done in two ways. One is to look at the resource costs of measures, including the introduction of low-carbon technologies and changes in land use, compared with the costs of the BAU alternative. This provides an upper bound on costs, as it does not take account of opportunities to respond involving reductions in demand for high-carbon goods and services.

The second is to use macroeconomic models to explore the system-wide effects of the transition to a low-carbon energy economy. These can be useful in tracking the dynamic interactions of different factors over time, including the response of economies to changes in prices. But they can be complex, with their results affected by a whole range of assumptions.

On the basis of these two methods, central estimate is that stabilisation of greenhouse gases at levels of 500-550ppm CO_2e will cost, on average, around 1% of annual global GDP by 2050. This is significant, but is fully consistent with continued growth and development, in contrast with unabated climate change, which will eventually pose significant threats to growth.

Resource Cost Estimates Suggest That an Upper Bound for the Expected Annual Cost of Emissions Reductions Consistent With a Trajectory Leading To Stabilisation at 550PPM CO_2e Is Likely To Be Around 1% of GDP by 2050.

This Review has considered in detail the potential for, and costs of, technologies and measures to cut emissions across different sectors. As with the impacts of climate change, this is subject to important uncertainties. These include the difficulties of estimating the costs of technologies several decades into the future, as well as the way in which fossil-fuel prices evolve in the future. It is also hard to know how people will respond to price changes.

The precise evolution of the mitigation effort, and the composition across sectors of emissions reductions, will therefore depend on all these factors. But it is possible to make a central projection of costs across a portfolio of likely options, subject to a range.

The technical potential for efficiency improvements to reduce emissions and costs is substantial. Over the past century, efficiency in energy supply improved ten-fold or more in developed countries, and the possibilities for further gains are far from being exhausted. Studies by the International Energy Agency show that, by 2050, energy efficiency has the potential to be the biggest single source of emissions savings in the energy sector. This would have both environmental and economic benefits: energy-efficiency measures cut waste and often save money.

Non-energy emissions make up one-third of total greenhouse-gas emissions; action here will make an important contribution. A substantial body of evidence suggests that action to prevent further deforestation would be relatively cheap compared with other types of mitigation, if the right policies and institutional structures are put in place.

Large-scale uptake of a range of clean power, heat, and transport technologies is required for radical emission cuts in the medium- to long-term. The power sector around the world will have to be least 60%, and perhaps as much as 75%, decarbonised by 2050 to stabilise at or below 550ppm CO_2e. Deep cuts in the transport sector are likely to be more difficult in the shorter term, but will ultimately be needed. While many of the technologies to achieve this already exist, the priority is to bring down their costs so that they are competitive with fossil-fuel alternatives under a carbon-pricing policy regime.

A portfolio of technologies will be required to stabilise emissions. It is highly unlikely that any single technology will deliver all the necessary emission savings, because all technologies are subject to constraints of some kind, and because of the wide range of activities and sectors that generate greenhouse-gas emissions. It is also uncertain which technologies will turn out to be cheapest. Hence a portfolio will be required for low-cost abatement.

The shift to a low-carbon global economy will take place against the background of an abundant supply of fossil fuels. That is to say, the stocks of hydrocarbons that are profitable to extract (under current policies) are more than enough to take the world to levels of greenhouse-gas concentrations well beyond 750ppm CO_2e, with very dangerous consequences. Indeed, under BAU, energy users are likely to switch towards more carbon-intensive coal and oil shales, increasing rates of emissions growth.

Even with very strong expansion of the use of renewable energy and other low-carbon energy sources, hydrocarbons may still make over half of global energy supply in 2050. Extensive carbon capture and storage would allow this continued use of fossil fuels without damage to the atmosphere, and also guard against the danger of strong climate-change policy being undermined at some stage by falls in fossil-fuel prices.

Estimates based on the likely costs of these methods of emissions reduction show that the annual costs of stabilising at around 550ppm CO_2e are likely to be around 1% of global GDP by 2050, with a range from 1% (net gains) to +3.5% of GDP.

Looking at Broader Macroeconomic Models Confirms These Estimates.

The second approach adopted by the Review was based comparisons of a broad range of macro-economic model estimates (such as that presented in Figure 4* below). This comparison found that the costs for stabilisation at 500-550ppm CO_2e were centred on 1% of GDP by 2050, with a range of 2% to +5% of GDP. The range reflects a number of factors, including the pace of technological innovation and the efficiency with which policy is applied across the globe: the faster the innovation and the greater the efficiency, the lower the cost. These factors can be influenced by policy.

The average expected cost is likely to remain around 1% of GDP from mid-century, but the range of estimates around the 1% diverges strongly thereafter, with some falling and others rising sharply by 2100, reflecting the greater uncertainty about the costs of seeking out ever more innovative methods of mitigation.

Stabilisation at 450ppm CO_2e is already almost out of reach, given that we are likely to reach this level within ten years and that there are real difficulties of making the sharp reductions required with current and foreseeable technologies. Costs rise significantly as mitigation efforts become more ambitious or sudden. Efforts to reduce emissions rapidly are likely to be very costly.

An important corollary is that there is a high price to delay. Delay in taking action on climate change would make it necessary to accept both more climate change and, eventually, higher mitigation costs. Weak action in the next 10-20 years would put stabilisation even at 550ppm CO_2e beyond reach—and this level is already associated with significant risks.

The Transition to a Low-Carbon Economy Will Bring Challenges for Competitiveness but Also Opportunities for Growth.

Costs of mitigation of around 1% of GDP are small relative to the costs and risks of climate change that will be avoided. However, for some countries and some sectors, the costs will be higher. There may be some impacts on the competitiveness of a small number of internationally traded products and processes. These should not be overestimated, and can be reduced or eliminated if countries or sectors act together; nevertheless, there will be a transition to be managed. For the economy as a whole, there will be benefits from innovation that will offset some of these costs. All economies undergo continuous structural change; the most successful economies are those that have the flexibility and dynamism to embrace the change.

There are also significant new opportunities across a wide range of industries and services. Markets for low-carbon energy products are likely to be worth at least $500 bn per year by 2050, and perhaps much more. Individual companies and countries should position themselves to take advantage of these opportunities.

Climate-change policy can help to root out existing inefficiencies. At the company level, implementing climate policies may draw attention to money-saving opportunities. At the economy-wide level, climate-change policy may be a lever for reforming

* Graphic has been retained in committee files.

inefficient energy systems and removing distorting energy subsidies, on which governments around the world currently spend around $250bn a year.

Policies on climate change can also help to achieve other objectives. These co-benefits can significantly reduce the overall cost to the economy of reducing greenhouse-gas emissions. If climate policy is designed well, it can, for example, contribute to reducing ill-health and mortality from air pollution, and to preserving forests that contain a significant proportion of the world's biodiversity.

National objectives for energy security can also be pursued alongside climate change objectives. Energy efficiency and diversification of energy sources and supplies support energy security, as do clear long-term policy frameworks for investors in power generation. Carbon capture and storage is essential to maintain the role of coal in providing secure and reliable energy for many economies.

Reducing the Expected Adverse Impacts of Climate Change Is Therefore Both Highly Desirable and Feasible.

This conclusion follows from a comparison of the above estimates of the costs of mitigation with the high costs of inaction described from our first two methods (the aggregated and the disaggregated) of assessing the risks and costs of climate change impacts.

The third approach to analysing the costs and benefits of action on climate change adopted by this Review compares the marginal costs of abatement with the social cost of carbon. This approach compares estimates of the changes in the expected benefits and costs over time from a little extra reduction in emissions, and avoids large-scale formal economic models.

Preliminary calculations adopting the approach to valuation taken in this Review suggest that the social cost of carbon today, if we remain on a BAU trajectory, is of the order of $85 per tonne of CO_2—higher than typical numbers in the literature, largely because we treat risk explicitly and incorporate recent evidence on the risks, but nevertheless well within the range of published estimates. This number is well above marginal abatement costs in many sectors. Comparing the social costs of carbon on a BAU trajectory and on a path towards stabilisation at 550ppm CO_2e, we estimate the excess of benefits over costs, in net present value terms, from implementing strong mitigation policies this year, shifting the world onto the better path: the net benefits would be of the order of $2.5 trillion. This figure will increase over time. This is not an estimate of net benefits occurring in this year, but a measure of the benefits that could flow from actions taken this year; many of the costs and benefits would be in the medium to long term.

Even if we have sensible policies in place, the social cost of carbon will also rise steadily over time, making more and more technological options for mitigation cost-effective. This does not mean that consumers will always face rising prices for the goods and services that they currently enjoy, as innovation driven by strong policy will ultimately reduce the carbon intensity of our economies, and consumers will then see reductions in the prices that they pay as low-carbon technologies mature.

The three approaches to the analysis of the costs of climate change used in the Review all point to the desirability of strong action, given estimates of the costs of action on mitigation. But how much action? The Review goes on to examine the economics of this question.

The current evidence suggests aiming for stabilisation somewhere within the range 450—550ppm CO_2e. Anything higher would substantially increase the risks of very harmful impacts while reducing the expected costs of mitigation by comparatively little. Aiming for the lower end of this range would mean that the costs of mitigation would be likely to rise rapidly. Anything lower would certainly impose very high adjustment costs in the near term for small gains and might not even be feasible, not least because of past delays in taking strong action.

Uncertainty is an argument for a more, not less, demanding goal, because of the size of the adverse climate-change impacts in the worst-case scenarios.

The ultimate concentration of greenhouse gases determines the trajectory for estimates of the social cost of carbon; these also reflect the particular ethical judgements and approach to the treatment of uncertainty embodied in the modelling. Preliminary work for this Review suggests that, if the target were between 450-550ppm CO_2e, then the social cost of carbon would start in the region of $25-30 per tonne of CO_2—around one third of the level if the world stays with BAU.

The social cost of carbon is likely to increase steadily over time because marginal damages increase with the stock of GHGs in the atmosphere, and that stock rises over time. Policy should therefore ensure that abatement efforts at the margin also intensify over time. But it should also foster the development of technology that can drive down the average costs of abatement; although pricing carbon, by itself, will

not be sufficient to bring forth all the necessary innovation, particularly in the early years.

The first half of the Review therefore demonstrates that strong action on climate change, including both mitigation and adaptation, is worthwhile, and suggests appropriate goals for climate-change policy.

The second half of the Review examines the appropriate form of such policy, and how it can be placed within a framework of international collective action.

Policy To Reduce Emissions Should Be Based on Three Essential Elements: Carbon Pricing, Technology Policy, and Removal of Barriers to Behavioural Change.

There are complex challenges in reducing greenhouse-gas emissions. Policy frameworks must deal with long time horizons and with interactions with a range of other market imperfections and dynamics.

A shared understanding of the long-term goals for stabilisation is a crucial guide to policy-making on climate change: it narrows down strongly the range of acceptable emissions paths. But from year to year, flexibility in what, where and when reductions are made will reduce the costs of meeting these stabilisation goals.

Policies should adapt to changing circumstances as the costs and benefits of responding to climate change become clearer over time. They should also build on diverse national conditions and approaches to policy-making. But the strong links between current actions and the long-term goal should be at the forefront of policy.

Three elements of policy for mitigation are essential: a carbon price, technology policy, and the removal of barriers to behavioural change. Leaving out any one of these elements will significantly increase the costs of action.

Establishing a Carbon Price, Through Tax, Trading or Regulation, Is an Essential Foundation for Climate-Change Policy.

The first element of policy is carbon pricing. Greenhouse gases are, in economic terms, an externality: those who produce greenhouse-gas emissions are bringing about climate change, thereby imposing costs on the world and on future generations, but they do not face the full consequences of their actions themselves.

Putting an appropriate price on carbon—explicitly through tax or trading, or implicitly through regulation—means that people are faced with the full social cost of their actions. This will lead individuals and businesses to switch away from high-carbon goods and services, and to invest in low-carbon alternatives. Economic efficiency points to the advantages of a common global carbon price: emissions reductions will then take place wherever they are cheapest.

The choice of policy tool will depend on countries' national circumstances, on the characteristics of particular sectors, and on the interaction between climate-change policy and other policies. Policies also have important differences in their consequences for the distribution of costs across individuals, and their impact on the public finances. Taxation has the advantage of delivering a steady flow of revenue, while, in the case of trading, increasing the use of auctioning is likely to have strong benefits for efficiency, for distribution and for the public finances. Some administrations may choose to focus on trading initiatives, others on taxation or regulation, and others on a mix of policies. And their choices may vary across sectors.

Trading schemes can be an effective way to equalise carbon prices across countries and sectors, and the EU Emissions Trading Scheme is now the centrepiece of European efforts to cut emissions. To reap the benefits of emissions trading, schemes must provide incentives for a flexible and efficient response. Broadening the scope of trading schemes will tend to lower costs and reduce volatility. Clarity and predictability about the future rules and shape of schemes will help to build confidence in a future carbon price.

In order to influence behaviour and investment decisions, investors and consumers must believe that the carbon price will be maintained into the future. This is particularly important for investments in long-lived capital stock. Investments such as power stations, buildings, industrial plants and aircraft last for many decades. If there is a lack of confidence that climate change policies will persist, then businesses may not factor a carbon price into their decision-making. The result may be overinvestment in long-lived, high-carbon infrastructure—which will make emissions cuts later on much more expensive and difficult.

But establishing credibility takes time. The next 10 to 20 years will be a period of transition, from a world where carbon-pricing schemes are in their infancy, to one where carbon pricing is universal and is automatically factored into decision making. In this transitional period, while the credibility of policy is still being established and the international framework is taking shape, it is critical that governments consider how to avoid the risks of locking into a high-carbon infrastructure,

including considering whether any additional measures may be justified to reduce the risks.

Policies Are Required To Support the Development of a Range of Low-Carbon and High-Efficiency Technologies on an Urgent Timescale.

The second element of climate-change policy is technology policy, covering the full spectrum from research and development, to demonstration and early stage deployment. The development and deployment of a wide range of low-carbon technologies is essential in achieving the deep cuts in emissions that are needed. The private sector plays the major role in R&D and technology diffusion, but closer collaboration between government and industry will further stimulate the development of a broad portfolio of low carbon technologies and reduce costs.

Many low-carbon technologies are currently more expensive than the fossil-fuel alternatives. But experience shows that the costs of technologies fall with scale and experience, as shown in Figure 5* below.

Carbon pricing gives an incentive to invest in new technologies to reduce carbon; indeed, without it, there is little reason to make such investments. But investing in new lower-carbon technologies carries risks. Companies may worry that they will not have a market for their new product if carbon-pricing policy is not maintained into the future. And the knowledge gained from research and development is a public good; companies may under-invest in projects with a big social payoff if they fear they will be unable to capture the full benefits. Thus there are good economic reasons to promote new technology directly.

Public spending on research, development and demonstration has fallen significantly in the last two decades and is now low relative to other industries. There are likely to be high returns to a doubling of investments in this area to around $20 billion per annum globally, to support the development of a diverse portfolio of technologies.

In some sectors—particularly electricity generation, where new technologies can struggle to gain a foothold—policies to support the market for early-stage technologies will be critical. The Review argues that the scale of existing deployment incentives worldwide should increase by two to five times, from the current level of around $34 billion per annum. Such measures will be a powerful motivation for innovation across the private sector to bring forward the range of technologies needed.

The Removal of Barriers to Behavioural Change Is a Third Essential Element, One That Is Particularly Important in Encouraging the Take-Up of Opportunities for Energy Efficiency.

The third element is the removal of barriers to behavioural change. Even where measures to reduce emissions are cost-effective, there may be barriers preventing action. These include a lack of reliable information, transaction costs, and behavioural and organisational inertia. The impact of these barriers can be most clearly seen in the frequent failure to realise the potential for cost-effective energy efficiency measures.

Regulatory measures can play a powerful role in cutting through these complexities, and providing clarity and certainty. Minimum standards for buildings and appliances have proved a cost-effective way to improve performance, where price signals alone may be too muted to have a significant impact.

Information policies, including labelling and the sharing of best practice, can help consumers and businesses make sound decisions, and stimulate competitive markets for low-carbon and high-efficiency goods and services. Financing measures can also help, through overcoming possible constraints to paying the upfront cost of efficiency improvements.

Fostering a shared understanding of the nature of climate change, and its consequences, is critical in shaping behaviour, as well as in underpinning national and international action. Governments can be a catalyst for dialogue through evidence, education, persuasion and discussion. Educating those currently at school about climate change will help to shape and sustain future policy-making, and a broad public and international debate will support today's policy-makers in taking strong action now.

Adaptation Policy Is Crucial for Dealing With the Unavoidable Impacts of Climate Change, but It Has Been Under-Emphasised in Many Countries.

Adaptation is the only response available for the impacts that will occur over the next several decades before mitigation measures can have an effect.

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* Graphic has been retained in committee files.

Unlike mitigation, adaptation will in most cases provide local benefits, realised without long lead times. Therefore some adaptation will occur autonomously, as individuals respond to market or environmental changes. Some aspects of adaptation, such as major infrastructure decisions, will require greater foresight and planning. There are also some aspects of adaptation that require public goods delivering global benefits, including improved information about the climate system and more climate-resilient crops and technologies.

Quantitative information on the costs and benefits of economy-wide adaptation is currently limited. Studies in climate-sensitive sectors point to many adaptation options that will provide benefits in excess of cost. But at higher temperatures, the costs of adaptation will rise sharply and the residual damages remain large. The additional costs of making new infrastructure and buildings resilient to climate change in OECD countries could be $15-150 billion each year (0.05-0.5% of GDP).

The challenge of adaptation will be particularly acute in developing countries, where greater vulnerability and poverty will limit the capacity to act. As in developed countries, the costs are hard to estimate, but are likely to run into tens of billions of dollars.

Markets that respond to climate information will stimulate adaptation among individuals and firms. Risk-based insurance schemes, for example, provide strong signals about the size of climate risks and therefore encourage good risk management.

Governments have a role in providing a policy framework to guide effective adaptation by individuals and firms in the medium and longer term. There are four key areas:

- High-quality climate information and tools for risk management will help to drive efficient markets. Improved regional climate predictions will be critical, particularly for rainfall and storm patterns.
- Land-use planning and performance standards should encourage both private and public investment in buildings and other long-lived infrastructure to take account of climate change.
- Governments can contribute through long-term polices for climate-sensitive public goods, including natural resources protection, coastal protection, and emergency preparedness.
- A financial safety net may be required for the poorest in society, who are likely to be the most vulnerable to the impacts and least able to afford protection (including insurance).

Sustainable development itself brings the diversification, flexibility and human capital which are crucial components of adaptation. Indeed, much adaptation will simply be an extension of good development practice—for example, promoting overall development, better disaster management and emergency response. Adaptation action should be integrated into development policy and planning at every level.

An Effective Response to Climate Change Will Depend on Creating the Conditions for International Collective Action.

This Review has identified many actions that communities and countries can take on their own to tackle climate change.

Indeed, many countries, states and companies are already beginning to act. However, the emissions of most individual countries are small relative to the global total, and very large reductions are required to stabilise greenhouse gas concentrations in the atmosphere. Climate change mitigation raises the classic problem of the provision of a global public good. It shares key characteristics with other environmental challenges that require the international management of common resources to avoid free riding.

The U.N. Framework Convention on Climate Change (UNFCCC), Kyoto Protocol and a range of other informal partnerships and dialogues provide a framework that supports co-operation, and a foundation from which to build further collective action.

A shared global perspective on the urgency of the problem and on the long-term goals for climate change policy, and an international approach based on multilateral frameworks and co-ordinated action, are essential to respond to the scale of the challenge. International frameworks for action on climate change should encourage and respond to the leadership shown by different countries in different ways, and should facilitate and motivate the involvement of all states. They should build on the principles of effectiveness, efficiency and equity that have already provided the foundations of the existing multilateral framework.

The need for action is urgent: demand for energy and transportation is growing rapidly in many developing countries, and many developed countries are also due to renew a significant proportion of capital stock. The investments made in the next

10-20 years could lock in very high emissions for the next half-century, or present an opportunity to move the world onto a more sustainable path.

International co-operation must cover all aspects of policy to reduce emissions—pricing, technology and the removal of behavioural barriers, as well as action on emissions from land use. And it must promote and support adaptation. There are significant opportunities for action now, including in areas with immediate economic benefits (such as energy efficiency and reduced gas flaring) and in areas where large-scale pilot programmes would generate important experience to guide future negotiations.

Agreement on a broad set of mutual responsibilities across each of the relevant dimensions of action would contribute to the overall goal of reducing the risks of climate change. These responsibilities should take account of costs and the ability to bear them, as well as starting points, prospects for growth and past histories.

Securing broad-based and sustained co-operation requires an equitable distribution of effort across both developed and developing countries. There is no single formula that captures all dimensions of equity, but calculations based on income, historic responsibility and per capita emissions all point to rich countries taking responsibility for emissions reductions of 60-80% from 1990 levels by 2050.

Co-operation can be encouraged and sustained by greater transparency and comparability of national action.

Creating A Broadly Similar Carbon Price Signal Around the World, and Using Carbon Finance To Accelerate Action in Developing Countries, Are Urgent Priorities for International Co-Operation.

A broadly similar price of carbon is necessary to keep down the overall costs of making these reductions, and can be created through tax, trading or regulation. The transfer of technologies to developing countries by the private sector can be accelerated through national action and international co-operation.

The Kyoto Protocol has established valuable institutions to underpin international emissions trading. There are strong reasons to build on and learn from this approach. There are opportunities to use the UNFCCC dialogue and the review of the effectiveness of the Kyoto Protocol, as well as a wide range of informal dialogues, to explore ways to move forward.

Private sector trading schemes are now at the heart of international flows of carbon finance. Linking and expanding regional and sectoral emissions trading schemes, including sub-national and voluntary schemes, requires greater international cooperation and the development of appropriate new institutional arrangements.

Decisions Made Now on the Third Phase of the EU ETS Provide an Opportunity for the Scheme To Influence, and Become the Nucleus of, Future Global Carbon Markets.

The EU ETS is the world's largest carbon market. The structure of the third phase of the scheme, beyond 2012, is currently under debate. This is an opportunity to set out a clear, long-term vision to place the scheme at the heart of future global carbon markets.

There are a number of elements which will contribute to a credible vision for the EU ETS. The overall EU limit on emissions should be set at a level that ensures scarcity in the market for emissions allowances, with stringent criteria for allocation volumes across all relevant sectors. Clear and frequent information on emissions during the trading period would improve transparency in the market, reducing the risks of unnecessary price spikes or of unexpected collapses.

Clear revision rules covering the basis for allocations in future trading periods would create greater predictability for investors. The possibility of banking (and perhaps borrowing) emissions allowances between periods could help smooth prices over time.

Broadening participation to other major industrial sectors, and to sectors such as aviation, would help deepen the market, and increased use of auctioning would promote efficiency.

Enabling the EU ETS to link with other emerging trading schemes (including in the U.S. and Japan), and maintaining and developing mechanisms to allow the use of carbon reductions made in developing countries, could improve liquidity while also establishing the nucleus of a global carbon market.

Scaling Up Flows of Carbon Finance to Developing Countries To Support Effective Policies and Programmes for Reducing Emissions Would Accelerate the Transition to a Low-Carbon Economy.

Developing countries are already taking significant action to decouple their economic growth from the growth in greenhouse gas emissions. For example, China has

adopted very ambitious domestic goals to reduce energy used for each unit of GDP by 20% from 2006-2010 and to promote the use of renewable energy. India has created an Integrated Energy Policy for the same period that includes measures to expand access to cleaner energy for poor people and to increase energy efficiency.

The Clean Development Mechanism, created by the Kyoto Protocol, is currently the main formal channel for supporting low-carbon investment in developing countries. It allows both governments and the private sector to invest in projects that reduce emissions in fast-growing emerging economies, and provides one way to support links between different regional emissions trading schemes.

In future, a transformation in the scale of, and institutions for, international carbon finance flows will be required to support cost-effective emissions reductions. The incremental costs of low-carbon investments in developing countries are likely to be at least $20-30 billion per year. Providing assistance with these costs will require a major increase in the level of ambition of trading schemes such as the EU ETS. This will also require mechanisms that link private-sector carbon finance to policies and programmes rather than to individual projects. And it should work within a context of national, regional or sectoral objectives for emissions reductions. These flows will be crucial in accelerating private investment and national government action in developing countries.

There are opportunities now to build trust and to pilot new approaches to creating large-scale flows for investment in low-carbon development paths. Early signals from existing emissions trading schemes, including the EU ETS, about the extent to which they will accept carbon credits from developing countries, would help to maintain continuity during this important stage of building markets and demonstrating what is possible.

The International Financial Institutions have an important role to play in accelerating this process: the establishment of a Clean Energy Investment Framework by the World Bank and other multilateral development banks offers significant potential for catalysing and scaling up investment flows.

Greater International Co-Operation To Accelerate Technological Innovation and Diffusion Will Reduce the Costs of Mitigation.

The private sector is the major driver of innovation and the diffusion of technologies around the world. But governments can help to promote international collaboration to overcome barriers in this area, including through formal arrangements and through arrangements that promote public-private co-operation such as the Asia Pacific Partnership. Technology co-operation enables the sharing of risks, rewards and progress of technology development and enables co-ordination of priorities.

A global portfolio that emerges from individual national R&D priorities and deployment support may not be sufficiently diverse, and is likely to place too little weight on some technologies that are particularly important for developing countries, such as biomass.

International R&D co-operation can take many forms. Coherent, urgent and broadly based action requires international understanding and co-operation. These may be embodied in formal multilateral agreements that allow countries to pool the risks and rewards for major investments in R&D, including demonstration projects and dedicated international programmes to accelerate key technologies. But formal agreements are only one part of the story—informal arrangements for greater co-ordination and enhanced linkages between national programmes can also play a very prominent role.

Both informal and formal co-ordination of national policies for deployment support can accelerate cost reductions by increasing the scale of new markets across borders. Many countries and U.S. states now have specific national objectives and policy frameworks to support the deployment of renewable energy technologies. Transparency and information-sharing have already helped to boost interest in these markets. Exploring the scope for making deployment instruments tradable across borders could increase the effectiveness of support, including mobilising the resources that will be required to accelerate the widespread deployment of carbon capture and storage and the use of technologies that are particularly appropriate for developing countries.

International co-ordination of regulations and product standards can be a powerful way to encourage greater energy efficiency. It can raise their cost effectiveness, strengthen the incentives to innovate, improve transparency, and promote international trade.

The reduction of tariff and non-tariff barriers for low-carbon goods and services, including within the Doha Development Round of international trade negotiations, could provide further opportunities to accelerate the diffusion of key technologies.

Curbing Deforestation Is a Highly Cost-Effective Way of Reducing Greenhouse Gas Emissions.

Emissions from deforestation are very significant—they are estimated to represent more than 18% of global emissions, a share greater than is produced by the global transport sector.

Action to preserve the remaining areas of natural forest is needed urgently. Large-scale pilot schemes are required to explore effective approaches to combining national action and international support.

Policies on deforestation should be shaped and led by the nation where the particular forest stands. But those countries should receive strong help from the international community, which benefits from their actions to reduce deforestation. At a national level, defining property rights to forestland, and determining the rights and responsibilities of landowners, communities and loggers, is key to effective forest management. This should involve local communities, respect informal rights and social structures, work with development goals and reinforce the process of protecting the forests.

Research carried out for this report indicates that the opportunity cost of forest protection in 8 countries responsible for 70 per cent of emissions from land use could be around $5 billion per annum initially, although over time marginal costs would rise.

Compensation from the international community should take account of the opportunity costs of alternative uses of the land, the costs of administering and enforcing protection, and the challenges of managing the political transition as established interests are displaced.

Carbon markets could play an important role in providing such incentives in the longer term. But there are short-term risks of destabilising the crucial process of strengthening existing strong carbon markets if deforestation is integrated without agreements that strongly increase demand for emissions reductions. These agreements must be based on an understanding of the scale of transfers likely to be involved.

Adaptation Efforts in Developing Countries Must Be Accelerated and Supported, Including Through International Development Assistance.

The poorest developing countries will be hit earliest and hardest by climate change, even though they have contributed little to causing the problem. Their low incomes make it difficult to finance adaptation. The international community has an obligation to support them in adapting to climate change. Without such support there is a serious risk that development progress will be undermined.

It is for the developing countries themselves to determine their approach to adaptation in the context of their own circumstances and aspirations. Rapid growth and development will enhance countries' ability to adapt. The additional costs to developing countries of adapting to climate change could run into tens of billions of dollars.

The scale of the challenge makes it more urgent than ever for developed countries to honour their existing commitments—made in Monterrey in 2002, and strengthened at EU Councils in June 2005 and at the July 2005 G8 Gleneagles Summit—to double aid flows by 2010.

Donors and multilateral development institutions should mainstream and support adaptation across their assistance to developing countries. The international community should also support adaptation through investment in global public goods, including improved monitoring and prediction of climate change, better modelling of regional impacts, and the development and deployment of drought-and flood-resistant crops.

In addition, efforts should be increased to build public-private partnerships for climate-related insurance; and to strengthen mechanisms for improving risk management and preparedness, disaster response and refugee resettlement.

Strong and early mitigation has a key role to play in limiting the long-run costs of adaptation. Without this, the costs of adaptation will rise dramatically.

Building and Sustaining Collective Action Is Now an Urgent Challenge.

The key building blocks for any collective action include developing a shared understanding of the long-term goals for climate policy, building effective institutions for co-operation, and demonstrating leadership and working to build trust with others.

Without a clear perspective on the long-term goals for stabilisation of greenhouse gas concentrations in the atmosphere, it is unlikely that action will be sufficient to meet the objective.

Action must include mitigation, innovation and adaptation. There are many opportunities to start now, including where there are immediate benefits and where large-scale pilot programmes will generate valuable experience. And we have already begun to create the institutions to underpin co-operation.

The challenge is to broaden and deepen participation across all the relevant dimensions of action—including co-operation to create carbon prices and markets, to accelerate innovation and deployment of low-carbon technologies, to reverse emissions from land-use change and to help poor countries adapt to the worst impacts of climate change.

There Is Still Time To Avoid the Worst Impacts of Climate Change if Strong Collective Action Starts Now.

This Review has focused on the economics of risk and uncertainty, using a wide range of economic tools to tackle the challenges of a global problem which has profound long-term implications. Much more work is required, by scientists and economists, to tackle the analytical challenges and resolve some of the uncertainties across a broad front. But it is already very clear that the economic risks of inaction in the face of climate change are very severe.

There are ways to reduce the risks of climate change. With the right incentives, the private sector will respond and can deliver solutions. The stabilisation of greenhouse gas concentrations in the atmosphere is feasible, at significant but manageable costs.

The policy tools exist to create the incentives required to change investment patterns and move the global economy onto a low-carbon path. This must go hand-in-hand with increased action to adapt to the impacts of the climate change that can no longer be avoided.

Above all, reducing the risks of climate change requires collective action. It requires co-operation between countries, through international frameworks that support the achievement of shared goals. It requires a partnership between the public and private sector, working with civil society and with individuals. It is still possible to avoid the worst impacts of climate change; but it requires strong and urgent collective action. Delay would be costly and dangerous.

The CHAIRMAN. Thank you very much, and as I said we'll have some questions, but before we go to the questions, let me call on our other two witnesses.

Professor Jacoby, why don't you go ahead?

STATEMENT OF HENRY JACOBY, PH.D., MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. JACOBY. Thank you, Senator. It's a privilege to be invited to speak to your committee.

The Stern Review argues that climate change is a challenge of risk management akin to other problems in private life and public policy, from controlling your cholesterol to defense against epidemic disease. Further, it argues that the risks are serious and we ought to be doing more to reduce them, importantly including the imposition of financial penalties on greenhouse gas emissions. I agree.

Now the Review's application of methods of economic analysis to bolster this position has been the subject of controversy among economists, as has been its call for urgent action. I'm pleased to give my interpretation of the issues raised. First the Review argues that failure to control greenhouse gas emissions will impose risks of damage that are the equivalent of 5 percent of GDP each year, and maybe as high as 20 percent, and that action to greatly reduce these risks need cost only about 1 percent of global GDP. These two numbers, 20 percent and 1 percent, have been prominent in public discussion of the Review. Then I will comment on its main recommendation, which is that we must mount an urgent global response to meet an extremely high capital on the atmospheric concentrations of greenhouse gases.

First, the damage estimate. The 5 and 20 percent loss figures are based on cascaded projections, human emissions impact; there is a climate which leads to negative and positive effects on market and non-market systems which creates gains and losses that are then converted into a common monetary measure. These projections extending to the year 2200 and beyond take account of estimates in the literature of uncertainty in temperature response and net damage to construct a picture of global risk in economic terms.

Then to recognize potential events in the extreme upper tail of natural climate outcomes, the authors added consideration of major changes in the climate system and hypothesized catastrophic damages that are not normally incorporated in formal analysis of climate response, because their likelihood and timing are so poorly understood. All these phenomena, both the well-understood and the more speculative, and the effects near-term and in the distant future, deserve attention in the discussion of climate change risk. They all figure, in my subjective judgment, but to interpret the Review's monetary damage numbers, three issues need to be sorted out.

The first is the handling of events of high consequence and unknown probability. To account for these effects the Review authors simply impose an upward shift in the range of outcomes, and this subjective judgment is a key to the expansion from 5 percent to 20 percent loss. I would have preferred to keep these extreme risks in the discussion but out of the formal monetary calculation.

A second task is to interpret the way the Review weighs up economic loss over time—that is, the discount rate—which has a huge effect on the results. The authors apply a standard discounting formula but they choose a set of parameters that, taken together, produce a rate substantially below the range judged in the literature to be consistent with the way the economy operates. Now because climate change is such a long-term problem, the authors justifiably may have wanted to ensure that distant risks were taken into account. Moreover, they may have felt that climate change should be treated differently from other economic sectors, but pushing the standard discounting formula outside of conventional bounds was arguably not the best or the most transparent way to accomplish that result. At the very least, the text should have made clear what fraction of the 5 percent and 20 percent losses are attributable to modeled damages that come 200 or more years in the future.

A third concern is the Review's application of monetary measures to non-market effects like human mortality, species loss, or forced migration, the task at which economists lack adequate methods. These damage estimates are poorly documented, so the reader has a hard time judging whether to accept them as reasonable. My own view is that the non-market effects are the heart of the issue. Many are described in the Review, but to provide a basis for interpretation, I wish they had presented a few summary indicators in natural units (people, hectares, species) alongside a more clear statement of the monetary values attached.

So how to pull all of this together? I believe the first concern implies that an underestimate of uncertainty and the second an overweighting of distant events. Opening up the evaluation of non-

market damage to closer scrutiny could lead either way, depending on what is inevitably a subjective evaluation. However one comes out on the specific damage numbers, however the Review does present ample justification of a serious global and environmental risk. It would be a shame, in my view, if useful insights into these risks were clouded by controversy over benefit-cost methods, or by charges that the Review goes too far in an effort to raise a sense of alarm.

Now to the mitigation cost: underlying the 1 percent estimate is a policy scenario whereby nations take universal collective action to reduce greenhouse gases and stop forest destruction. The assumed control regime yields an average price of $100 per ton CO_2 in 2015. Analysis recently completed by the U.S. Climate Change Science Program indicates that the 2050 cost would be higher than 1 percent under these conditions, but nonetheless that within intelligent policies and global participation, climate risk can be greatly reduced without taking a substantial bite out of GDP. More worrisome is the implied stringency of emissions mitigation within the next few years. The emissions price implied by the analysis is at least $100 per ton CO_2 and likely substantially higher. My own view and that of most previous economic studies of climate policy is that an emissions penalty substantially below this level is appropriate at the outset, to allow for adjustment of existing capital stock, and then a price rising steadily over time.

Finally, the issue of urgency and the question of, "What now?" We don't live in a world of universal participation, and the first step in approaching it is acceptance by 20 or so of the largest emitters of an international structure for negotiating equitable levels of national effort. The GATT is an example of such an arrangement. The Architecture for Ozone Destroying Chemicals is another. The Kyoto Protocol was the first try for the climate issue, but it has now fragmented, as serious research for a workable alternative will await further action by the United States. If this judgment is correct, then near-term U.S. decisions about new emissions measures have the character of a strategic move in a complicated multiparty game. With no additional U.S. action, the international process will stall. But decisions about new U.S. measures need consider not only the urgency of the problem, but also issues of international competitiveness, when trading partners lag behind.

The Review has made useful recommendations regarding policy instruments in this circumstance with a heavy emphasis on market-based measures. Among these, a universal national carbon tax, or cap and trade system, can serve the need. Moreover, either approach can provide flexibility to adapt to an evolving level of commitment by other nations. So if we can take a sense of urgency from the Stern effort, then I would suggest it is to move ahead with a careful consideration of these options and early adoption of one or another on a national basis. Thank you.

[The prepared statement of Dr. Jacoby follows:]

PREPARED STATEMENT OF HENRY D. JACOBY, PH.D., MASSACHUSETTS INSTITUTE OF TECHNOLOGY

INTERPRETING THE STERN REVIEW ON THE ECONOMICS OF CLIMATE CHANGE

INTRODUCTION

The Stern Review conveys a number of useful points about the nature of the climate threat on which there is broad agreement among analysts of this issue.

- Human-induced climate change is a problem of risk management. It cannot be proved that the outcome will be dire or shown with certainty that it will not. As with other problems we face in private life and public policy, from controlling your cholesterol level to defense against epidemic disease, uncertain dangers can warrant reasonable measures to reduce risk.
- Capping the level of greenhouse gas concentrations in the atmosphere at different levels is a useful way to think about long-term objectives in dealing with this risk.
- Because of the long lives of these gases in the atmosphere, waiting to take action on emission mitigation has the effect of gradually ruling out options for controlling the ultimate human influence on the climate system.
- Economically efficient and effective control will require efforts to develop low-emissions technology and the imposition of direct price and regulatory pressure on the emissions themselves. Neither is sufficient to make much difference alone.
- With intelligent policies and global cooperation, climate change risks could be limited without taking a substantial bite out of GDP growth.

My conclusion from these points is that the major nations, importantly including the United States, should be taking more action to reduce climate change risks.

The widespread visibility of the Review comes in large part from its two striking conclusions about risk and cost and its ultimate recommendation. First, the Review holds that if we don't control greenhouse gas emissions the risks of future climate damage will be the equivalent of 5% of GDP each year, beginning now and continuing forever, and maybe as high as 20%.[1] And the second main conclusion is that greatly reducing these risks need cost only around 1% of global GDP each year. These two numbers, 20% and 1%, have dominated public discussion of the Review and are used to bolster its main recommendation: we must mount an urgent global response to hold an extremely tight cap on the atmospheric concentration of greenhouse gases.

These results and the methods used to reach them have stirred both enthusiastic support and controversy. Let's look at each of these three points in turn—climate damage, cost of action and urgent global response—and how they might be interpreted.

CLIMATE DAMAGE

First the climate damage estimate. The 5% and 20% loss figures result from a policy scenario in which no action is ever taken to limit emissions. Estimates were made of the resulting economic loss based on a cascade of projections: human emissions impact the Earth's climate, which leads to negative and positive effects on market and non-market systems, which creates losses and gains that are converted to a common monetary measure. These projections, extending to 2200 and beyond, take account of uncertain ranges in the temperature response and in the damage estimates, in order to construct a picture of global risk in economic terms. Then to recognize potential events in the extreme upper tail of potential climate outcomes the authors added consideration of major changes in the climate system that are not normally incorporated in formal analysis of the range of climate response because their likelihood and timing are poorly understood (e.g., see IPCC, 2007), and they applied what were necessarily very rough assumptions about catastrophic social effects beyond those quantified in the current literature.

All these phenomena—both the well-understood and the more speculative, and effects near-term and in the distant future—deserve attention in a discussion of climate change risk. They all figure in my subjective judgment. But when I come to interpret the Review's specific monetary damage numbers three issues need to be sorted out. The first is the handling of events of high consequence but unknown

[1] This way of expressing damages can be thought of as an annuity, indexed to GDP, that has the same welfare implications over time as the as the projected damages. By this translation damage that occurs in particular years gets evened out across all time.

probability. The risk calculation requires estimates of the probabilities of climate outcomes and associated social costs, and the Review breaks this into two parts: (1) estimates based on the current literature, and (2) extreme events for which likelihood estimates are not available. To account for the latter Review authors simply imposed an upward shift in the range of outcomes, and this subjective judgment is a key element of the expansion from 5% to 20% loss. I would have preferred to keep these extreme risks in the discussion but out of the formal calculation. Also, I will note that the analysis was not able to consider uncertainty in the baseline emissions forecast. Our MIT analysis of temperature change to 2100 indicates that about half the uncertainty originates in the Earth science and half comes from uncertainty in projections economic growth, technical change and greenhouse gas emissions (Webster et al., 2003).

A second task is to interpret the way the Review weighs-up economic loses over time—their discount rate. Its selection has a huge effect on the results. The authors apply a standard discounting formula but they choose a set of its parameters that, taken together, produces a rate that is substantially below the range judged in the literature to be consistent with the way the economy operates.[2] The result is a low discount rate that, if applied to other realms of economic life, would justify increases in the savings rate and thus large reductions in current consumption to increase that of (much richer) people in the distant future. Because climate change is such a long-term problem the authors justifiably may have wanted to insure that distant risks were taken into account. Moreover they may feel that climate change should be treated differently from other economic choices. But pushing parameters of the standard discounting formula outside conventional bounds was arguably not the best or a transparent way to accomplish that result. At the very least the text should have made clear what fraction of the 5% and 20% losses are attributable to modeled damages that come 200 or more years in the future.

A third concern is the Review's application of monetary measures to non-market effects (e.g., human mortality, species loss, forced migration)—a task for which economists lack adequate methods. How these effects were handled is not clearly documented, so the reader has a hard time judging whether to accept the estimates as reasonable. My own view is that the non-market effects are the heart of the issue. Many are described in early chapters of the review, but more effort was needed to develop a few summary indicators in natural units (people, hectares, species), to be presented alongside a clearer statement of the monetary values attached (see Jacoby, 2004).

So how to pull all this together? I believe the first concern implies an under-estimate of uncertainty and the second an overweighting of distant events in the GDP calculation. Opening up the valuation of market damage to closer scrutiny could lead to either higher or lower estimates depending on what is inevitably a subjective valuation. However one comes out on the Stern economic analysis there is ample evidence in the Review to indicate that we face a serious global economic and environmental risk. It would be a shame if useful insights about the risk were clouded by controversy over benefit-cost methods or charges that the authors went too far in an effort to convey their level of alarm.

THE COST OF ACTION

With regarding to mitigation cost, underlying the estimate of a 1% GDP cost of mitigation in 2050 is a policy scenario whereby all nations, rich and poor, take universal collective action—reducing fossil and other industrial greenhouse gases and stopping forest destruction—by applying same emissions penalty everywhere, beginning now and continuing into the future.[3] This cost result estimate assumes a control regime that imposes measures with an average price of $100 per ton CO_2 in 2015, this cost falling over time as assumed technological change kicks in.

I will make just a couple of points in interpreting this result. First, the modeling approach adopted by the Review was capable of analysis only to 2050. What cost levels would be if the analysis were extended over a longer time period is not dis-

[2] The triplet of inputs at issue are the social discount rate or pure rate of time preference, set effectively to zero in the calculations, the elasticity of the marginal utility of consumption (the social weight attributed to a small increase in an individual's consumption) set to 1.0, and the rate of economic growth.

[3] In a study just completed for the U.S. Climate Change Science Program a similar calculation was carried out by three U.S. modeling groups (CCSP, 2006). For the case closest to the one analyzed in the Review the GDP loss in 2050 ranged from 1.5% to 5% (among modeling groups that is; this was not an uncertainty analysis). The CCSP authors are careful to point out that these likely are minimum estimates because computer models are very good at identifying mitigation actions of an economic efficiency that political processes rarely match.

cussed. Whether the cost would rise or fall with time depends on the outcome of a race between economic growth and technological change. My expectation is that costs would rise.

A second concern is the implied stringency of emissions mitigation in the early years. The Review does not report what marginal cost (and therefore emission price) is implied in 2015. Because there are some relatively cheap reductions in the mix it is somewhere above $100 per ton CO_2 and probably substantially above. This result may be compared with what the futures markets say is the likely price in the European Trading System (ETS) in the first Kyoto period, which is $15 per ton. My own view, and that of most previous economic studies of climate policy, is that an emissions penalty closer to the neighborhood of this ETS level is appropriate at the outset, to allow for adjustment of existing capital stock, then a price rising steadily over time.

AN URGENT GLOBAL RESPONSE

Whether or not one accepts the Review's stabilization target, a judgment that nations should do something more to reduce the risk raises the question "what now?" We don't live in the world of universal participation, and a necessary step in achieving it is acceptance by 20 or so of the largest emitters of an international structure for the difficult negotiations over equitable levels of national effort. The trade regime established at the end of World War II was one such arrangement, and the architecture for negotiating reductions in ozone destroying chemicals was another. The Kyoto Protocol was the first try at such a regime for the climate issue, but it has now fragmented. These most important nations will not seriously pursue the search for a workable architecture until the U.S. takes additional action on emissions, independent of any international agreement.

If my judgment about the international prospects is correct, then near-term U.S. decisions about new emissions measures have the character of a strategic move in a complicated multi-party game. If the U.S. doesn't take additional mitigation measures the international process will stall. But decisions about how stringent a policy to adopt need to consider not only the urgency of the problem and likely domestic economic effects but also issues of international competitiveness when trading partners lag behind and the tangle of this issue with our other foreign relations. The Review has very useful things to say about policy instruments, with a heavy emphasis on the use of market-based measures to the degree possible, and the fostering of more R&D and international technology cooperation. Among the market-based approaches a universal national carbon tax is the favorite of many economists. A cap-and-trade system, like the ETS or the one we apply to sulfur emissions, can serve the same purpose. Moreover either approach can provide flexibility to adapt to an evolving level of commitment by other nations. If we can take a sense of urgency from the Stern effort, then, I would suggest it is to move ahead with a careful exploration of these options and the adoption of one or the other on a national basis.

The CHAIRMAN. Thank you very much, and now let's hear from Professor Yohe. Thank you very much for being here.

STATEMENT OF GARY YOHE, PH.D., ECONOMICS PROFESSOR, WESLEYAN UNIVERSITY

Mr. YOHE. Thank you. Mr. Chairman, Senator Domenici, and members of the committee, I thank you very much for your invitation to present testimony today. It's indeed an honor, and I have to say it's a particular honor to be on the same panel with Sir Nicholas. His credentials speak for themselves, but I would like to emphasize that Sir Nicholas is a world-class economist whose contributions to our knowledge extend well beyond the issues of climate change and the specifics of his service to the World Bank and to her majesty's treasury.

I also fully recognize as I'm here that this is a hearing on the Stern Review, and not climate policy, but as you've heard these two issues are really quite inseparable, so that my remarks will sort of wander back and forth.

I'd like to begin by expressing appreciation for the Stern team for taking on the enormous challenge of constructing convincing eco-

nomic argument in support of taking immediate action to reduce the emission of greenhouse gases in general and carbon dioxide in particular. I think that a case can be made in a variety of different ways, as the economics of climate policy do indeed tell us unambiguously that it's time to act.

The major messages of the Review's assessment of the current science are sound; indeed, as has been said already, they're completely consistent with the conclusions presented by Working Group 1 of the Intergovernmental Panel on Climate Change in Paris. They are consistent, in other words, with the conclusions about the underlying science that were unanimously accepted by the representatives of the signatory nations of the United Nations from a convention on climate change who attended the meeting in Paris.

To my mind the major messages are as follows: climate is changing faster than was anticipated only 5 years ago in the third assessment report of the IPCC; significant climate impacts have been calibrated in terms of multiple metrics, some of which are economic and some of which are not; and thresholds of associated climate risk have been identified in terms of increases in global main temperature. Many of the temperature thresholds of critical impacts are now thought to be closer and lower than they were only 5 years ago. Achieving any concentration target, however, can not guarantee that any specific temperature threshold can be guaranteed. Achieving a concentration target can only reduce the likelihood of crossing these thresholds. This is evidence that we need not only mitigation in the short term, but also the adaptation that was mentioned earlier.

Figure two of the executive summary of the Stern Review has been reproduced here for the committee and for the audience, and in my mind it is a concise portrait of these essential results. If you look at it carefully you can see thresholds of critical impacts, you can see associations with temperature, and you can see ranges of concentration targets that would indicate certain likelihoods. Once you take a careful look at that, it follows that the confirmation of the IPCC conclusions in the Stern Review makes the case that some sort of policy innovation based on the economics of applied cost and benefit analysis couched in waste management terms will be required. It is important to note, though, that it is impossible to write climate policy in 2007 that will be valid for the entire century. Coping with thresholds and uncertainty over the long term will require adopting an adaptive risk management approach where a series of medium-term policy decisions will be formed by the evolutional long-term objectives. Taking medium-term action will require political leadership, but it strikes me that framing the mechanisms by which the long-term goals can be achieved will take political vision.

The Stern Review's estimates are—as has been noted by Jake—quite controversial, in part because they're difficult to understand, and partly because they're highly dependent on underlying assumptions about discounting, aversion to risk, aversion to inequality and evaluation of non-economic metrics of impacts and other significant risks.

In my written testimony I go through and make reference to a wide range of papers that have been published. Since the release of the Stern Review, it's actually turned out to be pretty much of a full employment act for economists who know a little bit about climate. To emphasize just a few, as Jake has mentioned, the damage estimates are difficult to understand, because they're expressed in terms of certain equivalent annuity metrics that convert expected discounted welfare values computed across thousands of possible futures into a single number, and those are the single numbers that get quoted. The Stern authors are very careful to say that these damages are equivalent to a 5.3 percent reduction in per capita consumption for now and forever. Unfortunately, a lot of times the conditional clause gets left off and people are left wondering where their 5.3 percent reduction of per capita consumption that was supposed to happen now actually is.

The damage estimates have been criticized because they're based on very low discount rates, a rate that virtually guarantees very high values. The damage estimates have also been criticized because they seem to be calibrated at the high end of current understanding about impacts and they sometimes miss the opportunity for adaptation, especially in the future where incomes become higher around the world. The mitigation cost estimates are expressed in terms of percentage losses and GDP, so it's difficult to make a comparison of the sorts that might be appropriate, in terms of expected losses and for mitigation as well as for climate damages.

So with all of that controversy, I would respectfully ask that the members of the Senate, specifically, and the members of the policymaking community in Washington, more generally, not to fall into the trap of focusing all of our attention on the controversies that surround the specific estimates, because you could easily miss the most important messages of the Review. I would urge you to let the economics profession continue to work the problems that we have identified, while you work on the near-term policy in recognition of the important insights of the Stern Review. Focus on the risks of climate change, that it identifies. Understand the efficiency grounds for buying insurance against the economic consequences of climate change and also the economic consequences of rapidly ramped-up climate policy in the future that would be required if nothing is done now.

As soon as you recognize that some sort of policy will be required in the near term—and I think reference to Figure 1 and the now verified science makes that easy—simple economics says that the least cost approach always means starting now.

The conclusion is true in large measure because atmospheric concentrations depend on cumulative emissions over time, so achieving a specific concentration target is fundamentally an exhaustible resource problem. The long-standing hotelling result that I teach my students in their first course in environmental and resource economics therefore applies: to maximize the discounted value set in initial scarcity rent and let it go up at the rate of interest, and it is this persistent and predictable increase in price that gives the policy attraction. Setting the initial tax can be an exercise in determining the appropriate short-term incentives for carbon saving inventive investments and energy conservation, rather than an exer-

cise in solving the climate problem, since no policy created in 2007 will indeed solve that problem. It is possible and maybe even desirable for this committee to step out from under the burden of trying to solve the climate problem, and try to answer the question, "What do we do now and how do we make progress toward a future that we can all be proud of?"

It's too early to state with any confidence what the political implications of the Stern Review might be. Initial fears in some circles that the Review's estimates were so suspect that they could only backfire and further polarize the debate have not materialized, but the climate doubters and policy opponents have certainly continued their attempts to focus their attention away from the fundamental messages. You simply don't want further evidence to be put forward that the climate is changing faster than we previously thought.

Perhaps most productively the Stern Review does seem to have induced a wider appreciation that climate can be approached as an economics problem, and that its questions about the appropriateness of emissions reduction can be illuminated with the tools of decision analysis. If that is true, then we ought to be grateful for Sir Nicholas and his team for having the courage to deliver his Review for us for our review and our consideration. Thank you.

[The prepared statement of Dr. Yohe follows:]

PREPARED STATEMENT OF GARY W. YOHE, WOODHOUSE/SYSCO PROFESSOR OF ECONOMICS, WESLEYAN UNIVERSITY

Mr. Chairman, Senator Domenici, and Members of the Committee on Energy and Natural Resources, thank you for your invitation to present testimony on the Stern Review on the Economics of Climate Change. It is indeed an honor to be here, today. It is especially an honor to be on the same panel with Sir Nicholas Stern. His credentials speak for themselves, but I would like to emphasize that Sir Nicholas is a world class economist whose contributions to our knowledge extend well beyond the issues of climate change and the specifics of his service to the World Bank or to Her Majesty's Treasury.

With my testimony, I will try to tell a story that supports the fundamental conclusion of the Stern Review that the discipline of economics can play a significant role in understanding how we should respond to the risks of climate change even as it identifies some of the reasons why the Review has been so controversial. I recognize fully that the Stern Review and not climate policy is the topic of this hearing, but I submit that the two issues are inseparable. The point of the Review is to make an economic case for immediate action to reduce the emission of greenhouse gases; and so it is as important to discuss the validity of that claim, based on the evidence presented, as it is to examine the validity of the underlying economic estimates. Therefore, my story will try to do both.

Before I start, I would like to acknowledge the contributions of Richard Tol, an economist from the University of Hamburg who is currently the Senior Research Officer at the Economic and Social Research Institute in Dublin, Ireland. Richard and I have collaborated on many things over the past ten or fifteen years, and we have authored a series of papers on the Review over the past three months. I have made those papers available to the Committee.

I begin by expressing our appreciation to the Stern Team for taking on the enormous challenge of constructing a convincing economic argument in support of taking immediate action to reduce the emissions of greenhouse gases, in general, and carbon dioxide in particular.

The Stern Review goes a long way in demonstrating how economics has something to say in informing the climate policy debate. Its release amounted to a full employment act for economists who know something about climate (and some who do not). Its release also inspired some scientists and others who don't know much economics to enter the fray, but that is fine, too.

To be honest, Richard and I are not convinced that the Review is the definitive word in this regard. Its numerical results are controversial and value-laden, but

that is the nature of the economic science. Please do not interpret the controversy over the numerical results as anything more than economists being economists—arguing over every point to make sure that the fundamental conclusions are sound. We have participated in that discussion, and I will highlight some of our concerns, today. I assure you, though, that we are both convinced that the Review provides sufficient evidence to support its fundamental conclusion with very high confidence: the economics of climate policy tell us unambiguously that it is time to act.

The major messages of the Review's assessment of the current science are sound. Indeed, they are completely consistent with the conclusions presented by Working Group 1 in its contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (the IPCC). They are consistent, in other words, with the conclusions about the underlying science that were unanimously accepted by representatives of the signatory nations of the United Nations Framework Convention on Climate Change who attended the IPCC plenary meeting in Paris two weeks ago. They include:

a. Climate is changing faster than was anticipated only 5 years ago (in the Third Assessment Report of the IPCC).

b. Significant climate impacts have been calibrated in terms of multiple metrics (some are economic, but many are not), and thresholds of associated climate risk have been identified in terms of changes in global mean temperature.

c. Many of the temperature thresholds for critical impacts are now thought to be lower than anticipated only 5 years ago. It follows that we are approaching them more quickly than we thought, and so we will reach them sooner than we thought.

d. Achieving any concentration threshold cannot guarantee achieving a specific temperature threshold; but achieving a concentration target can reduce the likelihood of crossing those thresholds at any point in time.

e. Achieving any concentration threshold may, however, only delay the inevitable unless the rate of change in temperature is diminished by persistent policy intervention over the entire century and perhaps beyond.

Figure 2 in the Executive Summary of the Stern Review offers a concise portrait of the essential results of the most recent science. I attach a version here as Figure 1. Notice that temperature thresholds are identified for truly dangerous impacts in many dimensions in the lower portion of the figure; their location in terms of warming are the basis for believing Senator McCain's assertion last month that the debate over the science is over.

The imprecise links between temperature targets and concentration targets are meanwhile illustrated in the upper portion of Figure 1. They summarize current understanding to show, for example, that holding concentrations

- below 750 ppm means a greater than 95% chance of exceeding 2 degrees (Centigrade) of warming above current levels and a 70% chance of exceeding 3 degrees of additional warming,
- below 650 ppm means a 95% chance of exceeding 2 degrees and a 60% chance of exceeding 3 degrees,
- below 550 ppm means around a 70%-80% chance of exceeding 2 degrees and a 50% chance of exceeding 3 degrees,
- below 450 ppm means a 50% chance of exceeding 2 degrees and a 25% chance of exceeding 3 degrees, and
- below 400 ppm means roughly a 30% chance of exceeding 2 degrees and still a 5% chance of exceeding 3 degrees.

Putting the two parts of the figure together allows the reader to judge the sensitivity of our experiencing any specific risk to changes in policy. It is, indeed, a spectacularly powerful portrait of the policy predicament.

It follows from its confirmation of the IPCC conclusions that the Stern Review makes the case that some sort of policy intervention, based on the economics of applied cost-benefit analysis couched in risk management terms, will be required.

It is important to note that it is impossible to write climate policy in 2007 that will be valid for the entire century. Coping with thresholds and uncertainty over the long term will require adopting an adaptive risk management approach where series of medium-term policy decisions will be informed by the evolution of long-term objectives. Designing such a program will be difficult, because it will need to give clear signals of intention over the medium-term even as it maintains flexibility so that it can respond to

- changes in scientific understanding,
- changes in social valuations of impacts, and

- changes in our expectations of how the policies are working.

In every case, however, this flexibility must somehow be immune to political and/or economic manipulation, and so designing such a mechanism will require a considerable amount of political leadership.[1]

The Stern Review's estimates of economic damages and the cost of mitigation have been controversial in part because they are difficult to understand and in part because they are highly dependent on underlying assumptions about discounting, aversion to risk, aversion to inequality, and the valuation of noneconomic metrics of impact and significant risk (abrupt change and extreme events, for example).

The controversies surrounding the damage estimates are fraught with detailed discussions of the technicalities involved in applying economic analysis to a complex problem like climate change. I highlight a few, here, but will shortly argue that the case for immediate action survives the controversy, especially if one takes a slightly different, but nonetheless economically rigorous tact.

The damage estimates are difficult to understand because they are expressed in terms of a "certainty equivalent and equity equivalent annuity" metric that converts expected discounted welfare values computed across thousands of possible futures into a single number.

The analysis underlying the computation of this metric is sound, if not brilliant; see Mirrlees and Stern (1972) for the details of its development. Its application to the climate problem is path-breaking, but it is vulnerable to the sort of misinterpretation that will make people roll their eyes and wonder if any of us know what we are talking about. The authors of the Review are careful to say that "total cost over the next two centuries . . . are equivalent to an average reduction in global per capita consumption of at least 5%, now and forever". When the results are reported in the popular press, however, the conditional phrase about equivalence is usually deleted, and that is a problem. Readers can react by saying "It's now, and I don't see my 5.3% reduction in consumption. Where is it? It's still now! Still not here!"

Notwithstanding this presentation problem, it is important to note that the damage estimates include not only the economic ramifications of climate impacts as they play out over time, but also a "risk premium" tied to the current level of uncertainty about the future as displayed in the simulation model. It is here that aversion to risk and aversion to inequality have an effect on the estimates. Weitzman (2007) argues that the Stern estimates undervalue these contributions because the tails of the distributions of our understanding of the climate impacts are so "thick". in other words, the representations of uncertainty upon which the underlying simulations are conducted do not adequately consider the likelihood of extreme consequences.

The damage estimates have been criticized because they are based on a very low discount rate—a rate that virtually guarantees high values.

Dasgupta (2006), Maddison (2006), Nordhaus (2006), Tol (2006), Tol and Yohe (2006), Tol and Yohe (2007), Varian (2006), Yohe (2006) and Yohe and Tol (2007) all make this point. Some argue that imposing such a low discount rate on investments to mitigate climate change in a world where other investments are required to earn higher returns is a prescription for the inefficient allocation of resources over time. Others argue that public investments can earn lower than market returns if they complement private investment; see for example, Ogura and Yohe (1977). Still others, including the Stern Review itself, make an ethical case for minimizing the rate at which impacts that will be felt by future generations are discounted in current policy deliberations.

Regardless of how one comes down on this debate, and the choice of a discount rate is in the purview of policy-makers, it is important to recognize the sensitivity of the damage estimates to that choice. Tol and Yohe (2007) report, on the basis of a simply model calibrated to the Stern Review baseline scenario where damages create the equivalent of a 5.3% reduction in per capita consumption, that lowering the rate further would have very little effect on the estimate while increasing the discount rate to 3% would reduce damages to the equivalent of a 1.6% decline in equivalent per capita consumption.

It should finally be noted that Weitzman (2007) expresses concern that the economic profession at large has not yet solved the problem of exactly how to discount the distant future when intergenerational transfers of wealth must be considered. His point is simple: there is a lot of fundamental work still to be done in this regard.

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[1] It strikes me, as an aside, that the Federal Reserve System of the United States (the FED) is an example of an institution designed to accomplish all of these tasks. While surely in a different context, the FED confronts the same sorts of short-term versus long-term tensions with the same sorts of price or quantity policy tools and protected from political manipulation by carefully designed insulation.

The damage estimates have also been criticized because they seem to have been calibrated to the high end of current understanding of impacts, because they sometimes miss the opportunity for adaptation especially in a future where incomes will be higher, and because they add estimates of catastrophic damages to a baseline that already included estimates of the willingness to pay to avoid such calamity.

Tol (2006), Tol and Yohe (2006) and Yohe and Tol (2007) have made these points, but it is important to note that the range of uncertainty reflected in the underlying simulations is not tied entirely to these upper-end estimates. Tol and Yohe (2007) confront the "So what?" question that we begged in their earlier comments by exploring the implications of simply assuming that the developing world's capacity to adapt will grow toward the current level of the world developed countries as their economies grow. The result is a reduction in discounted damages of more than 50%. Why so large? Because the small discount rate rewards increases in future adaptive capacity as heavily as it punishes future impacts.

Mitigation costs are estimated in terms of percentage losses in GDP, and so it is difficult to compare the costs of policy with its benefits (calibrated in terms of losses in equivalent per capita consumption).

Mendelsohn (2006) has remarked that the mitigation cost estimates are too low. Others have noted that they seem to run only through 2050. Tol and Yohe (2006) wonder why the conventional 550 ppm concentration target from earlier work persists as a policy target when damage estimates are so much higher than before. Perhaps most importantly, however, the Review never presents the net effect of mitigation in terms of the equivalent per capita consumption metric employed to track damages. Tol and Yohe (2007) have attempted to do so for a simple model calibrated, again, to support a 5.3% loss absent any intervention. They find that achieving a 550 ppm concentration target would reduce damages to 2.2%, that a achieving a 650 ppm target would reduce damages to 3.0%, and that achieving a 400 ppm target would reduce damages to 0.8%.

These are not net benefit estimates, of course, because they do not include the cost of mitigation. They do show, however, that no amount of mitigation can be expected to eliminate economic harm expressed in terms of per capita consumption equivalents even though mitigation does reduce the uncertainty with which we view future impacts.

I would respectfully ask members of the Senate, specifically, and members of the policy-making community in Washington more generally not to fall into the trap of focusing all of their attention on the controversies that surround the specific estimates because you could easily miss the most important message of the Review. Let the economic profession continue to work the problems that we have identified while you work to define near-term policy in recognition of the important insights of the Stern Review. Focus on the risks of climate change that it identifies. Understand the efficiency grounds for "buying insurance" against economic consequences of climate change and the economic consequences of rapidly ramped climate policy in the future if nothing is done now.

As soon as you recognize that some sort of policy will be required (and that recognition follows directly from Figure 1*), simple economics says that taking the least cost approach means starting now.

This conclusion is true in large measure because atmospheric concentrations of greenhouse gases depend on cumulative emissions over time, so achieving a targeted concentration target (and thus a corresponding range of possible temperature increases and associated climate risks) is fundamentally an exhaustible resource problem. The long-standing Hotelling result that I teach my students in their first course on environmental and resource economics therefore applies (at least to a first approximation): to maximize the discounted value of welfare derived from an exhaustible resource (that is, to minimize the discounted costs of limiting cumulative emissions over the long-term), simply calculate the appropriate initial "scarcity rent" (in this case, an initial price for carbon for 2007) and let it increase over time at the rate of interest.

Adjustments over time in the concentration target (borne of uncertainty about the climate system specifically and the future more generally) confound the issue, to be sure, but I have shown in Yohe, et al. (2004) that some hedging based on the Hotelling minimum cost result minimizes expected costs even if there is a chance that we will discover sometime in the future that the climate problem fixes itself and climate policy initiated now was unnecessary. Why? Not because it generated some energy independence for the United States, even though that would be a good idea. Rather, because the expected costs of adjusting to more pessimistic climate news sometime in the future if we delay taking action are higher than the expected

* Graphic has been retained in committee files.

costs of doing too much too soon (even with discounting at the market rate of interest).

To be more specific, the Hotelling result means that it is enough to specify an initial tax on carbon (or perhaps setting targeted permit price for a cap and trade system). This tax should be designed to get the attention of American business and to show political leadership in the face of a serious problem. It need not, however, be set so high that it would cause undo economic harm in the short-run. Allowing the tax to increase at the rate of interest year after year (following Hotelling) and acknowledging that adjustments for new knowledge about performance and risk will have to be accommodated over time will give the policy traction.

I personally favor a tax because permit markets can be volatile, and because responding to this volatility by building in a "safety value" on the price of permits sets up a loophole in the policy that could easily be manipulated. Indeed, it undermines the power of the policy. A tax, increasing at the rate of interest, would produce a persistent and predictable increase in the cost of using carbon that would inspire cost-reducing innovation and fuel switching in the transportation, building, and energy supply sectors of our economy.[2]

Be assured that providing incentives for American business to prepare for a carbon scarce future will put them in a good position when it comes time to compete in world markets, especially if their competitors in China and India do not follow suit. This is why 10 major corporations are on record in support of a U.S. (federal) climate policy that has some teeth and is predictable. There is money to be made, but only if uncertainty about climate policy is reduced.

Setting the initial tax can be an exercise in determining the appropriate short-term incentives for carbon-saving investments and energy conservation rather than an exercise in "solving the climate problem".

Since no policy created in 2007 will "solve the climate problem", it is possible and even desirable for this Committee to step out from under that burden to confront a more manageable problem (while still making progress towards an ultimate solution to the climate problem). You are not trying to "Solve the climate problem." You are trying to "Acknowledge and confront the climate problem in 2007 with the best information available." More specifically, your problem is "What do we do now?"

The answer is to design something for the near-term that will discourage long-term investments in energy, transportation, and construction that would lock in high carbon intensities for decades to come. Moving decisions in that direction would be consistent with long-term programs designed to "solve" the climate problem (however our understanding of it evolves) and with the minimization of long-term economic costs of the policies.

As an example, one might consider investments that are pending to replace coal-fire power plants along the eastern seaboard of the United States. Tens if not hundreds of power plants will be replaced over the next 4 or 5 decades, and new plants will be required to meet growing demand. They might be replaced with coal-fired plants, because that would be the efficient choice given current expectations of alternative fuel prices (absent any climate policy) over the next few decades. All or some of these plants could, however, be replaced by plants that burn natural gas with a 60% reduction in carbon emissions per unit of electricity.

People who know the business claim that a $30 per ton tax on carbon dioxide (a $110 per ton tax on the carbon content of fossil fuel) would make natural gas the more economical choice, but it is not necessary to impose a $30 tax in 2007 to inspire complete conversion to natural gas. Since investment decisions turn on the discounted value of returns over 50 or 60 year time horizons, the price of carbon would not have to reach $30 per ton for another 15 or 20 years to make natural gas the economical choice this year for investments in power plants that will come on line 5 or so years hence. Of course, Hotelling tells us to increase the tax by the rate of interest, and that helps.

Assume for the moment that private investors use a 5% discount rate in their present value calculations. So what are the options? The $7 per ton of carbon dioxide charge envisioned in the legislation being considered in this Committee would reach $30 per ton in 2036—probably too late to capture plants being designed this year, but sufficient to bring most of the plants constructed between now and 2050 over to a lower carbon technology. A $15 per ton charge in 2007 would reach the decision threshold in 2021.

That would do if the goal were to achieve 100% fuel switching, but what would it cost? A $15 per ton charge would add almost $6 to a barrel of oil. We have seen monthly variation in oil prices bigger than that, recently; the difference here is that

[2] The tax should increase, in real terms, at the real rate of interest. If expressed in nominal terms downstream, then it should increase at the nominal rate of interest.

it would be predictable, and it would affect different fossil fuels differently. It would add 14 cents to a gallon of gasoline. Given current fuel configurations for electricity generation in the United States, it would increase electric bills by 10% to 30% depending on location, but that percentage would decline over time. It would generate something like $90 billion in tax revenue in 2007 if it were paid on every ton of carbon embodied in every gallon of fossil fuel consumed in the United States. This is revenue that could be used to offset the regressive nature of an energy tax, invest in alternative energy sources that could lower the $30 per ton threshold, and otherwise reduce our dependence on foreign sources of oil without looking to domestic sources like the Alaskan wilderness.

It is too early to state with any confidence what the political implications of the Stern Review might be. Initial fears in some circles that the Review's estimates were so suspect that they could only backfire and further polarize the debate have not materialized. Climate doubters and policy opponents have certainly continued their attempts to focus attention away from the fundamental messages that can be drawn from its literature survey if not its economic synthesis. They simply do not want further evidence to be put forward that the climate is changing faster than previously thought and that no specific temperature target can be guaranteed by holding atmospheric concentrations of greenhouse gases below any specific threshold. Despite their attempts, however, the Stern Review has not interrupted a perceptible, sometimes slow, and sometimes noisy march towards meaningful climate policy, but neither has it done anything to halt wild exaggeration from all sides.

Perhaps most productively, the Stern Review does seem to have induced a wider appreciation that climate change can be approached as an economic problem, and that questions about the appropriateness of emission reduction can be illuminated (but perhaps not yet answered) with the tools of decision analysis. If that is true, then economists ought to be grateful to Sir Nicholas for having the courage to deliver Stern Review to us for "review" and consideration.

The CHAIRMAN. Thank you very much. Thank all of you. Let me start with the questions. We'll do 6 minute rounds of questions. Let me start and ask a few.

Sir Nicholas, in your statements, you say climate change is the greatest market failure that the world has ever seen. What leads you to that conclusion? Why is this different than other market failures that seem to be all around us?

Mr. STERN. Thank you, Mr. Chairman. The climate change is the greatest market failure the world has seen because of the range of the causes and the range of the consequences. Every one of us in our actions, every industry is involved in emitting greenhouse gases in some shape or form. It's very hard to think of other kinds of externalities—an externality is economist language for when we do something which affects directly the consumption or production possibilities of other people—that are associated with everybody around the world. It's the greatest market failure in the sense that everybody's involved in producing these damages. Second, it's the greatest market failure the world has seen in terms of consequences. The impact will be on everybody. Third, it's the greatest market failure the world has ever seen because it's the potential scale of the damages, as we tried to describe in the report and as is illustrated in the diagrams that Gary Yohe put out there.

The CHAIRMAN. Let me also ask: I think I heard Professor Yohe refer to your Review as advocating an adaptive risk management approach to the problem. Is that an accurate statement of what you said, Professor Yohe?

Mr. YOHE. That is an accurate statement of what I said.

The CHAIRMAN. Is that an accurate description of what you in fact have concluded with the recommendations coming out of your Review?

Mr. STERN. Yes, it is. It's understood as being about the economics of risk and reducing greenhouse gases in order to reduce risks, looking at the costs and benefits of doing that, and it also emphasizes that in the Review. It also emphasizes, as Gary Yohe and Jake Jacoby have, the importance of adaptation. We do know that even with strong action the climate will change quite strongly over the next 30, 40, 50 years and that means that we're going to have to adapt, so those two parts of the statement—adaptation and economic risk—are absolutely at the heart of what we did.

The CHAIRMAN. One of the issues that is going to be central to our debate here, on how to actually come to grips with this in a legislative way, is whether or not a cap and trade system—if we're able to get a consensus to enact a cap and trade system—whether there should be something that most to us refer to as a safety valve, which would essentially ensure that those who are emitting greenhouse gases would not have to pay more than a certain amount per year for those emissions, and that amount could then rise. This is something that's contained in the draft legislation that I've worked on with Senator Specter and others, that's not in many of the other bills that are proposed.

Sir Nicholas, did you have any thoughts as to whether that kind of approach would make any sense? I think Professor Yohe's testimony indicates that he thinks that would defeat the purpose of a cap and trade system, as I understand his comments.

Mr. STERN. I think the answer to that question, Senator, has to depend on the other parts of the story in which a cap is situated. I do think that it could have a role to play, to help with the transition—to give a certain amount of certainty in a new departure in a new kind of policy instrument. But I think the context is crucial, and in that I would emphasize that strong ambition in terms of carbon reduction is crucial to the whole story. So that means that one should not set any cap too low, and you judge "too low" in relation to the kind of quantity reductions you would expect, or that you find along the way.

Second, I think it's important to look at other possible ways of giving the kind of stability, the kind of ability to make decisions in the stable environment, that is behind the idea of a cap. There I think the importance not only is the ambition in the production but also in the size of the market and the openness of the market. If you have big markets and open markets, then you're more likely to get stability than when you have narrow and closed markets, so that route to stability in terms of ambition, openness and long-term nature of the challenge is also very important.

A third element to bear in mind when you think of caps is the ability to link up with other trading schemes. Linking up with other trading schemes will allow not only more stability, but also an efficiency in the allocation worldwide and an ability to start to produce carbon finance flows to developing countries that could help bring them along and establish the kind of coalition that Senator Domenici was describing. So within that broader context, I do think that in terms of stability and in helping people to adjust to a new regime, that safety valves could have a role to play, but it would be a problem if they were set too low.

The CHAIRMAN. Thank you very much. Senator Domenici.

Senator DOMENICI. I'm going to let Senator Thomas take my place for one round.

The CHAIRMAN. Alright, Senator Thomas.

Senator THOMAS. Ok, thank you. Well, thank you gentlemen. I appreciate that very much.

Mr. Stern, you mentioned the United Nations report in your testimony, the IPCC. That panel predicted a rise of 3 feet by 2100. Your new study cuts that figure to 17; how do you explain the variation in prediction from the same route within 5 years in their report?

Mr. STERN. Of course I'm not a member of the IPCC, so I'm not here to answer for them. But the IPCC is quite cautious in including different forms of evidence, and when it feels that there's some indications, but it's not sure or it doesn't feel the evidence is strong enough, then it can revise on that basis. Some of the impacts it revised upwards and some of the impacts it revised downwards. For example, it revised upwards its estimate of the frequency of intense tornadoes. It did some adjustment downwards—you're right—in the sea level story, but that's based on a group of scientists simulating and looking carefully at different forms of evidence. It's not for me to answer for them.

Senator THOMAS. I see. I guess it's one of the questions we ask ourselves as we get different kinds of reports from scientific studies with respect to this. Eighty percent of the world's energy comes from fossil fuels: this number is projected to be up to 40 billion tons by 2030. Your report says international cooperation is necessary, yet the Kyoto Protocol has been a failure. How do you have an alternative proposal with enough detail to accurately implement it?

Mr. STERN. The story that we emphasize in the Review is to for rich countries around the world particularly to take strong action through their own ambitions. So the European Union has got strong ambitions for its third phase of the European Union Emissions training scheme, ambitions being discussed now to cut greenhouse gases emissions by 20 or 30 percent by 2020. That's an ambition which it has taken on itself. Within that context France has taken on a 75 percent ambition for its reduction by 2050, UK over 60 percent. I do appreciate that California is not a country but it has its own ambitions of 80 percent reductions.

Senator THOMAS. But the Kyoto agreement has not had much of an impact.

Mr. STERN. Well what I'm saying is that the Review itself points to the importance of strong action and strong ambitions, country by country, which can then be linked up by trading schemes. If that can be fitted into a broader protocol internationally, then that would be very good. But what I'm saying is that we do not depend on the particularities of the Kyoto Protocol for making strong progress in this. What is does depend on is the strong ambitions of the rich countries, working in a way that is likely to bring in the poorer countries, and in that sense the international community can move strongly forward without necessarily getting all the details of an international agreement right.

In thinking about Kyoto, of course, we have to think that it is a very short-term agreement and it was something that set us along a path. I believe if you look at it in that context and ask if

the kinds of issues that it raised, the kinds of ambitions it set itself, initially—are those right? I think they are. They're the right kind of level of ambition because they were short-term ambitions, but you could fit them in the longer one. So I think the kinds of ambitions it set were right and the kind of mechanisms it pointed to, of trading, is right also. I think that is underlined in the discussions, if I understand correctly, that are taking place now on cap and trade, so I think a lot of the principles and ambitions of Kyoto were sound. We have to think how things will move forward after 2012.

Senator THOMAS. None of you mentioned particularly what some of the things are that we're doing now. We have a coal plant in my State that's going to eliminate CO_2. We're going to move more toward nuclear. We're doing quite a little bit, moving toward automobiles and so on. Do you think we're making progress at this point?

Mr. STERN. Yes, I do. If I might return to the issue of China in that context that Senator Domenici raised: we've traveled a great deal since the publication of the Review, and indeed prior to publication of the Review we did visit the biggest countries around the world from this perspective—including the United States, India and China—and we went back there after the Review. We spent a lot of time in China explaining and underlining and emphasizing that the United States is taking strong action. We pointed to the examples of California. We pointed to examples of the Northeastern States. We pointed to the importance of the technology investment and research that the United States is taking, and that is a big part of our argument in China. But also when we come here to the United States we emphasize just how much China is doing. If I could give you just a few examples, it's a very important context for the whole story. They're building collaboration.

China is no longer deforesting. It is now reforesting. China has, as I mentioned in my testimony, a 20 percent reduction in the energy intensity target within 5 years. Their eleventh 5-year plan started last year and they're implementing and working on that in a very strong way—for example, through direct targets for the 1,000 biggest firms in China, recently extended considerably to below our tier terms. You cannot sell an American car in China because it doesn't meet the emissions standards, which are pretty high. Beijing has made $8,000 tax on SUVs. China in late November, early December instituted an export tax on energy-intensive goods, such as aluminum, steel and cement. So China is grappling with this problem. There's a tremendous amount more that many of us believe it should be doing but I think it's not correct to say that China is doing nothing, and we try to explain through the examples I've just given how China is beginning to get its arms around this problem. Just as when we are in China, we emphasize very strongly what the United States is doing.

Senator THOMAS. Thank you.

The CHAIRMAN. Senator Domenici wanted to go next, so you go right ahead.

Senator DOMENICI. Thank you. Sir Nicholas, I did not know that you shared with China the information that you have gathered about what the United States is doing. I personally appreciate that

you're doing that. You are probably doing more and better at it than we are, so we thank you for it. We only wish that we could get with it and I think that they would listen. They sell us an awful lot of merchandise, for which they build many of those power plants, so they build the capacity for that.

I had some questions which were going to be critical of your report but let me just say I'll submit them in writing. I understand that from this discussion what the criticism is, and applaud you for your report in spite of the fact that there is some room for arguing with some of the economics that you use. I think that probably would have been there with any report like this, but I found that to be rather credible from some who submitted it.

Now I'm going to suggest this and ask for you, any of you to help us. I look at this and am very pleased to see that you have talked about adaptation, because now after 2 months or so of reading what I can, it is obvious that the capture of carbon or the capacity to get the world to greatly diminish its use is almost impossible. We can do some, but we can't do the big job, and part of that is because we cannot find a way to invest sufficient capital in the research for new equipment that will solve the problem of sequestration. We are spending money, but I ask that we check how much. It really won't get the job done.

There has to be some way to get all of the countries of the world to put in, literally billions of dollars in some major research effort and decide whether sequestration and return of that carbon is doable. If it is, it becomes a major undertaking and I'm not selling that short. If you could do it we don't know that you would find the money to do it, it's so expensive. We don't even know if we can do it and that has to take place.

Having said that, I believe that an adaptation policy is in order and that we ought to start thinking about it up here because States and others ought to be looking at what they might do. I thank you for bringing that subject up with a little more clarity. I wonder if you would agree about the need for more research money from the world and the areas that are contributing to this problem, and if you have any ideas on how we might get that done: any of you?

Mr. JACOBY. I'll respond to that.

Mr. STERN. Jake Jacoby will respond after me, if that's okay with you, Mr. Chairman. Jake knows a great deal about research and development in these areas.

On the various questions that economists around the world have raised on the report, let me first say that the report was never intended to be the last word. That would have been foolish and I hope that we didn't make that mistake. We welcome the discussions that have taken place. I believe that we have sound answers to all the questions that have been raised, including on the treatment of discounting. We did put three papers up on the web at the beginning of this week which deal with the some of the discussions that have taken place. We will be discussing them with academic colleagues at Yale later this week, so we absolutely welcome that public discussion. I would offer a fairly cheerful and robust response to the various points that have been raised and look forward to discussing these in detail with my academic colleagues. I was 30 years in academic life before I went into the service in

international institutions and her majesty, and I will go back to academic life in the near future, and those are exactly the kinds of discussions that I welcome. But as I say, we stand by what we've done and we give the reasons for that.

The emphasis you place on research and development and deployment I think is absolutely fundamental, and I do believe that the world taken together has been remiss in funding expenditures—public expenditures in our research and development declined by a factor of 2 over this last 25 or 30 years. Collectively, we made a big mistake. Now you can look at the reasons why we did that, and no country is alone in this story. It's a pattern around the world. But that's something I think we must act very quickly to correct.

Most economists, and we would be amongst them would say, "Let's see a price to carbon, let's correct this market failure, let's invest in research and development, both public and private." They're very highly correlated, public and private expenditures now are indeed. Let's do those things and let's see which technologies come forward. We're seeing pretty rapid change in solar technologies as we find ways to do photovoltaics which are different from silicon and using plastics and other materials for the photovoltaic effect. We could well see quite strong progress in cellulosic sources of bio-fuels, not just sugar and corn but switch grasses and rough grasses and other kinds of residue which could be grown on the marginal lands around the world. If we did find progress there, it would open up opportunities for bio-fuels far greater than if we keep it narrowly to sugar and to corn. So there are margins wherever you look on these technologies where we have strong progress, and I hope that we can be reasonably optimistic. But it will require a kind of effort on the scale which you so eloquently described.

There's one technology which we did emphasize and which you have emphasized, I believe rightly so, and that's carbon capture and storage for coal. The reason for that is because it's so widely used, around 50 percent of electricity consumption around the world. It will be over 70 percent in India and China for the foreseeable future. Why? Because they've got lots of coal, it's under their ground, they don't have to import it, and it can be done quickly. You can get those fire stations up quickly and they're there in a hurry because their economies are growing, and lots of their people and industries don't have electricity supplies. So it's pretty obvious that they're going to be using coal over electricity-powered generation for quite a long period of time. So, too, Poland and Germany and United States; it's not just India and China. But particularly in India and China, there's an issue there on coal.

What's the answer to that? In the short term, to use coal much more efficiently than they do, move to super critical, ultra super critical burners. That's the kind of technology which the rich countries can help with in terms of ordinary, private investment activities. But we have to have an open view and encourage the transfer of those kinds of technologies, and as soon as we can, we have to move to the carbon capture and storage for coal. We have to learn to do that well.

I have lived and worked in India for more than 30 years now, in various places. I've lived and worked in China for nearly 20

years. I've seen those two countries change quite remarkably in the last year or so in their attitudes toward energy efficiency and their attitudes to the environment. There is some way to go, but I believe that there is a partnership there of the kind you describe that can be forged. Friends say to us: you're emphasizing carbon capture and storage for coal, sounds like a good idea. It will be more expensive so we'll need some help with the carbon finance. It will require changes in technology and in development and deployment of these technologies. We'd like some help with that, too; in particular, show it works in your own countries. So I think if Europeans argue that carbon capture and storage is a good thing for India and China, they ought to show it works in Europe. I think it's a fair challenge, my friends in India and China, but I believe that we can rise to that challenge. That is a particular area where I think the United States and its ingenuity and creativity in technologies right across the board can not only have a big role in creating these technologies, but can also show how they can be deployed and indeed, get business from so doing.

So I think your emphasis is absolutely right. I would certainly share it. I don't believe that any one country should carry all the burden of the R&D. It should be shared around. One thing that we can do, or one thing that you can do as leaders of your nations, is to try to work out with your counterparts in other parts of the world just how those R&D—and deployment, of course—efforts can be built and shared.

Mr. JACOBY. May I respond?

The CHAIRMAN. Yes, if you can make a reasonably short response, we'd appreciate it.

Mr. JACOBY. Let me second, Senator, your comment about coal. It's located all over the world. It's cheap. It's not located in places that are security problems and it's hard to imagine we're not going to burn it over the next century, so carbon capture and storage is one of the essential technologies. If we can't make that work, we're in deep trouble. So I would just say that we're near the completion of a study in which I participated at MIT, on the future of coal. That study, which should be out within a month, is going to argue that we should be spending a lot more effort on the development of coal capture and storage technology, doing studies at commercial scale.

We are spending a lot of money in the United States. We do have the FutureGen program, but the argument is that is not enough. We don't know which is the right technology. We need more experimentation with the joint operation of these complicated chemical technologies that remove the CO_2 and generate electric power jointly with the storage process itself. We need more experience with that. There's an argument that we should not have one, but five or six of these, and that given the magnitude of the problem that's a small expenditure. You're going to hear a blast from the north on this topic in a few weeks. I think you're exactly right; I would second you with great enthusiasm.

The CHAIRMAN. Senator Dorgan was ready to go with his questions. Did you have a comment you just have to make, Professor?

Mr. YOHE. Yes, I'm just going to be very brief about the other part of the question about adaptation.

It's absolutely essential that we think about adaptation. We are committed to warming even if we stopped emissions of greenhouse gases tomorrow. There was, as you know, in Paris the release of the Working Group One report from the IPCC. There will be a second one, Working Group Two, released in April. I am on the writing team for that; its topic is adaptation vulnerability and sustainable development. It works to the nexus of the development and adaptation issues, as well as related to mitigative capacity of various countries, so stay tuned for that, please.

The CHAIRMAN. Well, thank you very much.

Senator Dorgan.

Senator DORGAN. Mr. Chairman, thank you very much. Let me say that I agree with Senator Domenici in respect to the use of coal. Mr. Jacoby we are going to use coal, the question just isn't "whether", the question is "how" do we use coal and I think these projects are very important to find ways for the development of zero emission coal-fired appliances, for example. We have in my State of North Dakota the only plant in America that produces synthetic gas from lignite coal.

About three decades ago we were going to produce a lot of those, build a lot of those plants. Only one was completed. We now produce synthetic natural gas from lignite coal. We have the largest application of sequestration of CO_2 at that plant. We take the CO_2 from this plant that turns lignite coal into synthetic natural gas. We pipe the CO_2 to the oil fields in Alberta, Canada, and invest that CO_2 back into the marginal oil wells to increase the productivity of oil wells. We sequester the CO_2 from the synthetic gas plant. You dramatically increase the marginal capability of these marginal oil wells. It is exactly the kind of thing we ought to look to do as we produce all of these bio-fuels. We ought to take a look at location, with respect to using and capturing CO_2, to further enhance the productivity of oil development.

But having said all that, Mr. Stern, first of all, thanks for your work, thanks to all of you for participating today. When I hear your description of China, India, I mutter under my breath, "I hope so." It sure does sound optimistic to me, but I hope so. I hope you're right about this. It appears to me that there is a natural tension and conflict with respect to the global economy and this issue of global participation with respect to climate change.

When we take a look at the jobs from the U.S. or England migrating to China or India in search of cheap labor, those jobs are also in search of not just cheap labor, but also less regulation and lower costs. One of the aspects of that has nothing to do with laws on the books of China or the laws on the books of other countries. Many countries have really strong laws dealing with the environment or minimum wages, but they are never enforced, in a number of circumstances that I have pointed out previously.

So my question is this: isn't there a natural tension with respect to the agents of production and the global economy's searching for the lowest labor cost and the lowest production cost, therefore less environmental regulation? Search around the world where they have those opportunities and the opportunity even in those countries, less developed countries, to oppose the kind of regulatory structure we have already imposed upon ourselves. We see it every-

day. We see it all the time; see it in China and in India. If that's the case, if there is this natural tension and I believe there is, what makes you so optimistic with respect to both China and India? Then if I might make one other comment.

Mr. STERN. I'm sorry.

Senator DORGAN. You say climate change is the greatest market failure the world has ever seen. I think there's probably a germ of an idea in my question about this issue of market failure, and I'd like to have you describe what you meant by that.

Mr. STERN. Just on that second question, it is an important one and I did try to answer it a little earlier.

Senator DORGAN. Senator Bingaman just told me, go ahead and skip that, if you'd answer the first question.

Mr. STERN. Thank you. What I said about China and India, I should say emphasized a bit more strongly for China than for India. I think that China's moving a bit faster than India was about direction of movement. I think that those countries, those two countries are changing very rapidly in their attitude to energy efficiency and the environment. They both realize that global warming really matters to them. Just for example, from the point of view of the receding snow and glaciers in the Himalayas: that would increase water stress in much of the year for both countries, both India and China which rely to a very large extent on water that originates in the Himalayas. Of course the glaciers and the snow act as sponges, and they spread it out over the year. Without that, you'll have torrents and floods in the rainy season and dry rivers in the dry season, so they really do understand increasingly strongly, how much it matters to them. They also realize their increasing weight in the world economy and their responsibilities as key players in the world economy. It's movement in the right direction.

I'm optimistic about movement in the right direction, but not necessarily about whether it will be fast enough and a big enough scale to deal with this problem. That's why I think collaboration and participation, as Senator Domenici was describing, is so important. But in order to do that, to collaborate effectively with other people, I think you do have to recognize what they are trying to do.

Just as I explained a little earlier, when we're in China we go to great lengths to emphasize just what the United States is doing. Because in China, you'll be told that the United States is doing nothing about this, and they're not going to move much more strongly unless the United States does. We try to show that that argument is not well-founded, that actually there's intense discussion and a lot of action in the United States on those issues; for example, the kind of plant that you described in your own State as well as the ambitions of California, the trading in the Northeast States, many cities in the United States, and so on. So we do emphasize that very strongly and it's vital to build the collaboration to have that mutual understanding.

On the migration of jobs we try to take that issue on directly in Chapter 11 of the report, to review the evidence that there is on the mobility in response to environmental regulations, and to think that through in relation to the increased costs. It could be an effect.

The question is how big that effect is likely to be, and we have to get quantitative about that. If we're right that the extra cost to production costs to getting serious about climate change, it is at the order of 1 percent of GDP. That's like a 1 percent one-off increase of costs. That's significant but in very few cases, I think would it be the kind that would trigger a big movement. That is small in relation to difference in wage rates at 5, 10, 15 a factor of, 5, 10, or 15.

So I think if you look at it carefully and empirically and look at the numbers and see how things move, that that particular aspect of the story, the extra costs in trying to do things differently in terms of energy, would be a very small part of that story and by itself, I think unlikely to trigger a massive movement. It could be different in a few industries, and in those few industries I think it's important to try to look for international agreement—steel, aluminum, cement—and we discuss those kinds of agreements in Japan and in China, and I think in those few industries which are very energy-intensive, it would be possible to build sectoral agreements. But that would involve governments and private sector working together.

Senator DORGAN. Well, Mr. Stern, thank you and I certainly hope you're right. I understand what you're saying now. This is about direction rather than progress. If you feel that the Chinese have at least started to think in terms of moving in a constructive direction, that's different then quantum progress, so I understand what you're now saying.

I would only observe—I don't mean to be either an optimist or a pessimist about this—that the agents of production, particularly those that have become much, much larger than they were decades ago, have always resisted additional regulations. When they move to find the lowest cost unit of production capability in China or India or the Philippines, they will similarly resist regulation just as they did here for many decades. Most of what we have achieved through regulation has been over the objection of some very substantial interests in this country.

This doesn't relate to the environmental issue but it relates to the same thing I'm talking about. The president of the Philippines, some while ago said, "I think we need to increase the minimum wage in the Philippines." One of our corporations that's in the Philippines, the very next day said, "You do that, we leave."

The same approach with respect to trying to retain low-cost production in these areas: I just ask the question, is there tension with respect to the global economy and the agents of production searching for the lowest cost? Is there a need for not only regulatory capability but enforcement that would produce real progress rather than just a positive direction in some of these countries?

So let me thank you all for being here. I apologize that I was late—I have three committee hearings going on at the same time—but I do think this is a very constructive opportunity for us, and I hope for you to exchange views on something that is very important to this country and to the world.

The CHAIRMAN. Senator Corker.

Senator CORKER. Yes, sir. Well, thank you for the testimony and for your leadership on the committee.

As you look at the various tensions that do take place and you look at the fact that any kind of legislation that may take place here in America—and I know there's going to be a lot of legislation introduced to deal with this—really drives investment by entrepreneurs and therefore ends up being something that both large companies that are investing large capital, small entities that are seeking capital need to count on in order to move in a certain direction. Based on the experiences that you've had in the European Union, where I suppose the cap and trade legislation over there has been not perfect, if you will, as it relates to trying to meet the guidelines that have been laid out—what are the components in your opinion of the perfect piece of legislation for a country like America?

Seriously, what would be those components that you would lay out knowing that again you look at discount rates? I was a former finance commissioner. I understand you can just with a small, small change make huge differences in outcomes. What would be the type of legislation that you would propose be put in place, that allows for changes that will take place, that we all know will take place? Our assumptions will not be correct, to allow a dynamic market, if you will, to adjust and take into account proper legislation.

Mr. STERN. Perfection's a tough ask. I think you need a combination of measures. In the report we argue that regulation and standards can play an important role in giving confidence in the direction of a market. If you require unleaded gasoline, and you state that that's going to come in, and it's definitely going to come in, people can plan clearly on that basis. Similarly with catalytic converters or the Star schemes that you have for electrical appliances. Those kinds of regulations, either direct regulations or regulation on transparent information can, I think, develop markets. The United States has shown the way in many cases on that. So partly I think regulation will have a role to play.

Second, cap and trade policies have a powerful role to play. They will have a role to play in different areas from tax policies. Cap and trade in Europe covers about half of Europe's emissions; I mean, it's a big scope of the scheme. It's been going for 2 years and we've learned a lot along the way and what we've learned is beginning to get embodied in our plans for the next stage.

One thing we learned, which may come in the category of the blindingly obvious, but it is that if you give away too many permits, you're going to have a very low price for a permit. That's economics 101, I guess, and that's something which did happen in the early stages and which we've taken lessons from now. In the second stage of the scheme which runs from 2008 to 2012, the plans for the permits around Europe are coming in now and the environment commissioner has to deal with them. He's taking a much more robust line than was the case the first time around, so the scheme itself is a good scheme, but the way it's operated, and the kinds of ways in which permits are issued, will of course make a very big difference.

So I think your emphasis on learning as you go, both of how the scheme operates and about how the technologies are coming forward to give you more opportunities, those kinds of ways have to

be enshrined and embodied in the schemes. So you have to be strong on the ambition. You have to have scarcity otherwise markets don't work.

You also have to in this case, look long. Our third phase in Europe will be 2012 to 2020. The current periods of up to 2012 are far too short for people to make investment decisions in these kinds of industries. So going long is an important part of the design of a scheme. Being open to other trading schemes, being open to the possibilities of linking up with Northeastern States, with California, with Australia as it comes through, with India and China as they start to develop; openness, I think will be important part of that story.

So within cap and trade, I'd emphasize scarcity, long-time horizons and openness with the ability to adjust along the way as information comes in. In Europe, taxation on gasoline is a very important part of the policy, and I think that has a role to play as well. So I would look across regulation, cap and trade, taxation, and we've already—with Senator Domenici—laid strong emphasis on research and development, and deployment, so I wouldn't cover that again. I think the cap and trade is going to be crucial, but as part of the suites of measures, the suites that policies, that look across the board in the way I just tried to describe.

Senator CORKER. Comments from any other?

Mr. JACOBY. I think a suite is correct. I realize this is perhaps an economist moving out of his area to talk about politics, but I'm sorry we don't have more discussion of the possible choice of taxes or cap and trade. You don't seem to be able to talk about a carbon tax as a possible mechanism. That would be worth some consideration, I believe. I think that cap and trade, as I indicated in my testimony, could do the same thing. Thank you.

Mr. YOHE. I would just like to agree with what Jake just said. It would be nice if taxes weren't so taboo, because they do all sorts of good things and could generate revenue with which you could fund adaptation, equity considerations, and R and D, as well as looking into carbon sequestration and a variety of things like that.

Of course, Senator I'm sure you realize that the converse of your question, that uncertainty about the regulatory environment and uncertainty about where carbon policy or climate policy is going to go, leads to uncertainty in the investment world. It has the potential of locked indecisions in very high carbon intensity technologies with which we will be dealing for 30, 40, 50 years, perhaps, and that increases the economic costs of making adjustments in climate policies as the future unfolds.

Senator CORKER. Thank you. Mr. Chairman.

The CHAIRMAN. Thank you.

Senator Salazar.

Senator SALAZAR. Thank you very much, Chairman Bingaman, for holding this hearing on this very important subject. Thank you for assembling this stellar panel that you have here today.

I have a question to you, Dr. Jacoby, and then a general question and I'd appreciate it if each of you would respond. Again we're under a time limitation, so I'd appreciate it if your responses are short.

First with you, Dr. Jacoby, a question on carbon sequestration: the work that you are currently doing, would it be beneficial for us here in the U.S. Congress to move forward with conducting a national assessment of where we can geologically move forward with respect to carbon sequestration opportunities here in our own Nation? So if you will respond to that question. Then second, for the entire panel: we started getting into a conversation here about emissions trading approaches versus putting a tax on carbon emissions—would you amplify which one of those two approaches, a few of you already spoke to it, but would each of you take a minute and give us some guidance as to the policy choice between moving forward with the cap and trade system versus putting a tax on carbon emissions? What you would pursue if you happen to be king for a day? So, Mr. Jacoby, and then why don't we just move across the rest of the panel?

Mr. JACOBY. I'm not familiar with the details, but I believe under the DOE programs there already is substantial effort on a set of regional studies to identify potential areas, particularly saline aquifers where you could do this storage. A lot of that work also went on in the competition that went on among various regions of the country to get the FutureGen project, which is the major DOE activity to bid your R&D commercial demonstration. So I think there's quite a bit going on here. I'm not really confident to say whether it's enough, but there is a lot already going on to identify these geological areas.

Senator SALAZAR. And my second question: why don't we start with you, Gary, and move across.

Mr. YOHE. Okay, thank you. I do favor a tax approach, and I describe that a little bit in some of my testimony that's written before you: an idea that would start somewhere around say $15 a ton of CO_2 go up at the rate of interest to inspire the appropriate decision-making in investments decisions, then avoid locked-in investments, as I spoke before.

Fundamentally, one of the reasons that I worry so much about the cap and trade is that volatility in the price that could obscure the signal. It is not where you set the initial tax that gives this policy or the carbon price its traction. It is its predictable, persistent increase, year after year after year, in ways that don't damage the economy but send a signal that carbon will be more expensive tomorrow than it is today, and it will be more expensive next year than it is tomorrow. Those inspire the appropriate decisions at times when they can be made at least cost. When they get buried inside signals of variability, it's a little bit harder to see that happening, so that the $15 that I'm talking about is $6 a barrel of oil.

Senator SALAZAR. That would be your preferred approach——

Mr. YOHE. It would be, yes.

Senator SALAZAR [continuing]. In dealing with this issue? Dr. Jacoby.

Mr. JACOBY. I would prefer a tax system, but not terribly strongly. I don't want to lose the good in fighting for the perfect here. So I think the cap and trade system can be quite satisfactory. I regret we don't spend more time thinking about the details of the two approaches.

On the volatility issue, two potential corrections can be built into these systems. One is the safety valve; now we can have more discussion if you want about the level of the safety valve, but that is what that's about and how it's set is important in terms of influencing volatility. The other thing that gets built into the current bills that are before you is banking, where you can do more now and save it to do more in the future. Banking also has an influence on reducing volatility, and if I may take off on Sir Nick's comment, on what's happened in the European trading system. One of the reasons that the European trading system's current price is so low is that there is so much restrictions on the banking into the next period. So banking has a big effect on this.

Senator SALAZAR. Thank you.

Mr. JACOBY [continuing]. So there are ways to moderate the volatility problem.

Senator SALAZAR. Thank you. Why don't we go to Ms. Peters and then come back to you for the final comment on this question, Mr. Stern?

Ms. PETERS. Just also picking up on volatility and other ways of managing it, using offset mechanisms to make any scheme which is open to trade with others is another very helpful way to manage volatility in emissions trading scheme, once it is established, once the rules of the game are established, and once there are clear guidelines to how to recognize emissions reductions evading across other schemes. So the cap and trade in its early stages is likely to be quite volatile, but I've seen some more established—you can do that rising long-term predictable price signal, which I highly agree is appropriate.

Senator SALAZAR. Sir Nick.

Mr. STERN. I think the controls on volatility that Jake on my left and Siobhan on my right have described are very important parts of the design mechanism, and can be taken forward in a way that does give you reasonable stability.

I would use cap and trade in some parts of the economy and taxation in other parts of the economy. In the European Union electricity generation and the big industries are particularly appropriate for cap and trade, but it's reasonably easy to observe what's happening in just a few plants. It does have the advantage, emissions trading, of allowing interaction with other countries. It allows you, through your own actions, to help build the international coalition that's going to have to be part of a whole story. So I think it's a great advantage in terms of international exchange and cooperation associated with emissions, trading. Also it gives you a take on the total quantity of the action. You have a take on just how much you're trying to reduce emissions which isn't so easy with a tax instrument.

Tax on the other hand can be more appropriate where you have lots of small firms where everybody uses gasoline in some shape or form. I would have a tax on gasoline rather than cap and trade on gasoline. So I would look at different parts of the economy. Look at what they offer, look at the advantages, and I think you get to some pointers as to where you'd want to use emissions trading and where you'd want to use taxation. But I would use them both, not

at the same time or in the same place, in different parts of the economy.

Senator SALAZAR. Thank you very much.

The CHAIRMAN. Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman and thank you to the very distinguished panel here this morning. You probably didn't notice since your back was to them, but earlier this morning there was probably 25 or 30 young people who were standing in the back. I'd like to think that the reason that they're still not here after almost 2 hours of hearing is that they had to move off to their classes, but I think it demonstrates the significance of the issue here before us. It's particularly important that our young people are part of the discussion as well.

I appreciate the focus that all of you have had in the discussion that has been had to this point on the adaptation. Dr. Yohe, you mentioned the term "adaptive risk management approach" and in your report, Sir Stern, you focus to a fair degree on the adaptation. Just reading my Alaska clips from home this morning, I'm reading about a new initiative at our university which is an endeavor at the university to get the research information into the hands of the policy-makers. So it's not just the scientists that are taking advantage of the research and then not moving forward further with it. They're using the example that if you're a shipping company, it's going to be helpful to know what the ice conditions might be over the period of the next decade or so. This is important as we move forward and recognize that we are dealing with climate change, and certainly in my State we know it, because we can see it, but we also know that we have got to figure out how we can be adaptive, how we can be responsive, so I do appreciate that discussion.

Sir Stern, I want to ask you: in your report, you state that the removal of barriers to behavioral change is the third essential element, and you say particularly as it relates to cost-effective energy efficiency measures. We had a hearing in this committee yesterday, in our subcommittee on energy efficiency. It was very interesting. You recognize how much more we can do in that area. Can you develop further how we can attempt to remove these barriers to energy efficiency that we are currently facing?

Mr. STERN. Thank you. I would share with the others on this panel, and it's emphasized very strongly in the report, the importance of adaptation. What you're seeing and what we're all seeing is the effects of the temperature increase of 0.7 centigrade relative to pre-industrial times. I think it's clear that however strong we are, and we hope we're very strong on reducing emissions, we'll probably see something like 2 to 3 degrees centigrade all together. So we've got another probably 2 degrees centigrade or close to 2 degrees centigrade coming, and we're only seeing at the moment the consequences of 0.7 degrees centigrade. So a lot of climate change will be there and even if we act very strongly. I think the adaptation story is fundamental, and information of course is fundamental, to people being able to adapt intelligently. I would certainly share that.

The removal of barriers to behavioral change in energy efficiency, they come in a number of ways, but one of them I think is just people's appreciation of the magnitude of the problem and the impor-

tance of their own personal actions. That I think comes with sharing of ideas, hearings of this kind, and education in schools, so that people understand what the consequences of their actions are. I do think they're influenced by more than simply the prices and taxes and subsidies and incentives that they face. They're also influenced by their understanding of the problem, so that itself is one part of the story, and the schools, of course, have a very important role to play in that.

There are problems in capital markets. How easy is it to borrow against the returns that you get from energy efficiency? The European Bank for Reconstruction and Development, which lends to eastern Europe and the former Soviet Union, has been quite innovative in coming forward with various kinds of loans which recoup, or which get their repayments, through energy efficiency. But I think capital markets are not well structured around that issue.

Regulation of new buildings: often people who are putting a building together might feel that the extra cost of the extra insulation wouldn't be too understood, wouldn't be too known by buyers, and they wouldn't get their full returns. So I think regulation on new buildings is one way forward as well.

Senator MURKOWSKI. Let me ask, because I just have a minute left here. I wanted to pose a question to you, Dr. Jacoby and to Dr. Yohe. It's been suggested, I think it was you, Dr. Yohe, that said that we needed to be flexible in developing whether it's a cap and trade system or a carbon tax, so that it can change with the scientific understanding and perhaps the changing expectations. Recognizing that you're suggesting we've got to be flexible, does this send perhaps a conflicting or inconsistent message? We've indicated, and Dr. Jacoby you've said, we need to send a strong signal on the importance of climate policy. Can we do both? Can we be flexible and still send a consistent message to other nations?

Mr. YOHE. That's fundamentally one of the questions. We will learn more about the climate. We will learn more about the drivers of climate change as the century progresses, but investment decisions need to be taken in an environment where there's predictable and persistent policies for the short- to medium-term. It's a matter of timing and it's a matter of being very creative in constructing the institutions by which new science and new understanding can be brought to bear long-term policy objectives while short-term policies are being set. The only example that I can refer you to off the top of my head that does something like that is the Federal Reserve system of the United States. They have long-term economic growth as a major objective but they set monetary policy at least quarterly and occasionally every month.

Senator MURKOWSKI. Dr. Jacoby, can we be flexible?

Mr. JACOBY. I think you've hit on one of the big problems that Congress has: how to do this in a way that provides flexibility?

I think it should start with some sort of scheme that puts a price on emissions, like a cap and trade system, with a plan for 5 or 10 years as to what you're going to do and to commit to that. It's not as if, with the schemes that we're likely to do, we're going to do significant damage or go very wrong in terms of cost in relation to what the rest of the world does. So the trick is to get something on the tracks with enough horizons so it has an influence on in-

vestment, on investment incentives, on expectations, for 5 to 10 years. We're never going to at any one time set a policy for a century. What you want is a policy that's long enough to have that influence, but is not so long that you give away the flexibility that you would need to adapt to what the rest of the world does, or adapt to what we learn about the problem.

Senator MURKOWSKI. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much.

Senator Menendez.

Senator MENENDEZ. Thank you, Mr. Chairman. I want to thank you for assembling a very distinguished panel here on a critical issue and I appreciate all of their testimony. Sir Nicholas, I appreciate your report, which I think creates an added sense of urgency that some have not adapted to this view. I think it's very important to look at this with a greater sense of urgency. Time flies quickly and I'm afraid that there are many who are still not of the belief that we need to move forward. While this is certainly a global issue, I sometimes think when we think locally, we may act differently.

In my home State of New Jersey, I look at the consequences of an action and I think of the tremendous cost of unmitigated climate change that you describe in your report. We have fragile barrier islands that provide homes and jobs for hundreds of thousands of residents, support a $26 billion tourist economy, and protects the rest of the State from storm surges, just to name a few things. So rising sea levels would either drown out these islands or they'd require expensive levees or sea walls or other protective measures, and I think about that in a way in which the residents of my State can think about their stake in a meaningful way. So one of the things I'd like to explore with you is that here in the Senate I've heard a lot of my colleagues—and rightfully so—be concerned about the impact of any carbon reduction proposals. I think some of the discussion that has been going on here is along that line on the U.S. economy. The Energy Information Administration has done a number of analyses on a series of legislative proposals that are out there, and I was wondering if you, Sir Nicholas or any of the panelists, are familiar with any of that work?

Mr. STERN. I've seen some of that analysis, Senator, but I'm not sufficiently close to it to answer in any detail.

I would like to emphasize what I think is the right approach to the problem of urgency because we are already at 430 parts per million. We're adding 2.5 parts per million a year, and that's rising as a world, so if we do nothing in 30 or 40 years time we'll be pretty close to the 550 parts per million that I suggested was the upper level of where we want to be. Because that level of stabilization would involve eventually a 50 percent chance of being above 3 degrees centigrade relative to pre-industrial times, hugely more than 0.7 degrees we've seen already. I think the urgency part of the story points strongly to a joint understanding around the world of a stabilization target that we argued in the Review should be no higher than 550 parts per million.

On the costs to economists, we do our own calculations in the Review and we come up with roughly 1 percent of GDP; that's like a one-off 1 percent increase in cost.

Senator MENENDEZ. I don't know any of the other panelists' views, but it seems to me from what I can gather from the information that there's no analysis of the costs of inaction. While we seem to be focused on the costs of any particular course of action, what I'm concerned about is, shouldn't we also be looking at the costs of inaction? Shouldn't there be an accounting for the benefits that we'll get by implementing these proposals, and for stalling a rise in temperature?

Mr. STERN. That is the kind of calculation, sir, we tried to do in the Review. And we came to the conclusion that the costs of inaction were much bigger than the cost of action, and the cost of acting strongly and urgently was very good economics.

Mr. JACOBY. The one thing that's going on is that under the climate change science program there's a set of synthesis and assessment products. One of them is out, one of them is about to come out. Those are a sequence of studies that are due to come out in coming months which draw together the information that's available in the climate science world, to answer questions like that. So there is work like that going on.

It will not go all the way that Sir Stern meant to, in monetary numbers, because the climate science program is not going to do that. But going down to the levels of changes in climate variables and then on to what might be some of the regional implications, that work is being drawn together. I don't know exactly the horizon of it, but those synthesis assessment products are one of the major activities within the U.S. Government. Of course, out in the academic world people are doing this all the time, not really official studies.

Senator MENENDEZ. It seems to me it's an incredibly important part of the ledger——

Mr. JACOBY. Yes.

Senator MENENDEZ [continuing]. That isn't necessarily being considered. We can look at how we fine-tune a strategy so that it has a minimum impact in the economy, but if we don't consider the consequences in the out-years just as we're having a great debate—I just left the budget committee before I was able to come here, having a great debate about entitlements and the costs in the out-years. Well, if we don't look at the out-years we certainly can't form policy now as a way in which to deal with the costs of rising entitlements. Similarly, it seems to me if we're not looking at the out-years of an action, the consequences in the long term are somewhat exponential. Doctor?

Mr. YOHE. Yeah, there are a couple of points. The second and third working groups of the IPCC will be issuing their reports later this year and both of them will have comments about such things. In particular, Working Group Two will be able to, not only for New Jersey in the United States, but for all of the continents and major sectors, have information from which you can glean answers to questions about the cost of inaction.

I would also, though, like to suggest that the cost of inaction is in some ways a simpler problem. Because if you look at these figures here, you see that it's quite likely that some sort of climate policy will be required. So you could say, "Well, what if we delay for 10 or 15 years?" Then the cost of inaction is the cost of ramping

up the policy much more quickly than otherwise would have been required.

I did a paper with some colleagues a couple of years ago and asked the question, "What if we don't do anything for 30 years?" Waiting for the next batch of new science, but we had sort of an equal likelihood of certain temperature targets, 2 degrees, 2.5, 3 degrees or whatever, and one of the possibilities was this climate business turns out to be a hoax and in 2035 we found out that we shouldn't have been doing anything at all. The least-cost solution, which was the least minimum adjustment cost solution and expected value over that, was $10 a ton of CO_2.

For sure if our climate turns out not to be a problem, we overdid it early. But because of the possibility that 2 degrees was the target, we wanted the cost of inaction to be No. 1, a huge amount of ramping up that cost a lot of money, even discounted at 5 percent back to the future. No. 2, there were temperature targets that were now precluded; we just couldn't get there from here, because we had thrown so much up into the atmosphere, the warming was already there. We were committed by our inaction to temperature increases that were above what might be reasonable targets, according to certain definitions of what's dangerous.

Senator MENENDEZ. I appreciate that. I mean there's other values here too, including the cost of the value to public health and some of these issues as well, that we haven't even equated.

Mr. Chairman, if I could just make one very last question, since I see that no one else is here. I appreciate your courtesy.

Part of what you say in the report as a key finding is action required to address deforestation, which is estimated to represent more than 18 percent of global emissions—more than the entire global transport sector. I sit on the Senate Foreign Relations committee, on the committee that deals with international environmental issues as well as foreign assistance, and wonder if you have any suggestions as to how we stem the tide of deforestation in the report?

Mr. STERN. I think it's crucial to work very closely with the countries in which the trees stand—in Brazil, Indonesia, Malaysia, Papua New Guinea, and so on. The vast majority of the deforestation occurs in seven or eight countries, so I think it's a question of building collaboration with those countries and indicating to them that if they come up with good plans for dealing with deforestation—plans that only they themselves can produce, because only they understand the environments, the communities, and social structures in which they live—if they come up with strong plans, they'll get very powerful international support. I think that's something which the World Bank could do a great deal on. I believe they are moving in that direction, and I think strong support from the shareholders at the World Bank, will be absolutely fundamental. But as you say, Senator, this is very much about foreign relations and building collaboration. I think building collaboration with developing countries in the ways that you describe—on deforestation, and in other ways—that we discussed earlier on carbon trading and sharing technology, will be fundamental. I also believe that a strong alliance between the European Union and the United

States on these issues could have an enormous influence on the speed and scale on which we tackle this problem.

Senator MENENDEZ. We'll look forward to exploring it with the World Bank at one of our hearings. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much. Let me just ask one additional question. I believe Senator Domenici is trying to get back to the hearing and he may before the answer is completed, in which case he may have a question.

Sir Nicholas, you indicated, as I understood your testimony, that one of the things we need to work on long-term is getting to a global price for carbon. Could you just briefly describe how you see us going from where we are today to a global price for carbon? That seems to me to involve some fairly major hurdles that need to be overcome.

Mr. STERN. The key element in that would be building an international trading scheme, so that when you design your cap and trade scheme, sir, for the United States, you should bear in mind that the technicalities of linking it with European Union trading schemes should be a big part of the story, so it's trading schemes that can speak to each other. The two biggest will be the European Union, which is on the way, and that of the United States, which is already in its early forms. I think with your leadership it will grow so the building of an international price depends on the linking of those schemes, and then the further linking as time goes by with India, China and the other main countries. I think that will be the main method.

Another method, of course, is if we go the tax route. We have to look at the taxes that other people are charging and try to do what you can to bring them into line. I don't think a formal structure in that case would be likely to get very far, but awareness of what others are doing and linking your tax prices to your cap and trade prices would, I think, bring that kind of harmony in a way that wouldn't be formal or heavy, that could actually create it.

The CHAIRMAN. Well, thank you very much. You've all been very generous with your time and it's very useful testimony. I think obviously a lot of the questions have demonstrated the interest the committee has on this subject, so thank you all very much for being here.

If there are additional questions, if Senator Domenici has any additional questions, or anyone else, we may submit those to you and ask you to respond if you could for the record, but again thank you for being here and we will adjourn the hearing.

[Whereupon, at 11:56 a.m., the hearing was adjourned.]

APPENDIX

RESPONSES TO ADDITIONAL QUESTIONS

RESPONSES OF SIR NICHOLAS STERN TO QUESTIONS FROM CHAIRMAN BINGAMAN

Question 1. In your testimony, you say that "Climate change is the greatest market failure the world has ever seen." Can you explain what you mean by this? Why is this different from other market failures?

Answer. Economic activities which emit greenhouse gases directly affect, via climate change, the consumption and production decisions of others. They are thus, in the language of economics, an externality. Climate change is a market failure since, without climate change policy, the costs of these impacts are not considered by consumers or producers when they make decisions that lead to greenhouse gas emissions.

There are two reasons why I believe that it is the greatest market failure the world has ever seen. First is the breadth of human activities that are involved. Most production and consumption actions have some greenhouse gas emissions associated with them (though a large proportion of emissions come from a limited number of activities). The sources of greenhouse gas emissions are diverse in their nature and motivation. As greenhouse gas emissions add to a global stock, it does not matter where the emission comes from—the impact is global. Each emission affects everyone on the planet albeit in a very small way. The actions of everyone have an impact on everyone. This is in contrast with other externalities such as road congestion and acid rain where the sources of the externality are fewer and the impacts are generally felt locally.

The second reason is the scale of the potential impacts. Other market failures may lead to under-provision of particular goods or higher prices for consumers whereas this market failure has the potential to seriously threaten the way we can live our lives in the future. If emissions continue to rise, following business-as-usual, by the end of the century there is a very real possibility of atmospheric concentrations such that, next century, we will see increases of 5 degrees C temperature change from pre-industrial levels. This is equivalent to the change between now and the last ice age and it is inevitable that this would have a profound effect on the physical and thus the human geography of the world. Some of these impacts are highlighted in Figure 2 of the Executive Summary that Professor Yohe brought to the Committee's attention and outlined in more detail in Chapters 3-5 of the Review.

Question 2. Dr. Yohe says in his testimony that building in a "safety valve" to a cap and trade program sets a loophole in the policy that could easily be manipulated. We are considering such a mechanism in the legislation that I have circulated and I would like to ask your thoughts on whether or not it makes sense to use such a thing.

Answer. Introducing a safety valve—some sort of cap on the price of allowances in an emissions trading scheme—is thought to have two potential advantages—one economic and one political. The supposed economic advantage is that it can reduce price volatility in the market by reducing the risk of any price spike, and also minimize uncertainty on the upper limit of prices by capping it. When prices reach the cap level, emissions are allowed to increase without a consequent increase in prices.

If such a cap on prices or 'safety valve' were in place for a short duration of time, then there are minimal risks to the environment, as it the total stock of emissions in the atmosphere that cause warming, rather than the timing of those emissions. In particular, if a safety valve were to operate over a long period of time, this could put the environmental credibility of the scheme at risk. Although it is the total stock of emissions in the atmosphere that cause warning, rather than the timing of those emissions, over a long period of time, the flow of emissions would cumula-

tively increase,[1] and the environmental risks would therefore increase. Over short time periods, it may be efficient to avoid high abatement costs or price peaks, because adjustments are more difficult to make in the short-term.[2] This leads to the political advantage of price caps; they can be used to avoid price spikes that may undermine support for emission reductions policy.

I am however skeptical of the merits of the price cap via a 'safety valve' and believe there are better ways to manage the risks of price volatility. First of all, it is difficult to ascertain how much a safety valve can contribute to minimizing uncertainty for investors. The price at which it is set would be a political decision, that is therefore subject to political risk in terms of when and at what level it would be set, what and how changes would be made to its level. Investors may not find the safety valve itself much more certain than estimating where the free market price of carbon could peak during a particular time frame.

Secondly, policy makers can use good market design to overcome some of the risks of peaking prices. There are a few design features that can help this. One is to have long trading periods (say at least 10 years), allowing banking of allowances between periods of trading. Allowing firms the flexibility in compliance options over time reduces risks of forcing abatement in short time periods and the subsequent peaks in abatement costs. A second is broadening trading schemes to include more diverse economic sectors that have different abatement costs and that are subject to different influences will tend to deepen markets and help to stabilize carbon prices. A third design feature is to expand trading schemes to allow them to link to purchases of emission reductions from the developing world (for example via Clean Development Mechanism credits or a revised equivalent) thus reducing overall compliance costs and therefore limiting the level of any price peaks. Unlike a safety valve mechanism where firms have unlimited emission rights once prices exceed the safety valve, using a link to reduction-credits in the developing world maintains the environmental credibility of the policy as it involves buying emission reductions from elsewhere. Importantly, linking to the CDM or similar mechanisms also builds cooperation with developing countries and provides options for them to benefit from investment in lower carbon technologies.

Thirdly, any price cap, by setting an upper limit on future prices, will reduce firm's central expectation of future prices. This is particularly the case if the cap is set too low and the price is expected to "hug the ceiling".[3] The safety valve reduces the incentive to invest in mitigation and increases the likelihood that the cap will be triggered. It also impacts on the incentive to innovate and adopt technologies that are currently higher in price but may fall. This means that either these technologies will not be adopted or that much greater support through other policies is required.

Finally, and crucially in terms of the benefits of moving towards a more efficient, least cost global carbon market, price caps form a potential obstacle to linking with other trading schemes. Linking schemes is efficient as it allows a given target to be met through reducing emissions wherever it is cheapest. It also reduces price volatility by increasing market liquidity. Countries will be reluctant to join another scheme with a low safety valve, as it will reduce the environmental credibility of their scheme, as their firms will pay the low price of the safety valve in another scheme. It also increases the risk of manipulation by firms operating across borders. Technical fixes to these problems are available but increase the complexity of the scheme.

In summary a well designed safety valve does have some potential advantages but these advantages can be enjoyed through other features of the scheme and a badly designed or very low safety valve will limit the effectiveness of any scheme.[4] The potential disadvantages of a cap are significant and so they should such an approach should be avoided if possible.

Question 3. You say that the three elements of policy required for an effective global response are: a carbon price, implemented through tax, trading, or regulation; support for innovation and the deployment of low carbon technologies; and action to remove barriers to energy efficiency, and to increase public awareness and en-

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[1] When the safety valve was triggered.

[2] Much of the same reasoning can also apply to a price floor (a minimum price for permits) since when prices are very low it is efficient to take advantage of low cost abatement. This can provide security to those investing in low-carbon infrastructure and thus potentially reduce the trading price. It does, however, suffer many of the same potential problems and as also a major risk to public finances.

[3] The price cap when set very low effectively takes the form of a tax rather than a trading scheme.

[4] For more on the design of emissions trading schemes see Chapter 15 of the Stern Review and Box 15.2 for price caps and floors.

gagement. I think we are familiar with some of the mechanisms needed to accomplish the first two, but what can we do to remove the barriers to energy efficiency and to increase public awareness and engagement, especially in places like China and India?

Answer. Action to remove further barriers, particularly relating to energy efficiency, is explored in more detail in Chapter 17 of the Stern Review. The choice of policy depends on the issue that is being addressed. We split the policy response to address these barriers into 3 categories:

- *Regulation*.—Regulation has an important role, for example in product and building markets by: communicating policy intentions to global audiences; reducing uncertainty, complexity and transaction costs; inducing technological innovation; and avoiding technology lock-in, for example where the credibility of carbon markets is still being established.
- *Information*.—Policies to promote: performance labels, certificates and endorsements; more informative energy bills; wider adoption of energy use displays and meters; the dissemination of best practice; or wider carbon disclosure, can all help consumers and firms make sounder decisions and stimulate more competitive markets for more energy efficient goods and services.
- *Investment/Finance*.—Private investment is key to raising energy efficiency but there may be market distortions (for example in property markets) or problems in obtaining finance for good investments. Generally, policy should seek to address the source of market failures and barriers. Investment in public sector energy conservation can reduce emissions, improve public services, fostering innovation and change across the supply chain and set an example to wider society.

Public discussion and awareness can have an important effect on individual behavior. It can also lead to society to act as an enforcement mechanism, ensuring that their national government sets policy and acts internationally in a manner that they consider responsible. How this can occur throughout the world was highlighted in Box 21.6 in the report.[5]

Both China and India have a significant emphasis on energy efficiency in their respective 11th 5 year plans. More can be done to support this. While not always the case, developing countries often install less efficient plant as they do not have access to or the capacity to adopt technologies with higher efficiency that are cost effective. Developed countries can do more to support the transfer of technologies to developing countries particularly by helping to build the capacity to adopt new technologies. This is explored in Section 23.4 of the Review.

Question 4. We talked quite a bit about China at the hearing. Can you expand on some of the points you made about what is going on in China right now?

Answer. During my travels in preparation of the review and since its release it was clear that there was often little understanding of the action undertaken by other countries. There is a tendency to underestimate action by others and falsely assume that in acting to reduce emissions any country would be acting in isolation. We outlined the goals of the 10 largest countries in Table 21.1 of the Review. Building a shared understanding of what other countries are doing helps encourage international co-operation and strengthen national action.

Turning specifically to China—as I outlined in the hearing—I have experience of working in living in China over the past twenty years and am pleasantly surprised by the huge shift in attitudes towards the environment that began in the early 1990s and accelerated rapidly in the past two years. The 11th 5 year plan has two headline targets—the growth target and a national objective to reduce energy intensity of GDP by 20% from 2005 to 2010. This includes a 10% reduction in air pollutants and 15% of energy from renewables within the next ten years. China has an impressive track record at meeting its targets.

China already has the world's largest renewable sector and is reforesting not deforesting. To achieve the efficiency targets the government announced its intention to give targets to the largest 1,000 enterprises[6] for which their chief executive is accountable. Enthusiastic local implementation has seen targets extended to the largest 8,000 enterprises. China is also seeking to close the 'dirtiest' sources of emissions. Efficiency standards for cars are higher than the U.S. and SUVs face an $8,000 tax in Beijing.

Such strong policy objectives are justified by the three inter-related objectives of local environment, climate change and energy security. There is much concern in rich countries about a shift of carbon activities to jurisdictions with less active poli-

[5] The issues of public awareness and responsible behavior are explored in more detail in Section 21.4 and 17.7 respectively.

[6] Covering 47% of industrial energy use.

cies but China, for example, has introduced export duties on energy intensive products (iron, steel, cement, aluminum, coal and copper) ranging between 5% and 15%. In most cases this is a larger price effect than would have been the case if Chinese firms had been subject to the carbon price from throughout the first trading period of the EU emissions trading scheme. I interpret this as a clear desire to avoid China becoming the locus of the world's pollution and energy intensive products.

That said, there is currently a rapid growth in the Chinese energy sector to sustain economic growth, giving rise to oft quoted statistics of the number of new coal-fired power stations that are produced each week. Lifting more of the population out of poverty through economic growth is an understandable priority in China (and India). Consideration of cost, local availability and speed dictates that coal will be the major fuel for energy growth and is forecast to remain at least 75% of electricity production for the coming decades. This emphasizes the importance of developing carbon capture and storage technologies and the transfer of efficient generation technology. It must be remembered when evaluating China's green credentials that even when China overtakes the U.S. as the leading emitter of greenhouse gases in the coming years the difference in population means that China will have a less than a quarter of the emissions per head of population.

RESPONSES OF SIR NICHOLAS STERN TO QUESTIONS FROM SENATOR DOMENICI

Question 1. Your review concludes, "the overall costs and risks of climate change will be equivalent to losing at least 5 percent of global GDP, now and forever." Economist Richard Tol calls this claim "preposterous," pointing out that society could adjust to higher temperatures and higher sea levels by developing technologies to adapt.

Isn't it possible that adapting to climate change might be best for the world economy?

Answer. Adapting to climate change is indeed wise for the world economy—it makes little sense to act as if there is no climate change when we are already seeing it and more is on the way. As set out in my written testimony—we strongly argue that adaptation is a crucial and central part of the response to the challenges of climate change. Without adaptation the costs of climate change will be significantly higher. Even with strong mitigation, adaptation will be required to address the impacts of climate change. Adaptation is discussed in more detail in the three chapters in Part V of the Review.

Adaptation can mute impacts, but cannot solve the problem of climate change. There are residual costs and limits to what adaptation can achieve particularly in the case of natural systems and due to sea level rise in the longer-term.[7] Adaptation can, at a cost, reduce the impacts of climate change but cannot be a substitute for mitigation. Adaptation does not address the issue of risk, which is at the heart of the story. The impacts at higher levels of temperature change are potentially very large. It is obvious that if these were borne out assuming that we could adapt would prove reckless. Local benefits ensure that much action will be autonomous but this is dependent on good information on future impacts and is difficult for poorer members of society.

When discussing the aggregated modeling of climate change impacts it is important to remember their role in assessing the risks of climate change. Modeling is inevitably dependent on aggregating much information and replacing much with simplistic assumptions. It loses much of the important detail and is dependent on often value-laden assumptions and what is included in the models. As was clearly expressed by Professor Yohe, the simplest way to look at the problem is to look at the disaggregated impacts alongside the cost of reducing emissions and consider whether it is worth paying for mitigation to avoid the risks associated with higher temperatures. That was the main argument of the review. Only Chapter 6 (30 pages of 700) embodies this type of modeling. The modeling supplements this approach and helps tell us what is important in terms of economic modeling approaches, scientific variables and ethical considerations.

The modeling in the Stern Review, using Professor Chris Hope's PAGE model, has produced cost of damage estimates that are higher than the existing literature for what I believe to be justifiable reasons. The major changes are, (i) the incorporation of the latest scientific information (ii), including the economics of risk and (iii) a full consideration of the economic and ethical implications of how we treat costs and benefits over time.

[7] In shorter time periods in low lying and poorer areas particularly low lying Island states and countries such as Bangladesh.

The model we used included a wide range of impacts and allows policy-makers to measure much of what counts rather than just counting what can be measured but many risks and potential costs are still excluded. In its construction it is based on the existing impacts literature and is thus in line with the cost estimates relative to temperature change in the literature. Many approaches do not include important impacts and effectively assume they are zero. Our estimates still exclude social contingent impacts such as the impacts of large-scale migration and conflict so is likely to be an under-estimate as so much is left out. Incorporating the latest science and the economics of risk does mean that the impacts at higher temperature are more likely to be triggered increasing average cost estimates.

Responding to developments in the science the Review, I believe, added considerable value to the economics of climate change by incorporating the economics of risk. Understanding risk and incorporating the full range of risk when making decisions is desirable when making sound policy decisions. Rather than using point estimates the Review incorporates probabilities and thus the worst- and best-case scenarios, and has explicitly built in aversion to risk. Risks and uncertainties should be the heart climate change modeling. It is this that concerns many people and it is important that economics reflects the distribution of potential impacts as otherwise the numbers are biased downwards.

Probabilities of temperature change from the science allowed outcomes to be weighted by their likelihood to ensure they are included in a balanced fashion. For climate change the damages increase more rapidly as temperatures rise. The distribution has a long tail so there are low probability high impact effects and these pull the average upwards. This is preferable to using a point estimate that does not include the full range of risk. The review also includes an aversion to large losses, as people routinely do in their daily lives, for example, in buying insurance. People are risk averse about a low probability of their house being destroyed and hence purchase insurance.

The modeling in the Review, using the PAGE model, assumed adaptation to 90% of the impacts of climate change in developed countries, but only adaptation to 50% of the impacts in developing countries where capacity to adapt is lower. Some have criticized this as being too optimistic (i.e. overstate the degree of adaptation and this underestimates damages). It is important to recognize that adaptation is not costless and that adapting to the impacts becomes increasingly difficult and more expensive as temperatures rise.[8] Our modeling does include the costs of adaptation though we do assume it is relatively cheap. Other approaches do this implicitly with lower impacts. Unless added later this removes the cost of adaptation from comparisons between costs and benefits of action.

Further sensitivity analysis on assumptions and modeling is available in the postscript and subsequent papers.[9] This shows that our main conclusions from this exercise—that the costs of strong action are less than the costs of damage avoided—are robust to a range of input assumptions. The question should be as to why the earlier estimates are so low. The main answer is that they ignored risks that we now know to be real and underestimated emissions.

Question 2. Notable economists have written that the Stern Review drew selectively from studies of the impacts of climate change, emphasizing those with high damage estimates—even when the studies were highly speculative.

Did the Stern Review intentionally seek studies that supported the worst-case scenario? If so, is this accepted practice among economists?

Answer. The Stern Review did not select the studies with worse case scenarios. It used only peer reviewed science and all key scientific assumptions have since been endorsed by the Working Group 1 report by IPCC[10] released in February 2007. The Stern Review only summarized the science. The IPCC remains the most comprehensive summary of the science and the Review team took advice from its con-

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[8] Adaptation costs are convex—see Box 3.1. As an intuitive example consider the following illustrative escalation of costs relative to temperature: at between zero and two degrees warming, agricultural output can be adapted and crops can change; some regions will see higher yields and longer growing seasons, levies can be strengthened and irrigation projects enhanced; between two and four degrees warming, new agricultural plant and processes may be required, levies and barriers must be rebuilt and new irrigation sources found; between four and six degrees some coastal areas must be abandoned and populations moved and former agricultural land must be abandoned. It is clear that the costs and impact of residual effects and adaptation costs are highly disproportionate—convex—to the linear change in temperature. Five degrees C temperature change would redraw the physical geography of the world and thus the human geography. It would ultimately lead to population movements on a massive scale that would inevitably entail great costs.

[9] www.sternreview.org.

[10] Inter-governmental Panel on Climate Change www.ipcc.ch/SPM2feb07.pdf.

tributing scientists to ensure that the Review was based on the best available science.

The Stern Review presented the impacts in two general forms, firstly through a disaggregated analysis based on peer-reviewed literature and secondly, through integrated assessment modeling. Neither of these approaches focused on worst-case scenarios.

- The disaggregated analysis presented estimated ranges of damages at different temperature levels for several key indicators, such as water availability and population at risk from coastal flooding. This analysis demonstrated the dependence of impacts on temperature, showing clearly that the impacts of climate change become more negative, severe and widespread as temperatures increase. The analysis also illustrated that the risk of surprise climate events, such as loss of the ice sheets, and large-scale socially contingent effects, such as mass migration and conflict, increase as temperatures rise.
- The integrated assessment[11] made the treatment of risk explicit. It used a model that explores probabilistically the range of possible outcomes. The model is based on the existing impacts literature and is not an outlier in any sense. The task requires considerable aggregation to make it feasible.[12] This loses the important detail of the disaggregated impacts that are set out in the early part of the Review. Many costs and risks are left out (such as weakened carbon cycles) or not treated formally (such as intra-generation distribution) in this approach. Had these been included the damage estimates would have been higher.

Economic and ethical assumptions do have a significant role to play. Economic assumptions such as the emissions path were based on the latest economic forecasts (using the International Energy Agency's World Energy Outlook 2006). Ethical factors are not related to best/worse case scenarios but rather the ethics and values that underpin them. We made these assumptions explicit.

On the costs of mitigation we present the full range and are central within the literature. The subsequent analysis in the IEA's World Energy Outlook 2006 released after the report found costs to be lower than our central estimate. Any claim that the Review always using worse case scenarios is absolutely untrue.

Question 3. Why did the British Government fail to subject the Stern Review to a peer review process before it officially released the document?

Answer. The Stern Review was an independent review that was commissioned by and reported to the UK Chancellor and Prime Minister. UK Government does not undertake peer review on commissioned reviews so this was not an option. We did hold a full call for evidence that provided some significant contributions (available on our website). We published papers outlining our approach as it developed and gave many presentations around the world that made our emerging thinking clear. Stakeholders were engaged throughout the Review and drew from the vast wealth of peer-reviewed literature, as the IPCC does in its own process. In an area such as climate change where it is subject to the media spotlight there are risks of early confused coverage if the reports contents were somehow leaked. The review also had a set timetable, which would have constrained the scope for peer-review given the time needed for review of a document of this size.

While the Review did seek to build on the foundations of the academic literature on the economics of climate change its target audience was not only academics but also policymakers, business and individuals. This diverse audience means that reviewing the document from only an academic perspective may have reduced the impact on other audiences. One of the things that has pleased me most since the release of the report, is the diverse range of people from around the world that have engaged with the report.

In many ways some peer review has been carried out since the Review's release in the public domain. Immediately following the Senate Hearing I had a public seminar on the review in Yale alongside Professors Nordhaus, Yohe, Sachs, Barrett, Cline and Mendelsohn.[13] The Review has been given the attention of many critiques, which we have responded to. I believe that process showed that our analysis and conclusions were very robust. Most of the attention was focused on ethical valuations on which reasonable people can differ, but we give powerful arguments for the ranges selected. Many of the other comments are based on misconceptions and false assumptions about what the Review did or failure to read the whole report. So, fortunately, there is nothing significant that I would change if this peer review

[11] Chapter 6 of the Review.

[12] There is not a comprehensive set of global studies for each impact that allows a bottom-up cost estimate from disaggregated studies.

[13] For more details and video see http://www.ycsg.yale.edu/climate/index.htm.

had been conducted before the release of the Review, other than to include the sensitivity analysis for Chapter 6 (contained in a Postscript) in the main body of the Review.

Question 4. In your written testimony, you referred to the Fourth Assessment report of the Intergovernmental Panel on Climate Change (IPCC), stating that "the panel's central estimate of further warming for the end of this century is 4 degrees C. This would also give a greater than 50% probability of increases over 5 degrees C in the next century beyond 2100—exactly in line with the analysis presented in the Stern Review last year."

I understand that the IPCC has a longstanding policy not to attach probabilities to its distinct emissions scenarios, and moreover does not identify any one scenario as a "central estimate." The Summary for Policy Makers of the Working Group I report does include "best estimates" of temperature change for the six scenarios range from 1.8 degrees C to 4.0 degrees C. The mean of 2.8 degrees C is clearly presented in table SPM-3 on page 13.

Can you explain the apparent discrepancy between your testimony and the IPCC report?

Answer. You are correct that the IPCC does not attach probabilities to emissions scenarios.

Your quote from my testimony is missing the first part of the initial sentence, which is "If emissions continue to rise". This introduction to my statement was critical to its meaning. The Stern Review, in line with estimates from the International Energy Agency, concludes that in the absence of abatement policies, emissions of greenhouse gases will likely continue to rise at a rapid rate, roughly doubling by the middle of the century (see Chapter 7). This puts us in the range of the three higher SRES marker scenarios: A1B, A2 and A1Fl.

The average of the IPCC's 'best estimate' temperature increases for these scenarios is 4 degrees C in 2100 (adding on 0.6 degrees C to change the baseline from 1990 to pre-industrial). However, the world would see a further warming after 2100, even if emissions fell to zero in 2100. This is called the commitment to warming: the inertia in the climate system means that the world would be committed to warming for decades after atmospheric concentrations are stabilized. It is this warming that I referred to in my statement.

The Stern Review states that if emissions continue to rise, by the end of the century we would be committed to at least 50% chance a warming of 5 degrees C above pre-industrial levels. This is consistent with the findings of the new IPCC report. For example, the A1B scenario, the lowest of the three discussed above, reaches a greenhouse gas level of 850ppm CO_2e in 2100 and applying the IPCC's 'likely' climate sensitivity range, this equates to a warming of between 3.2 and 7.2 degrees C above pre-industrial at stabilization, or a best estimate of 4.8 degrees C (i.e. around 50% chance of greater or less than 4.8 degrees C). The A2 and A1Fl scenarios reach well over 1,000ppm CO_2e, giving an even greater warming. Thus, my statement of "greater than 50% probability" was consistent.

The question of probabilities associated with different emissions scenarios is an important one and is now being discussed extensively within both the science and economics communities. Our analyses, alongside others, suggest that the lower emissions scenarios of the IPCC may be optimistic, including either low levels of economic growth or some sort of exogenous technological progress that allows emissions to fall autonomously.[14] Technological progress that substantially reduces the carbon intensity of economic growth seems unlikely without a pull from mitigation policies. Lower emission scenarios also mean that the cost of abatement is far cheaper than we estimated. Since emissions fall anyway reductions would be cheap and to a large extent free. The emissions scenario we chose did mean relatively higher temperature change but also implied that more mitigation was required.

The scenario we chose has a plausible emissions path and thus impact estimates but does incorporate questionable population assumptions that can have an effect on the impacts calculus if they were brought in line with latest U.N. estimates.[15] Estimating emissions scenarios is an unenviable task that may be re-visited before the next IPCC report. The IPCC scenarios were developed in 1997 and subsequent growth in energy demand in rapidly growing developing countries since then is one of the reasons why the higher scenarios look more plausible. We did not create a new scenario for our modeling, as it is important to ensure that there is com-

[14] Lower scenarios are manifestly implausible as assumptions of business as usual—they are likely to involve policies of the kind we discuss.

[15] This is explored in the sensitivity analysis on our website and further emission scenarios will be the subject of future analysis.

parability with scientific estimates (which are based on the specific scenarios used by the IPCC).

Question 5. If the world economy continues to grow, then future generations will be far wealthier than people are today. Future generations will also have more technology options for responding to climate change.

Doesn't it make sense to share the burden with future generations who in many ways will be better equipped to address it?

Answer. The modeling in the review does share the burden with future generations. All modeling in the Review incorporates the fact that future generations are expected to be richer: economic growth implies discounting precisely to take account of the higher incomes of future generations. The extent to which future generations are better off controls the extent to which we discount costs and benefits in the future.[16]

Climate change has a non-marginal impact on growth as it can affect future growth rates. To reflect this correctly when estimating costs in the future we discounted each of the thousands of the model runs on the basis of the growth rate in that run. This is a more accurate approach, but it is more complicated and has led to some false assumptions from commentators over discounting in the Review's modeling.

The cost of mitigation is expected to remain at around 1% of GDP so it remains a relatively constant share of GDP as people get richer, spreading the burden across generations. The mitigation paths[17] generally assume a slowing of emissions growth before increasing reductions before leveling off in the future. This path spreads costs: Initial reductions are smaller while mitigation technologies are developed but subsequent steady declines place pressure on future generations as low hanging fruit are taken earlier so it becomes harder and potentially more costly to get the final reductions requiring advanced technologies in the future.

The cost of mitigation may be shared between generations but the cost of climate change impacts are not. The long-term nature of the impacts of greenhouse gases in the atmosphere ensures that the cost of actions now will be felt for more than the next two centuries. So we are asking to share the burden of mitigation but ensuring future generations bear the burden of emissions we release in terms of impacts and adaptation costs.

There are many legitimate differences between climate change and traditional project appraisal involving an investment marginal to a growth path. As discussed, the outcomes with climate change are non-marginal as it can affect growth. Many impacts are also irreversible and the costs of overcoming many others will be very high. There are a number of reasons why a smaller scale project such as a new road may not be as valuable, or indeed relevant at all, in several years time as circumstances change. However, avoiding the impacts of climate change (the value of a stable climate, human life and ecosystems) are likely to continue to be relevant. The planet is unlikely to vanish (abstracting from climate change itself here). Further, as people become richer and environmental goods become scarcer it seems likely that, rather than fall, their value will rise very rapidly. Thus investing elsewhere and using the resources to compensate any later environmental damage may be very costly. This is not yet reflected in the modeling but is likely to be important in determining the value of impacts over time.

Though experts may differ over the initial pace and scale of emissions reductions, all economists agree that for any given target it is cheapest to start now. Failure to act strongly enough eliminates options we may retrospectively have preferred.

RESPONSES OF SIR NICHOLAS STERN TO QUESTIONS FROM SENATOR MARTINEZ

Question 1. I am concerned about the impacts of climate change. I believe it is happening and that humans at some point play a part in its exacerbation. I think you will find a lot of members on this Committee who share that opinion, but like me are confronted with a variety of proposals about what to do about it. Given the large amounts of legislation that have proposed cap and trade programs, how would you go about creating a carbon regulatory program that would not negatively impact the U.S. economy?

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[16] There is also a cautious estimate that we will not be around in the future that is included and assumptions on attitude to risks and inequality (the Elasticity of Social Marginal Utility of Consumption) also have an impact and along with other issues on discounting are explored in far more detail in Annex A of Chapter 2, the postscript and subsequent papers available on the internet.

[17] As illustrated in Figures 8.4 and 8.2 and from technology approach to modeling Figure 9.3.

Answer. While mitigation will have some costs, only extremely badly designed or drastic and rushed policy action could have a major negative impact at a macroeconomic level. The effect will be modest rise in costs but not enough to have an effect on growth of any magnitude across the economy. It would be more pronounced in a very limited number of 'carbon intensive' sectors. This cost is a good investment against the potential impacts of climate change. Having explored the costs of mitigation we concluded that the costs are likely to be in the region of 1% of GDP in 2050. This is equivalent to a 1% increase in a cost index: that is the sort of thing economies react to all the time such as a result of exchange rate fluctuations. This is not the sort of effect that can derail growth. There is some uncertainty around this figure of around +/−3% but the extremes of this range are unlikely. Successful innovation could lead to a negative cost (boost growth due to a 'Schumpetarian' burst of innovation) but conversely a lack of progress could increase costs.

Some policy actions may lead to rapid positive returns such as through improved energy efficiency. It is also important to consider the long run as well as short-run impact on growth and competitiveness. Failure to address the cost of emissions now will allow investments that lock-in a high carbon infrastructure, that would not be competitive in a move to a low-carbon world and risk costly premature retirement of investments. It would also fail to spur the innovation and expertise in sectors and products that are would dominate these sectors in such a world.

If policy-makers are specifically concerned about competitiveness it is important to get quantitative. Many "competition" claims are without numbers and refer to very narrow sectors of the economy. The 1% additional cost is very small compared to wage differentials between rich and poor countries. There are only a limited number of traded sectors where energy costs have a significant impact on prices. Even in these sectors studies show that environmental legislation has not traditionally played a major role in site location. Concern over competitiveness impacts should be harnessed in the push for international policy mechanisms, as this is the easiest way to avoid distortions and provide suitable incentives. It is possible to achieve this in the absence of over-arching carbon constraints such as through sectoral agreements (explored in Section 23.5). These can help prevent distortions and encourage participation of developing countries for this limited section of their economy. This is made more feasible by the prevalence of large multinational firms in these sectors. Alternatively it is possible to consider the allocation or tax treatment of vulnerable sectors, but this must be set against the long-run implications in these sectors of shielding them from the environmental cost.

Mitigation policy should look to address emissions from all sources and ensure that instruments gain benefits from scale but, where appropriate, are also tailored to the idiosyncrasies of individual sectors. Effective design of policy structures outlined in Part IV of the report. They include pricing the carbon, spurring technological innovation and removing barriers and changing behavior to reduce deforestation and improve energy efficiency. Within this framework it is important to look to make instruments international in the future to reduce costs and reinforce international action. This is explored in Chapters 22-24 of the Review.

Question 2. The Stern Report has received criticism from the Economist, the Copenhagen Consensus headed by Bjorn Lomborg, as well as other economists for either putting too much of the emphasis of climate change abatement on rich Western nations or not enough focus on the developing world. How would you respond to that assertion?

Answer. I had thought that Bjorn Lomborg's critique was more focused on his belief that climate change is less important to tackle immediately than many other world problems such as aids and malaria. I am not aware of specific criticism from these sources concerning the balance between rich Western nations and the developing world but I will address this shortly. But let me begin by stating why I think Lomborg's analysis, under the guise of the Copenhagen Consensus, was deeply flawed in many ways.

Many of the economists that participated in that process said afterwards that climate change should not have been on the list of issues considered—it is incomparable in so many ways with the other issues. His approach asks the wrong question. Correcting an externality is not like spending public money and does not come from a limited pot of finance. Requiring decision makers to reflect their impact on others is basic market economics.

The techniques used in the analysis are badly applied. They fail to deal with many dimensions of the problem such as the economics of risk (possibility of large temperature change and severe impacts we now know are possible) and the urgency of the reductions to achieve stabilization (costs of action for any stabilization level rise rapidly and ultimately become impossible if action is delayed). Indeed Lomborg's analysis truncates the kinds of spending that could be made; on aids and

malaria it was only preventing the spread of the disease not eliminating it. More importantly, the analysis did not take account of the fact that dealing with climate change itself can help deal with many of these problems in the future. The impacts of unmitigated climate change on health could be very severe, particularly in developing countries. It is not a discrete choice between competing options—tackling climate change has many, varied co-benefits.

Your question raises the issue of equity of effort between rich and developing nations. Several ethical perspectives have been advocated at international discussions—historical responsibility, per capita rights, ability to pay. All of these endorse the notion of "common but differentiated responsibility" recognized in the United Nations Framework Convention on Climate Change (UNFCCC). This discussed in Part VI of the Review—Chapter 22 in particular. The different ethical perspectives all point in a similar quantitative direction: Developed countries should take responsibility for reductions of around 60-90%[18] in 2050 as art of a global reduction of 20-30% to achieve 550ppm CO_2e.[19]

Asking poorer people to pay a proportionally larger share of the cost of avoiding a problem others played a larger role in would seem unethical to many. However, the equity split advocated above does includes significant reductions from these countries relative to business-as-usual. Developing countries have an active stake in a desirable stabilization outcome and should be prepared to contribute subject to an equitable allocation of costs. Much of the review addresses the challenges faced by developing countries (e.g. Chapter 20) and how to reduce emissions in these countries (e.g. Chapter 23).

Developing countries give priority to securing the economic growth to lift their people out of poverty: their efforts should be supported. Strong targets and carbon trading in richer countries can generate private flows of capital that can support emissions savings and investment in low-carbon infrastructure in developing countries. The scope for countries free-riding on a global problem means that it is important to create the conditions where all countries will be moved to participate. Equity considerations will be crucial given the history of rich country emissions.

Question 3. It is my understanding that the basic premise of the Stern Report is that our international response should act similarly to an insurance policy—pay some now to avoid big problems later. Considering that its recommendations urge spending 1 percent of global GDP per year (roughly $450 billion) to prevent climate change, how would nations be forced to comply? How would nations respond during economic downturns or recessions? Would other nations be required to pick up the difference if another country experiences severe economic circumstances?

Answer. Answered in combination with [sic.]

Question 4. Who would control the collection and allocation of funds to combat climate change under the Stern Report model?

Answer. It is important to be clear the 1% of global GDP is not a bill to be paid but rather an incremental cost that is spread throughout the market. It is not a measure of government spending but rather the additional cost of a low-carbon economy which affects people largely through price, tax and regulatory system. Taxes, trading and regulation all encourage firms and individuals to chose low-carbon approaches at an additional cost (though as discussed earlier this may prove to be at negative cost through innovation or energy efficiency savings). This also applies to deployment support for low-carbon technologies for which the costs are usually passed directly onto the consumer. These funds are not collected but allocated through the power of the market (if using market instruments). Depending of the choice and design of the carbon pricing policy tool, this can lead to transfers to governments in the form of revenue, but these are not a cost and are assumed to offset costs or taxation elsewhere.

One of the advantages of international emissions trading is that the market helps reduce emissions wherever it is cheapest, allowing flows to developing countries to be managed by the market minimizing total costs. Using tax instruments requires politically sensitive transfers to achieve this and recipients to use these funds effectively.

Furthermore, mitigation policy is likely to be counter-cyclical in that it does not exacerbate economic upturns or downturns but serves to moderate them slightly. At times of recession, the reductions in economic activity and reduced consumption ensure that emissions target are easier to meet and may provide a resource in trading schemes. In times of boom the targets are more stringent, but there is extra resources available to cover any additional costs.

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[18] Not necessarily within their own borders.

[19] Which is at the top of the range of stabilization goals we suggest—between 450 and 550 ppm CO_2e.

There are some areas where direct public support is required to support the introduction of public goods such as at the R&D stage of innovation and adaptation. As outlined in Chapters 23 to 26 there is an international element to these public goods that can be supported by international co-operation. This can generally be done through existing multilateral organizations. This may involve expanding their role and capacity and there may be some cases where separate agreements and institutions may be preferable. In the case of developing fusion technology[20] the scale of the costs ensured an international approach was preferable and the EU, U.S., Russia, China, India, Japan and the Republic of Korea agreed terms to split the costs. International agreement can reduce duplication, reduce costs and increase the scale of action by spreading the risk.

International agreements on emissions reductions are useful in building a shared understanding of appropriate action and building confidence in markets on the future direction of policy. Building a powerful enforcement mechanism is likely to be very difficult in the medium term. Formal compliance mechanisms are likely to only be effective for specific and limited infractions. However, we argue that such a mechanism is not necessary since the will of the domestic population and the desire to behave in a responsible manner is the most effective enforcement mechanism. Global public concern and awareness about climate change are growing rapidly. They both influence and sustain international co-operation, national aspirations and private sector leadership on climate change. Countries failing to act in a responsible manner will be pressured by their population and may damage international relationships elsewhere. California, France, the EU and China are all examples of countries or regions taking on stringent targets or policies without international agreements underpinning them.

Question 5. One figure that is often quoted by some critical of the Stern Report is the "social cost" of carbon dioxide. Under the Stern Report, that comes to $85 dollars a ton while the Yale economist William Nordhaus has determined that cost to be $2.50 per ton. Why is there such a large difference in these approaches?

Answer. It is very important to be clear exactly what the social cost of carbon relate to. The estimate you quote from our report relates to the business-as-usual social cost of carbon (the cost if we do nothing to reduce carbon emissions) for a more "sensible" path of emissions, stabilization at 550 ppm CO_2e, we estimate the cost to be around $30 per ton of carbon dioxide. Figures from Professor Nordhaus relate to an "optimal carbon price" which is the damage cost under what the model estimates to be the most efficient mitigation path. The comparison is not life-to-like and business as usual (no policy) estimates of the social cost of carbon will always be higher than under a policy path since the aim of the policy is to reduce the damages. More recent estimates from an updated model by Professor Nordhaus are higher than $2.50[21] per ton of carbon dioxide at $4.67 per ton of carbon.[22]

The reason our estimates are higher than much of the existing literature have been outlined earlier and are, I believe, for good reasons. Estimates of the social cost of carbon are heavily dependent on the modeling approach. Previous low estimates reflect high discount rates, omitted impacts and significant benefits from warming in the early decades.

Recently Professor Ackerman published a paper[23] using different variables in Professor Nordhaus' model and produced much higher estimates. Professor Sachs added what he believes are more plausible and up to date variables in the same model and reached figures much closer to our own. This highlights the importance of using models as a tool highlighting potential scale and what the important variables are. The ethical and structural parameters both have a significant impact on estimates of impacts. It is important to consider carefully the variables used, whether they are accurate or uncertain, and the implicit ethics of different approaches.

The social cost of carbon is a useful indicator but using it for policy is subject to a number of further considerations.[24] Our approach to pricing policies was different because of the constraints and uncertainties in estimating a social cost of carbon. We advocated the approach of picking a stabilization goal, which leads to a quantitative target and using the power of the market to determine the prices to meet this target. Market instruments determine the cost of reaching the target, an ap-

[20] www.iter.orq/.

[21] In his comment on the Stern Review he outlines the optimal carbon prices in the DICE-2006 model as being $17.12 in 2005 $84 in 2050 and $270 in 2100 (all per ton of carbon).

[22] Equivalent to £4.67 per ton of carbon dioxide.

[23] Ackerman, F. and Finlayson, I (2007) The Economics of Inaction on Climate Change: A Sensitivity Analysis, Climate Policy 6:4.

[24] Such as problems in quantifying many of the expected impacts of climate change. Other factors that suggest that the social cost of carbon cannot be assumed to be a suitable level of taxation. See section A7 of Paper A: The case for action to reduce the risks of climate change.

proach that bypasses the social cost of carbon. Comparison with estimates of the social cost of carbon is one of the ways of considering whether the goal is too stringent or not ambitious enough when this goal is under periodic review.

Question 6. When conducting economic analysis of the future impacts on climate change, what type of prognostications are usually given for hurricanes and other unforeseen weather disasters?

Answer. Basic science and climate modeling points towards an increase in the prevalence of many types of extreme events as the world warms. This includes intense hurricanes (and tropical storms in general), heat waves, heavy rainfall events and droughts. It remains unclear how the numbers and paths of hurricanes will be affected.

There has been significant debate over current trends in hurricanes. The IPCC concludes that there is evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, in line with rising tropical sea surface temperatures, but no clear trend in the number of hurricanes.

The economic impact of hurricanes is very sensitive to even small increases in intensity. This is well understood from studying past events. One study found that an increase in intensity of 5-10% leads to costs doubling. Thus, future warming could cause significant effects. One study found that a doubling of CO_2 levels would lead a 6% increase in the intensity of hurricanes, but this remains highly uncertain. Based on current knowledge, the cost of extreme weather events, including hurricanes and many other weather events, could rise to 0.5% to 1% of global GDP by the middle of this century. It should be noted that adaptation is a key factor in predicting future hurricane risks. For example, much of the current increase in damages from hurricanes is thought to be associated with the increase in population in hurricane risk areas.

RESPONSES OF HENRY D. JACOBY TO QUESTIONS FROM CHAIRMAN BINGAMAN

Question 1. You say that capping greenhouse gas emissions is a useful way to think about long-term objectives in dealing with this risk. What about in the short-term? Is it feasible, or economical to make some of the drastic reductions that are being called for within the next decade?

Answer. It is not feasible or economical, or indeed even necessary, to make drastic reductions within a period as short as a decade. Climate change is a century-scale problem and the urgent need in the current decade is to get started on policies that will raise the price of emissions and augment efforts to develop low-emitting technologies. These early efforts can then lead to drastic reductions below a business-as-usual path over coming decades.

Question 2. Do you have any thoughts on how the developing countries are weighing the risks of climate change against the need for rapid economic growth?

Answer. In most developing countries there is a growing cadre of environmentalists and public officials who are concerned about the climate change issue, and who argue for national policy to reduce emissions. At the level of national policy, however, the risks of climate change still rank below concern with the short-term economic well being of their citizens. This observation would apply most importantly to big countries like China, India, Brazil, and Indonesia. Others, like Singapore or South Korea, may be closer to taking action because their per-capita incomes are at a level where the issue can rise higher among social and political priorities.

RESPONSES OF HENRY D. JACOBY TO QUESTIONS FROM SENATOR DOMENICI

Question 1. A paper co-authored by Dr. Yohe criticized the Stern Report for failing to include a proper cost-benefit analysis. In particular, it notes that the analysis should compare marginal costs to marginal benefits. Instead the Stern Review compares total costs to total benefits.

If the cost-benefit analysis was done improperly, isn't the Stern review fatally flawed?

Answer. Chapter 13 of the Review contains an analysis of the benefits of moving from one level of atmospheric stabilization such as 650 ppmv to a tighter one like 550 ppmv. This calculation yields a rough estimate of marginal benefits of tighter long-term targets. The benefits of this tightening are then argued to be larger than the estimate of the cost of achieving the tighter target. This is a first step toward a benefit-cost analysis, but the Review does not carry this idea through to a complete marginal analysis. Most important, this component of the Review is confined to Chapter 13 and is not prominent in either the Review summary or in press coverage.

Whether because of this crude benefit-cost approach the Review as a whole is "fatally" flawed is quite another question. Its intent, in my view, was to raise the public visibility of the issue and argue that corrective actions would not be economically disastrous. In that sense the report can be argued to have achieved its objective.

Question 2. Could you please explain why it is difficult to calculate the economic cost of extreme, but highly unlikely, events?

Answer. Two types of information are required to support a monetary valuation of some possible extreme climate event. First, there is a need to define in a meaningful way what the event is. And second, an estimate is needed of how likely it is to occur: it makes a big difference whether it is a chance of one in 10 or one in 1,000. For some of the more troublesome potential outcomes of climate change, e.g., a rapid loss of Greenland or Antarctic ice sheets, the nature of the event and its likelihood are poorly known. In such a case these potential consequences should be prominent in any discussion of the climate change treat, but in my view their inclusion in the formal economic analysis tends to dilute the value of calculations for those parts of the problem that are well defined.

The fact that poorly understood but extreme outcomes are left outside the dollar valuation does not mean they are unimportant in climate decision-making, and here an analogy may help. The potential economic cost of the mutation to human transmissible form of the Avian flu virus is not well known: we do not know precisely how infectious the virus might become or how deadly, or how effective medicines might prove to be. Also, epidemiologists cannot give a confident estimate of how likely this mutation is to occur. This lack of specific information does not imply, however, we should be any less concerned with the threat, or less active in seeking ways to lower the risk.

Question 3. In your written testimony, you raise concerns over the methods used in the Review to monetary measures to "non-market effects."

What is accepted practice among economists for estimating the values of "non-market effects"?

Can you give us some examples, and contrast them with the methods used in the Stern Review?

Answer. The methods used to try to put dollar values on non-market effects of environmental change fall into three rough categories.

- Methods that apply indirect information from related markets, as when real estate values are seen to incorporate the value of cleaner air that may be found in some neighborhoods compared to others. Statistical methods are applied to sort out the value of clean air from the larger mix of influences that determine the market value of a house.
- The construction of surrogate markets, often using data on consumer activity that can be used to impute value to a non-market resource. Examples in this area include the use of information on the transportation expenses that people undergo to use a public park as an indication of its value to them and by extension to society, or the application of data from aspects of personal behavior regarding risk-taking and insurance to estimate a value for human life.
- The construction of hypothetical markets, through a methodology that has come to be known as "contingent valuation". Here two approaches are applied. In one, survey techniques are used to estimate what people would pay (perhaps in increased taxes) to achieve a particular environmental value, or to avoid its destruction. In a second method subjects are put into an experimental setting, trading small amounts of money in a "make-believe" market in which the environmental assets can be bought and sold. Contingent valuation methods came to prominence in the wake of the Exxon Valdez incident, when they were applied to the valuation of lost amenities and damage to native species.

These methods can be informative in application to non-market changes that are well understood and of relatively small scale (e.g., local air quality or the destruction of animal life in an oil spill). However, I question their adequacy when applied to large-scale, poorly-understood effects that may attend climate change (e.g., the loss of all arctic tundra).

The Stern Review did not itself do any analysis of this type but rather quoted results from a number of other studies, some of which used these methods and some which simply made rough guesses about the damage of climate change. Also, the non-market valuations included in the PAGE2000 model from which many of the Review's results were drawn is not sufficiently well documented to support an evaluation of the procedure employed.

Question 4. If the world economy continues to grow, then future generations will be far wealthier than people are today. Future generations will also have more technology options for responding to climate change.

Doesn't it make sense to share the burden with future generations who in many ways will be better equipped to address it?

Answer. Our generation will without doubt share the burden of any emissions mitigation with future generations as most studies show that the cost of reducing emissions continues into the future, with the magnitude of the task increased by growing population and rising incomes. Also, future generations will not have an opportunity to share the costs of climate damages in our current one. The question, rather, is how long our generation should wait before taking substantial action to reduce risks for future generations—which of course include our current children and grandchildren among those to come later. Because of the stock of long-lived greenhouse gases we are building in the atmosphere the longer we wait to begin emissions mitigation the more difficult the task we pass on. Also, although we hope our R&D our investments will yield much cheaper mitigation technologies we cannot know for sure that this form of technical fix will appear. Finally, although future generations probably will be wealthier than ours, and better able to deal with market-based effects of climate change, there likely will be effects on the natural environment which they will have no ability to correct or to compensate by their greater wealth.

RESPONSES OF HENRY D. JACOBY TO QUESTIONS FROM SENATOR MARTINEZ

Question 1. I am concerned about the impacts of climate change. I believe it is happening and that humans at some point play a part in its exacerbation. I think you will find a lot of members on this Committee who share that opinion, but like me are confronted with a variety of proposals about what to do about it. Given the large amounts of legislation that have proposed cap and trade programs, how would you go about creating a carbon regulatory program that would not negatively impact the U.S. economy?

Answer. Any carbon regulatory program will have impacts, both negative and positive, on particular sectors of the economy and regions of the country. But a well-designed policy need not have a substantial impact on the economy as a whole. A study carried out for the U.S. Climate Change Science Program indicates that the U.S. would continue to experience healthy economic growth even under ambitious targets for emissions mitigation.[1] If the policy is well designed the concern need not be with risk to the national economy but rather the compensation of those who may be hurt as the economy adjusts. A national policy that would minimize economic cost but achieve environmental objectives would start with a relatively low price on emissions, say in the neighborhood of $10 per ton CO_2-equivalent, and establish a procedure for this price to grow steadily and predictably over time. This pattern of increasing stringency would allow time for the natural turnover of the capital stock and adjustments in the labor market. Complementing the imposition of a price on emissions should be an aggressive program of government-supported R&D and commercial demonstration of emissions-avoiding technologies.

Question 2. The Stern Report has received criticism from the Economist, the Copenhagen Consensus headed by Bjorn Lomborg, as well as other economists for either putting too much of the emphasis of climate change abatement on rich Western nations or not enough focus on the developing world. How would you respond to that assertion?

Answer. The Stern Review calls for universal participation in greenhouse gas mitigation and attempts to show the advantages to the global economy if it can be achieved. Like almost everyone else dealing with this issue, however, the Stern Review authors do not have a clear plan of activities that will bring all nations to take mitigation commitments in the short term, although they do suggest that direct aid to developing countries may be useful, and that nations may be brought to control emissions through participation in a global emissions trading mechanism. Rather, the focus of the Review is on the essential first step in achieving some sort of global response, which is for the rich countries to take greater action than now. Clearly, developed countries like the U.S. can be expected to go only so far down the path the Review recommends without a substantial response by major developing countries, but without such leadership universal participation likely is impossible.

Question 3. It is my understanding that the basic premise of the Stern Report is that our international response should act similarly to an insurance policy—pay some now to avoid big problems later. Considering that its recommendations urge

[1] See U.S. CCSP [Climate Change Science Program], 2006: U.S. Climate Change Science Program, Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations (L. Clark, J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels). http://www.climatescience.gov/Library/sap/sap2-1/sap2-1a-draft3-all.pdf.

spending 1 percent of global GDP per year (roughly $450 billion) to prevent climate change, how would nations be forced to comply? How would nations respond during economic downturns or recessions? Would other nations be required to pick up the difference if another country experiences severe economic circumstances?

Answer. As with all international agreements there is no global institution that can force sovereign nations to comply. Incentives can be given through diplomat pressures or threats of trade restriction, but the participation in an international effort by any individual country ultimately will be determined by its perception of the effect of climate change on its own national interest. This is the core of the climate change problem. Nations have found it to be in their interest to participate in community responses to environmental issues that are similar to the climate threat, such as the Montreal Protocol, the Whaling Convention, etc., but the greenhouse gas control problem is a larger and more complicated challenge.

Regarding the response during recessions: over the past fifty years these types of economic fluctuations have been relatively short term in duration, lasting from a few months to a year whereas greenhouse gas control policies are longer-term measures, gathering in intensity over decades. In a recession pressure might arise to relax some aspects of greenhouse gas control policy, but we would not likely see a frontal assault on the whole campaign. Similarly, I would not expect provisions of an international regime to change in the face of one or more of its parties experiencing short-term economic difficulty, or that other nations would be expected to take additional effort while one was in difficulty. Indeed, during a recession emissions tend to decline, so it likely the troubled economy would likely over-comply during such a period.

Question 4. Who would control the collection and allocation of funds to combat climate change under the Stern Report model?

Answer. The Stern Review does not recommend a new international institution that would collect funds to fight climate change. It does support a continuation and augmentation of the existing Global Environmental Fund to which countries make voluntary contributions, and it calls for increases in bilateral aid and technology transfer. The proceeds of an emissions tax, or revenue from a cap-and-trade system with auctioning of permits, would accrue into the treasury of the implementing country. Proposals have been put forth of an international agency funded by mandatory taxes on individual countries, or their international emissions trades, but these ideas have not gotten serious attention in international discussions and the Review does not argue for this approach.

Question 5. One figure that is often quoted by some critical of the Stern Report is the "social cost" of carbon dioxide. Under the Stern Report, that comes to $85 dollars a ton while the Yale economist William Nordhaus has determined that cost to be $2.50 per ton. Why is there such a large difference in these approaches?

Answer. Several differences among these two studies, including the estimates of future damages, contribute to this variation in the estimate of the social cost. But the overwhelming source of the difference is the discount rate. The Stern Review applies a much lower discount rate than does the Nordhaus study, and Stern discounts damages that are occurring over many future centuries, leading to a much larger marginal cost for an additional unit of emissions today.

Question 6. When conducting economic analysis of the future impacts on climate change, what type of prognostications are usually given for hurricanes and other unforeseen weather disasters?

Answer. Only preliminary analysis is available of the potential increase in damage from severe storms caused by climate change. There is evidence of increasing intensity of hurricanes in response to rising sea surface temperatures, but no indication of increasing frequency or knowledge of potential changes in storm tracks and likelihood of landfall. Ultimately research on this topic may produce meaningful monetary estimates of the potential damage from these consequences of a changing climate, but as of now this threat is mainly treated as a risk to be kept in mind, yet difficult to quantify. To my knowledge there is no evidence of increasing frequency or intensity of tornadoes. Attempts have been made to calculate potential effects of increased frequency of floods and droughts, although these threats also are difficult to quantify in monetary terms because of uncertainty in projections of climate change at regional scale.

RESPONSES OF GARY YOHE TO QUESTIONS FROM SENATOR DOMENICI

Question 1. The value of the "social discount rate" is clearly important in estimating damages that occur in the distant future. We've heard that the Stern Review made a controversial choice for this value. Should the Stern Review have included

a discussion of how sensitive the cost estimates were to the choice of the discount rate?

Answer. I think that it was almost irresponsible not to do so. Tjalling Koopmans, a Noble laureate economist who was expert in optimal growth and discounting often remarked that reporting the results of a discounting exercise should always include a sensitivity analysis because the answers to any discounting question were so highly dependent on the underlying discount rate. Indeed, the relative valuations of alternative investment projects can be altered by the choice of a discount rate.

As indicated in my testimony, many economists have highlighted this issue in the Stern Review. In our own deconstruction of the underlying model—a simpler version calibrated to a 5.3% discounted damage estimate for a discount rate of 0.1%, Richard Tol and I have shown the following correlation:

[Amounts in percent]

Discount Rate	Discounted Damages[1]
0.01	5.4
0.1	5.3
1.0	3.6
3.0	1.6

[1] Calibrated in lost "certainty equivalent per capita consumption".

It is clear from these calculations that the rate used by the Stern authors was so low that it was nearly impossible to produce bigger damage estimates. Moroever, assuming the more conventional 3% would reduce damages even given the Stern calibration by almost 70%. A postscript to the Review does report the results of a sensitivity analysis; their results are entirely consistent with the ones quoted above.

Question 2. The Stern Review authors claim on their website that their damage estimates are higher than other studies because the Review uses more recent literature from the science. But a leading expert, William Nordhaus, contends that their higher damages are based on their choice of discount rate—not on new scientific findings. Which do you believe to be true?

Answer. I have known William Nordhaus for more than 30 years, and we have had several discussions about the Review. We were on the same panel discussing the Review at Yale University of February 15, 2007—the academic exercise about which Sir Nicholas spoke during his testimony. Truth in advertising—Professor Nordhaus and I have done a lot of work together over the years. He was a reader of my PhD dissertation at Yale; and I am in the climate field because he phoned in 1982 to invite my participation in the preparation of Changing Climate—one of the National Academy's first analyses of the climate problem.

I am convinced that the choice of discount rate is the primary reason why the Review's estimates are so high. There is, though, some merit to its authors' claim, especially given the way they tended to choose high-end impacts analyses when they calibrated their model. Much of the new science is high-end, of course, but not all.

Figure 1 below shows where the Stern Review's estimates fit in a survey of results published over the last 10 years (mostly over the last 5 years). Stern's $310 per tonne of carbon ($85 per tonne of carbon dioxide) estimate is at the 95th percentile among all estimates, but it is well above the 95th percentile for estimates reported in the peer-reviewed literature. Notice, though, that it is around the 80th percentile for estimates derived using a discount rate (pure rate of time preference or "PRTP") of approximately 0%. Even though none of the studies from which higher damages estimates were gleaned, this suggests that the low discount rate alone cannot explain fully why the estimate is so high.

Question 3. Should the Stern Review have been the subject of peer review before its release by the British Government?

Answer. Absolutely. Figure 1 shows clearly that its damage estimates lie outside the range of comparable estimates reported in the peer-reviewed literature. Sir Nicholas, himself, expressed interest in an ex post peer review; that is why he agreed to participate in the Yale event on the 15th of February. In his response to criticism that the Review had not been subject to peer review, he spoke of a concern about leaks to the press; but that response does not ring true to most of us. The press had copies of the Review well before the academic community was allowed access; indeed, many of us who were denied pre-release copies by the author team were able to obtain copies from friends in the media.

Question 4. If the world economy continues to grow, then future generations will be far wealthier than people are today. Future generations will also have more technology options for responding to climate change. Doesn't it make sense to share the burden with future generations who in many ways will be better equipped to address it?

Answer. Absolutely, but the critical word here is "share". Sharing does not mean postponing all expense, even if future generations will be better off. It means making prudent investments now so that the discounted cost of achieving a climate policy target is minimized across all generations. It means beginning now to minimize the risk that climate impacts that could overwhelm even future generations' capacities to adapt. It means not foreclosing the possibility of holding critical climate variables below thresholds that may trigger these overwhelming impacts. Of course, it does not mean imposing an excessive burden on present generations, either.

RESPONSES OF GARY YOHE TO QUESTIONS FROM SENATOR MARTINEZ

Question 1. I am concerned about the impacts of climate change. I believe it is happening and that humans at some point play a part in its exacerbation. I think you will find a lot of members on this Committee who share that opinion, but like me are confronted with a variety of proposals about what to do about it. Given the large amounts of legislation that have proposed cap and trade programs, how would you go about creating a carbon regulatory program that would not negatively impact the U.S. economy?

Answer. I argued in my testimony that setting the initial price of carbon in 2007 can be an exercise in determining the appropriate short-term incentives for carbon-saving investments and energy conservation rather than an exercise in "solving the climate problem". Since no policy created in 2007 will "solve the climate problem", it is perhaps even desirable to step out from under that burden to confront a more manageable near-term problem while still making progress towards an ultimate response to an evolving understanding of climate risk.

The answer to the "What do we do in the near-term?" question is to design something that will (1) discourage long-term investments in energy, transportation, and construction that would lock in high carbon intensities for decades to come and (2) encourage development of alternative energy sources, carbon sequestration technologies and efficiency.

As an example of how the first goal might be achieved, consider what it would take to make it economic to run existing natural gas-fired electric generators more, and run coal-fired generators correspondingly less (gas-fired generators emit only about half as much CO_2 per unit of electricity). Because natural gas is a considerably more expensive fuel than coal, it takes a substantial CO_2 cost to overcome this fuel cost disadvantage—about $30/tonne, on current fuel price expectations in the U.S.

On the other hand, consider pending investments to add new generating capacity in the United States over the next few decades. Much of this capacity is currently planned as conventional coal-fired technology. What would it take, in terms of a price for CO_2, to make it economic to install new gas-fired capacity instead, thereby cutting by half the carbon emissions from this new capacity? On current gas price expectations, a CO_2 price of only $5 per tonne would be sufficient to make new gas-fired generators as economical as new coal-fired plants, based on the present value of fixed and variable costs.

This number is much lower for new plants than the $30/tonne seen above for existing plants because the lower cost of building a new gas plant compensates for some of its higher fuel cost. Several factors may necessitate a somewhat higher CO_2 price to achieve this economic equivalence, however—e.g., greater fuel price volatility makes gas capacity relatively less attractive and increased gas demand might push up gas prices beyond current expectations. Even so, only a modest CO_2 price is needed to make lower-carbon gas-fired technologies attractive.

To make the full step to near zero carbon technologies (e.g., carbon capture and sequestration) would require a somewhat higher CO_2 price—estimated at around $25/tonne CO_2 by several sources. Since power generators last 30 to 40 years, if the CO_2 price increases over time, adding some cost for CO_2 emissions would make sequestration technologies attractive in the near term even if the price does not reach this "tipping point" until some years after the new plant starts operating.

The $7 per tonne of carbon dioxide charge envisioned in the legislation being considered by this Committee, if it were to climb at the rate of interest, would reach $30 per tonne after 2035—probably too late to inspire fuel switching in existing plants over the foreseeable future or much investment in carbon sequestration. It would, though, likely be sufficient to bring most of the plants constructed between

now and 2050 over to a lower carbon technology. A $15 per tonne charge in 2007 would reach the $30 threshold around 2020, and that could be sufficient to affect the retrofitting switch in most places in the very near future and inspire appropriate development of enhanced sequestration techniques.

Cap and trade systems have become the stock in trade of many who try to advocate climate policy, but this preference may be based on little more than an allergic reaction to the use of the word "tax". Since concentrations depend on cumulative emissions over long periods of time, there is no economic reason to favor a policy that would fix annual emissions in a way that otherwise minimizes the cost of hitting such a target. Fixing total emissions of any pollutant in any year of short-term period of time only makes sense if variability around a targeted average (that would improve economic efficiency) would unnecessarily increase expected damages over the long term, and this is clearly not the case for carbon emissions.

In addition, many have expressed concerns that the prices which clear cap and trade permit markets can be volatile. Volatility has certainly been the hallmark of the sulfur permit markets in the United States and the nascent carbon markets of the European Union. This Committee's proposed legislation has responded to threat of incapacitating volatility by proposing "safety valve" limits on the price of permits. Others have argued that volatility can be diminished by appropriate banking provisions. The fundamental problem with either solution, however, is that appropriate climate policy requires a clear signal that carbon will always be more expensive next year than it is today. Even a modest amount of volatility can obscure that signal.

On other hand, a tax, increasing at the rate of interest, would produce a persistent and predictable increase in the cost of using carbon that would inspire cost-reducing innovation and fuel switching in the transportation, building, and energy supply sectors of our economy.[1]

If carbon were taxed at the point it entered an economy (a couple thousand sources for the United States as opposed to millions of end-users), then it would be dispersed appropriately throughout the economy with relative prices of thousands of goods changing in proportion to the underlying carbon intensities.

Moreover, a carbon tax would generate revenue. The $15 per tonne of carbon dioxide tax noted above would, for example, generate something like $90 billion in tax revenue in the United States in 2007 if it were paid on every tonne of carbon embodied in every unit of fossil fuel consumed. This is revenue that could be used to offset the regressive nature of the carbon tax itself, by underwriting tax credits for citizens with taxable incomes below a specified level. Revenue could even be used to fund research into alternative energy sources.

A carbon tax would not, of course, provide any incentive to sequester carbon, but that can also be accomplished by appropriate use of some of the tax revenue. It should be possible to use some of the revenue to "buy back" carbon that was removed from the end of the effluent stream at a price that equals the tax applied at the beginning. Doing so would mean that the marginal cost of bringing in the last tonne would equal the marginal cost of taking it out—an efficiency criterion that "closes the loop". Interestingly, a $25-30 per tonne of carbon dioxide has been identified as the level for which current sequestration technologies might become economically efficient. Bringing these technologies up to scale would take more than a decade, of course, and large investment would be based on the same type of present value calculation outlined above. It follows that the same tax trajectory that starts at $15 per tonne in 2007 and reaches the $30 threshold around 2021 would also serve well in this context.

Question 2. The Stern Review has received criticism from The Economist, the Copenhagen Consensus headed by Bjorn Lomborg, as well as other economists for either putting too much of the emphasis of climate change abatement on rich Western nations and not enough focus on the developing world. How would you respond to that assertion?

Answer. The developing world must and will do its part, but it need not take the lead in 2007. Leadership has to be provided by the developed world, in general, and by the United States, in particular. The ideas outlined above would not do much harm over the near term, would improve our own energy security, and would show the world that we are willing to accept our leadership responsibilities. They will not solve the climate problem, though, unless they are accompanied by negotiations with and investments in developing countries designed to (1) promote improved capacities to adapt and to mitigate and (2) allow an effective "leap-frogging" of carbon-

[1] The tax should increase, in real terms, at the real rate of interest. If expressed in nominal terms, then it should increase at the nominal rate of interest.

intensive technologies that characterized economic activity at the end of the last century.

It should be noted in passing that Bjorn Lomborg's criticism of the Stern Review stopped with his concern that the damage estimates were inflated. He expressed admiration for the assessment of the underlying science and assessment of climate risk (just as he did when he commented on the Working Group 1 report to the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC) released in Paris last month). My argument before you was that this science was the basis for a case for near-term climate policy and that a least cost approach to such a policy would involve starting immediately. His concerns, therefore, do not apply to points outlined above or in my testimony.

Question 3. It is my understanding that the basic premise of the Stern Review is that our international response should act similarly to an insurance policy—pay some now to avoid big problems later. Considering that its recommendations usrge spending 1% of global GDP to prevent climate change, how would nations be forced to comply?

Answer. This question is beyond my expertise, and I have made it a practice not to respond to questions about which I am no more expert than the next person.

I have, though, used the insurance metaphor in trying to motivate the need for modest near-term policy. In those statements, the "insurance" purchased by near-term climate policy is not against the risk of climate change, per se; rather it is against the risk of costly adjustments in policy sometime in the medium term future and against the chance of rendering a policy target infeasible that might turn out to be critical. In a paper that I published in Science in 2004 (attached to this response), the near policy that minimized expected adjustment cost in Nordhaus's DICE model across 5 possible temperature targets that would be identified in 2035 (one of which was deciding that no restriction at all is required on greenhouse gas emissions) for a current distribution of climate sensitivity turned out to be $10 per tonne of carbon dioxide.

Question 4. Who would control the collection and allocation of funds to combat climate change under the Stern Review model?

Answer. To my knowledge, the Stern Review model does not presume any specific allocation mechanism; and if it does, the validity of its fundamental conclusion that there is an economic reason for near-term climate policy is independent of that mechanism. Of course, I think that the Stern Review is right for the wrong reasons, but allocation mechanisms are not part of my reasons for concern.

Question 5. One figure that is often quoted by some critical of the Stern Review is the "social cost" of carbon dioxide. Under the Stern Review, that comes to $85 dollars a tonne (of carbon dioxide) while the Yale economist William Nordhaus has determined that cost to be $2.50 per tonne. Why is there such a large difference in these approaches?

Answer. As noted in my answer to the second question from Senator Domenici, Figure 1 below displays the range of more than 100 estimates currently available in the published literature. I note above that the Stern estimate ($85 per tonne of carbon dioxide or $310 per tonne of carbon) is an outlier on the high side, especially when compared with peer reviewed estimates. The Nordhaus estimate ($2.50 per tonne of carbon dioxide or $9 per tonne of carbon) is much lower, but not as low as some (older estimates).

Why the disparity? The choice of discount rate and the incorporation of equity weights are extremely important, and both lie within the purview of decision-makers. High discount rates sustain low estimates because future damages become insignificant. Conversely, low discount rates produce high estimates because future damages are important. Meanwhile, strong equity weighting across the globe support high estimates because poor developing countries are most vulnerable. Conversely, weak or no equity weighting can produce low estimates because poor developing countries do not factor heavily in the overall calculation.

It turns out, however, that several scientific parameters that decision-makers cannot choose are even more important in explaining the variability depicted in Figure 1.* Indeed, climate sensitivity (i.e., the increase in global mean temperature that would result from a doubling of greenhouse gas concentrations from pre-industrial levels) is the largest source of variation. It is possible to derive high estimates for the social cost of carbon even if you assume low discount rates and almost no equity weighting. All that is required is the assumption that the climate sensitivity lies at the high range of the latest range of estimates. Andronova and Schlesinger (2001), for example, find that the historical record could easily be explained with

* Graphic has been retained in committee files.

climate sensitivities as high as 8 or 9 degrees Centigrade (even though the TAR reported an upper bound of 5.5 degrees).

How could one get an estimate below Nordhaus's? By assuming a high discount rate (decision-maker choice), low damages over the medium term (and even some benefits in the short term—the result of effective, timely and pervasive adaptation in developed and developing countries), and a low climate sensitivity (Mother Nature's choice, and she hasn't told us yet that this is so).

Question 6. When conducting economic analysis of the future impacts on climate change, what type of prognostications are usually given for hurricanes and other unforeseen weather disasters?

Answer. The answer here depends on the type of analysis. If it is a detailed impact analysis at a specific location over a specific period of time, then sea level rise is a driving force for climate stress. Exposure is magnified by coastal storms, and sensitivity depends on development patterns. Vulnerability analyses try to account for possible adaptations (good ones like set-back rules and bad ones like the withdrawal of properly priced insurance coverage). In these analyses, probabilistic representations of storm frequency and intensity are usually employed. With the current state of scientific debate, increases in either are usually included in sensitivity analyses around baselines that assume no change. It is important to note, however, that coastal storms become more threatening as seas rise regardless of whether or not climate change is influencing their likelihoods or intensities; a 10 foot storm surge is automatically an 11 foot surge after 1 foot of sea level rise.

Large integrated assessment like PAGE2002 (employed by the Stern Review author team) or RICE (William Nordhaus's regional model) include far less detail because they use aggregate measures of damage. There, unforeseen weather events are treated stochastically, and damages include estimates of what people would be willing to pay to have the risk eliminated—an economic construction of the sort employed by Stern in the calculation of equivalent per capita consumption.

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