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LOUIS BACHELIER
Economic and financial news seen through research
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Climate action: issues of coordination between actors

With Christian de Perthuis, Boris Solier, Simon Quemin, Clément Bonnet and Philippe Delacote of the Climate Economics Chair

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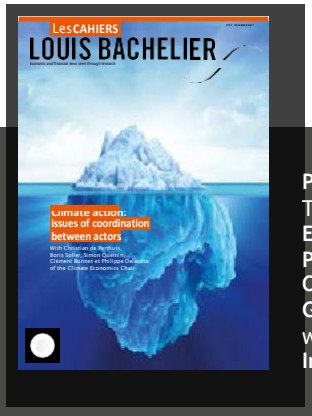

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EDITO

Two years after the adoption of the Paris agreement, a succession of warnings at COP23 revealed that the planet is not on an emissions trajectory compatible with keeping global warming below 2°C. This is the starting point of the One Planet Summit, convened on the initiative of Emmanuel Macron. Strengthening collective action calls for better coordination between actors. This necessity is the unifying thread of this issue of *Cahiers Louis Bachelier.*

Because global warming results from the total accumulated stock of greenhouse gases, there is no direct correlation between the cost of the actions taken by each actor and the benefits that can be derived from them. Individually, it is in the interest of every party to act as a "free-rider", so as to benefit from the actions taken by others. Brilliantly analysed at the local level by Elinor Ostrom, the issue of the coordination of actors to protect a common good arises acutely in the case of the climate.

The free-rider problem is addressed by Christian de Perthuis in the context of the reorientation of the climate and energy strategy in the United States. This policy shift is giving rise to reactions on the part of other actors wishing to coordinate better. But it may also encourage the proliferation of free-riders, using the thundering announcement of the US withdrawal to delay or even undermine the implementation of the Paris Agreement.

Boris Solier shows how the low-carbon transition raises new issues of coordination in terms of regulation. For several decades, Europe has been trying to build a unified energy market. The development of renewable energies subverts the architecture of this market based on marginal pricing. Will Europe be able to find a new set of rules? Doing so is a key issue, so that the development of renewables can go hand in hand with the smooth operation of the market.

Alongside the traditional energy markets, there are the CO_2 allowances markets, which give rise to a price for carbon, that us, the economic value that society concretely gives to climate protection. Simon Quemin analyses the conditions required for links to be established between national markets. In the long term such links could strengthen the carbon price signal at the international level.

An expected benefit from carbon pricing is the stimulation of innovation. Is it possible to assess progress in low-carbon innovation? Clément Bonnet warns against drawing hasty conclusions based simply on counting the number of patents. His qualitative approach leads to a much more fine-tuned assessment of the progress made in terms of innovation, with the aim of achieving carbon neutrality.

The interview with Philippe Delacote concerns the forest transition, a key area for moving towards carbon neutrality, which is the goal of the Paris Agreement by the end of the century. While nothing is certain in this area, an alternative approach suggests that a balance can be found between the protection of the existing primary forest and increased plantation. Though largely ignored, this is an aspect of prime importance for energy transitions.

Enjoy your reading!

Christian de Perthuis
is the founder of the Climate Economics Chair

&

Jacques Percebois
is the Chair's scientific director

THE PARIS AGREEMENT: THE UNITED STATES GOES ITS OWN WAY

Despite the non-binding nature of the Paris Climate Agreement, which came into effect in November 2016, on 1 June 2017 US President Donald Trump announced the withdrawal of the United States from this multilateral framework. The following article assesses the consequences of this unilateral decision.

Already signalled during his election campaign, Donald Trump's climate change sceptic position and his liking for fossil fuels was quickly confirmed when he took office.

Less than six months after his inauguration, on 1 June the President announced the withdrawal of the United States from the Paris International Agreement to limit global warming to two degrees Celsius in the coming decades.

Admittedly, this decision is not yet effective, since the rules set by the Paris Agreement impose a three-year waiting period for exit, but it sends a negative signal to the international community, especially as the United States is the world's second largest emitter of CO_2 and one of the highest per capita.

Donald Trump's announcement of the decision to withdraw from the Paris Agreement makes this the third US about-turn in the history of climate negotiations.

NOT THE FIRST US CHANGE OF HEART

Ever since they began in 1990 under the aegis of the United Nations, international climate negotiations have never been easy,

Due to the large number of stakeholders (nearly 200 countries), the search for compromises between states at different stages of economic development is very complicated. Added to this are the ambiguous positions of major industrialized countries, particularly the United States, which has never displayed any real determination to tackle climate change. The reason lies in an institutional system that requires the approval of the Congress – many of whose members are strongly opposed to measures to combat climate change – for any international agreement. In particular this opposition explains the US non-ratification of the Kyoto Protocol in 1997 and the shortcomings of the 2009 Copenhagen Summit.

Donald Trump's announcement of the decision to withdraw from the Paris Agreement makes this the third US about-turn in the history of climate negotiations. Yet there is no doubt as to the scientific consensus on the consequences of human activities on global warming, as shown by projections for the amount of carbon emissions for 2030, which would not allow the rise in temperature to be limited to 2°C.

In this situation where the world's second largest emitter is dragging its feet in implementing the energy transition, Christian de Perthuis has identified and analysed the disadvantages and possible advantages of this US "free-rider" position.

THE AMERICAN FOSSIL FUEL RACE

During his election campaign Donald Trump promised to "make America great again". As soon as he took office, he made fossil fuels (coal, gas and oil) a national priority for defending US energy independence and reviving areas suffering from high unemployment. It's no surprise, therefore, that his greatest electoral

Based on the paper *L'Accord de Paris: un "passager clandestin" nommé Trump*, by Christian de Perthuis, and on an interview with the author.

Christian de Perthuis holds a PhD in economics, is Professor of Economics at Paris-Dauphine University and founded the Climate Economics Chair, a research platform on the economics of climate change. His expertise in the European CO_2 allowances market and environmental pricing is internationally recognized. His publications include ***Le climat à quel prix? La négociation climatique*** (Odile Jacob, 2015), co-authored with Raphaël Trottignon.

Methodology

The research paper places climate negotiations in a historical context with a view to analysing the future American withdrawal from the Paris Agreement and the institutional issues involved in achieving the energy transition. Accordingly, Christian de Perthuis first examined the geopolitical dimension, focussing in particular on US reversals in terms of climate. He further developed his study by adopting an economic approach, based on game theory and the concept of the free-rider. The paper concludes with various recommendations.

support came from fossil fuel-rich states like Wyoming and North Dakota. But this policy of reorientation toward fossil sources – which the United States has in abundance – is encountering many reservations domestically. "A large part of the American economic world, especially in the sectors of the new economy, is convinced of the need for an energy transition. The same is true for many sub-national administrations represented by major cities and coastal states such as California or New York," says Christian de Perthuis.

THE RISK OF A DOMINO EFFECT ON OTHER COUNTRIES

As well as hampering the efforts of the most ambitious states to reduce the use of fossil fuels, Donald Trump's decision could be emulated by other countries. "The Paris Agreement is based primarily on the emissions reduction targets of every country, which are encouraged to gradually increase their ambition over time. However, the US withdrawal may tempt some of them to reduce their efforts," Christian de Perthuis says. "A more explicit domino effect would be the departure from the Paris Agreement of other major fossil fuel producing countries, even though at present they are not taking this route."

In addition, the US withdrawal from the Paris Agreement will have an adverse impact on financing to limit climate change. For the fact is that the United States is currently the largest contributor to the Green Climate Fund for developing countries and to the Intergovernmental Panel on Climate Change (IPCC).

REBOUND EFFECTS LIKELY TO THWART THE US POSITION

Over and beyond the risks, the US decision could, paradoxically, lead to a strengthening of the carbon reduction measures taken by the countries adhering to the Agreement, such as China and the European Union (EU).

For this ambitious scenario to come about, a number of conditions must be met. First, it is necessary to establish emissions measurement, reporting and verification rules in every country. This important aspect is absent from the Paris Agreement and many developing countries are opposed to it. "An independent monitoring system in every country is essential for reducing global carbon emissions. A parallel can be drawn with nuclear disarmament treaties that require impartial counting of warheads and launch vehicles," Christian de Perthuis says. Secondly, introducing a carbon price at a binding level for everyone would make it possible to escape the current situation. And here, the EU should play a leading role by reforming its emissions trading scheme. "The United States is clearly in a free-rider position, in which it wants other countries to make efforts. The solution, so that each country is at the same level, involves having an international carbon price that would result in the free-rider paying, "says Christian de Perthuis. Finally, other countries will have to increase their funding for climate to offset the drying up of US funding. While these measures may seem very difficult to implement, hopes are nevertheless still high. "The Paris Agreement has potential, but it requires strong economic incentives," Christian de Perthuis insists. I

Key points

- The announcement of the future US withdrawal from the Paris Agreement marks a reorientation of US federal energy policy in favour of fossil fuels (coal, oil and gas).
- The reorientation of US energy policy faces significant resistance from economic actors, major cities and coastal states.
- At the international level, Donald Trump's decision could produce a contagion effect for other countries, but also beneficial rebound effects from other actors remaining in the Paris Agreement.

ANOTHER HEADACHE FOR BRUSSELS: REMEDYING THE DYSFUNCTIONS OF A 28-MEMBER ENERGY MARKET

On 30 November 2016, the European Commission published a set of proposals aimed at reforming and strengthening the integration of the European energy market, especially in the field of the electricity sector. While this convergence trend in policies goes in the right direction, it has a number of serious shortcomings.

Although energy policy has long proceeded in an uncoordinated fashion in Europe, the European Commission has sought to promote the convergence of national policies, through a series of texts and directives known as "climate and energy packages". The most recent, announced in 2014, aims to achieve, by 2030, at least 27% renewable energy, 27% more energy efficiency and 40% less greenhouse gas emissions compared to 1990. These objectives were confirmed in the 5,000 pages of the "Clean Energy for all Europeans" package of measures, published on 30 November 2016. These dense and technical documents include proposals for reforms of the European energy market that are currently under discussion. They will then be put to a vote in the European parliament, with a view to possible application.

The proposals seek to increase the integration of electricity markets in Europe and to reinforce the cohesion between national energy policies, in particular by advocating reform of the support scheme mechanisms for renewable energies and further opening up of capacity mechanisms in Europe.

To get a clearer idea as to the coherence and the ambitions of these voluminous documents – daunting for most readers –, Anna Creti, Jacques Percebois and Boris Solier dissected the Brussels proposals by applying models specific to the energy market.

IMPROVING THE FUNCTIONING OF WHOLESALE ELECTRICITY MARKETS

Wholesale electricity markets in Europe, on which energy companies' offers depend, currently no longer transmit the right signals, because electricity prices are too low. *"The Commission realized that these wholesale markets were not able to cover costs, due to the low prices resulting from the massive development of renewables in a context of stagnant electricity demand. By proposing the ending of the €3,000/MWh price cap in the wholesale market, the Commission hopes that producers will be able to recover their costs during peak prices,"* says Boris Solier.

This weakness in electricity prices may be explained in particular by the increase in the proportion of subsidized renewables producing energy at zero marginal cost. As a result, the profitability of other sources of production – gas, coal, nuclear power – is under considerable pressure. To solve this problem and raise suppliers' revenues, European countries have introduced capacity mechanisms, though their operating rules vary considerably from country to country. These mechanisms ensure that every supplier is guaranteed sufficient capacity to cover the electricity consumption of its customers. *"In the name of the construction of the single market, the Commission recommends that Member States open up their national capacity markets to capacities located in other Member States. It also wants to exclude the most CO2 intensive electricity generation sources, such as coal-fired power plants. However, in the short term, these plants will not be excluded from*

The electricity markets in Europe, on which energy companies' offers depend, currently no longer transmit the right long-term signals to actors.

Based on the paper *The Clean Energy Package: Are its objectives always consistent?* by Anna Creti, Jacques Percebois and Boris Solier, and on an interview with Boris Solier.

Boris Solier has a PhD in economics from Paris-Dauphine University and is Assistant Professor at the University of Montpellier. He is also a researcher at the Climate Economics Chair, where he co-directs the "Energy Transitions" research programm. His work is primarily concerned with the evaluation of climate and energy policies in Europe, with a view to analysing the impact of carbon pricing on energy markets and the effects of overlapping public policy instruments.

Methodology

The authors analysed the texts of the European Commission's *Clean Energy for All Europeans.* They sought to measure the impacts of its main proposals on the functioning of energy markets in Europe. Their analysis was based on the use of a partial equilibrium simulation model of the European electricity sector, which is able to show the effects of overlapping public policies. The authors then made recommendations aimed at improving the effectiveness of climate and energy policies in Europe by enhancing the consistency between the different objectives pursued.

capacity markets, as the measure applies only to new plants. This creates a problem of consistency with regard to the objectives of reducing CO_2 emissions," Boris Solier explains.

SUBSIDIES FOR RENEWABLES ARE NOT APPROPRIATE

Although renewable energy, particularly from solar and wind sources, has become more competitive with widening diffusion, it creates distortions in the electricity markets, especially in terms of pricing. Brussels wants to reverse the situation by eliminating the priority access of renewables to power grids and in the long term to subsidies. *"Subsidies for renewables are increasingly no longer justified as these energies become competitive. The measure will have little impact at the level of the markets because renewables will always be a priority, insofar as their marginal cost of production is zero. On the other hand, they will no longer be prioritized in terms of the dispatching carried out by the grid operator,"* Boris Solier says.

THE PRICE OF CARBON REMAINS UNRESOLVED

Among the other inconsistencies noted by the researchers in the European strategy is the lack of reference to the price of carbon, despite the stagnancy of the European CO_2 emissions trading scheme. Yet a significantly higher price of carbon (compared to the current price of around €7/tonne) could reduce emissions, while promoting the use of renewable energy. *"Even if the reform of the carbon market is treated separately, it is curious that issues relating to emissions pricing have not been addressed in the Commission's proposals for reform. The interactions between energy and climate policies play an important role in the current market crisis. Treating these questions separately amounts to acting on the symptoms without worrying about the causes of the disease,"* Boris Solier says.

ELECTRICITY PRICING NEEDS TO EVOLVE

While electricity prices are struggling in the wholesale markets for the reasons mentioned above, Brussels has not addressed the question of pricing, which must necessarily evolve to take account of technological developments and the rise of renewables.

For the time being, electricity networks in Europe are largely priced according to the quantities consumed. But the future development of self-consumption – where individuals directly consume electricity they produce themselves through renewable energy – will upset this pricing model. In fact, these self-consumers will only use electricity from the grid when their own generations is insufficient. *"Given the current pricing of distribution grids, mainly based on the amount of electricity extracted and very little on the reserved capacity, the development of self-consumption will put pressure on their financing. To support this development without jeopardizing the financing of the grids, which in this case have strong insurance value, we must increase the capacity component in the tariffs,"* Boris Solier says. He concludes: *"This set of reforms proposed by the Commission goes in the right direction in that to a certain extent it draws lessons from past mistakes. That said, the policy harmonization and consistency effort that the Commission is attempting to promote remains timid in light of the issues at stake. The risk is not so much that of missing the targets but of achieving them at prohibitive cost."* I

Key points

- Subsidized renewable energy reduces both carbon prices and electricity prices in the markets, because policy objectives have been poorly defined. Brussels wants to change this situation, notably by reforming subsidies and by ending the prioritized access of renewables to the grid.
- The European Commission's energy and climate proposals do not directly refer to the carbon market, though this has always been portrayed by the Commission as the central instrument of climate policy.
- The way in which electricity and transmission/distribution networks are priced needs to evolve in response to the rapid growth of renewables, which jeopardizes cost recovery.

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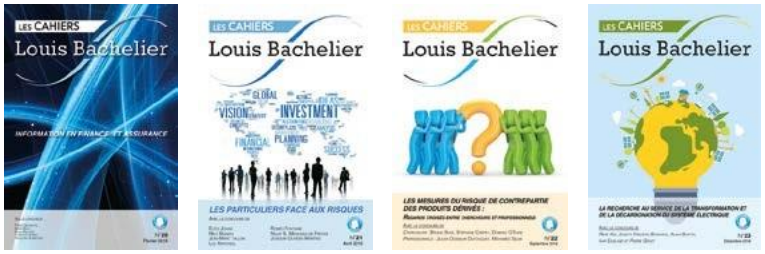

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INTERNATIONAL COORDINATION: SHOULD CO_2 EMISSIONS TRADING SCHEMES BE LINKED?

CO_2 emissions trading schemes are a cost-effective tool for reducing carbon emissions, but most of the existing systems operate independently of each other. The following article presents a theoretical model for analysing the underlying mechanisms and the benefits associated with multilateral interconnections between these schemes.

Limiting the rise in global temperatures to two degrees Celsius in the coming decades necessarily entails reducing carbon emissions. This goal, vital for the welfare of future generations, is embodied in the Paris Agreement, which was ratified in December 2015 and came into force in November 2016. To get close to this target – which will, however, be difficult to achieve, according to the latest scientific estimates – it is essential that carbon be priced, thereby inducing the development of low-carbon alternatives and encouraging industry to reduce its emissions. Emissions trading schemes (ETSs) have a major role to play here, despite the fact that their current state of development falls far short of the level expected and the level needed.

Several jurisdictions around the world have adopted this type of mechanism, including the European Union (EU) in 2005, Switzerland, South Korea, seven Chinese provinces (a national system is expected to be introduced shortly), California, Quebec, Ontario and a number of states in the north-eastern United States (RGGI). And other ETSs are scheduled to come into force in the near future.

However, for the time being, links between these different ETSs are largely non-existent, with the exception of California and Quebec, which will be joined by Ontario in a tripartite coalition in early 2018. The EU and Switzerland are also in the process of linking their respective markets by 2020. *"Links between ETSs involve connecting the markets with each other, by making the various emission allowances fungible and allowing them to be exchanged between the jurisdictions participating in a coalition. Although this mechanism is in practice emerging only gradually, it is economically advantageous because the gains from trading are higher when the market is larger. The efficiency of an integrated market, in terms of the costs of reaching a given emissions reduction target, is also better than that of fragmented markets,"* Simon Quemin says.

TWO NEW CONTRIBUTIONS TO THE ACADEMIC LITERATURE

Academic research has mainly focussed on bilateral links, particularly through case studies, for example, between the European and Californian ETSs. Simon Quemin and his co-authors thus addressed the question by introducing two new features. *"Our work incorporates multilateralism, which can be likened to a Lego game with several bricks connecting to each other. In our context, the different bricks correspond to jurisdictions with independently functioning ETSs. The second contribution lies in the formal introduction of uncertainty on demands for allowances in the different jurisdictions. We wanted to be able to easily calculate the economic benefits generated by a multilateral link between ETSs and to understand their determinants analytically,"* Simon Quemin explains.

While the formal and statistical analysis by the researchers was sometimes laborious, it provides concrete quantitative applications for public decision-makers.

Based on *A theory of gains from trade in multilaterally linked ETSs,* by Baran Doda, Simon Quemin and Luca Taschini, and on an interview with Simon Quemin.

Simon Quemin has a PhD in economics from Paris-Dauphine University (PSL). He is also an engineer from ENSTA ParisTech (energy track) and has a master's degree in environmental and energy economics from ENPC ParisTech. His work in the Climate Economics Chair focuses on economic instruments for climate change mitigation, in particular carbon emissions trading schemes.

Methodology

The researchers analysed the gains generated by multilateral links between carbon emissions trading schemes (ETSs). Accordingly they used a partial equilibrium model, including uncertainty in the form of Weitzman (1974). They then drew on historical carbon emissions data for the countries studied between 1950 and 2012 in order to calibrate their model. A quantitative application of the model can thus guide public decision-makers as to the best possible options for linking their ETSs in a given coalition, according to the levels of ambition and historical emissions characteristics of the countries concerned.

LINKS BETWEEN ETSs YIELD GAINS FROM TRADE OF TWO KINDS

The economic gains from a link between ETSs stem from harmonisation of the price of CO_2 allowances between linked systems in accordance with supply and demand in the areas concerned. In the researchers' model, these gains come from two sources: on the one hand, differences in ambition – and therefore in average autarky prices – between the partner systems; and on the other, risk sharing on idiosyncratic demand shocks – and thus the absorption of autarky price volatilities within the linked system. These two sources of gains are both positive and therefore militate in favour of the integration of ETSs. *"In addition, creating links between ETSs is a superadditive mechanism; that is, the gains associated with the linking of disjoint ETS coalitions cannot be less than the sum of the gains generated by these coalitions in isolation,"* Simon Quemin says.

A FLEXIBLE MODEL TO HELP GUIDE PUBLIC DECISION-MAKERS

To identify the gains from linking ETSs in a multilateral framework, the researchers broke them down with a view to isolating them and sharing them out among the various partnering jurisdictions. A key finding is that the gains from forming a coalition of ETSs can be decomposed as a function of the gains generated by the bilateral links internal to the coalition. In fact, the flexibility of the model resulting from this decomposition, associated with calibration on historical emissions data of the countries concerned, makes it possible to calculate the distribution of the individual gains within a multilaterally connected system, and thus to develop a classification of preferences in terms of links between the different jurisdictions. While this formal and statistical analysis by the researchers was sometimes laborious, it provides concrete quantitative applications for public decision-makers.

A GLOBAL MARKET WOULD BE THE BEST SOLUTION IN TERMS OF THE GENERAL INTEREST

This work shows in particular that a global market would be the best outcome for the public interest, since it could attain the aggregate objective of emission reduction at the lowest cost and could thus lead the various jurisdictions to raise their ambitions. However, despite the various initiatives mentioned above, it is clear that multilateral schemes are still not favoured, because what is in the general interest does not necessarily benefit all participating jurisdictions. *"A global market is more beneficial to society as a whole, but support for it is not unanimous. Indeed, not every country necessarily benefits from joining a larger system, let alone a global market. Clearly, countries' preferences in terms of joint markets are not aligned, making it difficult for a linkage agreement to be adopted,"* Simon Quemin says. But at a time when the energy transition is becoming increasingly urgent, countries will have to redouble their efforts to safeguard the planet. Linkage between ETSs is therefore a tangible option on which policy makers could build. I

Key points

- The formation of multilateral links between emissions trading schemes (ETSs) is of a superadditive nature, that is, the gains associated with the linking of disjoint ETS coalitions cannot be less than the sum of the gains generated by these coalitions taken separately.
- The model calculates the individual benefits to each jurisdiction operating in a multilaterally linked system of ETSs. Its flexibility enables it to serve as a decision-making tool for the public authorities and to guide them towards the most advantageous links.
- A global ETS market would be the best outcome for the collective interest. However, country preferences for a given coalition of linked ETSs do not match, making it difficult to establish a consensus for the creation of an integrated market.

LOW-CARBON INNOVATION: QUANTITY ASIDE, THE ISSUE OF PATENT QUALITY

If global warming is to be contained, there need to be innovations in low-carbon energy technologies. To this end, many countries have introduced policies to support low-carbon innovation. But the efficiency of these policies is difficult to assess due to the lack of a robust measure of innovation.

As many economists have shown, in particular the Austrian economist Joseph Schumpeter in the early 20th century, although innovation is essential for economic development and value creation, it sometimes seems abstract and can be difficult to measure qualitatively. Very often, as a proxy for a country's innovation capacity, the media use the number of patents filed. Yet not all patented innovations are equal and, in the absence of a qualitative dimension, the number of patents is a biased indicator of innovation. China provides a good example of this: in recent years, it has filed more patents than any other country, but it is not the most technologically innovative country in the world.

In terms of climate, these observations pertain to an even more crucial issue in the current context of global warming, given that the energy supply sector accounts for 46% of energy-related greenhouse gas emissions worldwide, in 2010. According to the scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), limiting the average temperature rise to two degrees Celsius requires the massive deployment of renewable energies and of carbon capture and storage (CCS) processes. *"These scenarios involve the implementation of very ambitious low-carbon innovation support policies. However, it is difficult to assess the effectiveness of these policies in the absence of a robust measure of innovation,"* Clément Bonnet says.

The study reveals a very high correlation between oil prices and low-carbon innovation, thus confirming the theory of price-induced innovation. There needs to a price signal by means of CO_2 taxation, which constitutes a powerful lever for engendering carbon-free solutions and achieving the energy transition.

THE QUALITY OF PATENTS VARIES GREATLY

Despite the extensive academic literature on innovation, assessing the quality of patents remains a difficult exercise because there are various methods, each leading to different results, depending on the criteria used. Moreover, the large number of patents filed means that their quality varies considerably and is difficult to determine. With regard to the quality of innovations in low-carbon technologies, this area has been relatively little studied. *"The aim of my research was to summarize the information about the different characteristics of patents on low-carbon technologies, in order to obtain a unique measure of their quality",* Clément Bonnet explains. *"The quality of a patent is expressed by the economic value of the invention attributable to the technological advance that the invention embodies."*

Despite the extensive academic literature on innovation, assessing the quality of patents remains a difficult exercise.

Based on the paper *Measuring Inventive Performance with Patent Data: an Application to Low Carbon Energy Technologies* by Clément Bonnet and on an interview with the author.

Clément Bonnet is a researcher in climate and energy economics. His work focuses on the evaluation of innovation support policies in low-carbon energy sectors, the use of data and patents, and the dissemination dynamics of new technologies. He completed his PhD in the Climate Economics Chair and at Paris Nanterre University, under the direction of Marc Baudry.

Methodology

Clément Bonnet has developed a unique measure for evaluating the quality of inventions in 15 low-carbon technologies, using a latent factor statistical model. He focussed his study on seven countries over the period 1980-2010, using data on 28,951 patents. By analysing the results, he was able to deduce the degree of specialization of the different countries and the quality dynamics of the technologies examined. This unique and robust measure can thus serve as a useful guide to the allocation of public spending on research and development in low-carbon technologies.

MODELLING CAPABLE OF TAKING SEVERAL INDICATORS INTO ACCOUNT

To construct a robust measure of the quality of patents in low-carbon technologies, Clément Bonnet focussed his study on seven major industrialized countries (Germany, Denmark, Spain, the United States, France, the Netherlands and the United Kingdom), over the period 1980-2010, and analysed the data of 28,951 published patents, covering 15 low-carbon technologies (wind, photovoltaic, smart grids, hydrogen, CCS, etc.). In this way he identified four main indicators: the geographical scope of the patent, the technological impact of the invention in one or more sectors, the number of citations received in the five years after publication of the patent and the number of citations referring to earlier inventions. He then developed a latent factor statistical model to integrate the various metrics selected. *"This model makes it possible to identify an unobservable characteristic, namely the quality of patents, using observable characteristics, that is, the metrics used. By observing how the metrics interact, we can identify a robust measure of the quality of a patent,"* Clément Bonnet explains. The results enable him to measure, by means of an index, each of the seven countries' degree of specialization on the 15 low-carbon technologies studied. This information can be used to guide the countries with regard to their public policies, according to their respective technological advantages in the different sectors. Unsurprisingly, France is the undisputed leader in nuclear power. Given France's lead, it would not be in the interest of other countries to start developing this technology. As regards wind power, Germany, Spain and the United Kingdom have a high degree of specialization, but Denmark is the most advanced. *"When you consider the top 10% of wind inventions, Denmark's weight is eight times greater than its weight in low-carbon energy technology patents as a whole,"* Clément Bonnet points out. With regard to solar photovoltaic, no single country has a significant lead at present and the technological leadership in this field will be decided on the basis of the public policies adopted. On the other hand, as regards to smart grids, the United States and the United Kingdom stand out in particular from the other five countries.

THE MOST PROMISING TECHNOLOGIES NEED PUBLIC SUPPORT

As well as specialization in these countries, the researcher also measured differences in dynamics regarding the quality of technologies, in order to identify the most promising sectors. For example, in nuclear power, the average quality of patents has fallen sharply since 1990. The best innovations in this sector in fact occurred between 1980 and 1990. On the other hand, in wind power and photovoltaics, the average quality of patents increased significantly between 2000 and 2010. "*These findings suggest that the allocation of public funds to innovation in a single low-carbon technology is not the most appropriate policy because, in the long run, there will be decline in quality. The ideal solution would be to develop several technologies simultaneously. For example, France is well positioned in hydrogen compared to other countries. A public impetus in this sector so as to gain a leading position would be a good strategy for France, while maintaining its lead in the nuclear industry,"* Clément Bonnet says.

Key points

- There is a close correlation between oil prices and low-carbon technological innovations. This finding confirms the theory of price-induced innovation, which indicates the need for a price signal through the taxation of CO_2 in order to encourage the development of carbon-free solutions.
- Leading countries in specific low-carbon technologies are clearly identified, such as France in nuclear power, Denmark in wind power and the United States in smart grids. Conversely, other technologies, such as solar and energy storage, are more open to competition, thus offering opportunities in terms of public investment.
- The average quality dynamics of low-carbon technologies differ greatly and need to be taken into account in the allocation choices of public funding.

THE FOREST TRANSITION: THE UNKNOWN ASPECT OF THE LOW-CARBON TRANSITION

Tropical deforestation, mostly occurring in developing and emerging countries, has direct negative consequences for the environment and climate change. In this context, the observation and economic analysis of the dynamics of deforestation must adopt a long-term perspective.

The issue of deforestation periodically attracts media attention in response to the on-going destruction of forest in the Amazon, the Congo Basin and Southeast Asia, especially Indonesia. In 2016 alone, 29.7 million hectares of forest were lost around the world – an area the size of New Zealand – according to the specialist open-source web application Global Forest Watch.

Despite growing awareness of the importance of safeguarding forests, deforestation continues unabated, a situation that is all the more dangerous in that it represents the world's fourth largest source of carbon emissions. Indeed deforestation generates CO_2 through the machinery used to transform the forests and especially the release into the atmosphere of the CO_2 contained, as a result of prior photosynthesis, in the felled trees.

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WHAT DOES FOREST TRANSITION THEORY SAY?

Forest transition theory originally came from geography. It was developed in the early 1990s, before being taken up by economists, with a view to studying deforestation in a country over a long period. Concretely, it involves observing how the forest cover of a geographical entity evolves over time, and deducing the key stages of this environmentally harmful process.

This theory, confirmed by the empirical observations made in a number of countries, involves three distinct stages over time. Initially, a country or region has extensive forest cover and little deforestation. Next comes a stages of rapid deforestation and reduction of the forest cover.

The third and final stage is characterized by stabilization and a possible increase in forest cover, defined by the term "turning point". Graphically, the forest transition takes the form of an inverted J curve. *"The forest transition is strongly correlated with the country's stage of economic development. At the outset, a country develops its agriculture, which involves taking land covered by forest. The more this activity intensifies with the use of machinery, the more it needs to expand. In the second stage, the economy diversifies into other sectors, which can slightly ease the pressure on forests. In the final stage, the forest cover has shrunk and become sparser. These three stages describe the rise in deforestation and can lead to the well-known turning point, when the forest cover begins increasing again,"* Philippe Delacote explains.

On the basis of this theory, it is clear that it is the developing countries which are most affected

Based on the papers *L'analyse économique de la transition forestière: quels apports à la lutte contre la déforestation?*, by Philippe Delacote, Serge Garcia and Julien Wolfersberger and *The Economic Analysis of the forest transition: a review,* by Edward B. Barbier, Julien Wolfersberger and Philippe Delacote, and on an interview with Philippe Delacote.

Philippe Delacote is a researcher in the Forest Economics Laboratory at INRA and head of the "Agriculture and Forestry" unit in the Climate Economics Chair. His work focuses on the economics of climate change, through the study of adaptation and mitigation of the forest sector, as well as policies to combat deforestation. He studied for his PhD at the European University Institute in Florence.

Methodology

The researchers analysed the determinants of the forest transition in order to assess a country's rate of the deforestation and quantify its deforestation. To do this, they drew on Julien Wolfersberger's thesis "Economic development and forest transition", carried out under the aegis of INRA's Forest Economics Laboratory and the Climate Economics Chair. In their work, they used dynamic economic models of land use change and panel econometric studies on real data from the countries studied.

by the forest transition, since the industrialized countries have already completed it. In terms of policies, it must also be remembered that the issue of deforestation was largely absent from the 1997 Kyoto Protocol and only began to be raised in the 2000s, when developing countries became more actively involved in climate issues. Forest transition theory has several advantages: *"It provides a long-term view of cumulative deforestation in a country and allows the existing forest stock to be observed, which is a valuable complement to the periodic studies carried out on this subject. It has also produced a better understanding of why deforestation ceases, which is an important source of information for analysing this phenomenon,"* Philippe Delacote says.

SECONDARY FORESTS DO NOT BENEFIT THE ENVIRONMENT TO THE SAME EXTENT

In addition to observation of the forest cover, the forest transition makes it possible to analyse the different dynamics at work. Rapid short-term deforestation does not have the same consequences as continuous deforestation over a long period. Consequently, the length of time it takes to reach the turning point can vary, and this in turn will have different consequences for the environment. *"Ancient forests sequester large amounts of CO_2 and are characterized by enormous biodiversity, whereas secondary forests, planted after the turning point, are less rich in biodiversity and have different sequestration dynamics. It is very important to distinguish the two,"* Philippe Delacote says.

VARIOUS POLICIES TO BE PURSUED ACCORDING TO THE FOREST TRANSITION

With the theory of forest transition, it is possible to promote different preservation policies, depending on each country's the stage of advancement. For example, Brazil, which has already undergone a significant phase of deforestation, should adopt financial incentive policies to maintain its forest cover. For a country such as Congo, however, which is at the beginning of its forest transition, it is better to focus on improving forest management, in order to avoid a stage of rapid large-scale deforestation. In general, the stronger a country's institutions and the less corruption it has, the more likely it is to protect its forest cover. Although climate negotiations are making little headway and appear to have set the countries of the north and of the south in opposition to each other, it is clear that the issue of global warming concerns everyone on the planet. Policymakers should therefore focus more on the contributions of scientific research in this area. I

Key points

- The use of forest transition theory allows a country's deforestation to be analysed over a long period. The theory is complementary to periodic studies on deforestation, which provide an insight into this phenomenon in the shorter term.
- The dynamics of deforestation takes two forms: on the one hand, the disappearance of old-growth forests that have high carbon sequestration rates and greater biodiversity; and on the other, secondary forest plantations, which are less rich in stored carbon and in terms of biodiversity.
- Policies to combat deforestation in a country must take into account the degree of advancement of its forest transition, because the consequences are dealt with differently, depending on the stage the country has reached.


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