Conference Transcript
The macroeconomic implications of climate action

Session 2: Is climate action good or bad for productivity and potential growth? Over what time horizon?
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Kimberly Clausing: Hello, everybody. We're going to get started on the next panel, which is about whether climate action is good or bad for productivity and growth. So, if people could settle down. All right. So, we have two speakers in this session. Philippe Aghion from College de France, Insead, and LSE will be speaking on green innovation and the energy transition. And he's going to be followed by Steven Fries, our very own Peterson fellow, who will be talking about macroeconomic implications of decarbonization.

And then our discussants today are going to be Jason Furman, who's at Harvard Kennedy School, and Neel Mehrotra, who's at the Minneapolis Fed. And so, I will just leave it at that. I'm going to be doing timing. So, for speakers, you can watch out for that. I'm going to give you five- and one-minute warnings. Philippe, are you in the room? It's your turn. He was here a second ago. Okay. We could switch the order, but his slides are up, so. You're up. Sorry. Yeah.

Philippe Aghion: No, it's okay. Thank you very much. So, thanks very much. So, it was very intimidating to be in front of such a distinguished audience. So, this is based on joint work with Daron Acemoglu, Lynn Bahaj, David Amos, and we got help also from Ali Gershan. So, in France, I don't know how in other countries, but in France, whenever you want to talk about green innovation, you face the décroissance, the people who believe in degrowth, that the solution to the climate problem is to just stop growing and go back to pre-1820 because as you know, temperature started to increase when growth took off. And that's true historically.

So, you become very easily Malthusian and anything that has to do with growth should be totally prohibited. And of course, those are Malthusian because, of course, in their world there is no innovation. And they believe in a finite world where resources are finite, where there are new sources. No new sources of energy. And when you say, well, no, the world is not finite, you can innovate to find new sources of energy, to find new ways to save energy. When you produce, to innovate in our way of producing and transporting. And that's when you introduce innovation, you stop being Malthusian, okay?

Now, in fact, it's true that if you look at the climate models, starting with Dodos, the main climate models assume exogenous technology. And there the debate revolves mainly around the discount rate. And should we act now if we believe that we have a lower discount rate or we should act more progressively? If, like Nordhaus, we believe that the discount rate is higher than what Nixon believes. And of course, in a world where you have only one type of externality, which is environmental externality, you don't need more than one instrument to achieve the first best you.

The carbon tax would do the job. But we know that the growth process is driven a lot by innovations. We are in a world with firms and firms decide not only whether to produce clean or dirty, but they're also there to decide whether to innovate, clean or dirty. So now I'll talk about climate. In a world where you have firms that make both production and innovation decisions and they can decide on whether to innovate, clean or innovate dirty.

Now, when you get into that world, and that's already the work that we did with Darren, Leo Burstein, and David, the 2012, you get various things that prop up right away. First, you have the phenomenon of path dependance in green and dirty innovation. What does that mean? It means that if I'm a firm that in the past I innovated mainly in dirty technologies, I continue innovating in dirty technologies because I tend to continue doing what I'm already good at doing and in subsequent work.

So that's we spoke about that in the in the paper with Darren, Leo, and David, but we provided evidence of the path dependance in joint work with Antoine Lopez, David Amos, Ralph Martin, and John Van Reenen in the Journal of Political Economy in 2016. And we had this kind of table here. You look at the clean patents in automotive industry versus dirty patenting in automotive industry. And the important thing is that if you have in the past, the firm or the individual innovated a lot in clean, then you have a high propensity to innovate clean.

And if you do clean minus dirty, which would be the propensity to innovating rather than dirty, it depends positively on the stock of clean innovation that you had, and it depends negatively on the stock of dirty. If you have done a lot of dirty innovation in the past, it will make you tend to innovate more dirty than you would innovate clean. So, if you put this colored minus, this colored, you see that the stock of the stock of past clean innovation have a positive effect on the propensity to innovate clean. But and the stock of dirty innovation increase your propensity to innovate dirty.

So, if we leave the world as it is firms that took bad habits, who used to innovate mainly in dirty technologies, they will continue innovating in dirty technologies. The technological gap between dirty and clean will widen up, and as a result, you may get into environmental disaster. Of course, one thing to get out of it is to is to have the carbon price and of course the carbon tax helps you. And we heard a lot about the carbon price. Of course, I am in favor of any policy should have at the heart of it the carbon tax.

So, if you increase the price that firms the fuel price that firms are facing, a higher price that firms are facing will obviously direct their innovation away from dirty into clean. So dirty in automotive industries is combustion engines. Innovation clean is more having to do with electric car innovation or hydrogen innovation. So that's the bad news is that in the past dependance if you used to innovate dirty, you innovate, you continue innovate.

The good news is that, for example, the carbon tax can help redirect innovation firms' innovation from dirty into clean. And that's the good news. Now, usually people have they say, you know, there is the big suspense with me is whether or not I will fall from stage. But here what's good is that I'm already at floor level. So, the risk is not there. So thanks so much to Jean and Adam to limit that we have the climate risk but not the risk that I will fall.

So, another implication of a of the of the innovation so the government can avoid disaster by redirecting innovation towards green. There is one implication is the act. Now you have this debate between Nordhaus and Stern because they didn't have in mind the same discount rate. Nordhaus would assume a higher discount rate of 1.5% than the 1% that Nixon would assume.

And so, in a world of Nordhaus, you would say, well, let's go progressively, because otherwise too much burden will be borne by current generations. Whereas, Stern would say, no, we have to think about the future generations more and therefore we should. We should. You don't need a microphone with me. I mean, you need a microphone because it's recorded. Oh, my God. Yes, that's right. That's an externality. Yeah, but. But maybe negative. And so there was that debate.

But you see, what made Nick Stern very happy with our research is that even when you are in a world with endogenous directed innovation, the problem is that if you don't intervene right away, firms that innovated dirty will continue to innovate dirty. The gap between dirty and clean will widen up and it will increase the cost of subsequently intervening to redirect innovation towards clean.

And so even with a Nordhaus discount rate, in a world with endogenous directed innovation, you want to act right away, even though you have the Nordhaus discount rate, you see, because the gap between clean and dirty would widen up if you don't intervene now, therefore, the cost of intervention, which is reduced growth, why is it reduced growth?

Because of course when you force firms that innovated dirty in the past to stop innovating dirty and start innovating clean, you force them to move away from something they knew very well how to do to something they don't know so well, how to do. So, of course, there is always a cost of intervention. John said that this morning. Of course, we know that there is always reduced productivity during a certain transition time. When you implement the policy, when you force firms that innovated clean, dirty to innovate, clean you, you have reduced reduce.

So, for example, you look here, you see you can see the trajectory here is when you delay policy here you have the optimal policy. And when you delay policy, output is higher growth faster. But then eventually, of course, because of the damages, in the long run, it's worse. So delaying action is good in the short run because you don't force firms to move away from things they know how well to do, which is dirty innovation. But in the longer term it's bad to delay. You see what I mean? And that's the tradeoff.

And we talk in this conference mainly about the short and medium term cost to achieve something which in the long run will be better. But for example, Michael Porter is wrong when he believes that you never have a growth loss when you have environmental policy. No, you have a growth loss, and the growth loss is there. If I act now, you see I am below. The green line is above is below the red line.

So, another implication of having endogenous directed innovation is that you need several instruments, not only the carbon tax. Why? Because you have several externalities. You have the environmental externality that you already have in the neoclassical growth model that that John spoke about this morning. And we still this glass of water. But on top of that, you have a knowledge externality, which is the path dependance. I already told you that when I innovated a lot dirty in the past. I continue to innovate dirty because I build on my previous knowledge.

So, because you have these two externalities, the environmental and the knowledge, we know that you need at least two instruments to implement the social optimum. You need the two legs. I need the Blanchard report and john and I; we were part of the Blanchard and Adam you were involved. We remember the big discussions we had with Christian Gollier and Reagan, because they were very much pro carbon tax only. And we told them with Nick and Peter Diamond, no, you need more than one instrument. You need a carbon tax and something else.

Call it subsidy, call it industrial policy. And the basic reason is because you are in a world where you have more than one externality. So that's just to lay out the ground. And now I will focus on this research which I'm doing with Acemoglu Barrage and Amos, and we hope to finish up the paper within a month. We've been five years working on this paper. And what we do there is we introduce an intermediate source of energy, think of shale gas.

And the question is, should we subsidize production and research in that intermediate source? And so first we think you can do is to analyze the effects of an exogenous improvement in the extraction technology for gas. We call that the shale gas boom on aggregate pollution in the short and long run. So here you have a think of discrete time economy and the final good is produced with a production input, which is the YP. There is no point pointer. Yeah, there is a pointer. Wow. Beautiful. And you produce it with an energy aggregate. And this here is the damage from carbon concentration.

So, you have a damage term which we borrow from the work of John and his coauthors. And the damage and the carbon concentration, the carbon stock is evolves dynamically as a function of pollution in past periods. And that's exactly taken from Golosov et al. And so, you have this production technology. And so now I zoom on the energy part of it, which is here. And the energy part is that you have an energy, you can produce energy, you can produce electricity with coal or with or with natural gas, which is that that coal is here.

Natural gas is here or with green energy, which is here. And you produce each type of energy using an energy input. Think of a plant and extraction, okay, which is here and the use the extraction, of course, whether you extract coal or natural gas or green, the amount that you extract and use lead to pollution. And of course, we assume that you have higher pollution on the extracted coal than you have on the extracted gas and which and no pollution on the extracted green. And that's how you get the Ps.

So, you produce the electricity using extracted resource that you process in a plant, which is the Q part. So now the Q part there you have inputs in the plant, and you can and the inputs you use labor to be to be produced. And we assume that there is innovation, quality, improving innovation that makes it easier to produce those inputs. And so, the source of growth in this model is innovations that improve the inputs or the make cheaper inputs to operate the plants.

So that's what the innovations are innovations they turn a into gamma A where gamma is greater than one. And that's the source of. And so, what we want to look at the end is we say suddenly there is a shock that makes it easier to extract shale gas. What will be the effect of that shock on the innovations of the machines in the in the in the power plant with coal on the machines, in the power plant, with shale gas and on the machine, with the power plant, with the with green. And that's what we are after.

So, we have we call B the extraction productivity. We take it to be exogenous. BC is the productivity for extracting coal. BS is the productivity in extracting gas. And we assume that for green, in fact you don't have to extract you have we abstract from it? We also say there is a BG, and the shale gas boom is an exogenous increase here in BS. And what we try to look is that when you increase BS, what will be the effect on endogenous innovation in each type of power plants?

So given that you have, of course, one thing, that you have a lot of technology. Given that your technology, the effective productivity of energy of type I will be the harmonic mean of the power plant, technology productivity and the extraction productivity. Yes. Five minutes. I need a bit more. I'm sorry. Yeah, this was just the introduction. I was just -- yeah, we need a bit more than five. So now in this model, you have short run and long-term effect of a shale gas boom.

In the short run, the shale gas boom in the short run means I abstract from innovation. I just look at the immediate effect of the shale gas boom. You have two effects. One effect is that you substitute gas for coal because gas is less polluting, pollution will go down. That's the substitution effect. But on the other hand, you make energy at large cheaper because you have a bigger supply of energy that will create more demand for energy, more consumption that induces a scale effect. The scale effect is bad for pollution.

So, the short run result of the boom is the result of these two counteracting effect substitution and shale scale effect. It turns out that if gas is sufficiently cleaner than coal, substitution effect dominates. And in fact, we show, we calibrate our model, and we show that indeed what happens when you have the shale gas boom, the emission intensity, how much emission per unit of electricity that goes down a lot. Of course, energy consumption goes up indeed, because the price of energy goes down. But you see the intensity effect, the substitution effect more than counteracts the scale effect.

And overall, the good news is that indeed the short run effect of the shale gas boom was to reduce pollution. And it's exactly what you see. You can see that the CO2 emission that increase up to the before the 20 tens it went down thanks to the shale gas boom. You see, I mean, even though you had the scale effect, the substitution effect was so big that it really made the emission go down after 2010.

So that's what we so really the data match the prediction of the model. So now what are the long run effects? The long run effect is that there we looked at innovation. So, we have endogenous innovation. You have scientists, they can decide whether they want to innovate on machines that produce that work, that are used in fossil fuel plants, which is coal or shale gas plant, or if they want to work on machines to improve machines in the green technology.

And so, each scientist has a probability of success on Technology I, which is this the minus side there reflects the fact that you have congestion where you have too many researchers already there. The marginal productivity of each research scientist working in that sector goes down. And when you innovate, but you generate a patent, and you get a monopoly right and you get profit from this patent, and this is the prospect of these profits that make you decide or not to innovate.

And so, what happens then is that you compare If I am a scientist, I decide to innovate green That's the profits that my probability of innovating. And if I innovate, I get the jackpot and the jackpot is this, and that's the profit you get from innovating and that's the energy clean. But if I innovate in fossil fuel, I get this expected profit. The C of A are the are the share of revenue of energy, of type I that accrues to the power plant because the remaining accrues to extraction.

So, in equilibrium you should be indifferent between innovating in green or innovating in fossil fuels. So, in equilibrium you should have these two terms equal and that defines the ratio in equilibrium of the number of scientists going to green innovation versus fossil fuel innovation. And one thing you can see right away with this expression is a better green technology tends to make you go more greener. That's the path dependance that you have here.

Better gas technology makes you want to innovate more fossil innovation. That's by dependence going the other way. But what's very interesting is the effect of B when you have the shale gas boom, it encourages innovation in shale gas, you see. And that's this term there because they are Leontief you see, if you innovate in if there is a shale gas boom, it makes it more profitable to innovate shale gas.

And the problem with the shale gas boom is that it has this undesirable effect, is that it diverts it makes that people who would have innovated green, suddenly they find it profitable to innovate shale gas. So, it diverts research resources away from shale gas, away from green to shale gas. And that's the downside. So, we saw in the short run the substitution effect more than counteracted the scale effect was okay, but the long run is that you divert research resources away from green into shale gas.

And in fact, the calibration of our model, you derail the transition, even if in the long run you are going towards green, you are moving towards shale gas, towards fuel, because you divert research resources. Okay. It may move the economy from a path with declining CO2 emissions, with a path with increasing CO2 emission. And in fact, if you look at patents, renewable, the ratio of renewable to total patents or green to total patents since 2010, it has gone down, it went up of 2010 and then went down.

So, I'm sorry, I need a few more. We can look at the welfare effects of the shale gas boom. So, we have this welfare function. Rho U is the is the discount rate of the social planner. We take it to be 1.5%. ST is the damage exactly calculated in the carbon cycle of John and coauthors. And V of S represents the welfare costs from climate damage abroad. And exactly model as they do.

So we have this welfare function. We calibrate the model, so I don't have to say blah blah, blah calibration. And what do we find the effect of the shale gas boom? So here what we find is the following. If you look at the first thing you find is that if the boom is unmanaged, you see you compare without the boom and the boom, the share of scientists will go down if you have no policy because they will go away from green into shale gas. You can see the drop of scientists into green.

When you have the shale gas boom here, that's a boom where you do nothing else than the boom. So that's the left. The middle is that you have a small decline in emission. Initially, you see that the dark blue, but then the you will have an increase in emission bigger than without. Why? Because in fact, the reallocation of researchers away from green into shale gas will make emission very quickly grow faster. So, you have a small, short-term effect, which is okay, but it's more than counteracted in the long run. And the right-hand side, what happens is that you look at net output, output net of damages.

What happens is that you have a small positive effect initially you can see here, but then right away you have a negative effect on damages on the net output of the shale gas boom, unmanaged. Now what you do is that you can look at the welfare impact of the of the shale gas boom and you see that it's there, but small when you have a discount rate of 1.5. But of course, the smaller the discount rate, the closer you get to an external discount rate or even lower, the bigger the welfare impact of the of the shale gas boom.

So now what you want to do is that I want to introduce the optimal policy. We consider a social planner who maximizes welfare in the US but takes emission from the rest of the world as given. Remember, we have two externalities, so a priori we can entertain two instruments the carbon tax to correct the environmental externality and the clean research subsidy to take into account the private value of innovation is too shortsighted.

And so here, what do you get? You compare in the left the laissez faire and optimal policy, and you can see right away that under the optimal policy, when you have the you see the boom, the you see the optimum policy with a boom compared to laissez faire, you want to increase a lot, the scientists. You see what I mean to counter the fact that with the shale gas boom, you would divert research resources away from green into fuel. You want to compensate that by putting a subsidy to green innovation. And that's what you have there. You really push more than ever green innovation.

So that's the left-hand side. The second one is that you look at the optimal policy with and without the boom, the boom requires higher green research subsidy. You see, that's then you would have without the boom. And the carbon tax remains essentially the same. So, you see you have a big role there for tax, of course, but also green subsidies to prevent this, to limit the extent of the diversion of resources away from green into the shale.

Now we can do a last exercise and then I'm done. We look, we take down the shale gas boom as given, and we look at the effect of delaying or not the optimal policy and of using one versus two instruments. And you can see again that if you delay the optimal policy, the optimal is there and the delayed is there. Of course, you are doing better in the short run, but worse in the long run. You see, that's exactly what we had before. So, what I said about the acting now as a and you can compare, you can look at the welfare effects and they are quite substantial effect of delaying is a big effect of delaying.

We looked also at the effect of using only carbon tax. In this calibration, we didn't find big an effect of subsidy only. But remember, we take the we take the subsidy as given. We take the shale gas boom as given. Whereas when you have the shale gas boom to accommodate it, you need. Now I'm conclusion. Innovation based climate models suggest that action may be taken urgently, even with an order of discount rate and that multiple instruments should be used, or calibration confirmed the delay cost. But so far, we find no big loss from using carbon tax only when we take the shale gas boom as given.

But when we introduce the shale gas boom, we restore the role for green subsidy. And the last one? That's the last one I can give you my I give it there. We are now currently in a there is a big debate about green industrial policy, beyond subsidy. And there's been very much fashion the model Al-Abassi Farahi model with production networks where you have input, gives input. And what we've done and there's been no attempt so far to look at green policy in a model where you have several layers of input.

So that's what we are doing in current research with Amos and Ernest Liu is at Princeton. We consider the green energy transition along the value chain. So, you have a value chain with several layers up to the downstream. And we looked at what would happen with Pigouvian taxation. So, you have complementarity across sectors. And of course, this complementarity can lead to multiple equilibria where either where either you have all technology clean, adopted, everybody electrifies, or you might have an equilibrium that where nobody electrifies because the other one have not electrified.

In a world like this, you could do a carbon tax to make sure everybody electrified, but it would be a huge carbon tax, which would be deadly. Nordhaus would go on riot completely, you see. I mean, it would be a huge carbon tax to make sure that all the sectors electrified. So, the optimal policy is to have a combination of a carbon tax and targeted subsidies because of course from one layer to the other, you may not need the same amount of subsidy to induce electrification.

And you can see very easily that when you enrich the model by introducing production network, you really get the two legs more beyond the green subsidies. You get the carbon tax and then smart industrial policy. And I think when we have the debate this morning, Europe is good at carbon tax, and we are good at regulating. We are what I call a regulatory giant and budgetary dwarf in Europe. In the US, you do more, you do the policy and not regulation. And I think you really need the two. And I think it's important to move away from just the neoclassical growth model, which I love Bob Solow. I owe everything to him, but I think you need to enrich the model, introduce firm heterogeneity, firm dynamics, endogenous innovation, production networks.

And I think we need I agree with John. You need model John, but you need models that are rich enough to embody those things. And there I think you will see the two legs coming very robustly. And now the whole thing is to say, how do we design a smart industry, green industrial policy, which is competition compatible, which is pro-competition. And I think now we have to go more into how to smartly design green industrial policy and combine it with smart carbon tax policy. And I think we need both. I'm sorry, I've been long. Thank you so much. Thank you.

Kimberly Clausing: I'm sure you can go on for hours. But --

Philippe Aghion: It's clean. It's clean energy.

Kimberly Clausing: I hope you'll be more compliant. Yes.

Steven Fries: No worries. So again, thanks very much for the opportunity to today to speak on the topic of the macroeconomic implications of decarbonization. Now, I'm going to try to do something much simpler than what Philippe just did. And so, my paper develops a very simple macroeconomic model and tries not to set out a normative ideal policy for the getting us to net zero, but rather to use a simple macroeconomic framework to look back and to try to understand the policy decarbonization policy sequences that we've observed over the last two decades.

So, my paper is very positive in approach rather than normative. Now, the starting point for my model is to think about what are the important characteristics of an energy system for, for assessing their macroeconomic implications. And I think there are three aspects of energy systems in general and low carbon energy systems in particular that are relevant for assessing the implications of decarbonization. Now, first, and most importantly, we now know that it's technologically feasible to decarbonize an energy system as this very well-known schematic from an article in Science a few years ago sets out.

Now, a low carbon energy system will consist of lots of low carbon electricity that is produced from a range of renewable resources and nuclear power. It will also consist of a range of low carbon fuels, from ammonia to biofuels to synthetic hydrocarbon fuels. And of course, there'll be the need for management of carbon dioxide emissions from industrial processes and for those uses of fossil fuel that we can't substitute away from. So, it's feasible. And of course, energy and use technologies must also either electrify or adapt to low carbon fuels or carbon management technologies. So that's the energy transition.

The second characteristic of energy systems that I think are important from a macroeconomic perspective is that. The capital stock that produces the range of energy carriers that we use and transform it into useful goods and services and materials is very heterogeneous and you can see that just visually from this diagram. So, it's a very diverse capital stock that reflects the range of energy carriers and end use, energy services and materials that are produced from it.

And the third point that I'll develop is as we go along is that this heterogeneity to the capital stock also extends to the substitutability of low carbon technologies to the fossil incumbents. And so, the heterogeneity aspects I think are quite important. So that's what it is we're trying to create and some of its characteristics. Now the next framing point that I want to make is around what are the sequencing of decarbonization policies that we've observed so far in the transformation of energy systems. And I think this figure from a recent IMF working paper summarizes at least some aspects of the sequencing very well.

This figure shows the chronology with which decarbonization policies were deployed in their chronological sequence, reading from left to right, the earliest to the latest. And these policies are aggregated across energy sectors, so electricity, buildings and so forth and across countries. And these figures also aggregate across sectors within individual countries. And the easiest way of interpreting this figure is to look for carbon pricing and of course carbon pricing, which is shown in orange. And it invariably comes last no matter how you look at it.

And so carbon pricing in this assessment of the sequencing of decarbonization policies, it's preceded and particularly in the early stages of decarbonization, by a very unorthodox mix of direct energy regulation, low carbon investment subsidies, not the subsidies for research and development, but the subsidies for investment in low carbon technology and cross-cutting policies that set decarbonization goals. Um, and the other aspect of policy sequencing that's not brought out in the IMF paper, I think is but also important to emphasize is that this sequence of decarbonization policies was applied earlier and with greater intensity in those sectors in which low carbon substitutes, low carbon technologies were stronger substitutes for the incumbent fossil technologies.

And so the sequencing that the IMF report draws out has been long observed in, for example, in Germany as a pioneer in decarbonization policy or indeed in the UK, which was if you want a fast follower in these decarbonization efforts and there are several explanations for the sequencing of decarbonization policies which are largely rooted in applied microeconomics.

And one explanation is an argument around that there are essentially multiple market failures, which there undoubtedly are in transforming energy systems, and that this unorthodox early mix of policies counters not the environmental externalities, but some of the positive spillovers that arise from early investments in low carbon technologies, and that it's a compliment to carbon pricing rather than a substitute.

The second is that this unorthodox mix of early policies manages the regressive impacts of decarbonization and avoids some risks of inconsistent carbon pricing if it's used too early in the sequence. And the third is essentially a political economy argument around increasing scale, lowering costs, and building interest in the low carbon transition. Now I'm interested in thinking about whether there's a macroeconomic rationale for this observed sequence of policies.

And so, to do this, perhaps at the risk of some simplicity, I use a very old-fashioned Solow growth model of a decarbonizing economy. And to start out, I start with a single good in this single final good in this economy, and I'll come to the heterogeneity point a bit later and it's produced from an energy related intermediate input that can be either low carbon or fossil, and that these intermediate inputs can be combined in in a range of ways to produce the intermediate output.

And I use in particular a variable elasticity of production function that can capture a range of potential interactions between low carbon and fossil inputs in producing the final good. So, this interaction term to help kind of locate this, if the interaction term in this production function is B, if it's zero, then this simplifies to a Cobb-Douglas, so that should be familiar to everyone.

So, the technical elasticity of input substitution in this model is a linear function of the ratio of low carbon to fossil capital. If B is zero, the elasticity of substitution is one, as you would expect. If B is greater than zero, inputs are substitutes in increasingly so with decarbonization. If B is less than zero, the low carbon and fossil inputs are complements and you can only achieve decarbonization by shrinking your economy.

But given that we know that there are sufficient technological substitutes for the incumbent technologies, low carbon substitutes for the incumbent technologies, I'm going to assume B is greater than zero. But then why might the elasticity of substitution increase with decarbonization? Hicks a long time ago argued there are essentially three reasons why in this type of aggregate model, the elasticity of substitution might change, and that's a substitution amongst existing technologies. Intersectoral substitutions and of course, innovation. And of course, it's also important to recognize that infrastructure and institutions can also influence technology choices.

So, if they change, the elasticity of substitution can also change. And so, this production function is a simple device for capturing network effects and complementarities amongst low carbon technologies, particularly in the early stages of transforming energy. I complete the model with simple AK production functions. So, the intermediate inputs are produced only with capital with a, but I assume for the fossil capital stock that the fossil input is fixed in relation to the capital stock.

Now, if the economy's implemented with competitive markets for the final good in the intermediate inputs, these cost production. For the final good and pricing the inputs that their marginal products. It's possible to express the ratio of fossil to low carbon capital in terms of the fixed production parameters alone. And this then allows a simplification of the nested production function for the final output. So, it can be expressed in terms of low carbon capital, a weighted average of the productivity weighted average productivity of the capital stock, and a term that depends on the elasticity of substitution. And of course, the savings and depreciation rates are exogenous and that gets you to very familiar terrain.

And so, this figure shows the capital accumulation curve for this solo growth model. And it's very straightforward to show that it has a unique steady state. And there is a simple analytical solution for the steady state, low carbon capital stock. Now, I'd like two introduce to decarbonization policies into this model, a low carbon investment subsidy and a carbon tax that's proportionate to the fossil capital stock and assume that these the subsidy attacks are offset by other transfers in the economy. So, the saving investment balance doesn't change, of course.

Either the subsidy or the tax drives a wedge between the price that final goods producers face and the marginal product of the intermediate inputs. And that necessarily induces a substitution of away from fossil input in fossil capital into the low carbon capital. And also, it's possible to show that there are equivalent policies in this model in terms of the strength equivalent in terms of the transformation of the capital stock that they induce. And for equivalent subsidies and tax rates.

It's essentially the subsidy rate applied to the flow of investment has to be an order of magnitude higher than the carbon tax rate. And then it's also the other consequence in this model of decarbonization is that it creates a negative productivity shock, as we've seen in a number of the models and simulations so far. And it lowers the equilibrium, the steady state, low carbon capital stock and output, and so it shifts down the capital accumulation curve. And it's also the model.

It's straightforward to show that the extent to which the output decline is dependent on the strength of the substitutability of low carbon for fossil capital. And so, if you have stronger substitutes, which are essentially the parameters B and the ratio of the productivity of low carbon to fossil capital, if there are stronger substitutes, essentially the output decline is smaller.

Now, there are two macro issues to manage in this simple model. One is the choice of policy instruments between the low carbon investment subsidy and the tax rate. Each creates the same investment and can create the same investment incentive. But policy costs will differ. It's straightforward to show that the scale of equivalent policies really depends on the base to which the policy instrument is applied. So, the low carbon subsidy is applied to the low carbon capital stock. The fossil the carbon taxes obviously apply to the fossil capital stock.

And so, the scale of the intervention in absolute terms depends essentially on the base to which it's applied in the steady state. And so, I take the view in the paper that the smaller the intervention, the better. And I frame that in terms of some simple public finance considerations, though I'm sure others will differ on, on the public finance aspects of this. But if you're in a situation, if the preexisting tax system is optimal in the sense of that Jacobs defined it as in terms of where the distribution of benefits from progressive income taxation are essentially at the margin balancing the deadweight losses from incremental taxation.

The cost of public funds is one in that setup. And so, if the low carbon capital stock is relatively small and you're attaching your subsidy to a relatively small flow, it's going to be the smaller intervention. Whereas we know carbon tax is highly regressive. And if you want to restore the initial distributional outcome in this system, you'll have to have a very large redistribution program to get there.

The second macroeconomic issue that is managed in that needs to be addressed is how to minimize the short run output loss. And I would argue that what we've seen so far in the transformation of energy is that policymakers have largely done this by targeting their decarbonization efforts on those sectors and those activities for which low carbon technologies are better substitutes for the fossil incumbents. And we know that largely from the empirical literature on induced innovation in energy, that the easier margins of substitution that have been revealed by past energy shocks are essentially renewable power, alternative drivetrains for vehicles, some biofuels in particular ethanol and energy efficiency.

And this is in fact the three main areas which decarbonization policies in almost every country focused on in the early stages. And so, to express this sectoral heterogeneity, think of an economy of simply consisting of two goods, one that's relatively easy to decarbonize. Think of that as EVs, heat pumps and well insulated buildings and low carbon power and that think that those are hard to decarbonize good, which is heavy industry, heavy transport, low carbon fuels and carbon management.

And for simplicity, just assume that these are very separate capital stocks, which is a bit of a simplification, but. If that is the case, then you end up with a very simple production possibilities frontier for these two goods in the economy. And as well as the social indifference curves for choosing between these two goods. If you were to impose an economy wide uniform decarbonization policy, called it a carbon tax. On -- well, I'm sorry, I should clarify. The horizontal axis shows the easier to decarbonize goods. The vertical axis shows, the more difficult to decarbonize good.

And the application of a uniform economy wide policy would obviously shift down the production possibilities frontier, more for the harder to decarbonize good. And so you would end up moving from in this simple diagram, moving from not doing anything, point A to point C, but we've seen uniformly that almost every country has chosen to go from A to B and to target its decarbonization policies only on the easier to decarbonize sectors, at least in the first instance. We're now at the point where that's starting to change.

But of course, by focusing decarbonization policies in this way, the cost of this policy is that you're having too much production of the harder to decarbonize good and too many emissions from that sector. And so, the challenge is to induce innovation without lowering output in the short run. And I would argue that what many governments have tried to do is to essentially induce innovation by promising to implement decarbonization policies in the future through their long run decarbonization goals.

There are some evidence to suggest that this works. The evidence on induced innovation and energy shows that, for example, that the innovation responses to the energy shocks increased after the introduction of the Kyoto Protocol. And in the paper, I set out some more anecdotal evidence that following the Paris agreement, and particularly after the 2019 1.5 degree report from the IPCC, we've seen a noticeable step up in private investment in in low carbon R&D.

And the recent IEA World Energy Investment Report also anecdotally shows or makes the argument this is increasingly flowing into harder to decarbonize sectors. And of course, the other way you could do this is the policy instrument that Philippe was emphasizing, which is you can essentially target sectorally, your decarbonization, your investment, sub R&D investment subsidies.

And the last point that I'd make about induced innovation is that we've seen also in the empirical evidence that it appears that low carbon investment subsidies have induced a stronger innovation response than carbon pricing. At least looking back, that doesn't mean it's true necessarily going forward. But the implication of that is that the stronger the innovation response from the policy instrument, possibly because the investment subsidy is more credible than a carbon pricing commitment, is that you minimize the short run output loss.

And indeed, we know, at least in some of these sectors, you're going to be better off in the long run. So, I think yeah, so just to wrap up. So, I think using this very simple kind of old-fashioned Solow growth model, I think you can provide two macroeconomic rationales for the two policy sequences that are strongly in evidence in the transformation of energy. So far, the low carbon investment subsidy is the more targeted intervention in the early stages of transition.

Transforming energy and arguably it's better has been better at inducing low carbon innovation. And policies have been focused on the easier to decarbonize sectors to manage the short run output losses and other tactics have been used to induce low carbon innovation. But we know that that that strategy, that policy strategy isn't going fast enough. But hopefully there are one or two insights in this. Look back as to how to capture some of these elements in a forward looking, normative analysis about how best to go fast. So, thanks very much.

Jason Furman: So, thank you very much for including a non-climate person in this discussion. For some reason I've been discussing a lot of climate papers lately. I've been a hobbyist reader of Philippe Duran and the rest of this research program for about a decade have had all sorts of musings and thoughts in my head. I want to share some of them with you now. And I'm grateful that Philippe took so much time because he won't be any time after this for him to explain what I got wrong.

I should say I've generally been of the view that the quality of slides is inversely proportional to the quality of thought. But there's this new feature that I discovered in PowerPoint that does things like this automatically so you can infer what you want from that. The title of this particular panel is, Is Climate action good or bad for productivity and potential growth? Neither of the papers actually even attempted to answer that question. I think possibly because economists all think the answer to it is so obvious.

So, I'm going to start my discussion by answering that. Then I want to engage with Philippe discussion of whether the shale gas revolution was good or bad for carbon emissions and welfare. And then finally, just broadly raise a set of questions and provocations about the role for green industrial policy. So, starting with that first question, the question we were supposed to be answering is climate action good or bad for productivity and potential growth? My answer is that I hope it is not good for productivity.

The reason I hope it is not good for productivity is precisely what Jim was talking about before. Much of the damage associated with climate change goes well beyond things that we measure in GDP. I can speak quite comfortably about the my love of human life. I'm not quite as fluent in the tree hugging rights of nature as Jim is, but I'll get there eventually. But none of that is measured in GDP. You think of the classic RFK quote about what you're counting, what you're not counting in GDP. And I think it's a perfect example of where if you only do enough for productivity growth, you've probably done too little.

You want to do enough to do all these other things. Put another way, I don't think we would have invented this problem as a growth strategy. I don't think that mitigating this problem is a growth strategy. It's a saving lives strategy, a saving nature strategy. It'll maybe offset some of the economic damage, but that's not the main reason for it.

So that's the so-far unchallenged answer to the question that this session posed. The second question in Philippe’s provocative paper is you look at what happened as the shale gas revolution, and in a period of a decade, roughly 25% of the emissions increases over the 70-year period prior to the shale gas revolution were undone for the first time since the industrial Revolution, you were making large scale progress in reducing emissions.

You'll occasionally hear a conservative or whatever insulting name Jim had for them. You know, say like, oh, look, look, we finally made progress on climate change and why do we do it? Because of all the frackers, not because of anything that came out of any conference of a bunch of green loving right of nature sorts of people. But is that really true? Did this end up diverting us and was a sort of dead-end trap that we got locked into? The fracking, got less of everything else? I have to say, before this paper I thought it was possible having read the paper and it's, by the way, 92 pages and I think it's ten-point font, single spaced.

So, you've got a very short version of it. Having read the paper, I think it's possible. I frankly haven't changed the odds that I ascribe to the proposition being true. And let me explain why. There's this striking figure of the decline in patenting of renewable over fossil fuels. Do I think that this decline was caused by fracking? The paper has some regressions. It's very careful to say correlation. It says it over and over and over again, not causation. And I think it probably was correlation.

First of all, there are attempts to estimate the originality and radicalness of patents and their importance and quality that doesn't increase as much. And in fact, if you look at the output, the progress we're making in reducing the cost of producing energy through wind and solar that was increasing throughout this period of up and down patents, some of this big increase may have been a bubble. There was a huge wave of clean tech. A lot of it didn't pay off. A lot of VCs lost a lot of money on it, and it went away.

Some of it is an exogenous policy shock that happened at the same time when Barack Obama was elected. Everyone thought the entire world was going to be saved, and it turned out he was only able to save part of the world, but not pass his climate bill. And that reduced some of the incentives as well. And then finally, look, you see this up and down pattern in other countries, even though fracking innovation barely went up in those other countries, fracking patenting barely went up. But you see basically the same up and down patenting.

And by the way, you see it in a lot of other technologies, some of which are not substitutes for fracking. So, I'm not convinced that this dramatic up and down goes beyond the correlation that the paper asserts. Moreover, shale has been running into diminishing returns. There was an initial wave of innovation. An initial wave of patenting. Patenting has come way down in the shale sector. This is total R&D at Halliburton and SLB. The share of green innovation and research they've been doing has gone up steadily over that period.

So the total devoted to fossil is going down even more. And so, when I look just at the last decade, it makes me frankly a little bit skeptical of the results. These are the results, by the way, The welfare equivalent of the boom with a global social cost of carbon is -0.1. If you just do domestic, it's plus 0.1. If you do it with the optimal policy sort of plus 1.3 or 1.5. That's from their paper. And there's the figure Philippe showed. Look at that left panel. Look at the years on the bottom.

Do I really think that 400 years from now there are going to be a larger fraction of scientists engaged in fossil fuel research as a result of this boom and fewer in green? Moreover, do I think there's a fixed number of scientists, which is an assumption that is in this paper? And so, when you have that fixed number of scientists, they get drawn from one sector to the other. In fact, within the decade you've already seen the shift going back the other way.

Moreover, to the degree that, for example, electricity prices haven't fallen in the United States and have actually risen in Europe, you have all the incentives to do research into wind, solar and the like. If that's going to lower electricity prices, you'll bring new scientists in, I think, on a four-year horizon to say a fixed number of scientists might be right on a 400-year horizon may be less so.

Moreover, it looks to me and I didn't run through the numbers, especially if you look at something like output, that the two strategies are roughly about the same for the next 200 years and then they turn dramatically different thereafter as the stock of innovation changes so much over those 400 years. To me, this looks like you're trying to estimate a butterfly effect and I just have a hard time taking away from this a great degree of confidence that the more obvious point of we've reduced emissions by a huge amount in a decade isn't the right one to take away from it.

So, this segues into what role for green industrial policy? This is a paper from a paper by Veselin Malhotra and Wolfram that's already been mentioned a couple of times today. And this shows the generation share estimated in the United States from their modeling from a carbon tax and from the Inflation Reduction Act. If you compare those two, the big differences I'd call your attention to is under the Inflation Reduction Act, you're going to see a much bigger reduction in natural gas than you otherwise would have seen, 21 percentage points instead of five.

And you'll see a much bigger increase in renewables than you otherwise would have seen, 28 percentage points instead of 19. I look at that and I'm a little bit agnostic. Part of me says the gold standard for the efficient way to reduce carbon is a carbon tax. Both of these get to the same emissions, but a carbon tax does it at $15 a ton and the Inflation Reduction Act does it at $83 a ton and the burden of proof for spending an extra $68 a ton is really, really high, that it's putting you on a better path.

But I do think it's possible if you go past 2035, that all the extra effort you're going to get on wind and solar under the IRA relative to what you would have gotten in a carbon tax is going to potentially pay off over time. Jim’s stocks lines didn't really look didn't bear that out. I don't think that's most of what I think someone could persuade me of it, but for the most part, I'm more persuaded by the old fashioned.

Why would you want to pay five times more for something than you need to? Which is to say, under the Inflation Reduction Act, we're actually going to be using too much wind and solar and, by the way, too much coal and not using enough natural gas. When it comes to industrial policy, there's some theoretical considerations. Of course, if you get the externality pricing right, you're going to still have knowledge spillovers. You have knowledge spillovers everywhere in the economy. We want basically more research funding for just about everything that we do.

We probably want more R&D subsidies for just about everything that we do. I think there's some things that make Green somewhat special in terms of the capital intensity of some of it, the long-time horizon. But you have some of those considerations in health care as well. So, I agree that we need two instruments, but we sort of had that two-instrument view for the economy in general. I don't know anyone that would think even in industries without externalities, that there isn't some knowledge spillover externality.

The second and I thought Steven was a little too sort of casual here in talking about some of the earlier instruments before a carbon tax. I can't remember what he said, something like they could manage some of the distributional consequences. I think most of the industrial policy approaches aren't ways to manage the distributional consequences. There are ways to obfuscate the distributional consequences. No one would look at a carbon tax without looking at a distribution table for that carbon tax.

A carbon tax, moreover, generates a set of revenue you can use to get whatever distribution you want. At the end of the policy. I have very rarely seen anyone do a distribution table for regulations where you're raising, for example, the cost of the durable goods that households are buying, or businesses are buying. I pretty rarely see distributional tables for industrial subsidies or even subsidies for different types of fuels.

Moreover, when you take into account the welfare effects of revenue loss, that needs to be made up in some distortionary way, and it's changing the distribution of income and it's doing it in a nontransparent and obfuscated way that can often dwarf a lot of the climate impacts that we focus on. So, I think we need to have more of the distributional conversation in the industrial policy conversation.

And finally, most of the industrial policy we've put forward lower the price of electricity, which increases its use and reduces the incentive for energy efficient innovation, which is potentially a large downside when you translate theory into practice and PowerPoint like pick those pictures for me, I didn't put any time and effort into it. You know, what's industrial policy? Is it funding for R&D? I think we spent about five, $6 Billion now on clean energy R&D in the United States.

If we double or triple that, my guess is that's almost certainly welfare improving and at most you've wasted a few billion dollars a year and I think it's unlikely you would waste that. Industrial subsidies here it starts to get trickier. A lot of the incidences on business and their profits which industry subsidizing which are you not, you make a mistake technology goes in the wrong direction. Regulation, as I said, there's a certain opacity to them. It was not me that picked the check mark for domestic content rules. I would have given it an F if it was up to me.

And so how much is research getting past the we should do industrial policy to providing guidance on what the magnitudes of that industrial policy is, what the types of that industrial policy. And then another bigger fear I have is even if research is doing that, how much are policymakers listening to that research? Which brings me to my final point, the politics of industrial policy.

There's an argument that goes carbon taxes are impossible, industrial policy isn't as good, but we can do it, so we might as well do it. I should say I have a lot of sympathy for that. I'm in favor of anything you can do, you should do. But the jury is still out on the question of whether the industrial policy approach is scalable. The Inflation Reduction Act is the equivalent of $15 a ton on carbon, I think just in the electricity sector, right? Not even an economy wide, just in the electricity sector.

Could that approach scale to $150 a ton for the economy as a whole? We actually don't know yet whether it can. European approach is actually scaled over the last 10 - 20 years. In a way, it's hard to imagine this can countries with less fiscal space than the United States pursue this path. Will it lead to the race to the top globally or more barriers and slower innovation?

And finally, one of the hopes was that an industrial strategy would be more politically sustainable than a carbon tax. The House of Representatives recently passed something that would have repealed the entire Inflation Reduction Act. My hope is that by the time they come around to trying that again, it'll be more entrenched, and it will be politically sustainable. But even that we're not sure of.

So just to summarize. If we are doing enough to address climate change, then it should reduce productivity growth, although it may be a small amount. I think we should be concerned about path dependance, but I don't think it's proven and I don't think we quite know where we want to be on that yet. And finally, I do think it's easy to get a carbon tax right in theory may be harder to get industrial policy right. Absolutely need both of them. But the more we push industrial policy towards innovation, where we think there's a very high return and a very low downside, the better off we'll be. Thank you.

Neil Mehrotra: Thanks very much for inviting me to participate in this esteemed panel. I am a relative newcomer to the macroeconomics of climate change, but I learned a lot by reading these papers. And I want to spend my discussion unpacking a little bit more the argument about subsidies versus the carbon tax and what is the economic case for subsidies? I think we understand that there may be a political case for subsidies, but what is the economic case for it?

So, this is my sort of high-level takeaway of both papers. And from Steven's paper, I think the question is, what is the macroeconomic rationale for sequencing clean energy subsidies before a carbon tax? And the insight here is that clean energy becomes more substitutable for fossil energy as the clean energy capital stock grows. That's the variable elasticity of substitution production function that he assumed. And from that he argues that macroeconomic factors could favor subsidies over a carbon tax.

Philippe’s paper asks a very specific question about whether the shale boom was beneficial for the clean energy transition. And the basic insight there is that directed technical change can result in excessive path dependance and excessive innovation in dirty technology. And so, you need two instruments. You need both a subsidies and a carbon tax to implement the transition. And what I want to do is I want to really try and unpack the case for a subsidy versus a tax.

So, I'm taking a simple macroeconomic framework that I think can be adapted to both of these papers to try and understand the case for a tax versus a subsidy. This comes from my work with Katherine and John Baseline in our Brookings paper. The basic macroeconomic framework is let's think about a representative agent economy where there is a clean energy technology and a fossil fuel technology. So, there's investment in clean and fossil fuel technologies. ITC and ITF have relative prices PTC and PTF, which is the underlying technology of how expensive it is to invest in each of these technologies. And those two technologies are used to generate energy.

So E is energy that comes from a production function that combines these two types of capital goods. There's a law of motion for each type of capital, and the policymaker has two instruments. They have a subsidy tausi and they have a fossil fuel tax tau F. Energy is used as an input into production along with along with a fixed stock of labor. And the price of electricity is just the marginal return, the marginal product of energy. And what you can show in this simple framework is that a clean energy subsidy will act like a supply side policy. It will shift out the marginal product.

So, what I'm showing here is, is just the steady state level of fossil fuel capital and clean energy capital. A clean energy subsidy will raise the marginal product of capital for clean energy, raising the steady state level of clean energy capital. What does it do on the fossil fuel side? Well, there's no there's no tax here. So, the tax is zero. But by reducing the price of electricity and by reducing the price of electricity, the marginal product of fossil fuel energy is reduced. That shifts in the marginal product and reduces demand for fossil fuel energy.

A carbon tax does exactly the opposite. It will it moves these lines in exactly the opposite way. But a clean energy subsidy looks like a beneficial supply side policy. It lowers energy prices, it results in higher output, higher productivity, higher wages. So, these seem all like good things. And potentially it may be the case that we want to have a subsidy instead of a instead of a tax. Now, this setup allows us to think about the optimal policy problem very clearly.

So, in what I showed you before that we can think of as the market equilibrium, what is the optimal climate policy? Well, there's some damages from climate change. So, ST here is the stock of carbon emissions. And so the externality here is that the household is not taking into account its climate damages. So, D of ST is the damages, the cumulative damages from climate change and ST plus one is the law of motion for carbon emissions which depend on the fossil fuel carbon stock.

So, the planner is now going to make a decision about how much clean energy capital, how much fossil fuel capital to hold subject only to underlying technology. So, what is the price of clean energy capital and what is the underlying production function G? And what you get from this problem is you can compare the planner's allocation, which are the third and fourth line to the first and second line, which is what would be the allocation under the market equilibrium.

So, the first two equations here are Euler equations describing the optimal path for clean energy capital and for fossil fuel capital. Both of them depend on the price of electricity, the future price of electricity, and they depend on taxes, they depend on the subsidy in one case and the carbon tax on another. So, both of those margins can be distorted by the fiscal instrument. But what does the planner want to do? The planner wants to leave the clean energy margin undistorted.

So even though there potentially may be a role for clean energy capital, there's this benefit from clean energy in terms of lower electricity prices and higher output. The planner still doesn't want to rely on clean energy, doesn't want to incentivize clean energy. All they want to do is to levy a carbon tax. That carbon tax shows up as a distortion in the in the last equation.

And so, the carbon tax would be set to vary over time with the level of damages. And this comes to sort of the first comment that I have on Steven's paper, which is he's assuming a production function that has a variable elasticity of substitution. So that's making a specific functional form on this G function. But in this equation, in these set of equations, I've made no restrictions on that G function.

So my conjecture is that in his if you were to set up the optimal policy problem in his setup, it would still say that the optimal subsidy is zero, that there should be no clean energy subsidy and there should only be a carbon tax because the carbon tax is operating through its effect on the price of electricity.

So, let's go to Philippe's paper. Philippe's paper is different in that it's now thinking about innovation and remember that the planner's resource constraint depends on underlying technology. And if we have a way to change the underlying technology over time, maybe that gives us another reason to rely on a subsidy instead of a tax. So, what I'm trying to do here is adapt my basic setup to include what Acemoglu, Aghion, Burstein and Hamus in their AER paper, the setup they had for technological progress.

So now the price of each type of technology, the price of clean energy capital and the price of fossil fuel capital can evolve over time, and they evolve over time depending on the allocation of scientists. So that last line is there's a unit measure of, of scientists. I can allocate them to fossil fuels or clean energy. And that's going to affect the rate at which the relative price of clean or fossil fuel technology drops.

So, the question is now how would the planner choose to allocate innovation effort between these two technologies? And it turns out that the optimal allocation of innovation so the equations at the top describe the optimal allocation of innovation. New IT here is the is the multiplier on the on those two constraints. The laws of motion for the price of clean and fossil fuel technology and the optimal allocation of innovation is undistorted relative to the private sector allocation.

So again, even in this setup, you only want to rely on one instrument. You only want to rely on a carbon tax. Now, Philippe's paper, this paper, and the earlier paper both find that they find otherwise, they find that there's a reason to both have a carbon tax and a and a research subsidy. So why are they finding a difference relative to sort of the simple setup that I've used here? And the answer, I think, is that because of the assumptions that they make on the market structure and the underlying technologies in those papers, private sector innovation is insufficiently forward looking. In the shale boom paper, it's static.

So basically, they're making decisions about which technology to invest in on a static basis. But in some other papers it they allow for innovation to be forward looking. But even when innovation is forward looking, there's it's insufficiently forward looking. It's not as forward looking as the setup that I that I wrote down here. So, this setup, by the way, does allow for the scale effects that Philippe described. It is the case that you do want to innovate in the sector that is bigger. But it is the case that with a carbon tax, you take into account that in the future the clean energy sector is going to be pretty large.

So, there are benefits to investing in in clean energy. And you're the private sector choice is not distorted relative to the optimum. So, what do I think is going on in Philippe's paper? In in in this line of research, generally, innovation is generically undersupplied due to investment horizon and market structure. And innovation in clean energy is disproportionately impacted because it starts out at low scale and low initial productivity.

So, the only way to get around that is you need innovation to be the innovation decision to be sufficiently forward looking. And that doesn't happen in in their setup. Now, I think one thing to emphasize is that the Inflation Reduction Act, the subsidies in the Inflation Reduction Act are not research subsidies. These are subsidies that are relying on a price mechanism.

And so, the IRA investment and production incentives, they induce upstream innovation only indirectly. There's some money in there for energy research, but most of what is being done is I'm going to invest in figuring out how to sequester carbon only because somebody might downstream be using that technology. And so, I think the incentives in IRA are not reliant on this research incentive. But what matters is learning by doing or financial frictions, other reasons why we might think that there that there needs to be incentives but that that begs Jason's question about why this sector why green energy relative to anything else.

So, the last comment I'm going to make is there is a strong in Philippe's paper, there's a strong difference between fossil fuel innovation and clean energy innovation. And that's not entirely clear to me with shale. So, the model says that there's no applications for clean energy production from shale technology. But fracking and fossil fuel technologies more generally could have important applications for clean energy.

In particular, enhanced geothermal requires fracturing rock formations and achieving greater drilling depths. Arguably, those are things that have been benefited by the shale revolution, and existing carbon capture is right now used for enhanced oil recovery. So, the techniques that are being developed in the fossil fuel industry might eventually allow us to sequester carbon at a large scale. So, I'll end there. Thanks.

Kimberly Clausing: Let me start with a moderator's question, if I can, and then we can maybe we have about 15 minutes left, and I'll see if there's pressing ones from the audience. And if there's not, then we'll let you all talk among yourselves. I had a question for Steve first, although I think or Steven first, but I think it applies a little bit to Philippe's paper as well. Which is, does it matter that we live in an open economy?

So if you look, for instance, at the policy sequencing laid out in the grid in Steven's paper, it sort of implies that, you know, it's easier once these things are more substitutable for macro reasons or the micro reasons that we've seen before to sequence such that carbon pricing comes later. But you might think of enough countries that already sequenced that way. Then subsequent countries could start further down the road.

So, I wonder if you agree with that. And to Philippe as well. I think when we look at your paper, it almost seems very US oriented. But when you realize that scientists can vary both across time and across space, I think Jason got to the across time point quite nicely. But, you know, maybe this is somewhat less discouraging if countries can learn from what's happening in other countries. And then we only have to worry if shale is happening in each and every country of the world. But let's start with Steven.

Steven Fries: Okay. Thanks very much. So, I think the issue behind your question is, are there more international spillovers with a low carbon investment subsidy, as I described or used in a very stylized way in my paper? Or is it easier to coordinate decarbonization policies with a carbon tax? And I have a sneaking suspicion that your priors are that it's easier to coordinate on the basis of a carbon price.

And I think and we know how to do that. But I would give some simple examples of what has actually been done in practice on low carbon investment subsidies, which was the focus of my paper and how it played in that plays in an open economy context. Now most low carbon investment subsidies have been allocated essentially through feed in tariff policies in Europe that take on a range of different designs. But those lower carbon subsidies since the early to mid-part of the last decade were essentially allocated through competitive tenders and in the electricity sector, which is largely non-tradable.

Even in a European context where essentially you have a single energy market, as long as you're not restricting who can compete and which technologies can play in those auctions for essentially long-term contracts, for subsidies. I think there's no difference. There are no negative implications for low carbon subsidies for international trade. I think we've gotten away from that approach in the most recent IRA legislation where the subsidies have been essentially guided by local content considerations. And I think that is a step towards making that policy approach much less efficient. Thank you very much.

Philippe Aghion: Yep, that's better. I would like to take this opportunity to respond to you, but to respond to Jason's comments. Thanks so much for this great discussion. Yeah, but I need to respond. I mean. I mean, obviously sorry, but yeah, that's right. But, you know, we were criticized on things, and I think I need to respond. That's democracy. Yes. So, the climate action. So first you said, we didn't look at the effect of climate action on productivity. It's not true because we showed that in the short run, when you act right away, you have a decline in productivity compared to, for example, delaying action.

So, the various papers beat the 2012 or this current paper. We show that there is a short run cost in terms of productivity of acting now, but you can minimize these costs by acting sooner or by using certain kinds of instruments that are not using them. So, the whole starting point is the fact that you have a decline in productivity growth in the short run, and you try to find the timing and mix of policies that would minimize this short-term loss. So, the fact we don't look at productivity, you might have been a bit late yesterday evening.

The second thing is that you say, well, I'm not convinced by the turning point. So, in fact, the relationship between so if you read the fracking paper, we have a whole section where we have regressions between gas price and clean versus dirty innovations. And the relationship is pretty systematic. It's not just around 2008, I showed some illustrating figures about 2008, but the regressions show that it's a systematic figure.

And by the way, when you said about France and Germany, in fact they will respond to the shale gas boom because the natural gas price has fallen globally, and innovations aim to produce new technologies are potentially used throughout the world. And in fact, there's been work by Peters et al or by Shell and Glashow showing, for example, the effects of global incentives on renewable innovation that links to what you were asking. The effects even of the shale gas boom in the US are global effects and there is big evidence that it's global. Okay. And therefore, it would also encompass France and Germany.

So the next point is that of course you there are other effects that could play a role on the collapse of green, but the gas price had a big effect. So, there might have been other things, but there is pretty evidence that gas prices have had a big effect. Again, I refer to this whole section on regressions. Then you had kind of humorous part on the 400 years, but in fact the effects indeed takes a while to materialize. But it is because we take very conservative values for innovation response. And in fact, the positive effect on emissions takes only 20 to 30 years, well beyond the 400 years.

Why do we look at 400 years where climate is a long run problem and we think it's good to show graphs which go long run, but the effect is already there. After 20 - 30 years. You refer to fracking innovation, but in fact we don't look in the paper at innovation in the extraction technology. We only look at the innovation in the in the plant technology. So maybe that would be another thing. But it's orthogonal to what we do in the paper. So, coming to the two Neel's comment, it's not so much that innovators live for one period, it's the main thing is the building on giant shoulders externality.

That's really what makes the discount rate of the private different from the discount rate of the [inaudible 01:31:51]. So, you could have an infinitely lived as soon as you have the you know the path dependance externality you get the effects that that we get, you are asking about the global and so the global is very interesting. We had extension in other papers on the global for example you could imagine a north and a south. The north innovates and the south builds on the north.

The good aspect is that if there is enough green innovation in the north, the spontaneously the South will want to go to what is best in the north. And that's a virtuous aspect. The non virtuous with the global is the pollution have an effect is that if you have free trade, some countries, if the if some subset of countries become virtuous, some countries may specialize in welcoming all dirty producers to reexport the goods. So, you have to deal with that with carbon tariff. And so, the good aspect is the fact you imitate the best. If the best becomes the green, you will push towards the green, but you have the pollution have an effects that that you are playing against. Sorry for being long. Thank you.

Kimberly Clausing: No. Yes, absolutely. Well, Jason's talking if you have other questions, you might line up by the mic and then I'll make sure we get to you.

Jason Furman: I'd be curious to hear what your response was to the thing I thought was the most at odds with the way I think the world works, which is just the fixed number of scientists over 400-year period. I also did want to address that 400 years. Obviously, this is a long-range problem. I don't want to say let's just look at the next decade and who cares what. Happens after that.

But when you have so many different parameters in a model, no sensitivity analysis of those different parameters and it looks to my eyes and I didn't run it myself, like the sign of the result switches from positive to negative based on things happening between the year 2300 and 2400. And that is that there's a different number of scientists doing green innovation 300 years from now. I guess I confess that just doesn't move the priors I came into this with. But.

Philippe Aghion: Response to a response. But I want --

Jason Furman: Oh, no, no. But I also have a number of scientists. But I had a specific question.

Philippe Aghion: We'll continue because I think otherwise. Okay.

Kimberly Clausing: I saw John in the back and then Pierre and someone behind John. Sorry. Yeah.

Audience question: So, Philippe, you had basically two key arguments for subs, green subsidies, and the first was path dependance. And the other multiplicity in it would be helpful if you can kind of give us an idea of which industries you think the path dependance is really a big hurdle. Often a transportation is used as an example, but I think what we see now in Europe that it is that it has been relatively easy for the industry to switch to EVs rather than fossil without any real subsidies.

But of course, you need credibility in the policies that caused the transition. And the other thing is, is multiplicity. And there I can see surely possibilities for multiplicity. And in particular, if you bring in policy also. But I think there are other ways of dealing with that. So, in your set up, you say that the tax alone is bad because you might need a very high tax to prevent multiplicity, but a cap and trade that really credibly phases out fossil would also work because that wouldn't leave room for the bad equilibrium. Right?

Philippe Aghion: Can I? Yeah. Okay. So, thanks a lot, John. I think you're is a good I think is true. In the automotive we looked at past dependency in the automotive industry. So, there it seemed to be a big deal. I showed this first table, you know, on the past dependance aspect without sorry.

Audience question: In Europe they switch now.

Philippe Aghion: Oh okay. No, no. I was looking at the. That's right. No, no. And I was not saying that. Okay. No, no that that may well be that that you could you don't need high carbon tax to have the switch. In fact, in the automotive I showed that already carbon tax can make you switch. So, we have not quantified there how much you would do. I try to quantify with the shale gas paper how much you do with carbon tax alone and with the two policies. And it's true that I believe to really get big effects of what you could call industrial policy on top of carbon tax, the network effect, and the coordination problem I think have to be brought in that that's what that was my last slide. I think there, it becomes very natural.

And then you come to your second question. Can you deal with it just with a cap and trade? It's about innovation incentives. It's incentives to adopt. And so, the question is, would you do as well with cap and trade and targeted carbon trade because they should not be uniform. You see, they are different from sectors. Some you have imagine a production chain, different inputs have different costs of moving to electrification or through how would you adapt the cap and trade to you need something which is targeted. So, can you have a targeted cap and trade which absolutely replicates, you know, the, you know, the targeted subsidies?

You are about trying to encourage people to innovate green differently in different layers of the production chain. And the question is you need something targeted, something which is uniform would not do would be very costly to do. And you are asking me, could you do it with cap and trade instead of subsidies targeted? Is that the question that you are asking? You have a network model. I mean, I haven't worked it out.

So we talk about model like we are still working. So is your conjecture is that you could replicate with cap and trade whatever we could do with targeted subsidies. I mean, we need to look at that because I don't want to answer a question before I do the research. My hinge is that for innovation incentives, there will not be equivalent. But I will look at that. And because I want an informed response to that question, which I find totally well-taken.

Kimberly Clausing: Okay, so let's collect the next three questions, two by the mic and Pierre. And then if you can say when you're asking the question who you would like to answer and then we'll let a round of answering. And then I think that gets us to the end.

Stefan Dalagaard: Thank you. I'm Stefan Dalgaard from the from the World Bank. First, a quick comment that in all of our conversation today, it seemed that political economy has been equated to distributional impacts. And I think this is missing a lot of the reasons why we see these type of policies, because, I mean, first, we have evidence that people opposing some of the policies would be winners of the policies, and they do it for a whole range of reasons, including ideas and political opinions. And I think it's really missing that. And the interest groups are currently missing in the discussion.

You can compensate the losers as much as you want. There is this question of interest groups. And so how much of those policies are just going to cater to different interest groups instead of trying to achieve any form of optimality? I think would be one question. And the second thing that was really surprising is you have discussed quite a lot the whether to do this policy.

But my impression is the big question is how? How do you do it without getting capture from some of those industries that you're supporting? And we have a lot of lessons from Asia versus Latin America, for instance, showing how to do it better or in a terrible way. And so, the question is in your models, can you find a way of taking into account that you can do it in the right way or in the wrong way? And probably it changes completely all of your results depending on how it's implemented. Thank you.

Pierre Wunsch: It might be an observation, but I can turn it into a question. I would like to relay the issue of subsidies with one of the slides that Antonio showed, which is we tend to underestimate technological progress in greening the economy. And what we've seen in the past is many times that when you give subsidies, they are sticky and they end up being way too generous and basically producing windfalls for typically, you know, relatively high-income individuals, typically, you know, the subsidies on solar panels and so on. So, I think at some point one should integrate that into the analysis because if there is uncertainty on technological progress, the risk that you would over calibrate the subsidies has been very high, and we've seen that in the past. But the question is, what do you think about that?

Jeromin Zettelmeyer: Jeromin Zettelmeyer Bruegel. So, I'm persuaded by, you know, the papers of Aghion and others that there is a strong rationale for green renovation subsidies. I'm also persuaded by the fact that there may be a rationale for renewable energy subsidies, particularly when we do not have a carbon price. But then we have another category of subsidies in the IRA, which are just clean manufacturing subsidies, right? So, we have the, you know, $12 per square meter of photovoltaic wafer. Can anyone here find an argument of why that is a good idea from a climate perspective, or is this justified by other things, jobs, political economy, whatever you like.

Kimberly Clausing: That's a good last question. So maybe what I'll do is just go down the road and let everyone say one minute of final thoughts in response to one of those questions or of their own. Yeah. Philippe, you can start.

Philippe Aghion: I've spoken too much. I feel very bad. No, Steven. No, you don't want to know. Yeah. No, I mean, just one. One word. I mean, the. So, all this question, I think the political economy is very important. You know, we had the yellow vest movement then escape you and the question could we do some things, you know, to get around it and so for example a mechanism that works is the values. If consumers value green and there is competition also, then firms escape competition by innovating green. It turns out that this kind of mechanism can do the more like a big carbon increasing carbon price without provoking yellow vest.

So, it's interesting to look to play on the political economy to see whether we can find ways that would be, you know, acceptable. And also, it's important that you the big thing of the yellow vest is that, you know, they didn't have people live in suburbs, they didn't have transportation. They didn't have, you know, they had to use their cars and gasoil, they had no alternative. So you need to provide them with the alternative. Here is a good example, by the way, where carbon tax alone doesn't do the job because you need these people, they need the transportation. So you need to invest in the transport, the transport and all that too, so that they would accept politically the increase in carbon price. So, in the U.S. that's a good example where the political economy reinforces the need for carbon tax and other instruments to complement it.

Kimberly Clausing: Okay. Steven.

Steven Fries: Okay. Picking up on a couple of points. So how do you avoid being captured? And implicit in that, I think there is a view that it's easier to capture the allocation of subsidies than to politically capture a carbon pricing regime. But I'm not quite sure that is in fact the case. But I would say on ensuring that you're allocating your subsidies for low carbon investments through competitive allocation mechanisms, I think is key to limiting the extent for capture and the allocation of rents under those systems.

Equally, you could point out that the EU ETS was not very well designed in its first go round in the mid-2000. Its flaws were revealed by the great financial crisis, and it took essentially a decade of protracted negotiations to put the ETS on a much more sound footing. And in that whole process there were strong political and economy considerations that shaped how all of that came out. I think Pierre's point on the risk of allocating subsidies to high income groups or not allocating them efficiently I think is extremely important.

And I would say that the US IRA provisions where you're essentially assigning a fixed subsidy for green hydrogen production, for example, over quite a long period of time risks repeating the mistakes that were made in Europe when we designed the initial feed in tariffs for renewable power generation in a way that was overly rigid and we struggled to adapt them quickly enough to the pace of technological change that unfolded. So, I think the story, the political economy considerations, and the efficiency considerations around both of these instruments are a bit more complicated.

Kimberly Clausing: Jason and Neil. I don't know if --

Jason Furman: To answer German's question. Of course not. I don't think there's any good argument for this. Look, there's two differences between the United States and Europe. Europe is raising the cost of electricity. The United States is lowering the cost of electricity. The European way of doing it is better. But the United States way of doing it is pretty good. And if you can't do a carbon tax, as Neel showed, you're getting a lot of the way there with that. But then layered on top of that, there's this whole other thing in terms of where you're sourcing the stuff from.

And I think the main defense of that is that a bunch of that may end up being less binding than you think. And so, it may just be automatically that those subsidies, the bonuses you get for it, sort of go automatically to everyone. So, the defense of it would be that it's not really going to work. But the criticism of it would be that it does work as intended. And, you know, you have to do things politically. So, I don't necessarily fault people, but I do think it's good to at least keep your own understanding clear.

Neil Mehrotra: I mean, to respond to the question about clean energy manufacturing and your point about it, it seems like the rationale for having an incentive for clean energy manufacturing is because you want to build up the domestic supply base and you think that there are these learning by doing effects. And as you build up scale, you learn how to do this stuff more cheaply and efficiently. And I think that one industry we should think about a little bit in this context is nuclear.

So, in the US for nuclear we've had, you know, forgetting by not doing and because we don't build, we haven't built nuclear power plants very much in the last 20 or 30 years. That entire supply chain is not that we don't know how to build a nuclear power plant. It's that you don't have the labor and the supply chain needed to build it at an economical at a in an economical way. And so, I think that that would be the most, you know, sort of optimistic case for why you need these types of subsidies.

Kimberly Clausing: Thank you, everyone.