Fighting global warming with carbon pricing : how it works, field experiments and elements for the Belgian economy

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Introduction

The last few years have seen growing public concern about the environment in general, and global warming more particularly, which has led to massive demonstrations throughout the world. They have been temporarily stopped by the COVID-19 pandemic which has severely hit the global economy. Even though global warming is a long-run structural problem and the pandemic hopefully only a temporary one, several lessons can be drawn from the coronavirus crisis to better assess the climate issue, which is still a bit too abstract. First, the pandemic has illustrated the huge dependence of our economies on the use of carbon-intensive fossil fuels : when the global economy suddenly froze, carbon emissions dropped accordingly. Let us imagine for one minute that the causality had been reversed, that the fall in economic activity was forced by a need to reduce emissions. The dramatic COVID episode has the pedagogical virtue of highlighting the huge economic costs associated with a brutal reduction in carbon fuels combustion. The drop in carbon emissions in 2020 is forecast in the range of 4 to 7 %. It is revealing to compare this number with the 7.5 % yearly drop that is recurrently required to reach carbon neutrality by the 2050 horizon. Another comparison can be made regarding the time lapse during which the virus spreads through the population without perceivable consequences before provoking a sudden and exponential burst in hospitalisations and deaths. The same way, anthropogenic atmospheric carbon accumulated relatively unnoticed in the high atmosphere over the last two and a half centuries, but now comes the time where changes become more and more tangible. Even though lockdowns are extremely compelling and economically costly, they at least have the merit of being enforceable and stopping the virus from spreading while waiting for a vaccine. Once the costs of global warming explode, no lockdown will be possible and there is no encouraging sign that any medicine helping to reduce the existing atmospheric carbon stock could soon be in sight.

The only alternative is to make efficient use of the window of opportunity during which the human and economic costs of global warming remain limited to stop feeding further emissions into the existing atmospheric carbon stock and resolutely aim for a carbon-free global economy. Even though environmental concerns are growing, it seems still difficult to accept that the transition cannot be obtained for free, as illustrated by the *Gilets Jaunes* movement in France, the repeal of the carbon tax in Australia in 2016, and the withdrawal of the United States from the 2015 Paris Agreement. The aim of this article is to set out the solution recommended by economists to help address the externality of carbon emissions and launch as smooth a transition path as possible : via carbon pricing. Even though it cannot claim to be a panacea, it would enable a correction of relative prices in favour of low carbon consumption behaviour, technologies, investment and research and development.

The first section rapidly sketches the problem of carbon emissions at the global level and the challenges it raises for the decades to come. The second section presents the theoretical foundations for an efficient carbon pricing system in order to counter the usual criticisms raised against it in terms of loss of households' purchasing power and firms' competitiveness. It also explains the way in which economists are trying to establish a fair price path for carbon by weighting the welfare of the current and future generations. It ends with a brief discussion about the impact of carbon pricing on the fossil fuel prices. The third section focuses on the existing experiments with carbon pricing around the world and briefly reviews the empirical evidence regarding the effect of carbon pricing on greenhouse gas emissions on the one hand and on economic activity and employment on the other hand. Section four describes the Belgian emissions by sectors of activity in comparison to those of the European neighbours. This makes it possible to identify the sectors more at risk if ever a carbon tax were introduced in Belgium and/or in the European Union. It also insists on the difference between the emissions resulting directly from fuel combustion on national territory and those linked with our ways of producing and consuming. In this way, it gives an idea as to where to direct our efforts in the coming years to reach the ambitious climate objective of the recently installed governing coalition. Section five continues with some macroeconomic fiscal simulations of the introduction of a carbon tax in Belgium. This exercise compares the effect of a tax levied on households, on the one hand, and on firms, on the other hand. It also tries to assess the consequences of introducing a tax at the European rather than Belgian level. Finally, it assesses the importance of using the tax dividend for redistribution purposes rather than to improve the public authorities' budget deficit in order to counterbalance the negative effects of the induced shock on energy costs.

1. A brief description of the carbon problem

1.1 Atmospheric carbon and the global warming

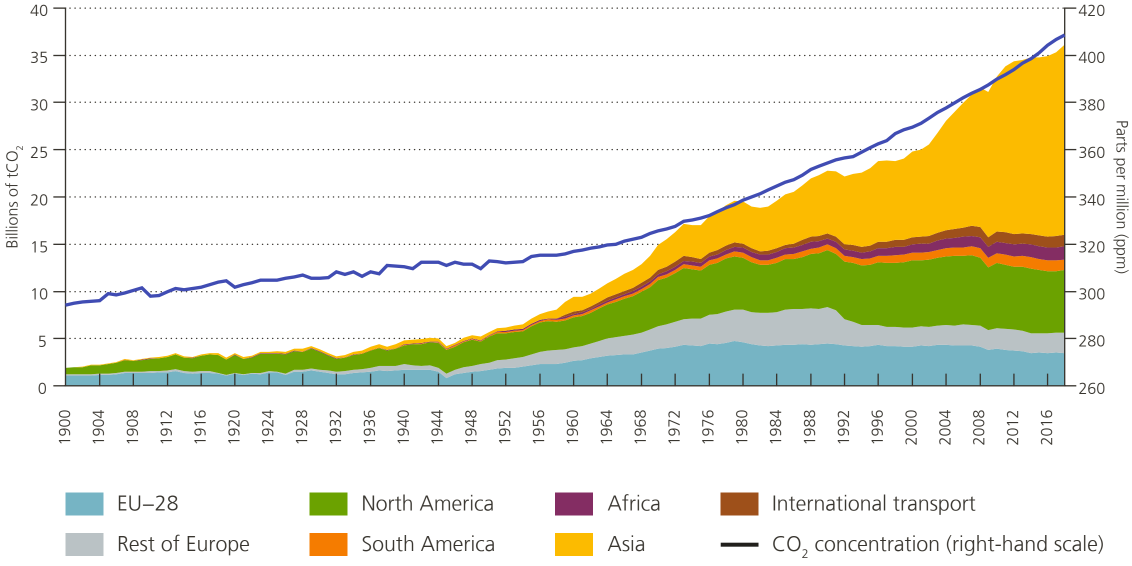
The Industrial Revolution was characterised by the transformation of energy from combustion into mechanical power that multiplied the efficiency of human labour. The continuous rate of innovation in this process made it possible to reach an incredible pace of economic development compared to previous standards. As most of the new energy requirements came from carbonated fuels, production and consumption released larger and larger quantities of carbon dioxide into the atmosphere. Carbon is a chemical element that is key for life on planet Earth. The bulk of it (about 99.9 %) is contained in the lithosphere, i.e. in rocks and sediments. The last tiny part is shared among the hydrosphere (93.4 %), the biosphere (4.8 %) and the atmosphere (1.8 %), with continuous flows between these four carbon stocks through geological activity, photosynthesis, respiration, fossilisation, etc. Given the relative size of the atmospheric carbon reserve compared to the other ones, any modification of the transfer flows between these four stocks will affect the atmosphere composition much more. This is particularly true on our human time scale, since, once released into the atmosphere, carbon is expected to stay there for a long time, between 300 and 1 000 years if natural processes alone are at work.

As pointed out by the Swedish chemist Svante Arrhenius around 1890, atmospheric carbon has the particularity of being a greenhouse gas[1], i.e. that a higher concentration of this gas in the upper atmosphere goes hand in hand with the warming of the Earth's surface. According to paleoclimate evidence, we know that over the past million years, carbon dioxide atmospheric concentration has never exceeded 300 parts per million (ppm). Before the Industrial Revolution started in the mid-1700s, the global average concentration was about 280 ppm. By the beginning of the 20th century, it had risen to 294 ppm and pursued its increase to reach 409 ppm in 2018 (see chart 1), with a correspondent rise in Earth surface temperature of 1.1°C compared to the pre-industrial era.

1 Together with methane, nitrous oxide, ozone, chlorofluorocarbons and hydrofluorocarbons. Throughout this article, we focus on carbon, which is the most important source of greenhouse gases produced from fossil fuel combustion and which lasts longest in the upper atmosphere.

Chart 1

Global yearly CO_2 emissions and average concentration of CO_2



Sources: Carbon Dioxide Information Analysis Centre, Global Carbon Project; National Oceanic and Atmospheric Administration.

With the 2015 Paris Agreement, most countries in the world agreed to keep global warming well below 2°C. This implies that concentration should be limited to about 450-480 ppm by the time we reach carbon neutrality. Given the past growth of the atmospheric carbon stock (about 2 200 gigatonnes since the mid-18th century), scientists evaluate the remaining carbon budget to be about 600 to 800 gigatonnes. Given current global emissions are around 36 gigatonnes of CO_2 (as in in 2018, see chart 1), this budget would be exhausted within 15 years if emissions continue to grow at the current rate. It goes without saying that the 2°C target has very little chance of being met without strong and radical action. Scientists meeting for the International Panel on Climate Change (IPCC) predicted in 2013, at unchanged policies, an increase of 4°C above pre-industrial levels by the end of the 21st century (IPCC, 2013)[1].

1.2 Risks and costs associated with global warming

The reason why international experts from the IPCC and other fora insist on limiting the rise in global temperature by about 2°C is that, above this threshold, they fear that we will enter into an even more uncertain era as it increases the likelihood of tipping points being reached[2]. However, the warming observed so far already has important consequences. The best-known of them is the melting of the ice stored on the North and South Poles and high mountains. This directly ends up in rising the sea level with dramatic repercussions for the millions of people living in coastal and floodable areas, notwithstanding the cost related to the potential destruction of

1 By way of comparison, during the last glaciation 20 000 years ago, the average Earth surface temperature was 6°C lower than now and Belgium was on the borderline between a region of polar desert and one of dry tundra. There was nearly no forest cover in Europe at that time.

2 Such non-linearities could be triggered by the consequences of global warming on oceanic flows or on the release of greenhouse gases stocked in the permafrost, among other things. A reversal of the Gulf Stream would lead to a drop in temperatures in Europe, while the melting of the permafrost will accelerate the greenhouse effect.

capital in terms of buildings and (harbour) infrastructure. The increase in the temperature difference between the Earth's surface and the upper atmosphere also modifies atmospheric mass fluxes, generating more frequent and more violent extreme weather events. Globally, the number of floods and other hydrological events has doubled since 2004 and quadrupled since 1980. Extreme temperatures, droughts and forest fires have more than doubled since 1980. Meteorological events, such as storms, have also doubled since 1980. This is obviously costly in terms of welfare, lives and capital losses[1]. Numerous studies prove that raising temperatures also affects productivity *per se*. Heal and Park (2013) and Park, Bangalore, Hallegate and Sandhoefner (2018) have gathered data about the impact of heatwaves or cooling systems on labour productivity and cognitive capacities. They conclude that labour productivity could drop by 2 % for each increase of 1°C above an optimum temperature, evaluated at 21°C. Kahn, Mohaddes, Ng, Pesaran, Raissi and Yang (2019) estimate that a persistent increase in the average global temperature by 0.04°C per year, in the absence of mitigation policies, would reduce global real GDP per capita by more than 7 % by 2100. All these studies emphasise that the cost of global warming will be very unevenly spread geographically, with the warmer countries, that are often the poorer ones, being the most heavily impacted.

There is no longer any room for doubt about the anthropogenic origin of the current global warming, and there is also a large consensus that the warming process is costly in terms of productivity and welfare, and that these costs will accelerate in the future. Could the growing stock of carbon dioxide in the upper atmosphere be the modern version of the demographic Malthusian trap? The question draws the border with territories dominated by huge uncertainties. First, as mentioned above, the relationship between atmospheric carbon and global warming is subject to non-linearities and tipping points, so experts now provide statistical distributions of temperatures in correspondence to given carbon concentrations. Second, there is still a fierce debate among economists concerning the scale of the economic cost associated with global warming, a discussion which is fuelled by huge uncertainties regarding the potential of technological progress to address the issue in due time[2], on the one hand, and by the concerns about the ability, willingness and effectiveness of public authorities around the world to take action, on the other hand. Atmospheric carbon obtained from fuel combustion is produced locally but generates global damage. It is produced at a time where this damage is only weakly perceivable, and will actually be borne by future generations. Both elements are captured by what is called "the double tragedy of the horizon and of the commons". Governments therefore have to convince their citizens/electorate to accept to endorse the costs of a policy which will mostly be fruitful at a horizon behind their life expectancy and that will be shared by the whole future of humanity.

These uncertainties crystalise into risks associated with the climate change, risks that are probably neither fully understood nor correctly valued. The literature usually divides them into physical and transition risks. Physical risks arise from production factor destruction or lower productivity and the implied losses in economic activity and asset performance attributable to climate-change-related shocks and stresses. Transition towards a low-carbon economy – whether triggered by changes in policy, by shifts in consumer preferences or by technological breakthroughs – will be responsible for some Schumpeterian creative destruction, accelerating the obsolescence of carbon-intensive installed capital. Transition risks cover the losses these stranded assets could bring in terms of economic activity together with the impact on the financial system caused by asset value writedowns. Together with the above-mentioned carbon budget, physical and transition risks draw the ridge path to a safe and cost-minimised switch to a low-emission economy. Given the very slow natural decay of the stock of atmospheric carbon and the scale of current emissions, the later the transition is seriously considered and launched, the most perilous and expensive it will be.

1 For the United States only, the National Oceanic and Atmospheric Administration and the National Centers for Environmental Information evaluate that, on the basis of a 5-year moving average, the costs of climate related disasters have been multiplied by seven between the end of the 1980s and now, from US$ 15 up to 105 billion (source: Keenan, Martinez-Diaz and Moch, 2020).

2 First, through greater efficiency of fossil fuel use, second, by increased production and storage of renewable and non-carbon sources of energy and third, via the potential of carbon capture.

1.3 A brief description of the problem

Between 1990 and 2018, the area that has been the most successful in reducing its carbon dioxide emissions is the part of the European continent that does not belong to the EU28 (–44 % by 2018, see chart 1). However, this is mostly the consequence of the economic collapse following the dissolution of the former Eastern bloc rather than the outcome of some ecological concern. The reduction in emissions has been much tinier in the EU28 (–23 %), though sizeable, and the effort became more sustained since the great financial crisis. On the same time span, the industrialised countries of North America managed to limit their increase in emissions by 10 %, while emissions from the developing countries of Africa and South America doubled, and those of the rapidly growing Asian countries tripled[1]. The limited or reduced emissions in the old industrialised economies result from the combination of their progressive deindustrialisation – and manufacturing activities relocated to emerging economies[2] – with lower use of coal – the fossil fuel with the highest carbon content – in the energy mix, from 22 % and 30 % respectively in North America and Europe, down to about 17 % in both. In both areas, it has more or less been substituted by natural gas, mostly shale gas in the US. By contrast, the coal share rose from 36 % to 49 % in the Asian energy mix[3]. We draw three lessons from this birds-eye view. Firstly, as learned from the former Eastern bloc experiment, and also from the various economic crises, in the past, emissions have dropped hand in hand with value added. The challenge is therefore to reduce the first without affecting the latter. Secondly, given the global dimension of carbon emissions, it makes no sense to reduce emissions in one part of the world by shifting carbon-intensive activities towards another area. Third, managing to reduce and stop coal combustion and replace it by a less carbon-intensive fuel is the cheapest and most effective step in the path towards a low-carbon economy. Economies which have already shifted away from coal face a more abrupt step.

Several countries have announced and/or passed laws about a zero-carbon target. The European Union is committed to reducing its emissions by 40 %, or even 55 %, compared to 1990 levels within ten years and to reaching carbon neutrality by 2050. Sweden, Japan, France and the United Kingdom, among others, also target the 2050 horizon for full decarbonisation and, China, the largest emitter in absolute terms, has announced plans to approach this objective by 2060. Such programmes appear extremely ambitious: they imply that emissions would have to come down by about 7.5 % every year from now on. Just to have an idea, let us compare this number with the performance over the 2008-2018 period: on average, yearly emissions declined by 1.8 % for the EU28, 1.1 % for Germany, 1.6 % for France, 1.7 % for Belgium, 2 % for Sweden and 3 % for the United Kingdom, while Chinese emissions continued to grow at a rate of 3.2 % per year. The relative success of the United Kingdom compared with France is attributable to the fact that carbon emissions per capita are historically lower in the latter than in the former, among other reasons due to wider recourse to nuclear energy. This has made it easier for the UK to bring its emissions down by switching from coal to natural gas to generate electricity.

However, the next steps towards a low-carbon economy will be more costly and painful, requiring the gradual replacement of oil and natural gas by non-carbon energy sources (hydropower, nuclear or wind and solar energy). Japan substantially cut back its production of nuclear electricity in the aftermath of the Fukushima accident and reduced more oil-related emissions, keeping coal combustion relatively constant, so there is ample room for switching to less carbon-intensive fossil fuels as in China. Even though Belgium seems to have performed better than Germany in terms of emission reductions over the last ten years, Germany has, first of all, more "coal utilisation reserves" to reduce emissions further at a low cost, and second, it has managed to improve its energy efficiency. Both the German and Belgian efforts are nevertheless dominated by the performances of the UK and Sweden, two countries with very different initial profiles which introduced carbon-pricing mechanisms.

1 Interestingly, the reduction of emissions in Europe has been exactly offset by growing emissions in Africa and South America, so Asian economies appear as the only contributors to global emissions growth.

2 The doubling in international transport emissions reflects the internationalisation of the production process and supply chains, with Asia having become the world's main manufacturing centre.

3 All these numbers are computed from data compiled by the International Energy Agency.

Table 1

Emissions, energy and fossil fuels for some industrialised countries

(in units, unless otherwise stated)

	China	United States	Japan	Belgium	Germany	France	United Kingdom	Sweden
	2008							
Emissions								
Mtonnes CO_2	7 375	5 928	1 232	120	854	399	545	51
(index 1990 = 100)	*304.7*	*115.8*	*106.4*	*99.9*	*81.1*	*99.6*	*90.6*	*88.1*
tCO2/capita	5.45	19.53	9.59	11.16	10.53	6.42	8.76	5.48
(index 1990 = 100)	*264.9*	*96.2*	*103.0*	*92.7*	*79.1*	*90.7*	*83.3*	*81.8*
kgCO2/GDP	0.69	0.39	0.26	0.29	0.27	0.17	0.23	0.13
(index 1990 = 100)	*50.9*	*70.7*	*86.8*	*73.2*	*60.4*	*71.2*	*59.0*	*58.2*
Energy								
Mtoe	2 168	2 283	498	57	337	271	208	49
(index 1990 = 100)	*245.7*	*119.2*	*113.6*	*118.2*	*95.9*	*118.8*	*101.4*	*104.5*
Fossil fuels (in %)	90	85	83	75	80	50	90	34
of which: Coal	*78*	*29*	*28*	*11*	*30*	*9*	*19*	*14*
	2018							
Emissions								
Mtonnes CO_2	10 065	5 416	1 162	100	759	338	379	41
(index 1990 = 100)	*415.8*	*105.8*	*100.3*	*82.7*	*72.1*	*84.3*	*63.1*	*71.4*
tCO2/capita	6.92	16.21	9.32	8.54	9.65	5.34	5.81	4.24
(index 1990 = 100)	*336.7*	*79.8*	*100.1*	*71.0*	*72.5*	*75.5*	*55.2*	*63.3*
kgCO2/GDP	0.45	0.30	0.24	0.20	0.21	0.14	0.15	0.09
(index 1990 = 100)	*33.6*	*54.6*	*78.5*	51.0	50.1	*57.8*	*37.3*	*41.7*
Energy								
Mtoe	3 211	2 227	419	55	306	252	174	51
(index 1990 = 100)	*363.8*	*116.3*	*95.4*	*114.4*	*87.2*	*110.5*	*84.7*	*107.8*
Fossil fuels (in %)	88	82	88	76	78	46	79	27
of which: Coal	*70*	*18*	*31*	*8*	*29*	*8*	*6*	*16*

Sources: World Bank and Global Carbon Project; GDP per capita based on purchasing power parity (PPP), 2011 international dollars; International Energy Agency.

The fact that old industrial economies have managed to stabilise their energy requirements over the last 30 years and to modestly reduce their carbon emissions is nevertheless encouraging as it reveals that this is possible without affecting the economic growth of the most deserving cases compared to the others. In other words, it is proved that technological progress may help increase the energy efficiency of modern economies and to steadily reduce the carbon content of GDP. The challenge for the years to come is twofold. First, this movement must be strongly reinforced in the developed economies to meet their zero carbon commitments. Second, technology sharing with less-developed economies is essential for these efforts not to be ruined by the increase in emissions by rapidly growing economies.

2. Setting a price for carbon dioxide emissions to fight climate change

2.1 Elements of the debate around carbon pricing

There is a wide consensus among economists that the introduction of a carbon price mechanism is essential to addressing the global warming problem. This mechanism was introduced in Scandinavian countries thirty years ago. The European Union followed 15 years later, by launching the EU Emissions Trading System (ETS) in 2005; it is one of the first measures adopted by the European authorities in this perspective. Even today, such a mechanism is at the forefront of the policy recommendations: it has for instance been strongly advocated for the United States by prominent US economists in a famous address in January 2019[1]; it is the top recommendation of the Litterman Report (see Keenan *et al*., Eds, 2020) to manage the climate risk in the United States.

Why do economists back a "carbon price" policy so much? They describe the problem of greenhouse gas emissions as a market failure: it is the by-product of other activities, but there is no demand for it, and therefore it is neither traded nor priced. This implies over-investment in carbon-intensive technologies, and over-consumption of fossil fuels, with greenhouse gases produced in excess with respect to what would be socially desirable. Based on the pioneering works of Arthur Pigou and Ronald Coase, environmental economists[2] state that public authorities should structure the missing market so the price of fossil fuels correctly reflects the social cost induced by their combustion. This has been popularised as the polluter-pays principle. By giving a value to the "bad" carbon emission by-product, economic agents take its production into account in their choices and energy options regarding transport, heating, electricity, etc. The goal of such Pigouvian mechanisms is not to raise money for government coffers, but to modify behaviour by setting a level playing field for market forces and restore the convergence of individual and social optima in a fully decentralised way. The effect of carbon pricing is not limited to the relative price of carbon fuels: it is also directly reflected in asset prices which are then revalued according to the carbon price exposure of firms and sectors.

However, the consensus among economists percolates with difficulty into political cenacles and the principle of carbon pricing is far from straightforward to put into place. The opponents' arguments claim, first of all, that a national carbon pricing policy would be ineffective at global level and that initiatives should be transnational[3]. Secondly, they claim that valuing carbon emissions would come at a high social and economic cost for the country introducing such a measure: local firms would lose competitiveness and market share, investors would choose to install production capacities abroad to alleviate the pricing system and households would suffer from price rises and higher unemployment. Thirdly, besides the dangers that such a mechanism would bring for economic growth and investment, it would also lead to inequalities between economic sectors and between households. Sectors are not alike, neither in terms of carbon intensity, nor regarding trade and competitiveness exposure. Fossil fuels are basic consumer goods and, as such, they make up a larger proportion of lowerincome households' consumption basket. Fourthly, some fear that a carbon pricing system would be too complex to organise and administratively costly. Finally, *a priori*, it seems hugely challenging to put a value on carbon externality.

1 This column, entitled "the Economists' Statement on Carbon Dividends" has been published simultaneously in the Wall Street Journal, Axios, the Financial Times and the Washington Post, signed by 3589 US economists, including 28 Nobel laureates, 15 former chairs of the Council of Economic Advisers and 4 former chairs of the Federal Reserve.

2 For example, Dales (1968) and Montgomery (1972).

3 This is the well-known "tragedy of the commons" leading to generalised free-riding and ending up with the complete destruction of the common good.

2.2 How to organise carbon pricing

The arguments put forward in the carbon pricing debate are important to keep in mind in order to set a pricing mechanism in a way which is both economically and politically sustainable. How should the carbon trade best be organised? A carbon price can be fixed either directly, by imposing a carbon tax trajectory, or indirectly, through the distribution of a limited number of emission permits. In the latter case, the induced scarcity gives emissions a price on the newly created secondary market where allowances can be traded[1]. Under certain conditions, including perfect information, deciding on prices or on quantities is equivalent. However, without these assumptions, fixing quantities implies that all the uncertainty related to imperfect information and foresight turns into price volatility. This was dramatically demonstrated during the great financial crisis. In a right-to-pollute system like the ETS introduced in the EU from 2005 onwards, any cyclical or structural drop in demand for permits affects the carbon price and distorts the virtuous role of the relative price signal. As belatedly recognised, it can only be restored by adjusting the volume of emission rights, as was done using the so-called Market Stability Reserve. On the contrary, if prices are set through a carbon tax system, the uncertainty moves to quantities, i.e. to the horizon at which the targeted emissions are reached.

Both types of policies have been implemented in the last three decades, as reported in section 3.1 below. For example, with the ETS, the European Union has opted for a cap-and-trade system, which was the only available option given that the Commission has no fiscal powers but it is in charge of setting competition rules. However, such a polluting permit market is only bearable for a limited number of participants, i.e. the large polluting firms. Smaller firms and households who also burn carbon fuels are left out of this pricing mechanism and so their consumption and investment behaviour is not affected by the ETS. Nowadays, sixteen[2] of the thirty-one countries concerned by the EU ETS supplement this allowance mechanism with a carbon tax to fill this gap.

In order to address the above-mentioned criticisms raised by the opponents of carbon pricing, the US Economists' Statement on Carbon Dividends calls instead for a carbon tax with no exemption regime and endowed with the following features:

– It should be paid by the buyers of fossil fuels as far upstream as possible in order to minimise its administrative cost;

– Ideally, the carbon tax should increase over time and the entire tax path should be disclosed, in order to let agents anticipate this gradual change in relative prices and adapt their behaviour and their technology mix smoothly. This is particularly important in the case of energy transition where a lot of research and development is still required, where technology diffusion may take time and new technologies are costly to put in place, demanding long-term investment plans. An obvious reason to increase the tax gradually over time is that the first efforts to reduce emissions could be not too demanding. They can be obtained by some savings measures and by switching away from the most carbon-intensive fossil fuels, like coal and lignite, to less intensive ones, like natural gas. However, the transition path towards a low-carbon economy will require at some point switching to fully decarbonated sources of energy and/or carbon capture technologies that still need to be developed;

– The tax should be revenue-neutral and all its benefits redistributed to citizens via lump-sum transfers so that the majority get back more in carbon dividends that what they pay in higher energy prices. This point

1 It is noteworthy that each time a carbon pricing mechanism has been introduced, its first consequence has been a sharp reduction of coal in the energy mix, coal being the most carbon-intensive fossil fuel. In his 2020 EEA presidential address, Per Krussel claimed that imposing a global carbon tax at the global level or banning the use of coal are two policies yielding roughly similar outcomes in terms of emission reduction and costs.

2 These countries are Finland (1990), Poland (1990), Norway (1991), Sweden (1991), Denmark (1992), Slovenia (1996), Estonia (2000), Latvia (2004), Switzerland (2008), Ireland (2010), Iceland (2010), United Kingdom (2013), Spain (2014), France (2014) and Portugal (2015). However, the sectors concerned by these taxes and their overall coverage may vary widely from one country to another (see chart 3 on this point).

is essential to oppose the counter-redistributive consequences of taxing basic necessities like fossil fuels and should help ensure the political acceptability of the system;

– Finally, a border price adjustment should be introduced to limit competitiveness losses for domestic firms and avoid relocation of energy-intensive activities. Beyond this, the goal of the border tax is mostly to give trade partners an incentive to join the carbon coalition, or the "carbon fight club" as it was nicknamed by Nobel laureate William Nordhaus. He proposed a trade tax to be applied to all goods originating from countries not taxing carbon. Such a tax would overcome the complexity of computing the carbon content of each good. In addition, the idea is that trade partners should prefer to tax carbon themselves and keep the tax dividend instead of letting the revenue from the border tax inflate the importing country's coffers.

2.3 How to decide on the starting level of the carbon price and its growth pace?

The above proposal answers all the criticisms raised earlier. The only missing point is at which level to start the tax, and at which rhythm it should increase? Climate-integrated macroeconomic models[1] are nowadays economists' central tools for producing a cost-benefit analysis of climate policies, including carbon pricing. These models have been used intensively in international fora like the Intergovernmental Group of Experts on Climate Change (IGEC) and the Intergovernmental Panel on Climate Change (IPCC). They make it possible to estimate the future economic cost implied by one tonne of carbon dioxide emitted today. Given the huge persistence of atmospheric CO_2, this cost is spread over a very long period. According to Gollier (2019), climate-integrated assessment macromodels suggest that this distribution of costs over time may average € 1200/tCO_2 within 80 years from now. Using a discount factor of 4 %[2], this amounts to € 50/tCO_2 today, which is then considered as the carbon price enabling emissions costs to be internalised. The discount factor should then be used as the yearly growth rate of the tax, which gives carbon a value of € 74 in 2030. This estimate is fully in line with the recommendations of the Report of the High-Level Commission on Carbon Prices (2017) co-chaired by Stern and Stiglitz, which estimated that carbon should be priced in the range of € 38–75/tCO_2 by 2020 and € 47–84/tCO_2 by 2030 in order to reduce emissions cost-effectively in line with the ambitions of the Paris Agreement[3].

However, there are huge uncertainties surrounding the economic models' estimates and the assessment of climate sensitivity, so these numbers should largely be viewed as indicative. They nevertheless provide a useful basis for thinking further about implementing a carbon tax and moving forward in the fight against global warming. The macromodels' uncertainty is illustrated in chart 2 which displays the interquartile and 5th-95th percentile ranges computed from the IPCC (2013) database of simulations targeting an atmospheric CO_2 concentration of 450ppm. While Gollier's proposal (indicated by the dashed blue line) seems to correspond to these simulations up until 2030, it tends to undervalue somewhat the carbon price at longer-term horizons, indicating that there is potential room to accelerate the growth rate of the carbon price. The economic and climate models' uncertainties should encourage decision-makers to adopt a very pragmatic approach. An excellent example in this regard is given by Switzerland where the carbon price path is announced together with a medium-term emission target. If the target is not reached, the price path is revised upwards.

1 Known in the literature as Integrated Assessment Macromodels (IAM). They are basically neoclassical growth models in which the greenhouse gas emissions and energy requirements are taken into account, together with the expected economic cost of global warming. They were pioneered by the 2018 Nobel laureate William Nordhaus (DICE model, 1991, 2018) and Chris Hope (PAGE model, 1993) and since then intensively used and developed by Martin Weitzman, Nicholas Stern, Per Krussel, Simon Dietz among many others.

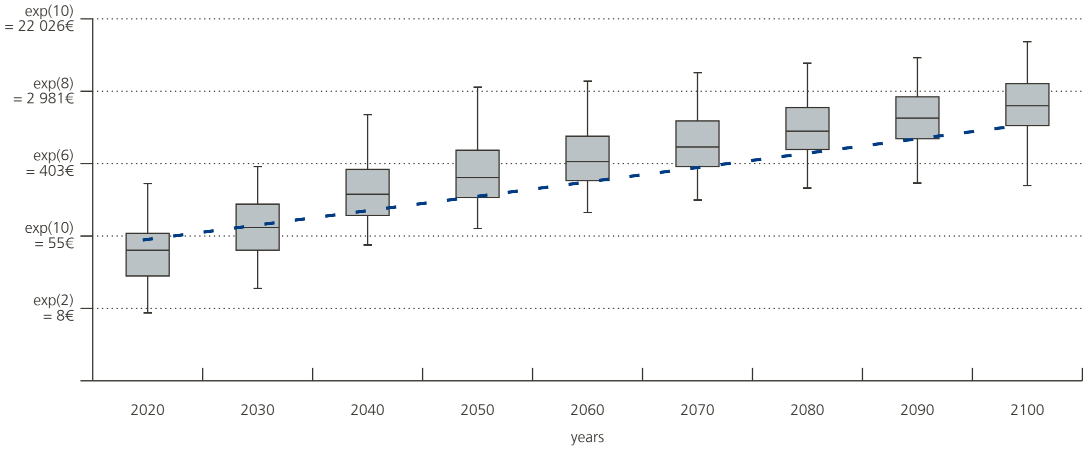
2 The discount factor to be used in these computations has been the topic of an important academic debate which is summarised in Gollier (2019, pp. 287-304), for example.

3 More recently, the Quinet-2 Commission in France computed that to reach carbon neutrality by 2050, the tax should be set at € 69 in 2020, raising by more than 11 percent each year to reach € 230 in 2030 and then more slowly at a 6 percent rate to be settled at € 750 in 2050.

Chart 2

Distributions of carbon prices as obtained from 374 simulations of IAM models in the IPCC database compatible with the Paris Agreement target of a 450ppm CO_2 concentration (log scale)

(median, interquartile range, 5th - 95th percentile range, dashed blue line: Gollier's proposal of a € 50 tax in 2020 growing at a 4 % yearly rate)



Sources: Fifth Assessment Report (AR5) of Working Group III of the Intergovernmental Panel on Climate Change (IPCC), re-assessed in real 2020 euro.

2.4 Implications of a carbon tax for fuel prices?

What does a carbon price of € 50/tCO_2 as recommended by Gollier (2019) mean in terms of fuel prices? This computation depends of the carbon emitted by the combustion of the different fossil fuels. For one liter of petrol or diesel, it would respectively amount to 11.5 and 13 eurocents, i.e. about one-fifth of the current excise duties levied in Belgium on these fuels[1]. At fuel prices prevailing in Belgium in 2020, the introduction of such a carbon tax would push up the price of petrol and diesel by about 10 %. For coal and natural gas, which are currently less taxed, prices would rise by slightly more than 20 %. Given that fossil fuels are already heavily taxed, one may wonder whether some of the excise duty could not be considered as an existing carbon tax. This is exactly the reasoning that the Swedes followed around the year 2000, when they reinforced their carbon tax mechanism. At that time, the Swedish government re-labelled some of the existing fuel taxes as carbon tax, which neutralised the effect of the carbon tax increase on the total fuel price. The future carbon tax path was clearly announced at that time. The French government used the same idea by fully offsetting the introduction of the carbon tax in 2014 by an equivalent cut in an existing indirect tax[2], allowing for a smooth transition. Again, the tax path was clearly communicated. Excise duty is often viewed as a Pigouvian tax and it may make sense to substitute one for the other. However, carbon emission is not the only externality public authorities have to consider in their global assessment. Fuel combustion is also responsible for local air pollutions and health troubles, for noise, for ground pollutions and for the wear of the road infrastructure. As discussed in section 3 below, the most important distinguishing feature of a carbon tax compared to a normal excise duty is its growth path. Nevertheless, the later a carbon price is set, the tighter the carbon budget, and the higher its introduction value – or the slope of its increasing path – should be in order to reach carbon neutrality before global temperature rises above 2°C.

1 If VAT is due on the carbon tax as it is on excise duty, such a fiscal instrument would increase taxes by about 14.5 eurocents per litre instead of 12.

2 The so-called taxe intérieure sur la consommation de produits energétiques (TICPE).

3. Some lessons from carbon pricing initiatives around the world

Even though it might not be the only explanation, there is a feeling that the very low level of excise duties and taxes on petrol and diesel in the United States – about one-fifth of the total price – plays an important role in the fact that emissions per capita are about two to three times those observed in Europe (see table 1), where taxes represent about 60 % of the consumer fuel price. Let us try to better assess how carbon prices and carbon emissions interact using the information disclosed by existing carbon pricing experiments. Since carbon taxes were first introduced at the beginning of the 1990s in Scandinavian countries, other initiatives have been taken, targeting emissions either from production or from transport. The data released on these occasions have been scrutinised by researchers in order to assess whether carbon pricing has actually helped to reduce emissions, on the one hand, and whether it has had detrimental effects on production, investment and employment, on the other hand. The results obtained are summarised in the following sub-sections after a quick glance at the carbon price initiatives around the world.

3.1 How are carbon emissions valued in 2020 ?

The recent report entitled "State and Trends of Carbon Pricing, 2020" by the World Bank gives an exhaustive view of the different carbon pricing schemes that have been implemented since the early nineties. In April 2020, 59 carbon pricing initiatives were in place either at the supranational, national or sub-national level[1], 29 of which are based on emission trading systems (ETS) and 30 using carbon taxes. The earlier initiatives were carbon taxes, introduced in Scandinavian countries in the 1990s. The coverage of global emissions significantly increased to some 5 % in 2005 with the introduction of the EU ETS. In 2012, Japan and California introduced their own carbon pricing mechanisms, raising the global coverage to 8 %. Since then, new initiatives have doubled the share of global carbon emissions concerned by a pricing mechanism. Less than 5 % of the emissions covered are priced within the € 38 – 75 / tCO_2 range recommended by the Report of the High-Level Commission on Carbon Pricing (2017) and half of them are valued at less than € 10 per tCO_2. Chart 3 below scatters for most of the carbon pricing initiatives the percentage of the (locally-produced) emissions covered and the price per tCO_2, which summarises the environmental ambitions of the different political entities. In the countries with the higher price for carbon, carbon pricing devices cover between 40 and 50 % of their (locally-produced) emissions. In countries with more ambitious coverage rates, the carbon price is on average lower, even though it is still relatively high, as in the case of Norway, South Korea or British Columbia. California and Quebec have green taxation that covers the largest share of locally-produced greenhouse gas emissions, above 85 %, with a carbon tax fixed at about US$ 15 / tCO_2.

3.2 Assessing the impact of carbon pricing on emissions

There are essentially two ways of assessing the potential of carbon taxes to reduce emissions : theoretical computable general equilibrium models, on the one hand, and econometric studies, on the other hand. It is noteworthy that both strands of the literature feed each other. Theoretical models make it possible to represent technology innovations and general equilibrium responses that econometric studies cannot assess. The reverse of the coin is that the results are driven by the models' assumptions / calibration which may not be fully transparent and are subject to (improved) empirical validation. A second way is to use traditional econometric methods, with the problem that there are not yet many observations from existing long-term carbon pricing experiences. However, when available, these pieces of evidence help to improve the calibration of general equilibrium models. Let us summarise here some studies in these two areas.

1 This number should double in 2021, with the introduction of the Chinese and German ETS systems.

■ A quick hint from simulations of (climate-integrated) general equilibrium models

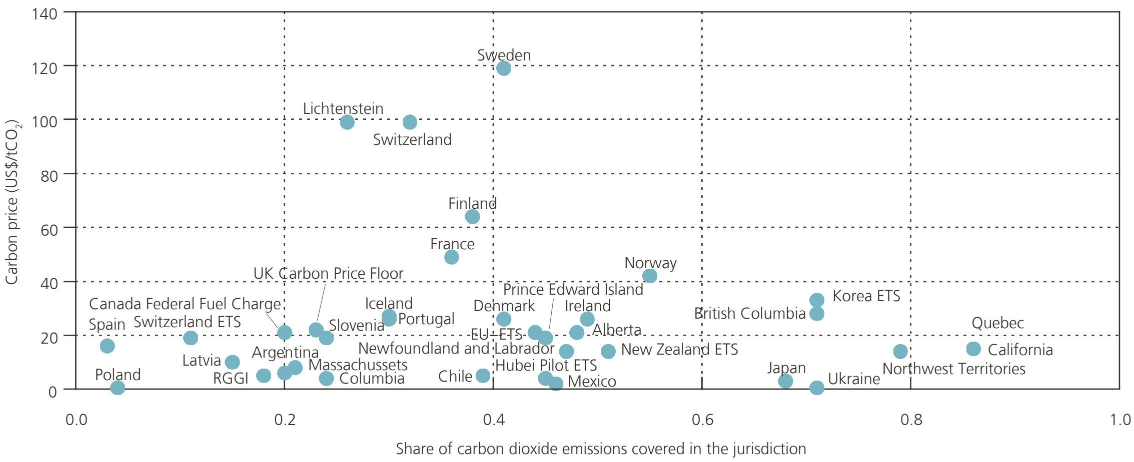
The Stanford Energy Modelling Forum has recently completed a study of the economic outcomes of introducing a carbon tax in the United States. Eleven models took part in the experiment and are briefly described in McFarland *et al.* (2018), while Barron *et al.* (2018) summarise the results. The key findings were consistent across the eleven modelling teams. First, a carbon tax is effective at reducing carbon pollution, although the structure of the tax – i.e. the price and the rate at which it rises – is important. A tax implemented in 2020 at US$ 25 per tCO_2 emitted from fossil fuels would reduce yearly emissions by about 6-18 % in the short run, mainly due to the substitution away from coal towards natural gas to produce electricity. The study also finds that the rate of increase of the carbon tax is more important than the starting price. For example, a tax of US$ 50 per tCO_2 rising by 5 % per year would cut carbon pollution by 33 – 56 % in 2040, while a tax of US$ 25 per tonne rising at 5 % per year would cut it by 25 – 50 % over the same horizon. However, the policies including a tax rising by just 1 % per year would result in only a short-term cut, but carbon pollution would remain stable at those levels. These results suggest that the most effective carbon tax might start relatively low to give taxpayers time to adjust but should increase rapidly over time.

■ Some lessons from applied experience

Observing just the trend in CO_2 emissions before and after the introduction of such taxes may already give an *a priori* view of the effectiveness of the policy, even though it does not enable the exact role played by the tax to be assessed. Let us consider four examples here, two about carbon taxes targeted to the electricity generation sector, and two about taxes more geared towards transport and heating. In the United Kingdom, the Carbon Price Support (CPS) introduced in 2013 tops up the EU ETS allowance prices for power firms in order to reach a carbon floor price target fixed by the government. As a result, coal-generated emissions dropped by 78 %, from 140 $MtCO_2$ in 2013 to 31 $MtCO_2$ in 2018. Australia imposed a carbon tax in July 2012, covering fuels used to generate electricity and several other sectors, although not motor fuels for passenger transport. The tax was rescinded in July 2014 when a new national government repealed it. Therefore, it provides a test case for looking at changes when the tax began and again when it ended. Between July 2012 and July 2014, the combined emissions of the sectors covered dropped by 12.5 Mt CO_2, and rose again by 7.5 Mt CO_2 between July 2014 to July 2015 (Nadel, 2016). As for the United Kingdom, the biggest share of the drop in emissions

Chart 3

Carbon pricing initiatives around the world: carbon prices in 2020 US$ (as of April 1) and shares of the covered emissions



Source: World Bank.

(and rise after the tax was abandoned), came from the switch from (respectively to) coal to (respectively from) alternative fuels to produce electricity.

The case of the British Columbia (Canada) carbon tax is interesting compared to the two above-mentioned ones, as it does not rely on the production of electricity[1], but covers 70 % of the emissions generated by production and transport. The carbon tax started in 2008 at C$ 10 per tCO_2, scheduled to increase by C$ 5 per year until it reaches C$ 50 per tonne in 2021. The tax is applied uniformly to all fossil fuels burned within its border[2]. It is one of the carbon tax initiatives with the highest coverage among the carbon pricing experiences listed by the World Bank. Up to now, given the existing federal taxes, the CO_2 tax has raised the overall excise duty on petrol by about one-fifth. In 2018, the tax brought in over C$ 1 billion – over five percent of provincial tax collections – and all the revenue is returned to businesses and households through a combination of tax rate reductions, grants to businesses and households, and other business tax breaks. In a simple exercise, Komanoff and Gordon (2015) compare the pre- and post-tax periods (respectively 2000-2007 and 2008-2013) in British Columbia and the rest of Canada. They find that, excluding the electricity sector, the province's emissions declined by 6.1 % while emissions in the rest of Canada rose by 3.5 %, i.e. a difference of 9.6 percentage points. Emissions per capita and per dollar of GDP are respectively 9.2 and 12.4 % lower in British Columbia. For Sweden, Metcalf (2019) reports that the carbon tax rate, mostly focused on transport-generated emissions, has been multiplied by 4.7 since the introduction of the carbon tax, while tax revenues were only 3.4 times larger in 2017 than in 1994 (first year of available data), displaying an effective reduction in emissions. Still for Sweden, Andersson (2019) evaluates that the per capita emissions from transport were 15 % lower in 2005 than what they would have been in the absence of the carbon tax. Such outcomes are encouraging since emissions from transport are amongst the most challenging to reduce[3].

Besides such simple comparative analysis exercises, other studies attempt to identify the role of the tax itself on the demand for fossil fuels and emissions reduction. In this regard, several authors compare how demand for petrol reacts to a price change depending on whether it is dictated by taxation, on the one hand, or by the market, on the other hand. Among others, Davis and Kilian (2011), Li, Linn, and Muehlegger (2014), Antweiler and Gulati (2016), Rivers and Schaufele (2015) or Andersson (2019), respectively for the United States (first two), British Columbia (next two) and Sweden (last), find that demand for petrol reacts between two and four times more to an increase in fuel taxes than to a market price increase. The reason is that the tax is expected to last (and even increase steadily in British Columbia and Sweden), while the fuel price itself is known to fluctuate widely with the conditions on the oil market. The Andersson (2019) result is worth pointing out as it is the only one related to a European market, whereas the other studies focus on the United States and Canada, where petrol taxes are significantly lower, making the tax-inclusive price much more volatile.

Other studies have focused on the emissions due to the production sector and use firm-level micro data. For the period preceding the introduction of the EU ETS, two studies use observations related to tax schemes targeting firms' use of fossil fuels decided in the United Kingdom and in Sweden respectively. For the United Kingdom, Martin, de Preux, and Wagner (2014) focus on the Climate Change Levy (CCL) introduced in 2001. Over the analysis period, the CCL added 15 % to the energy bill of a typical UK business, with a discount granted up to 80 % of the tax rate for plants in selected energy-intensive industries. The CCL system provides a unique opportunity to study the effects of a carbon tax in an industrialised economy by comparison of outcomes between plants subject to the full tax and plants that paid only 20 % of the tax. Focusing on the first three years following its introduction in 2001[4], the authors use longitudinal data on manufacturing plants to estimate the impact of the CCL on energy use, emissions and economic performance. They find that the carbon tax had a strong negative impact on firms' average emissions, which fell by 8.4 % over the three-year period analysed.

1 Almost 100 % of the electricity produced in British Columbia is of hydraulic origin, which is not the case for the rest of Canada.
2 The only major exemptions are inter-jurisdictional shipping and flights, i.e. journeys between British Columbia and the rest of Canada.
3 This is evidenced for Belgium in table 3 below, where households' transport emissions are shown to have risen strongly between 2000 and 2018, while most of the other items declined or stabilised.
4 The reason is to avoid overlap with the EU-ETS that where introduced in 2005.

Brannlund, Lundgren and Marklund (2014) provide another firm-level study applied over a longer time span, for Sweden. Even though the Swedish CO_2 tax is mostly geared to transport, the industrial sector saw the carbon price rise from zero to € 20/tCO_2 from 1991 onwards[1], but with a system of sector-related exemptions that come down over time. Brannlund *et al*. (2014) use micro data at the firm level for the years 1990-2004[2]. With the series of the actual effective tax rate per firm at hand, they distinguished the effect of the change in fossil fuel price from changes in the effective tax rate. They find that firms' carbon intensity performance responds to changes both in the tax and in the fuel price, with a higher sensitivity to the tax, for the same reasons as mentioned above for demand for petrol. They compute that manufacturing output rose by 35 % from 1990 to 2004 while related emissions fell by 10 %. The biggest reductions in emission intensity are observed in the electricity, chemicals and motor vehicles sectors, which are among the heaviest emitters.

De Jonghe, Mulier and Schepens (2020) use the database of the firms subject to the EU ETS. Their estimation strategy is based on the structural break induced by the recent change in the allocation of allowances. In May 2017, the announcement of a credible revision of the Market Stability Reserve mechanism aimed at dealing with the excess of carbon emission allowances on the market led to a sharp increase in the price of carbon, from around € 5 at the date of announcement, to above € 20 from mid-2018 onwards. The authors use the difference-in-difference methodology and compare, within the same NACE 2-digit code sector, firms that were *ex ante* in strong shortage of allowances to firms *ex ante* in low or no shortage both three years before (2014-2016) and three years after (2017-2019) the tightening of the regulatory mechanism. They show that the more polluting firms adapted to rising carbon prices: on average, compared to less polluting firms, they reduced significantly more their emissions by 5, 9 and 11 % respectively over the three ensuing years. Furthermore, this reaction is stronger in sectors given fewer free allowances, i.e. where the cost constraint is more binding. It is noteworthy that heavy-polluting firms adapt partially by taking control of firms with a cleaner technology within the EU (extended to Norway, Switzerland and UK). In line with such results, Dussaux (2020) evaluates from a dataset covering 8 000 French manufacturing firms between 2001 and 2016 that a 10 % increase in the price of energy via a carbon tax causes a 6 % decline in energy use and a 9 % drop in carbon emissions.

3.3 Assessing the impact of carbon pricing on economic growth and employment

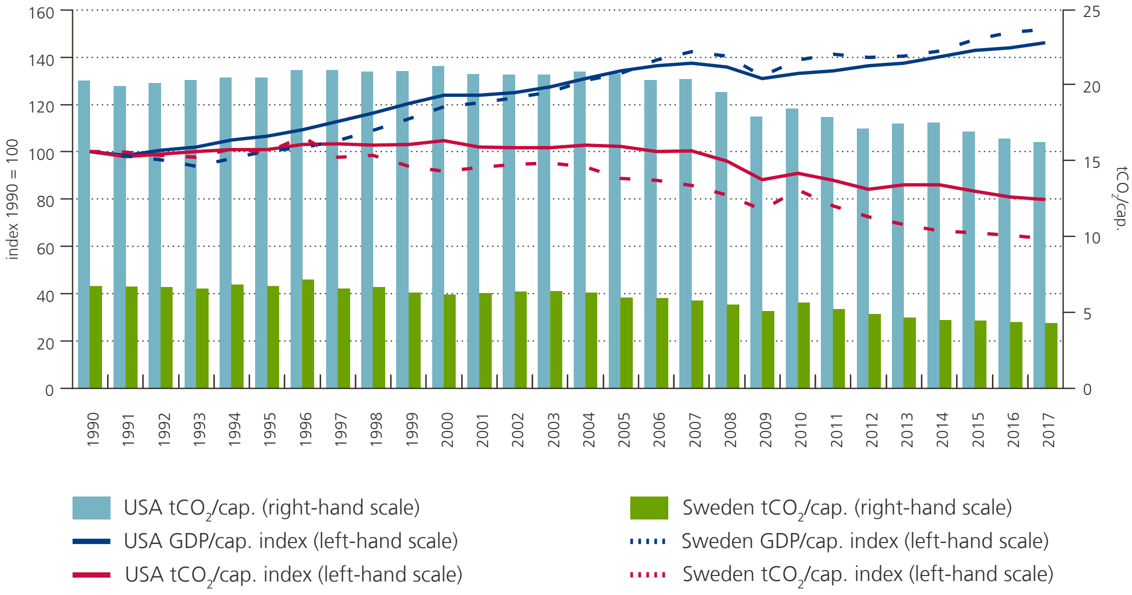
The economic theory view that carbon taxes represent a cost-effective approach to reducing emissions seems to be confirmed by the above case studies. However, many policy-makers and citizens still fear that they might impose a large burden on the economy. Still, some economic studies, such as Andersen *et al*. (2007), point that modest carbon taxes are unlikely to cause significant negative impacts on economic activity. According to the so-called "double dividend hypothesis", some claim that it might even have a positive effect on economic output: as income taxes produce price distortions and reduce economic activity, lowering income taxes thanks to the dividend of a carbon tax could at the same time reduce emissions and raise total economic output (see, for example, Pearce, 1991, and Tullock, 1967). The conclusion of the theoretical models used by the Stanford Emerging Modelling Forum project (see section 3.2 above) confirms the "weak" double dividend hypothesis that revenue recycling can compensate for economic losses from a carbon tax, but not the "strong" double dividend hypothesis that the tax generates net economic growth: "*We find robust evidence that even the most ambitious carbon tax is consistent with long-term positive economic growth, near baseline rates, not even counting the growth benefits of a less-disrupted climate or lower ambient air pollution.*" This outcome is also reached by Beck *et al*. (2015) in a general equilibrium model calibrated for British Columbia.

Besides such purely model-driven analysis, the various fiscal experiments listed above have produced data that make it possible to assess which one of the two opposed views is empirically validated. First of all, one may take a naive view and consider whether the economies with the heaviest carbon taxes seem to suffer particularly. Let us just consider two extremes. Between 1990 and 2017, GDP per capita grew by 46 % in the United States

1 At 2009 prices.
2 Like Martin *et al*. (2014), the authors also stop the analysis in 2004 to avoid any overlap with the introduction of EU-ETS.

Chart 4

Economic and carbon performances of Sweden compared to the USA 1990-2017



Sources: World Bank and Global Carbon Project; GDP per capita based on purchasing power parity (PPP), 2011 international dollars.

and by 52 % in Sweden, as illustrated in chart 4[1]. At first sight, there is little reason to think that the Swedish economy suffered strongly from the introduction of the most aggressive carbon tax scheme in 1991 and from its EU ETS membership since 2005. Its carbon pricing policy seems to have been fruitful in terms of emission reductions. While Sweden ranked among the lowest emitters among industrialised countries in 1990, with 6.7 tCO_2 per person, it had managed to reduce it by more than one-third at the 2017 horizon, with absolute emissions dropping by one-fourth. Over the same time span, US emissions continued to rise by 5 % in absolute terms, while emissions per capita slowly declined from 20 to 16 tCO_2.

Few studies focus on the relationship between the introduction of a carbon tax and economic activity. However, some of the above-cited articles confirm that taxing carbon dioxide has not led to any sort of economic collapse. For example, in the case of the United Kingdom's CCL experience, Martin *et al*. (2014) find no statistically significant impact for employment, revenue or manufacturing plant exit. Besides, they find a (statistically insignificant) production factor substitution effect from energy towards labour. Regarding the British Columbia experiment, Metcalf (2019) uses the same difference-in-difference methodology as for emissions, simply adding control variables to cover the sectoral composition of economic activity. Without these composition variables, the effect of the carbon tax on economic activity is insignificant, while, controlling for this aspect, it turns out to be significantly positive. For Sweden, Andersson (2019) clearly points towards the neutrality of the transport carbon tax with respect to economic activity. In their econometric study of firms subject to the EU ETS and their reaction after the strengthening of the system in 2017, De Jonghe *et al*. (2020) find no significant impact on firms' operating revenue for the three years of data availability. Metcalf and Stock (2020) run dynamic estimations over the period 1985-2018 for the 16 countries belonging to the EU ETS which, in this period, adopted a carbon tax to supplement the cap-and-trade mechanism. The effect they find regarding of the "carbon tax shock" on GDP is positive for most of their specifications and at all horizons, although not statistically significant.

1 In real terms, using Purchasing Power parity for a meaningful international comparison.

Yamazaki (2017) focuses on the labour market effects of the British Columbia carbon tax with a partial equilibrium demand model for labour as a function of the carbon tax. He estimates a labour demand function using industry-level data from 2001 to 2013 on employment across provinces, controlling for industry, province, and time-fixed effects as well as the emissions intensity and trade intensity of an industry. He finds negative employment effects for emissions-intensive and trade-exposed sectors but positive effects for other sectors and for the overall labour market. In particular, he estimates a 30 % drop in employment in basic chemical manufacturing but gains in other sectors that more than make up for it. Yamazaki finds evidence that the labour supply effect is stronger than the demand effect, causing the wage rate to decline. Similarly, in the above-cited study on French manufacturing firms, Dussaux (2020) finds that increases in the price of energy mostly reallocate employment between firms and sectors, from the more to the less energy-intensive ones, but does not lead to any net employment losses. Such outcomes point up the important role complementary labour market policies can play to ease the implied employment reallocations and minimise the associated social costs. Bijnens, Hutchinson, Konings and Saint-Guilhem (2020) raise the important point that with a more stringent European-wide carbon policy, some countries could suffer more than others due to their sectoral composition and would not necessarily manage to absorb the energy price shock as smoothly as stated by the previous studies. They also insist that the financial constraint faced by firms strongly conditions their reaction to the shock.

4. CO_2 emissions in and for Belgium

The most obvious way of thinking about Belgian carbon emissions is CO_2 emissions generated within Belgian territory by companies during their production processes or by households when consuming. But these territorial emissions do not correspond to the global emissions induced by Belgium, as one also needs to take into account emissions which are incorporated into Belgian imports and exports. In this section both concepts are discussed.

4.1 Carbon emissions in Belgium

In 2018, some 100 million tonnes of CO_2 were emitted in Belgium, which, according to the International Energy Agency (IEA), accounted for 0.27 % of global carbon emissions. As a reference, World Bank statistics show that, in that year, Belgium hosted 0.15 % of the world population, while the Belgian economy accounted for 0.46 % of global GDP[1]. While emissions per capita are therefore larger than the world average, Belgium is relatively more carbon-efficient than the world as a whole per unit of value added generated.

Over the period 2000-2018, Belgian carbon emissions fell by 25 %. Over the whole period, there was a gradual decline, although, since 2014, no clear further decrease has been observed. Emissions of companies, accounting for almost three-quarters of total emissions, dropped by 29 %, while the reduction of household emissions remained more limited, at some 12 %.

As far as enterprises are concerned, large differences are found between branches of activity. In industry and market services, emissions dropped by more than 30 %, but, in 2018, both branches taken together still accounted for about two-thirds of our country's total emissions. The decrease remained more limited in agriculture and construction, while emissions even rose slightly in non-market services. CO_2 emissions of households declined considerably for heating and cooling purposes, but for transport, emissions largely increased.

The carbon emissions of companies are of course linked to their economic activity, while those of households depend amongst other reasons on the population figures. Therefore, it is useful to calculate emission intensities.

1 Gross domestic product (GDP) expressed in current international dollars, corrected to eliminate the effects of the differences in price levels between countries (purchasing power parity or PPP).

Table 2

CO_2 emissions in Belgium

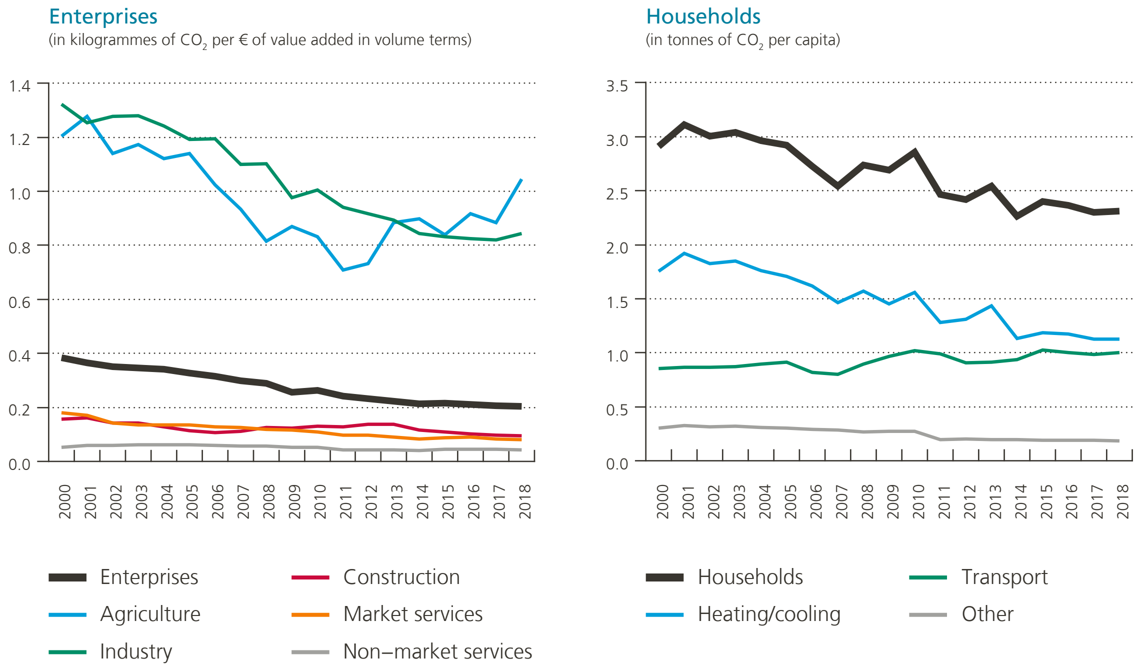
	2018 (millions of tonnes)	Evolution 2000-2018 (in % change)
Enterprises	74	–29.1
Agriculture	2	–12.6
Industry	50	–30.1
Construction	2	–8.1
Market services	16	–34.6
Non-market services	4	3.5
Households	26	–11.5
Heating and cooling	13	–28.8
Transport	11	31.2
Other [1]	2	–31.3
Total	100	–25.2

Source : EC.
1 Includes emissions from working machinery such as lawn mowers, hedge clippers and other gardening equipment, for example.

For companies these reflect the carbon content of one unit of value added produced, while household emissions can be expressed per capita. The CO_2 intensity of companies has considerably decreased. Over the period under consideration, it was reduced by almost half, as the above-mentioned drop in carbon emissions materialised, while value added in volume terms rose by one-third. A downward trend is observed in all large branches of

Chart 5

Carbon intensity of enterprises and households in Belgium



Source : EC.

activity, with the notable exception of agriculture. In that branch, carbon intensity fell sharply until 2011, but since then, a clear upward movement has been observed, reflecting a renewed increase in CO_2 emissions. Nevertheless, carbon intensity in agriculture was still some 15 % lower in 2018 compared to 2000. In non-market services, a comparable drop is observed after a gradual reduction over the whole period considered. In industry and construction, the decline reached almost 40 % and even 55 % in market services.

While some economic activities, like manufacturing, are very energy-intensive and therefore lead to large CO_2 emissions, others are intrinsically less polluting. Comparing directly the carbon intensity of branches of activity is therefore not appropriate. However, the carbon intensity of the Belgian branches, calculated as total CO_2 emissions per unit of value added at current prices, can be much more meaningfully compared to that of their European counterparts. Of course, even at very detailed sectoral breakdowns, one can still observe differences in the specific activities conducted in a given branch in two countries, implying that the results of this exercise still need to be considered with some caution.

According to the available data, in 2018, the average carbon intensity of the Belgian economy was largely comparable to that of the EU as a whole and to that of Germany and the Netherlands. By contrast, the French economy was on average less carbon-intensive. While the Belgian economy produced considerably less CO_2 per unit of value added than Bulgaria, the most carbon-intensive country in the EU, it was some 70 % more CO_2-intensive than Sweden, where carbon intensity is lowest. These observations hold in general for all large branches of activity, with the exception of agriculture, for which carbon emissions per unit of value added in Belgium are more than twice as high as on average in the EU, and clearly higher than in the three neighbouring countries. In industry, construction and non-market services, carbon intensity is slightly higher than on average in the EU, while in market services, it is somewhat lower. Nevertheless, in all large branches, a considerable gap is found with respect to the most CO_2-efficient country. This conclusion is confirmed at a more detailed level of economic activity. In 2017, Belgian carbon intensity was higher than on average in the EU in 34 out of 63 branches. In none of the 63 branches was our country the most emission-efficient and, in all branches, the gap with the least carbon-intensive country was large.

The above-mentioned reduction of CO_2 emissions of households was achieved although the population rose by 11 % over the 2000-2018 period. As a result, carbon intensity of households declined by 21 %. Carbon intensity of heating and cooling dropped by 36 %. By contrast, CO_2 intensity of transport increased by 18 % over the whole period, but since 2010 no further worsening has been observed. According to the available data, Belgian households are clearly less carbon-efficient than the EU average. This is mainly due to its mediocre performance regarding heating and cooling[1]. The carbon intensity of transport of Belgian households is comparable to that of their EU counterparts. The results for both companies and households at least seem to indicate that it should in principle be possible to (further) reduce the carbon intensity of their activities in Belgium, by using existing, more emission-efficient techniques.

4.2 Carbon footprint of Belgium

The emissions produced within the Belgian territory do not reflect Belgium's total contribution to worldwide carbon emissions. Indeed, in order to fully evaluate the burden of Belgium on global warming, one must also take into account CO_2 emissions generated abroad in order to produce goods and services that are used or consumed by domestic companies and households. On the other hand, one must correct for the emissions made for locally-produced goods and services which are later exported and finally used elsewhere.

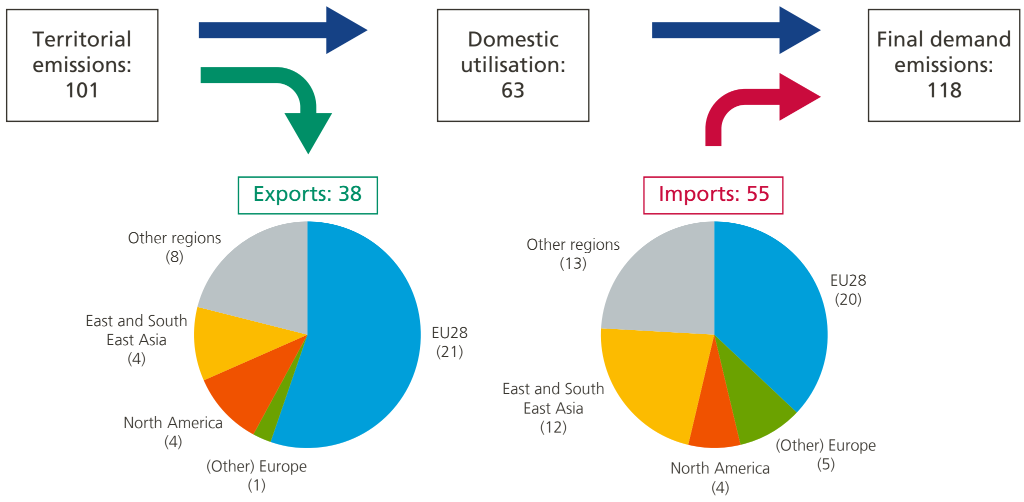
To this end, the environmental accounts, compiled by the OECD amongst others, are very useful. Indeed, by using international input-output data at sectoral level, these accounts attribute CO_2 emissions to the countries where

1 For more views on emissions related to the heating / cooling of buildings and the potential financial challenges, please refer to Van Tendeloo (2020).

Chart 6

Explicit and implicit carbon emissions of Belgium

(in million of tonnes of CO_2, 2015)



Source: OECD.

final demand is situated. This process can be illustrated by using the most recently available data for Belgium, with respect to 2015. In that year, 101 million tonnes of CO_2 were emitted in Belgium, of which 63 million were linked to domestically-used goods and services. The remaining 38 million tonnes were emitted to produce goods and services destined for foreign demand. While those "exported" emissions have to be attributed to the country where final consumer use takes place, the Belgian carbon footprint includes the 55 million tonnes of CO_2 emissions generated abroad in order to produce goods and services which are imported and finally used or consumed in Belgium. So, while Belgium emitted 101 million tonnes of CO_2 itself, its total final demand implied total CO_2 emissions of 118 million tonnes. The total carbon footprint of our country is therefore not equal to the 0.27 % of global emissions if just territorial emissions are taken into account, but accounts for 0.37 % of worldwide CO_2 emissions.

Of the total implicitly imported amount of 55 million tonnes of CO_2, 20 million tonnes (37 %) stems from other EU countries. Some 5 million tonnes were emitted in other non-EU European countries. About 12 million tonnes originate from East and South-East Asia, 8 million tonnes of which come from China. North America, and in particular the United States, accounts for another 4 million tonnes of imported CO_2. Of the total implicitly exported carbon emissions of 38 million tonnes, 21 million tonnes are implied in exports to other EU countries. North America and East and South-East Asia both account for some 4 million tonnes.

5. Assessing the macroeconomic effect of introducing a carbon tax in Belgium

In this section, an attempt is made to estimate the possible impact of a carbon tax of € 50 per tonne of CO_2 rising by 4 % every year, following the Gollier (2019) proposal. Note that in these exercises, for the sake of simplicity, we follow our Dutch colleagues (Hebbink *et al.*, 2018) and simply impose the carbon tax on top of existing ones (excise duties, VAT, EU ETS)[1]. In a first step, we evaluate the burden that, *ex ante*, such a tax would represent for households and enterprises, the latter broken down by branch of activity, and compare it to the EU on average and our neighbouring countries. In a second approach, we will use the Bank's econometric models, in order to assess the impact of a carbon tax on the Belgian economy under different assumptions.

5.1 The (potential) implied burden of a carbon tax in Belgium and neighbouring countries

In 2018, a total of 3 701 million tonnes of CO_2 were emitted in the EU. *Ceteris paribus*, an EU-wide imposed tax of € 50 per tonne on top of the EU ETS mechanism would therefore have yielded € 185 billion[2]. Pricing CO_2 emissions generated in Belgium would have cost firms and households € 5 billion, or 1.09 % of GDP. So, the total cost for our country would have been slightly lower than on average in the EU (1.16 % of GDP). The total tax burden would have been lowest in Sweden (0.56 %) and highest in Bulgaria (3.90 %). The calculated figures show a clear East-West divide inside the EU, reflecting technological gaps and differences in energy mixes between EU Member States. Reflecting their contribution to total Belgian CO_2 emissions, Belgian enterprises would have had to pay € 3.75 billion. The cost for companies in the market sector would have been € 3.5 billion, representing 1.12 % of their total value added.

In most services branches, the impact of a carbon tax would remain very limited, around or below 0.3 % of value added. Transport activities are, not unexpectedly, notable exceptions. That is particularly the case for air transport services, for which a carbon tax of € 50 per tonne of CO_2 emitted would imply a cost of 43 % of their value added. For manufacturing as a whole, the impact would be around 3 % of value added, but large differences are found. While the cost would be limited to 0.14 % of value added for the manufacture of chemicals and of electronic products, it would rise to 23 % of value added for the manufacture of refined petroleum. The impact would have been about 0.46 % in construction, but it would have been clearly higher in agriculture (almost 5 %) and, in particular, in the production of electricity (14.5 % of value added).

By using the same calculation method for all EU countries, the burden for Belgian companies can be estimated from an international perspective. For the market sector as a whole, a carbon tax would hurt Belgian firms somewhat less than their counterparts in the rest of the EU, in Germany and the Netherlands, while French companies would pay relatively less. The fact that the relative burden for all Belgian firms taken together would be close to the EU-average hides the big differences per branch of activity. In manufacturing in particular, the cost for Belgian companies turns out to be clearly higher than for competitors in most European countries. By contrast, firms active in transport activities or the production of electricity[3] would pay a carbon tax, expressed as a percentage of value added, below that in Germany, the Netherlands and in the EU as a whole.

1 Remember hower from sections 2 and 3 above that no government so far has introduced the tax so abruptly. Most of the time, it substitutes out part of existing excise duties and the sectors most exposed to carbon prices and international competition benefit from exemptions. The exercise examined here is rather radical. It nevertheless helps to fix ideas and to understand the order of magnitudes at stake. Reactions to the initial impulse being mostly linear, the reader can easily assess the effects of introducing the tax at a lower level.

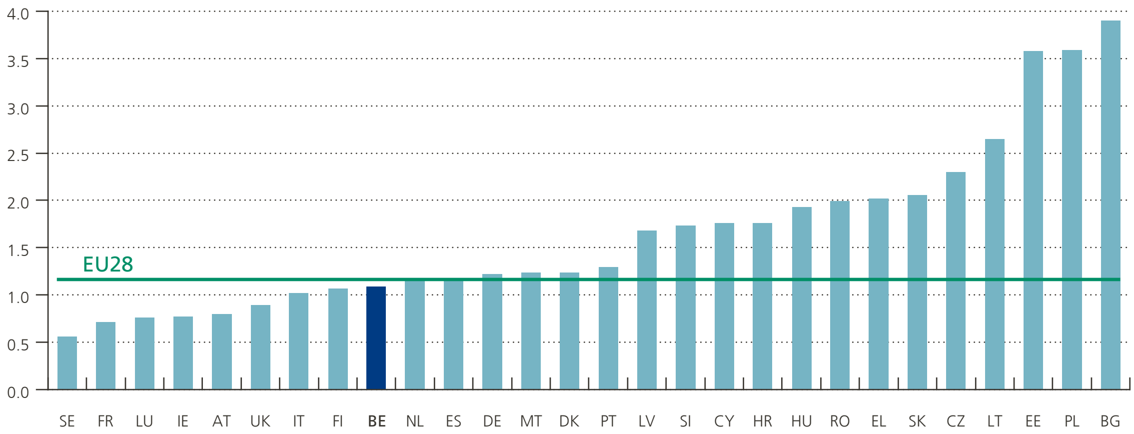
2 Note that 11 EU countries have already introduced a carbon tax with different amounts and coverages. To be perfectly fair, this should have been taken into account and, for these countries, the tax should have been increased only for the difference between the existing and the € 50/tCO_2 considered here. In other words, the comparison made here is biased in favour of Belgium where no carbon tax mechanism has yet been formally introduced.

3 It should nevertheless be noted that, given the current plan to phase out nuclear power plants, emissions from electricity generation might increase in subsequent years if the energy mix relies more heavily on the use of fossil fuel (e.g. with natural gas production units).

Chart 7

Total cost of an EU tax of € 50 per tonne of CO_2

(in % of GDP, 2018)

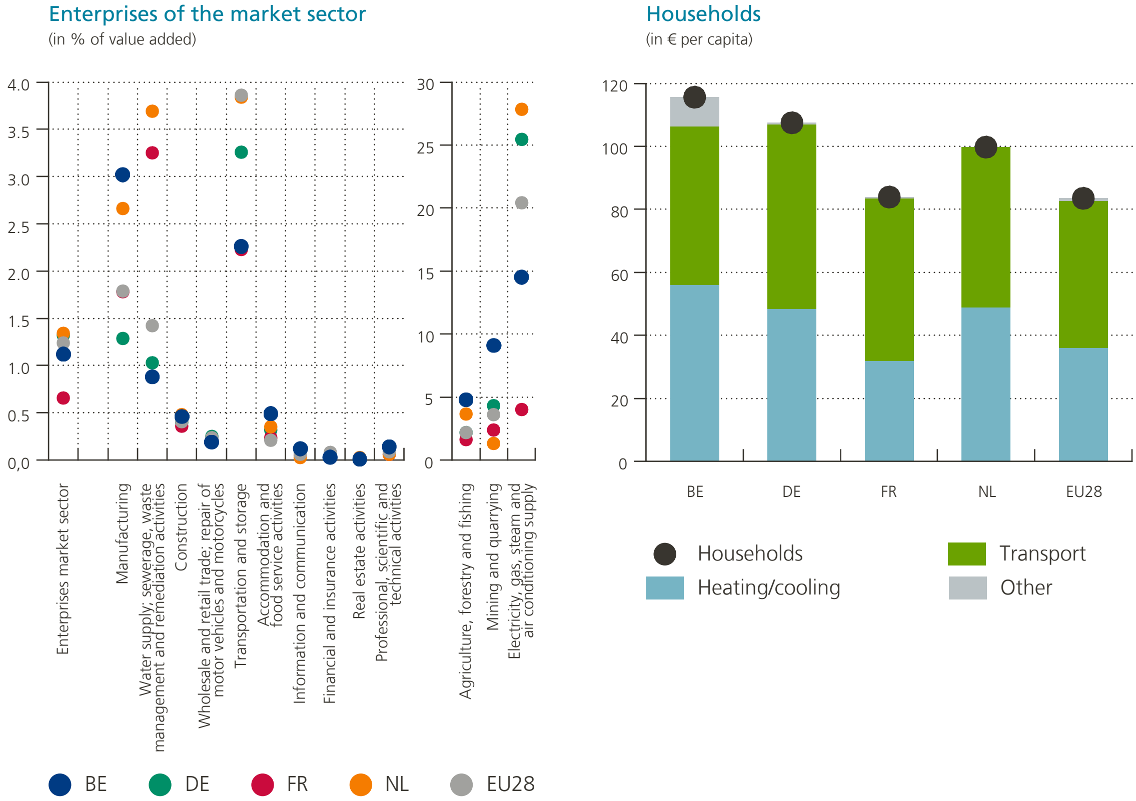


Sources: EC, own calculations.

Chart 8

Cost of an EU tax of € 50 per tonne of CO_2 for enterprises and households

(2018)



Sources: EC, own calculations.

In this scenario, Belgian households would in total have paid € 1.25 billion, which amounts to € 116 per person in the population. This cost is high from a European perspective: this tax would on average cost € 84 per person in the EU, and only in two countries – i.e. Luxembourg (€ 148) and Ireland (€ 132) –would households have to pay more than in our country. Both transport and (in particular) heating and cooling appear to be relatively polluting in Belgium.

5.2 Assessing the macroeconomic effect of introducing a carbon tax in Belgium

Macroeconomic general equilibrium models in use in central banks are certainly not best equipped to simulate the macroeconomic implications of introducing a carbon tax along the lines presented in section 2. Such models are mostly dedicated to the dynamic analysis of fiscal and monetary policies along the business cycle and their sophistication in these dimensions is obtained at the cost of other simplifying assumptions which are detrimental for the topic considered here. First, they are built on the assumption of "representative agents" – one representative household, one representative firm – and they consider only one single final good that can be either consumed or invested. This prevents them from studying the consequences of the introduction of a CO_2 tax on the statistical distribution of households' revenues, the reallocation of economic activity among the production sectors, and the changes in consumer behaviour and investment choices driven by relative prices, as expected from a Pigouvian tax. Second, they consider only one production technology and few of them consider energy and fossil fuels among the production factors. This implies that, in such models, once the introduction of the tax is announced, firms cannot decide to invest in a low-carbon technology or in the research and development required to obtain it in the medium to long run. Consequently, these models cannot assess the cost of stranded assets implied by the transition away from carbon-intensive technologies. Even the elasticity of substitution between energy and other production factors is not reliable: by default, pure complementarity is assumed. Furthermore, such an elasticity is difficult to estimate at aggregate level and, as discussed at length above, estimates based on past energy price fluctuations would probably underrate the actual reaction of firms to a permanent tax introduction. Third, they do not take into consideration the possibility for carbon-intensive activities to relocate.

Even though these shortcomings certainly disqualify these models from studying the long-run consequences of introducing such a tax[1], they may nevertheless prove useful to think about some important transmission channels of this tax to the real and nominal sides of the economy in the short to medium run. For these reasons, the simulations are mostly indicative, and the results are not reported beyond a five-year horizon. As the energy intensity and energy mix are fixed, they most probably describe a worst-case scenario. The different econometric studies mentioned in sections 3.2 and 3.3 unanimously find that firms and households adapt their fossil fuel combustion when facing carbon pricing much more quickly than within the five years. A reduction of the share of fossil fuels in the consumer basket or in firms' marginal costs would limit the effect of the tax on prices, while substituting from taxed energy sources should favour investment and employment. However, the fact that models disregard the possibilities of firms' relocation might somewhat tip the balance.

In the following simulations, various scenarios for introducing a carbon tax in Belgium are assessed through the lens of the National Bank of Belgium's workhorse model "Noname", which is described in Jeanfils and Burggraeve (2005). Noname is a medium-sized Neo-Keynesian model, where demand is driven by the business cycle in the short to medium run and by fundamental supply-side parameters (such as productivity, population growth, etc.) in the medium to long run. Its equation specifications try to strike a balance between economic theory and data-matching, while taking into account that optimal behaviour can only be reached in a context of costly adjustment processes that take time. Households provide labour to firms, which in turn generate labour income to consume or save. Profit-maximising firms import intermediate goods and set prices as a mark-up over costs, after which their goods and services can be bought by households (private consumption and housing

1 Macroeconomists are developing new tools to better assess this dimension, such as dynamic stochastic general equilibrium models together with the environmental bloc of climate-integrated assessment macromodels.

investment), domestic firms (investment) and firms abroad (exports). The model is supplemented with a complete income framework that traces both primary income and redistributive transfers between households, firms, government and the rest of the world, in order to calculate disposable income and net financial surplus for each of the domestic sectors. The model has an exogenous monetary policy, but endogenous fiscal policy through a set of adaptable policy rates for tax and social security contributions that generate government revenue while it simultaneously traces the main social transfers to households and other government expenditure.

The following scenarios will shed some light on how such a tax of € 50/tCO_2, subsequently rising by 4 % every year as proposed by Gollier (2019), would affect the Belgian economy. We illustrate different transmission channels through which the tax would affect the main macroeconomic variables by changing our focus along three different axes. Is the tax paid by households, by firms or by both sectors? Is the tax introduced in Belgium alone or is it decided upon at European level? And finally, are the newly generated tax revenues simply used by the government to reduce its outstanding debt or will the government try to mitigate the negative economic effects through additional transfers and tax rebates? The simulation results for the different scenarios are displayed in table 3 and show how the main macroeconomic variables of the Belgian economy react to the tax respectively one, three and five years after its introduction.

■ Introducing a carbon tax, in Belgium alone, levied on Belgian households, without tax refunds

In a **first scenario**, we consider the case of the Belgian government collecting € 1.25 billion through a carbon tax levied on household fuel combustion through the end-user price of petrol, diesel, heating oil and natural gas. In this scenario, the introduction of the carbon tax is a purely Belgian measure, not followed by governments of other Member States of the European Union. Moreover, the Belgian government will use the proceeds of this tax to accelerate its debt reduction and not to finance any new initiatives.

It is important to note that, in order for this result to be meaningfully comparable to other scenarios, households should be the ultimate sector to carry the burden of the new tax. For the sake of these simulations, we will therefore also exclude natural gas and heating oil prices from the consumer basket (as diesel and petrol prices are already excluded from the socalled health index) used for the calculation of the reference index through which all wages and social benefits are automatically updated. Updating nominal wages as a result of the direct price effects of the household carbon tax would shift the burden of this tax back to firms, which will react by raising their output prices. Such a wage-price spiral would be particularly ill-advised and detrimental for competitiveness in a small open economy like Belgium[1]. It is also assumed that unions and employers cannot engage in new wage-bargaining negotiations after the introduction of a carbon tax and will thus stick to the real wage trajectory from the baseline scenario.

The tax represents *ex ante* some 0.5 % of household total consumption and the private consumption deflator increases accordingly on impact. Given that households cannot renegotiate their wages, the only way in which they can react to this real income shock is by reducing their overall consumption. This drop in aggregate demand incites firms to lower their own demand for production factors, i.e. labour and capital goods. After five years, the introduction of such a carbon tax would reduce GDP by 0.3 % from a no-carbon tax benchmark scenario, implying the destruction of about 15 000 jobs and an increase in the unemployment rate of 0.2 of a percentage point. The public debt to GDP ratio would be lower by 0.5 percentage point compared to the baseline no-tax scenario.

■ Introducing a carbon tax levied in Belgium alone, on firms, without tax refunds

In a **second scenario**, we consider the case of the Belgian government raising *ex ante* € 3.75 billion through a carbon tax levied on fuel combustion by firms in the production process. Given that Noname does not use energy

1 Also, it will enhance the difference with the transmission mechanisms at play in this scenario compared to subsequent ones, where we will directly put the burden of the tax on firms or where the government directly compensates the households for the real income loss through a lump sum transfer.

as a production factor in its production function, we emulate this measure by raising the tax through a levy on firm's value added, where € 3.75 billion corresponds to 1.1 % of private value added. As in the previous scenario, the introduction of the carbon tax is supposed to be a purely Belgian measure, and once again the Belgian government will use the proceeds from the tax to speed up its debt reduction. Firms are price-makers and have the possibility of passing on the extra cost to buyers of their goods and services, i.e. to households (private consumption and housing investment), domestic firms (business investment) or firms abroad (exports). However, in a monopolistic competition environment with nominal rigidities, firms adjust their price only sluggishly to the implied surge in their marginal cost, temporarily absorbing the difference in their profit margins[1]. Firms put up their prices for all their customers and, in so doing, allocate the tax burden across households, domestic and foreign firms, through which the price rise will be broader-based than in the previous scenario. The rise in domestic prices erodes households' and firms' real income and the rise of the export deflator cuts into Belgian exporters' competitiveness. Given that the tax is levied on every unit of value added (a proxy for the amount of fossil fuel combustion linked to that product), the price increase for households will weigh on the prices in their entire consumer basket and not on their consumption of fossil fuels alone, as was the case in the previous scenario. We therefore let the automatic indexing mechanism play, which supports households' real income and entails more demand for private consumption and housing investment. This is done at the expense of firms' operating surplus, implying a further drop in corporate investment. On the nominal side, the wage indexation process leads to further price rises for all demand components. These wage indexation feedback effects also have further negative consequences for firms' competitiveness. Once the carbon tax has been introduced, producers face depressed domestic and export demand and reduce their output accordingly, together with employment and investment. The fall in all final demand categories causes a drop in import demand that is higher than that for exports, which softens the impact on GDP somewhat. All in all, compared to a no-carbon-tax baseline scenario, consumer prices will be 1.2 % higher after five years, while economic activity is expected to drop by 0.7 %, implying job losses of around 39 000 people and the unemployment rate is expected to increase by 0.7 of a percentage point. Also, after five years, the public debt to GDP ratio would be lower by 2.7 percentage points compared to the baseline.

In comparison to the first scenario, the tax shock is three times bigger and the transmission channels are somewhat more complex. Correcting for the size of the shock, the second scenario has a bigger effect on the average price in the economy, as measured by the GDP deflator, but a smaller effect on GDP. The activation of the automatic indexing mechanism in the second scenario is of course one cause. Another one is the fact that the price effects are now allocated over more demand components than private consumption alone and that the price elasticity of these demand components is somewhat lower. The fact that the Belgian economy holds up comparably better in the second scenario implies that second-round effects will be less detrimental for the government's accounts, especially for household direct taxes and social security contributions. Accordingly, the government will be able to reduce its debt comparably further than in the first scenario.

- Introducing a carbon tax, levied in Belgium alone, on households and firms, without tax refunds

In the **third scenario**, we simply add up the results for both previous scenarios, in order to get an idea of the total macroeconomic effects on the Belgian economy of introducing a € 50/tCO_2 tax initially and thereafter increasing by 4 % per year, on all the fossil fuel combustion by Belgian households and firms, in a scenario where only the Belgian government decides upon such a measure. After five years, GDP would be 1 % under and consumer prices 1.6 % above the baseline level, implying job losses of around 54 000 people and an unemployment rate increase of 1 pp. Taking into account all detrimental second round effects, the government would still be able to reduce its debt in proportion of GDP by 3.2 percentage points with respect to baseline.

1 This general feature of New Keynesian models about the progressive pass-through of the marginal cost to sales prices has been verified for the particular case of energy costs by Ganapati, Shapiro and Walker (2020) for the United States. Noteworthy, these authors find that consumers support no more than 75 percent of the burden of shocks to industrial energy prices, the rest being supported by the firms.

■ Introducing a carbon tax, levied EU-wide, on households and firms, without tax refunds

In a **fourth scenario**, we consider the case where the tax is not set in Belgium alone, but where the decision to introduce a carbon tax is taken at the European Union level, for every country under otherwise exactly the same conditions as described above. One of the reasons for studying such a scenario is to assess the difference regarding the repercussion on the competitiveness of Belgian firms compared to the previous scenarios. In the previous Belgium-alone scenarios, the European monetary authority did not react to idiosyncratic Belgian price dynamics as its weight is too small to have any impact on the European macroeconomic aggregates. In an EU-wide tax scenario, the European Central Bank will raise its short-term interest rate in order to calm the

Table 3

Simulations results of a CO_2 scenario: € 50/ton CO_2 emission (growing at 4 % per year) for the Belgian economy

(in % of deviation from baseline, unless otherwise stated)

	Belgium alone tax levied on									Belgium and EU tax levied on			Belgium alone tax levied on		
	households only			firms only			firms and households			firms and households			firms and households		
	no tax refund			no tax refund			no tax refund			no tax refund			full tax refund		
	Y1	Y3	Y5	Y1	Y3	Y5	Y1	Y3	Y5	Y1	Y3	Y5	Y1	Y3	Y5
Price and cost developments															
Household cons. deflator	0.5	0.5	0.5	0.5	1.0	1.2	1.0	1.4	1.6	1.0	1.2	1.4	1.0	1.5	1.9
of which:															
Energy component	5.5	5.9	6.4	0.3	1.0	1.3	5.7	6.9	7.7	5.4	6.1	6.8	5.7	6.9	7.7
Export deflator	0.0	0.0	0.0	0.2	0.4	0.4	0.2	0.4	0.4	0.1	0.2	0.3	0.2	0.4	0.5
GDP deflator	0.3	0.2	0.2	0.5	0.9	1.1	0.8	1.2	1.4	0.8	1.1	1.3	0.8	1.2	1.5
Nom. compensation per hour	0.0	0.0	0.0	0.3	1.0	1.1	0.3	1.0	1.1	0.3	0.8	1.0	0.3	1.0	1.4
Real compensation per hour	–0.5	–0.5	–0.5	–0.2	0.0	0.0	–0.8	–0.5	–0.5	–0.7	–0.4	–0.5	–0.8	–0.5	–0.5
Economic activity															
Real GDP	–0.1	–0.3	–0.3	–0.1	–0.5	–0.7	–0.1	–0.8	–1.0	–0.3	–1.1	–1.3	–0.1	–0.3	0.1
Private consumption	–0.2	–0.6	–0.5	–0.1	–0.4	–0.4	–0.2	–0.9	–0.9	–0.2	–0.9	–0.9	–0.2	0.0	0.5
Business investment	–0.1	–0.8	–0.9	–0.2	–1.8	–2.6	–0.2	–2.6	–3.6	–0.4	–3.2	–4.1	–0.2	–1.3	0.3
Residential investment	–0.1	–0.4	–0.4	0.0	–0.3	–0.4	–0.1	–0.7	–0.8	–0.1	–0.7	–0.9	–0.1	–0.1	0.5
Exports	0.0	0.0	0.0	–0.1	–0.2	–0.3	–0.1	–0.2	–0.3	–0.5	–0.8	–0.9	–0.1	–0.2	–0.3
Imports	0.0	–0.1	–0.1	–0.1	–0.4	–0.4	–0.1	–0.5	–0.6	–0.4	–1.0	–1.1	–0.1	–0.3	–0.1
Real disposable household income	–0.5	–0.5	–0.5	–0.3	–0.1	–0.2	–0.8	–0.6	–0.7	–0.8	–0.6	–0.7	–0.8	0.5	0.7
Labor market															
Unemployment rate (in pp dev. from baseline)	0.0	0.2	0.3	0.0	0.4	0.7	0.0	0.6	1.0	0.0	0.7	1.1	0.0	0.4	0.3
Employment (in thousand)	–0.3	–9.1	–15.4	–0.9	–21.7	–38.7	–1.2	–30.8	–54.1	–2.2	–37.9	–62.9	–1.2	–23.5	–19.4
Fiscal developments															
Balance [1]	0.3	0.1	0.1	0.7	0.4	0.3	1.0	0.4	0.3	1.0	0.3	0.2	1.0	–0.4	–0.2
Debt to GDP ratio [2]	–0.5	–0.4	–0.5	–1.2	–2.1	–2.7	–1.6	–2.5	–3.2	–1.5	–2.0	–2.5	–1.6	–1.3	–1.5

Source: NBB.
1 % of baseline GDP.
2 pp deviation from baseline.

inflationary consequences of the new tax on producer and consumer prices. This monetary tightening has a direct and additional negative effect on domestic demand on the one hand and will entail an appreciation of the effective euro exchange rate on the other hand. Also, in this scenario, oil prices denominated in euro will fall as a result from both the euro appreciation vis-à-vis the dollar and reduced demand for oil stemming from depressed European domestic demand.

A priori, one may expect that the synchronous introduction of the carbon tax in all EU Member States would strongly attenuate the negative competitiveness effect for the Belgian firms, as all EU trade partners now face more or less comparable price effects of the higher tax pressure. However, the international scenario outlined above shows that the total picture will be more complex. Member States also trade outside the EU and introducing a carbon tax at EU level might solve intra-EU competition issues, but it will entail reduced competitiveness vis-à-vis the rest of the world. The expected increase in the effective exchange rate of the euro will only amplify this effect. Moreover, and most importantly, the reduction in demand that will follow the price rises will now take place in all other EU Member States and this will result in a reduced need for imports from Belgium, entailing a general reduction in Belgian exports through second-round cross-border trade effects. The EU-wide carbon tax consequences have been assessed with the NBB-2C model described in de Walque, Jeanfils, Lejeune, Rychalovska and Wouters (2017), and the outcomes in terms of exchange rate, prices and intra- and extra-EU foreign demand have been used to calibrate the simulation run with the Noname model and are displayed in table 3.

How would the introduction of a carbon tax levying 5 billion on Belgian households (25 %) and firms (75 %) in combination with the international environment outlined above affect the Belgian economy ? Prices for Belgian importers will increase through price rises resulting from introducing the carbon tax in all other EU Member States, but will fall for goods and services coming from trade partners outside the EU as a result of the appreciation of the euro and the fall in oil prices. Domestic firms and households will react as in the first and second scenario, but external demand for Belgian products is further reduced, given that the carbon tax will reduce demand from all trade partners within the EU and demand from outside the EU will be depressed through the euro's appreciation. After five years, GDP would be 1.4 % under the baseline level and consumer prices 1.3 % above it, about 63 000 jobs would be lost, and the unemployment rate would increase by 1.1 percentage points. The government would be able to reduce the debt to GDP ratio by 2.5 percentage points compared to baseline.

■ A carbon tax levied in Belgium alone, on households and firms, with tax refunds

We remember from the previous discussions in section 2 that the goal of a Pigouvian tax is not to improve the government's budget balance, but that it should instead encourage a change of behaviour in a desired direction. This is even more important if the tax is expected to be anti-redistributive by weighing more on low-income households whose energy expenses represent a larger share of the consumer basket. By investing the tax proceeds back intro the economy, this fact can somehow be offset, if not for reasons of fairness than at least for gaining political support for this tax instrument. Some production sectors might also need compensation for the fact that they are, by nature, more carbon-intensive, and will require more time to adapt to the low emissions target. We therefore consider a scenario where the tax proceeds are not used to improve the government budget but are instead redistributed evenly between households and firms. A lump-sum transfer[1] will unwind the regressive nature of the carbon tax for lower-income households and firms will get a rebate on the taxes due on their profits. While it can be expected that the extra money for households will largely be consumed through a positive real income effect, the effects on the economy from firms' tax rebates can be expected to be smaller. It will improve firms' disposable income and, through this liquidity channel, ease the financing of their investment, but there is no real incentive to pass on this benefit to prices and, according to the model logic, a large share of the benefit will just improve firms' financial balances.

1 As recommended by the US Economists' Statement on Carbon Dividends.

The simulation results for this scenario can best be compared with those of the third scenario above, where an identical simulation set-up was considered but without any tax refunds to either households or firms. The amount of the lump sum transfer to households (€ 2.5 billion) more than offsets the cost of the carbon tax directly levied on them (€ 1.75 billion), but they will of course also suffer indirectly when firms pass on their carbon taxes to final consumer prices. In this simulation set-up, it is assumed that the lump sum transfer and tax rebate are retroceded with a one-year delay, so the introduction of the tax depresses the economy first while the refunds stimulate it afterwards. After five years, real GDP is slightly above baseline (+0.1 %), while the consumer price deflator is 1.9 % above its baseline level. Employment needs more time to find its baseline again, and after five years, some 19 000 people will have lost their jobs[1]. The debt in proportion of GDP is reduced by 1.5 percentage point compared to baseline. This is almost entirely due to a denominator effect, as nominal GDP increases due to the rise in the GDP deflator. Clearly, the one-year discrepancy between the beginning of the tax policy and the transfers and tax rebates is responsible for the remaining job losses after five years: the sooner tax dividends are redistributed, the lower the economic costs.

Key messages from the simulation exercise

Using macroeconomic structural models available at the National Bank of Belgium, we have assessed on a five-year horizon the macroeconomic consequences of introducing a carbon tax in Belgium, fixed initially at € 50/tCO_2 (on top of all the existing fuels and emissions taxes) and growing at a yearly rate of 4 %. Such a tax would *ex ante* yield 1.1 % of GDP, a quarter of which would be paid by households and the rest by private firms. The main conclusion from this fiscal exercise is that, with no accompanying measures, such a tax levied at Belgian level would cost about 1 % of GDP at the end of the simulation horizon. Contrary to popular belief, things would not be better if the tax were to be levied at European Union level. Even though it reduces the problem of Belgian firms' competitive edge over their EU counterparts, it worsens EU firms' competitiveness in general with respect to the rest of the world and, more importantly, the inflationary effect of the tax reduces EU domestic aggregate demand, and consequently, EU demand for Belgian goods. Compared to a Belgium-only scenario, GDP would then drop by 1.3 % after five years. However, as shown by a simulation where the tax is set in Belgium only, redistributing the tax dividends to households and firms strongly mitigates the negative consequences for economic activity, and reverses them at the end of the considered horizon. This scenario confirms that a timely redistribution of the tax return is key and enables the energy cost increase to be fully offset, even if Belgium decides to introduce a carbon tax unilaterally. If the tax were to be set at EU level and accompanied by the same kind of redistribution policy in the other Member States, then the aggregate demand problem pointed up earlier would be neutralised, while coordination at EU level reduces *per se* the loss of competitiveness for domestic firms induced by a Belgium-alone scenario.

1 This highlights the importance of reducing the delay between the tax and the refund, especially for households. In British Columbia and in Switzerland, the transfers are paid on a quarterly basis.

Conclusion

The window of opportunity to reach the Paris Agreement targets is narrowing rapidly and huge efforts are still required worldwide for this goal to be attained. The group of countries committing to strict objectives regarding carbon neutrality is growing slowly but it still includes some of the largest emitters, such as Japan and the European Union. China shows encouraging signs, both in actions and intentions, and the election of Joe Biden as the next President of the US may certainly be considered as a good omen. Economists have come to a consensus about carbon pricing which they view as the first and more efficient policy instrument to adopt in order to fight the carbon emission problem in a decentralised way, leaving agents to adapt their behaviour optimally to the new constraint and the re-designed system of relative prices. The most important aspect to achieve this goal at minimal cost is to clearly announce the future carbon price growth path together with the emissions objective. Such a policy also has direct implications for the financial markets, rebalancing relative asset values in favour of light-carbon-emitting firms.

Carbon pricing initiatives have flourished around the world in the last thirty years, differing in scope and coverage. These field experiments have made it possible to collect economic data both at the macro and firm level, data that have been used in econometric studies. Research work surveyed in this article is unanimous about the carbon-reducing effect of the instrument, and none of them points to any important and unsurmountable social and economic costs of a carbon pricing policy. However, they all insist that it is highly advisable to agree on accompanying measures. First and foremost, when the tax weighs directly on households' shoulders, its dividends have to be redistributed in order to counter the fact that energy makes up a larger share of low-income households' consumption basket. This is not only important from the viewpoint of social fairness, but it is also essential to ensure political support. When the pricing mechanism is geared towards the production sector, it is also well advised to bring some temporary support to the firms and sectors that are the most exposed to fossil fuel prices, either directly or indirectly, as well as those exposed to foreign competition. Labour market measures are certainly also welcome to smooth the transition process of workers from carbon/energy-intensive jobs to often more skills-demanding low-carbon jobs.

A fiscal simulation exercise for Belgium confirms the findings of Hebbink *et al*. (2018) for the Netherlands, and of the abovementioned literature: redistributing the tax dividends enables the negative consequences of the tax on real activity and employment to be strongly mitigated in the short run, and later fully neutralised, notwithstanding the improvement in air quality and the contribution to reducing climate-related risks. Even though coordination of carbon tax policy at the EU level is certainly the preferred option both in terms of emissions coverage and competitiveness issues, simulations suggest that this conclusion is independent of such a cross-border synchronisation, as already proved by several single country experiments. Early starters could then benefit from a competitive advantage when other countries join the carbon pricing club: this has obviously been the Swedish bet. It is noteworthy that any enlargement of the "carbon pricing coalition" not only helps overcome the eternal free-riding and competitiveness problem, it also improves the returns to scale of low-carbon-oriented research and resolutely helps in the quest for a path out of a warm world.

However, it is important to recall that, although empirically validated, this conclusion remains limited to the first few years after the tax is introduced[1]. As time elapses and the fruits from the lower branches have been gathered, reaching the upper ones will become more and more dependent on technological progress which is costly to develop and diffuse. Furthermore, if low-carbon technologies were limited to rich advanced economies, emissions by emerging economies may totally ruin the efforts from a global viewpoint. It is therefore of the utmost importance that, together with research and development, low-carbon technologies are transferred at as low a possible cost for developing economies.

1 Though in Scandinavian countries the experiment has now been running for 30 years.

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