A TRIBUTE TO THIERRY BRÉCHET, AN ECONOMIST OF THE ENVIRONMENT AND OF THE PUBLIC INTEREST

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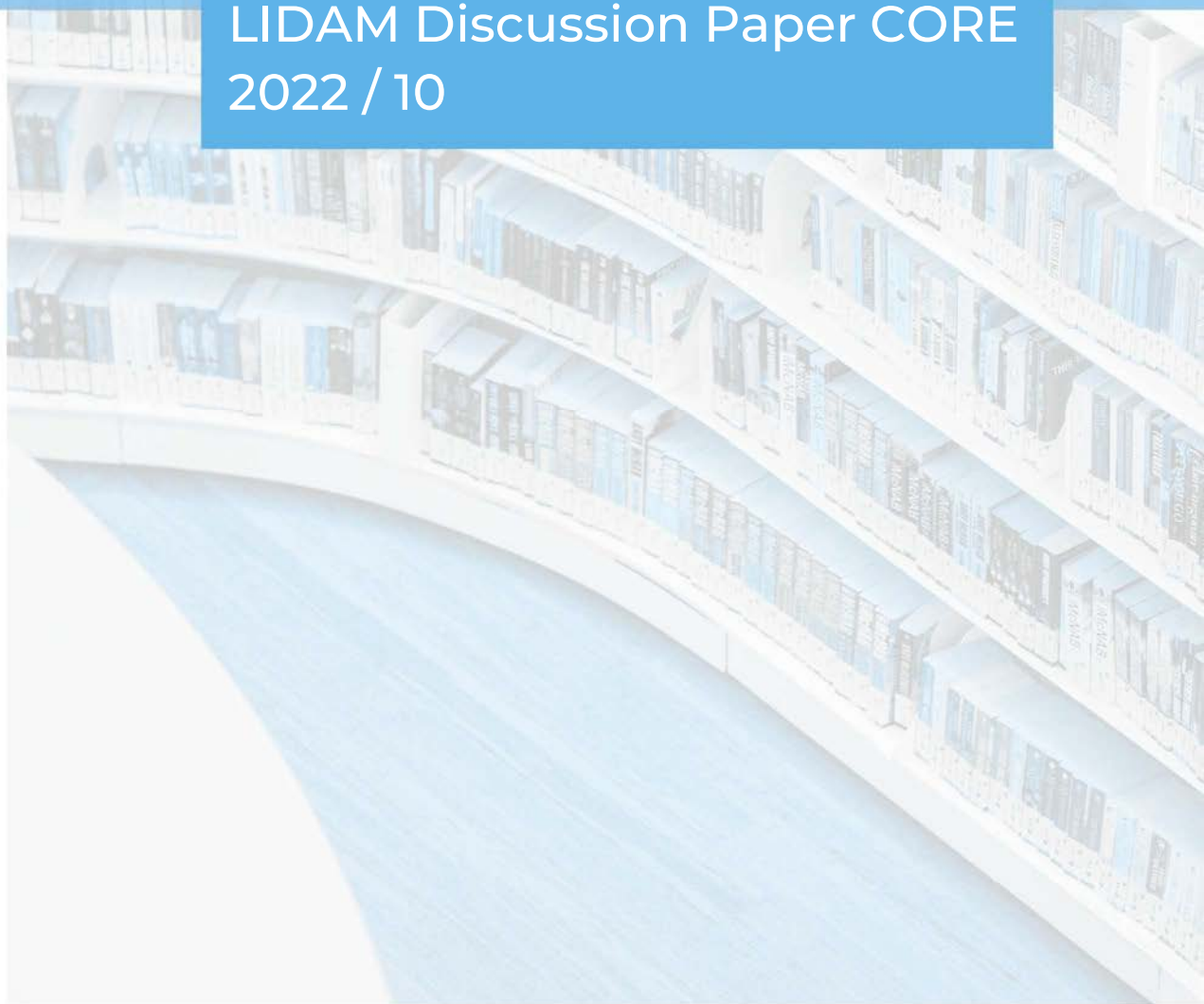

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A tribute to Thierry Bréchet,
An economist of the environment and of the public interest

by[1]

Henry Tulkens, Kirill Borissov, Johan Eyckmans, Stéphane Lambrecht, Pierre M. Picard, Tsvetomir Tsachev and Vladimir Veliov [2]

CORE, Louvain la Neuve, December 2021

Born in Louviers, Normandy on May 24, 1965, Thierry Bréchet, a French citizen, deceased in Brussels on July 20, 2021. He was a professor of environmental economics at Université catholique de Louvain in Belgium, holder of the Chaire Lhoist Berghmans[3] « Entreprise, Économie, Environnement », and a member of the Center for Operations Research and Econometrics[4] .

In this obituary we evoke a few of the many areas in which he worked, focusing on results and his personal contributions. In the last section we review the main stages of his career.

[1] Thanks to Katheline Schubert, Paul Belleflamme, Sophie Mertens and Maria Bréchet-Sharoshkina for the part they took in the preparation of this obituary.

[2] Respectively: Université catholique de Louvain, European University at St. Petersburg,, Katholieke Universiteit Leuven, Université Polytechnique des Hauts de France, University of Luxembourg, Bulgarian Academy of Sciences and Technische Universität Wien.

[3] The Lhoist Group (Jean-Pierre Berghmans president) is a world leader in the production of lime and related minerals.

[4] "CORE" (acronym for *Center for Operations Research and Econometrics*) is a research center of the University founded by Jacques Drèze in 1968 devoted to the use of mathematics and statistics in economics, engineering, and management science.

The environment in general

In his inaugural lecture (2002)[5] of the Chaire Lhoist Berghmans, Thierry Bréchet draws for himself an intellectual project characterized by three dominating ideas : the search for the economic « optimum », the handling of externalities, whose varieties in environmental matters often requires multidisciplinary approaches, and the conciliation of private and public interest. For such a program, he finds inspiration in the public economics literature.

He pursues in (2005) by arguing that modelization, whereby the necessary links are established between the physical, economic, and environmental realities, is an unescapable tool for implementing the stated ambition, at the levels of both analysis and policy advice.

Pollution in dynamic macroeconomics

Within the framework of overlapping generations analysis, Thierry Bréchet has, with his co-authors, considered two main kinds of questions: the global pollution problem of reconciling growth and environmental quality, and how to ensure a sustainable management of natural resources. The building blocks of the models are well known: individual preferences, production technologies, multimarket interactions, characterization of the economic optimum and instruments for its decentralization, collective decision-making processes, *e.g.*, voting. The works touched upon each one of these aspects.

Emission permits and macrodynamic equilibrium

Thus, the effects were scrutinized of emission permits systems on the macro-dynamic equilibrium. In (2010c and 2012d) a heterogeneous optimal control model is used, the heterogeneity being represented by vintage physical capital, i.e. machines of different vintages. It is assumed that newer machines are more productive and less polluting. In this context the issue of optimality is raised when part of the permit endowments must be allocated free for reasons of acceptability. Also, the flexibility over time of a permits system is considered by means of transfers « backward » « forward » of the allowances. More precisely, an emission cap for the whole economy is imposed at both a previously announced level and a previously announced future moment. An anticipation effect is thereby established — the firms start lowering the emissions prior to the date of imposition of the cap. As cases of market failure, as well as of market volatility are exposed, it is also shown that the imposition of aggregate emission caps over periods of specified length has a regularizing effect on the market for emission permits: it reduces or even removes the market failures and volatility.

Altruism and green preferences

Starting from the idea that anything that has value may be the object of preferences, including natural resources and global public goods, he shows in (2009d) that in an economy with altruistic agents owning privately natural resources, a demographic shook entailing a reduction of the population size does not necessarily reduce the pressure on natural resources.

[5] For all works quoted here, those of Thierry Bréchet and coauthors, as well as the other ones, bibliographic references are given at the end.

In (2011b) is shown an ambiguity with altruism in a problem of preservation of a natural resource, due to an interaction between the preferences of altruistic famili es and substitutability / between productive capital and natural resources. The mere existence of the bequest motive does not guarantee that the resource will be conserved in the long run. When the resource is highly substitutable with capital, the equilibrium exhausts the resource stock whatever the intensity of the bequest motive. Be the economy in over-accumulation or in under-accumulation of the natural resource, it always increases aggregate consumption to run the stock of capital at a level lower than the efficiency level.

In (2013) the effectiveness of education expenditure is studied when it aims at greening preferences. If education enhances environmental awareness, the equilibrium properties are modified. Yet the economy can nevertheless reach a steady state or converge to an asymptotic balanced growth path. Therefore, education does not necessarily promote sustained and sustainable growth.

Voting on the environment along a growth path

In an effort to endogenize environmental policies in the analyses, processes of collective decision making are studied in (2014a). How would agents vote for environmental quality or natural resource preservation, when they are heterogeneous in their discount rate ? From a methodological viewpoint, this work provides a solution for characterizing voting equilibria along a growth path. As to results, it shows first that environmental quality and resource preservation are lower in a model with heterogeneous agents, compared with the homogeneous agents case. Next, it shows that the identity of the median voter, patient or impatient vis-à-vis the future, influences the quality of the environment as well as the sustainability in the use of a natural resource— or still how other inequalities between voters have similar effects. Finally, a tax-financed maintenance policy is compared with a debt-financed policy; it is proved that in empirically relevant cases an increase in public debt leads to a decrease in maintenance and environmental quality.

Predictive and adaptive behaviors

Building on the integrated assessment model DICE of Nordhaus (2007), the paper (2014b) formally introduces several types of behavior of possibly co-existing economic agents, including *central planning*, *business as usual* and *free riding*. In each case the agents' policies are based on predictions of the future economic-environmental changes and are adaptive, taking into account current measurements and updates of predictions. The policies are defined in a unified way, by modifying ideas from the so-called *model predictive control* method.

The model is substantially extended in several directions in (2015b). The concept of Model Predictive Nash Equilibrium (MPNE) is introduced within a general framework involving heterogeneous economic agents operating and interacting in a common environment. This concept captures the fact that agents do not have a perfect foresight for several parameters of the economy and the environment. The concept of MPNE is then enhanced to include adaptive learning, where agents gradually improve their knowledge about the environmental dynamics and the damages caused by global warming. Endogenous discounting depending on the agent's wealth is also included. In a particular version of the model, the world is split in two parts (reach and poor countries) and the calibration is done for initial

year 2005 using IPCC reports. Among other effects, the results show that the "natural" evolution of a myopic ignorant agent to a far-sighted knowledgeable one may be too slow, hence, a transfer from reach to poor countries is beneficial for both in the long run.

Stability of international environmental agreements

While taking over the direction of the research project CLIMNEG III financed by BELSPO[6], Thierry Bréchet pursued, with his colleagues at CORE and others, the exploitation of the so called CWS model[7] formulated initially in 1999 (final version published by Eyckmans and Tulkens in 2003). This model served as his starting point for most of his work on the theme of this section.

The « grand » coalition: *two theories confirmed.*

He first took an active part in a long-lasting confrontation of two theories concerning the stability of the coalition of *all* countries involved in the worldwide climate change problem. According to one of them, stability is to be understood in the "strategic" sense of the core of a cooperative game associated with the underlying economic-climatic model in use. According to the other theory, the appropriate stability concept is "economic" in the sense of a collusion between the members of a cartel.

It was known for some time, from analytic results, that an emissions strategy stable in the core sense can be defined and exhibited for the economic-climatic model in use, while by contrast no stable strategy in the sense of a cartel can logically be found for that model. By means of the empirical CWS model, Bréchet (2011a) and his two colleagues confirm for the first time in numbers the two facets of this confrontation.

Other coalitions.

But Thierry Bréchet wishes to consider other coalitions than the « grand » one, and ask whether cartel stability could possibly hold for smaller ones. Thanks to his mastery of the CWS model, Johan Eyckmans had already examined the cartel stability of all conceivable coalitions with that tool in Carraro, Eyckmans and Finus (2006). Pursuing with Thierry Bréchet, they obtained the following new results in (2012a): (*i*) agreements that bring together countries with similar emission reduction costs and climate change damage characteristics, *i.e*., homogeneous agreements, tend to be more stable than heterogeneous ones. However, heterogeneous agreements have a tendency to aim for more ambitious greenhouse gas emission reduction targets. (*ii*) Appropriately designed transfer schemes can stabilize more ambitious heterogeneous climate agreements, both in the cooperative and non-cooperative game theory frameworks. It is desirable, but not always possible, that the transfer schemes be designed to limit free riding behavior. (*iii*) In addition, small institutional changes are shown to have important stability implications. For instance, allowing for a multitude of small fragmented co-existing multiple agreements can yield better global welfare and environmental results compared to a scenario limiting from the outset

[6] Acronym of the Ministry of Scientific Policy in Belgium.

[7] The model dubbed *CWS* (acronym for *ClimNeg World Simulation*) is a version, modified in 1999 by Eyckmans and Tulkens of the model *RICE* (Nordhaus and Yang 1996), a multi-region world growth model of climate change. This modification intended to allow, in a previous project CLIMNEG I, to introduce the cooperation concepts offered by game theory in the analysis of climate negotiations. Chapter 8 of Tulkens (2019) provides a detailed account of this preliminary work.

cooperation to a single unique agreement architecture only. (*iv*) Finally, making membership to international climate agreements exclusive, *i.e.*, conditional upon consent of the other members, can foster instead of hamper cartel stability of a future climate agreement.

Illustrations.

In (2012a), an ingenious diagram shows how the various coalitions ranked according to their size (*i.e.*, the number of their members) can be characterized in terms of their respective environmental and welfare performances, both measured with CWS and synthesized in indexes designed by Carraro, Eyckmans and Finus (2006). This illustrates well point (*iii*) above.

In (2015a), Thierry Bréchet aims at showing relations between the results obtained with CWS for the grand coalition and benefit-cost analysis. Starting from ideas presented at the *MIT Forum* held in Brussels (2010b), the quoted paper presents a diagram that shows the various regions of the world according to the costs they incur and benefits they obtain from alternative climate policies at the global level. The likeliness of each region's participation in these policies is thereby visualized, as well as the possible necessity of transfers to induce such participation in each case.

Evaluating policy alternatives.

In (2010a), the CWS model is used in a non normative way. Indeed, it serves here only as a tool for comparing the outcomes of alternative policies, somewhat arbitrarily defined outside of optimization. The occasion is given by a European "climate initiative" of 2007, comprising the proposal of two alternative such strategies: one consists in a unilateral 20% reduction commitment by the EU, the other consists in a multilateral 30% joint reduction commitment by all Kyoto Annex-B countries. Either strategy is inserted in the CWS model in terms of constraints on emissions, and the results are then compared, as a reference, with those of the strategies that all countries, signatories and non-signatories, are supposed to follow, given the Kyoto Protocol. The comparisons bear on the countries' welfare levels, emissions' evolution, and ensuing temperature changes.

Among the many results, computations show that under the first strategy, the welfare levels is reduced in the countries that are signatories, whereas welfare is increased in the non signatories. Yet, parallel to that, leakages (increases in emissions by non signatories, as a result of the reductions of the signatories) are not very important. The paper also investigates whether if a conditional strategy to reduce emissions by 30% with all other industrialized countries following, is combined with the threat to revert to a 20% unilateral emission reduction if others do not follow, would induce outsiders to join the coalition. The conclusion is negative.

Defense and critique of the Kyoto protocol: on cap and trade and the CDM

Cap and trade

Tradable emissions permits are an economic instrument that Bréchet refers to systematically in most of his papers. Amongst his many presentations of the system, he co-signs the following interestingly succinct one: « The Kyoto architecture presents a logically justified allocation of the respective roles of the public sector (the States) and the private sector (the markets). Indeed, in this framework, there is on the one hand the *global cap* on

emissions, specifying quantitatively as an upper bound the overall amount level of the ambient pollutant. This is chosen by the States, consistent with the nature of that commodity, namely, a public good. On the other hand there is the *trade,* whereby the use of emission rights is distributed among emitters via markets, supply and demand, consistent with the private good nature of these rights » (from 2009b).

The CDM

In its Article 12, the Kyoto Protocol has organized the Clean Development Mechanism (CDM) as a means to stimulate a sustainable economic development and emission reductions in least industrialized countries while at the same time providing industrialized countries with more flexibility to meet their emission reductions commitments. Accordingly, the industrialized countries, that commit to emission reductions targets by signing the so-called Annex B of the Protocol, could partly fulfill their obligations by funding emission reductions projects (e.g. dam, reforestation, …) in developing countries that had made no such commitments. The United Nations was in charge of this process. For each project, it granted Certified Emission Reductions (CER) that could be sold in the carbon market (e.g. European Trading System) and counted towards meeting Kyoto targets. The CDM included a significant share of emission reduction targets during the 2008-2012 period. However, the efficacy of CDM had been subject to strong criticism because of its administration costs and the existence of asymmetric information and moral hazard issues.

In (2005b, 2006, and 2016) Thierry Bréchet and his co-authors highlighted an unseen and important flaw in the CDM. Indeed, the CDM is justified on the ground that carbon emission reductions exactly substitute for the additional carbon emissions made above the countries' targets. However, in reality, countries endogenously set their carbon emission targets during the protocol's negotiation period and therefore anticipate the benefits of CDM projects. It turns out that the global emission level is larger with CDM than without it and countries thus internalize less carbon damages under CDM. The CDM therefore has a negative impact on climate change.

Last but not least, Thierry Bréchet explains that redistribution towards least developed countries may (unfortunately) not be aligned with an efficient climate change policy. Indeed, each CDM project creates an economic surplus that is split between the least developed nations and the firms transferring their clean technologies and headquartered in rich countries. The poor nations have often complained about their too small bargaining power. It is however shown that global carbon emissions increase further with a stronger bargaining power given to those receiving countries. Countries tend to diminish their abatement targets when CDM rents flow to countries that do not commit. As a result, CDM generates a new kind of carbon leakage and has a negative impact on climate change, unless firms in poor countries have no bargaining power.

Uncertainty and the benefits from international cooperation

While almost all the scientific literature using IAMs was dealing only with deterministic models, Bréchet initiated an extension of the CWS model to uncertainty. In (2012f) a stochastic version dubbed "S-CWS" was produced. Stochasticity is introduced by letting a key parameter of the climate module, namely climate sensitivity, be treated in the model as a random variable described by a given, discretized, probability distribution.

The original contributions of the paper are several. (*i*) Optimal policy scenarios are now determined in an expected utility framework. This allows to introduce risk aversion in the analysis. (*ii*) A much finer discretization of the probability distribution is used than had been done thus far in other models – an improvement that allows the computed optimal climate policies to be subjected to a "robustness" validation process[8] never seen in climate models. (*iii*) It is shown that the well-established gain of cooperative solutions (in the sense of Pareto efficient) over individualistic non cooperative solutions (in the sense of Nash equilibria) is reinforced. (*iv*) Moreover, the existence of an additional benefit of cooperation , namely risk reduction, is shown to be brought about by cooperation. Finally, from a sensitivity analysis it appears that the impacts of uncertainty just listed critically depend on the shape of the damage functions.

Clearly, Thierry Bréchet played a major role in the diffusion of the CWS model and in the promotion of its potentialities.

Noise as an environnemental nuisance

Existing airport noise regulations mostly use command-and-control approaches which are often disconnected from the subjective damages of local residents. One key component of the noise environmental problem is the absence of statistical information on residents' preferences. In (2009c) Thierry Bréchet first contributed to this debate by measuring the impact of the aircraft noise on the hedonic price of housing in the large area around the Brussels airport. He turned later to another approach that makes residents reveal the value they attach to the noise externality.

Indeed, moving to a more general level with Pierre M. Picard he called upon the Coase theory of externalities and its extension by Dales (1968a and b) to propose in (2010d, 2012b, c, and d) that noise – a public good – be considered as a good endowed with property rights, rights of emitting in a given area a number of well-defined noise units at well-defined periods of time. The key feature of the proposal is that such rights, *i.e.*, licenses, – that are private goods – be tradable by their owners (namely the residents along the routes, who receive them from the public authorities) and that the air companies be compelled to acquire the relevant licenses when they travel a given route within the area. This is just in the same way that one defines property rights on carbon quotas and lets them be traded in the European Trading System.

The result is a geographical dispersion of aircraft movements over the different routes existing within the area. The prices at which residents consent to sell their noise licenses now reveal the value they attach to silence in the various areas. The market equilibrium for noise licenses expresses acceptability by residents, it spreads over the routes the aircraft activity efficiently, and it gives companies incentives to use quieter aircrafts.

Clearly, such noise licenses would generate and distribute monetary gains to residents, and this would in turn alter the urban structure in the long run, according to the value citizens attach to silence — a fact to be considered if urban planning is to be democratic.

Technological choices and Eco-Efficiency

[8] Due to Ben-Tal & Nemirovski (2002).

(2009a) is a case in environmental microeconomics, where the problem is handled by starting its formulation at the technical engineering level. The message is essentially a pedagogical one, being motivated by the frequently encountered illusion with regulators who endeavor to determine a "best available technology". But technological choices are multi-dimensional: one thus needs a multi-dimensional methodology to identify best available techniques. Moreover, in the presence of environmental externalities generated by productive activities, 'best' available techniques should be best from Society's point of view, not only in terms of private interests.

In the paper a modeling framework is presented by the authors, based on methodologies appropriate to serve these two purposes simultaneously, namely linear programming and internalization of external costs. An operational decision tool is developed in terms of an optimization model, which is of interest for both firms and regulators. It is applied numerically to a plant in the lime industry. The results show why, in this context, there is in general not a single best available technique (BAT), but well a best combination of available techniques to be used (BCAT). The model identifies these technologies numerically, given the prevailing values of the parameters.

At a more general level, a sound methodology for defining and measuring eco-efficiency of firms, to be used e.g. in ranking their performance from that point of view, is sought for in (2007) where a novel *Equilibrium Eco-Efficiency Index* is proposed. Its interest lies in the fact that while depending upon the firms well identified technological parameters, it also takes into account the market equilibrium conditions under which the firm operates, which are shown to influence considerably the eco-performance achieved.

Biographical landmarks and organizational achievements

After completing an undergraduate DEA degree in 1991, and working temporarily as a consultant on models Hermès and Midas of the Belgian Planning Office, Thierry Bréchet presented at the university Paris 1 Panthéon Sorbonne in 2000 a doctoral dissertation entitled «Politiques de lutte contre le changement climatique et modélisation macroéconomique : un modèle d'équilibre général pour l'économie belge» (Paul Zagamé director). Being selected in 2001 to hold the Chaire Lhoist Berghmans, he begun an academic career at Université catholique de Louvain (UcL), Louvain la Neuve.

He taught four courses and seminars, just created in Louvain thanks to the Chaire. His undergraduate audiences consisted not only of economics students but also of students from engineering and management schools.

As a research promotor at CORE, he directed five doctoral students. He received in Louvain-la-Neuve a dozen of post docs and established connections with colleagues in several French universities (Paris, Nanterre, Montpellier, Lille, Valenciennes) as well as with the European University in Saint-Petersburg, Russia. He organized numerous seminars and conferences, that his congenial personality made enjoyable for all.

For quick diffusion of the research output and related materials, he launched a series of preprint/reprint documents entitled *Environmental Economics and Management Memorandum* totalling over 150 titles.

More formally, he co-founded in 2004 with Philippe Michel and Katheline Schubert (Université Paris 1 Panthéon Sorbonne) a series of quarterly « Rencontres de l'Environnement", bringing together environmental economists from Paris 1, Paris 10, Lille 1 and CORE-UcL.

He also co-founded in 2007 with Johan Eyckmans (KU Leuven) the BEED network (Belgian Environmental Economics Days), a yearly meeting now in its 14th session that gathers academic specialists from the Universities of Gent, Leuven, HUBrussel and CORE-UcL.

In 2010, at his initiative and with Henry Tulkens, he received and organized in Brussels, on behalf of CORE-UcL and of the Chaire Lhoist Berghmans, a two-day meeting of the *Forum on Climate Change* of MIT. This *Forum* is a periodical gathering of about a hundred scientists, academics and policy makers from the US and other countries active on the climate change problem. The research paper 2010b was presented there.

From 2010 on also, Thierry made an important contribution to environmental economic thinking in Russia. He participated in several summer schools in Saint-Petersburg, where he gave lectures in the field to young researchers and professors.

Finally, several consulting reports have been commissioned to him by Belgian institutions: the Région Wallone as well as the Institut du Développement Durable in Ottignies.

A 40 page brochure, entitled *Bilan d'activité synthétique de la Chaire Lhoist Berghmans 2002-2010,* issued by the Fondation Louvain, reports in detail all activities of Thierry Bréchet during the first nine years of the Chaire.

Conclusion

It can be said that the intellectual profile of Thierry Bréchet is characterized in two ways: an eclectic mind, and care for the public interest. Eclectic mind, in view of the variety of subject matters for which he showed interest and contributed effectively, methodologically as well as substantially. Care for the public interest, an attitude that appears in the conclusions of most of his papers. More precisely, such care takes each time the form of searching for and identifying sources of cooperation. In this perspective, he views the environmental economics discipline as a tool for serving Society at large. This is in the spirit of the great French line of thought called "le calcul économique public".

With the creation of the Chaire Lhoist Berghmans, Louvain benefitted at CORE from a powerful teaching and research instrument in environmental economics. Thierry Bréchet has implemented in both the best that this instrument could help to provide. In so doing, he excellently responded to the exceptional generosity of those who made possible his coming to the University, and he contributed substantially to the progress of knowledge and ideas in the field that was his.

" Thierry, …, a serious loss for Louvain and the profession more broadly. "
Taken from a message dated August 5, 2021 by Professor Henry D. Jacoby,
M.I.T. Sloan School of Management
and Co-Director of the M.I.T. Joint Program on the Science and Policy of Global Change.

References

Works by Thierry Bréchet and co-authors, quoted above

2002 Leçon inaugurale de la Chaire Lhoist Berghmans « Entreprise, Économie, Environnement », prononcée à l'ouverture de la Chaire au cours d'une séance académique de l'UCL organisée par le CORE au Musée d'Ixelles à Bruxelles, le 22 mai. Mimeo.

2005a "Models for policy-making in sustainable development: The state of the art and perspectives for research" in *Ecological Economics* 55, 337– 350. (With Paul-Marie Boulanger).

2005b "The clean development mechanism in Belgian climate policy". In: Bert Willems, Johan Eyckmans, Stef Proost (eds), *Economic Aspects of Climate Change Policy : A European and Belgian Perspective*, Acco:Leuven, p. 68-75. (With Benoit Lussis)

2006 "The contribution of the Clean Development Mechanism to national climate policies. In: *Journal of Policy Modeling*, Vol. 28, p. 981-994 (2006). (With Benoit Lussis)

2007 « Environmental performance and equilibrium ». In: *Canadian Journal of Economics/Revue Canadienne d'Économique*, 40, (4), p. 1078-1099. (With Philippe Michel).

2009a "Beyond BAT: selecting optimal combinations of available techniques, with an example from the limestone industry". In: *Journal of Environmental Management*, Vol. 90, no. 5, p. 1790-1801. (With Henry Tulkens).

2009b « Mieux répartir les coûts de la politique climatique"- recension de *Politique climatique : une nouvelle architecture internationale*, rapport de Jean Tirole au Conseil d'Analyse Économique. In : *La Vie des Idées*, décembre, electronic journal (www.laviedesidees.fr). (With Henry Tulkens).

2009c « Une évaluation objective des nuisances subjectives de l'aéroport de Bruxelles-National », *Regards Économiques* No. 66, février, electronic journal of IRES, Université catholique de Louvain. (With A. Gérard & G. Mion).

2009d "Family altruism with renewable resource and population growth". In: Mathematical Population Studies, 16, p. 60–78. (With Stéphane Lambrecht).

2010a "The impact of the unilateral EU commitment on the stability of international climate agreements". In: *Climate Policy*, Vol. 10, no. 2, p. 148-166. (With J. Eyckmans, F. Gerard, Ph. Marbaix, H. Tulkens and J-P. van Ypersele).

2010b "Taking account of benefits in climate policy evaluation: Global and local aspects", paper presented at the *XXXIst MIT Global Change Forum on Climate Change*, a meeting of the MIT Joint Program on the Science and Policy of Global Change, Brussels, October 20-22 (With Henry Tulkens).

2010c "Prices versus quantities in a vintage capital model". In: J.C. Cuaresma, T. Palokangas, A. Tarasyev (eds.), *Dynamic Systems, Economic Growth, and the Environment*, Dynamic

Modeling and Econometrics in Economics and Finance Series, 12, p.141-159, Springer New York. (With Tsvetomir Tsachev and Vladimir Veliov).

2010d "The Price Of Silence: Markets For Noise Licenses And Airports," *International Economic Review*, 51(4), p. 1097-1125. (With Pierre M. Picard).

2011a "Efficiency vs. stability of climate coalitions: a conceptual and computational appraisal", *The Energy Journal* 32(1), 49-76. (With François Gerard and Henry Tulkens). Reprinted in Carlo Carraro (2016)

2011b "Renewable resource and capital with a joy-of-giving resource bequest motive", Resource and energy Economics, 33, p. 981–994. (With Stéphane Lambrecht)

2012a "Coalition Theory and Integrated Assessment Modeling: Lessons for Climate Governance", In: Eric Brousseau, Tom Dedeurwaerdere, Pierre-André Jouvet, Marc Willinger (eds), *Global Environmental Commons: analytical and political challenges in building governance mechanisms*, Oxford University Press p. 162-179. (With Johan Eyckmans).

2012b "Airport noise pollution: how to regulate efficiently by confronting victims and polluters?". In: B. Sébastien and B. Hamaide (eds), *Développement durable et économie environnementale régionale*, IWEPS, FUSL, p. …. (With Pierre M. Picard).

2012c "The Economics of Airport Noise: Managing Markets for Noise Licenses", *Transportation Research: Part D* 17, 169–178. (With Pierre M. Picard).

2012d "Markets for emission permits with free endowment: a vintage capital analysis". In: *Optimal Control Applications and Methods*, 33, (2), p. 214-231. (With Tsvetomir Tsachev and Vladimir Veliov).

2012e "The economics of airport noise: How to manage markets for noise licenses". In: *Transportation Research. Part D: Transport & Environment,* Vol. 17, no. 2, p. 169-178. (With Pierre M. Picard).

2012f "The benefits of cooperation under uncertainty: the case of climate change" in: *Environmental Modeling & Assessment*, 17, 1-2, p. 149-162. (With Julien Thénié, Thibaut Zeimes and Stéphane Zuber).

2013 "Can education be good for both growth and the environment?". In: Macroeconomic Dynamics, 17, 5, p. 1135-1157 (2013). (With Fabien Prieur).

2014a "Environmental Policy in a Dynamic Model with Heterogeneous Agents and Voting". In: E. Moser et al. (eds.), *Dynamic Optimization in Environmental Economics*, Springer, pp. 37-60. (With Kyrill Borissov and Stephane Lambrecht).

2014b "Model predictive control, the economy, and the issue of global warming". *Annals of Operations Research*, 220, p.25-48, 2014. (With Carmen Camacho and Vladimir Veliov).

2015a "Climate policies: a burden, or a gain?" in: *The Energy Journal*, 36 (3), p.155-170. (With Henry Tulkens).

2015b "Adaptive Model-Predictive Climate Policies in a Multi-Country Setting". In: *The Oxford Handbook of the Macroeconomics of Global Worming*, L. Bernard, W. Semmler (Eds.), p. 114-138, Oxford University Press. (With Carmen Camacho and Vladimir Veliov).

2016 "The Clean Development Mechanism in a world carbon market". In: *Canadian Journal of Economics/Revue Canadienne d'Économique*, 49 (4), p. 1569-1598. (With Yann Ménière and Pierre M. Picard).

Other references

Ben-Tal, A. & Nemirovski, A. (2002), "A Robust Optimization – Methodology and Applications", *Mathematical Programming Series B*, 99, p. 453-480.

Carraro, C. (ed.) (2016), *Coalitions and Networks: 12 papers from 20 years of CTN workshops,* The FEEM Series on Climate Change and Sustainable Development, FEEM Press, Milan.

Carraro, C., Eyckmans, J. and Finus, M. (2006), « Optimal transfers and participation decisions in international environmental agreements », *Review of International Organizations* I, p. 379-396.

Dales, J.H. (1968a), "Land, Water, and Ownership", *The Canadian Journal of Economics / Revue Canadienne d'Économique* I(4), p. 791-804.

Dales, J. H. (1968b). *Pollution, Property & Prices: An Essay in Policymaking and Economics*, University of Toronto Press, Toronto.

Eyckmans, J. and Tulkens, H. (2003), "Simulating coalitionally stable burden sharing agreements for the climate change problem", *Resource and Energy Economics* 25, p. 299-327.

Nordhaus, W. (2007), *The Challenge of Global Warming: Economic Models and Environmental Policy,* Yale University Press.

Nordhaus, W. and Yang, Z. (1996), "A Regional Dynamic General-Equilibrium Model of Alternative Climate-change Strategies", *American Economic Review* 86, p. 741-763.

Tulkens, H. (2019*), Economics, Game Theory and International Environmental Agreements: The Ca' Foscari Lectures*, World Scientific Publishing, London and Singapore.