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A QUANTIFIED EVALUATION OF THE FRENCH « CARBON TAX »

Stéphane GLORIANT[1]

Termed a "climate-energy contribution", the carbon tax was introduced in France in 2014 to price energy-related CO_2 emissions not covered by the European emissions trading scheme. Its ramp-up is likely to accelerate, at least as far as the rate is concerned, calling for an initial assessment of its actual effects. Such an evaluation is what this edition of Information & Debates provides, concentrating on the sectors most concerned. Evaluating the impact of the tax is not just a matter of comparing emissions before and after the tax came into force, but requires a comparison of the emissions observed over the period with the evolution of a "counterfactual" scenario representing the hypothetical trajectory that emissions would have followed in its absence.

In the first part, we look at the contextual elements needed to understand how the price signal of carbon affects economic actors by way of energy prices. In the second and third parts we then evaluate the impacts of the tax by taking an ex ante approach and an ex post approach respectively.

The ex-ante approach is based on calculating price and tax elasticities. It is carried out indirectly by comparing the carbon tax with an increase in the prices of fossil fuels. Although this raises the question of transmission from the one to the other, it has the advantage of not requiring a temporal distance in relation to the introduction of the tax. The results suggest that the carbon tax led to a reduction in emissions from the transport sector of between 0.6 and 1.7 Mt of CO2 in 2017. Taxation of heating oil for its part reduced emissions from the heating of buildings by 0.7 Mt CO2. For transport and fuel oil, the method leads to the prediction that by the end of the five-year period the tax should lead to a reduction in emissions of between 3 and 5.7 Mt of CO2 compared to 2017. These various estimates likely to be a minimum, since it seems that consumers are more responsive to a price increase resulting from higher taxes than to one induced by a change in the price of fossil raw materials.

The ex post approach is based on the "synthetic control" method, and involves reconstructing France's hypothetical emissions from a group of comparable countries that have not introduced a carbon tax during the period. This approach produces a direct evaluation in that the impact of the tax is estimated is implemented over the period the tax has been in force. Applied to France over the period 2014-2017, it does not allow a robust conclusion to be drawn as to the impact of the introduction of the carbon tax on emissions from the transport or building heating sector over the period concerned. This result may be explained by the small number of observations currently available since the introduction of the tax.

KEYWORDS

Carbon tax | Evaluation | Contrefactual

[1] Climate Economics Chair

I. The carbon tax in France: theoretical foundation and practical implementation

A. The theoretical foundations of the carbon tax

1. The carbon tax: a Pigouvian tax

The carbon tax is an environmental tax on emissions of carbon dioxide, the main greenhouse gas of anthropogenic origin. Since it is proportional to CO_2 emissions, this tax aims to encourage economic actors to reduce their emissions and thus limit climate change. The tax is levied at the time of purchase of fossil fuels.

In theoretical terms, the carbon tax is a Pigouvian tax. It aims to correct a market imperfection by internalising the cost of negative externalities caused by climate change into the price paid by actors in the energy sector. This point is fundamental because it highlights the essentially behavioural and non-budgetary aim of the tax, in that its purpose is not to augment the State treasury. On the contrary, and very unusually in the realm of taxation, the carbon tax aim to reduce its tax base. Thus, logically, if the yield from the tax became zero, it would mean that it had been a complete success, since France's long-term goal is carbon neutrality.

In practical terms, the introduction of the carbon tax in 2014 did not involve creating a new tax, but introduced into the calculation of existing energy domestic consumption taxes (DCTs) a "carbon component", calculated pro rata on the carbon content of different forms of energy. This carbon component is calculated by the customs service but is not explicit for energy buyers, who pay DCTs expressed in euros per litre or per kWh at the time they make their purchases. While all DCTs are classified as environmental taxes in national or international statistics because their base is a physical quantity related to environmental damage, only the carbon component of DCTs explicitly aims to correct the "climate" externality and to reduce CO_2 emissions from burning this energy.

2. The three pillars of the construction of a carbon tax

Three basic principles must be combined in order to build an economically relevant carbon tax.

- The tax base must cover all CO_2 emissions resulting from the use of fossil fuels. This base is therefore calculated, for the different types of energy, solely on the basis of the CO_2 emissions produced by the energy in question. Any exemption or bias in this principle of the universality of the carbon base will result in distortions that detract from the goal of reducing emissions at the lowest cost.
- The rate of the tax is the price per tonne of CO_2 applied to the carbon content of each fuel used. To set this price, governments have at their disposal two indicators: either the estimated value of future climate damage (the social cost of carbon) or benchmark values calculated from a cost-effectiveness method. In France, the second method that is used, through the calculation of periodically updated carbon "shadow prices".[1] In practice, the important thing is to set a medium-term trajectory for the tax, if possible approaching those of the shadow prices and potentially of the social cost of carbon, whose estimation can fluctuate widely depending on the calculation methods used. This increase needs to be gradual and predictable so as to guide investments over the long term and allow time for the various economic actors to adapt.
- The use of the proceeds from the carbon tax is the third pillar of carbon pricing. To limit the negative impact of the carbon tax in macroeconomic terms, the behavioural and non-budgetary aims of the tax should be adhered to. Consequently most economists advocate the introduction of a carbon tax with constant tax revenues, in other words, reducing other existing taxes by the amount of the budgetary return from the carbon tax. This tax reduction should primarily focus on the most distortionary tax deductions. Studies have shown that, in certain circumstances, the introduction of a carbon tax accompanied by an equivalent reduction of the most distortionary statutory levies could prove to be positive at the macroeconomic level.[2] But this conclusion should not let us forget the anti-redistributive character of carbon taxation, that argues in the short term in favour of a lump sum repayment

to households of a portion of the proceeds from the tax, in order to combat fuel poverty. Although doing so would make it possible to counter the anti-redistributive effects of the tax, there would cease to be a constant tax revenue.

In reality, the introduction of carbon taxation responds to political contexts in which economic principles apply in varying degrees, as shown by two successful experiments in introducing the carbon tax, in British Columbia and Sweden.

Example 1: Carbon taxation in British Columbia

The Canadian province introduced a carbon tax in July 2008. Initially set at 10 dollars per tonne of CO_2 equivalent, the amount increased by 5 dollars a year, and stood at 30 dollars in 2012.[3]
British Columbia's carbon tax was designed to be budget neutral: all carbon tax proceeds are required to be redistributed. The redistribution was achieved by lowering taxes on household incomes (reduction of the first two tax brackets) and corporation tax and by a lump sum tax credit targeted at lower income and rural households. Every year, the finance minister is required to publish a three-year plan describing how carbon tax revenues are being used in order to ensure budget neutrality..
The base of this tax is broad and concerns all emissions from fossil fuel combustion. This represents 70% of the province's greenhouse gas emissions.[4] There are very few exemptions, even if they have become rather more numerous in recent years.[5]

Example 2: Carbon taxation in Sweden

Sweden was one of the world's first countries to introduce a carbon tax. In 1991, as part of a major tax reform, it added two new taxes on energy, which was already subject to an excise tax (energy tax). These were VAT and a carbon tax. Initially set at 27 euros, the carbon tax was then gradually increased to 108 euros in 2009 and stands at nearly 120 euros today. At present, the Swedish carbon tax is the highest in the world. This gradual increase in the carbon tax has been accompanied by lower income taxes and social security contributions.
The tax concerns all forms of energy and initially applied to all economic actors (households as well as companies and industries). However, in order to maintain Sweden's economic competitiveness, the rate has been sharply reduced for some industries. Over time, the differential between the standard rate and the reduced rates has decreased, but industries subject to the European emissions trading scheme are exempted.

B. The French solution: an ambitious carbon trajectory in a complex system

1. Current situation regarding French energy taxation

In France, the marketing of energy products is subject to two taxes: an excise tax (with its base being the quantity of products sold) and VAT (with its base being the value of the products sold, including excise duties). This dual tax system is governed by European directives,[6] the aim of which is to partially harmonize these different taxes at EU level.

At the national level, excise duties on energy products are known as "domestic consumption taxes" (DCTs) and are defined in the Customs Code.[7] For each category of energy products, a DCT is defined, within which the energy produced per energy product and the amounts of tax per quantity of energy are set. Thus the domestic tax on the consumption of energy products (DCTEP) mainly applies to petroleum fuels and the like, the domestic tax on consumption of natural gas (DCTNG) to natural gas for fuel use, and the domestic tax on coal consumption (DCTC) to coal, lignite and coke.

From the price tax excluded, the tax-included price is obtained from the following formula:

$$Price\ tax\ included = (Price\ tax\ excluded + DCT) * (1 + \mathrm{VAT})$$

VAT therefore also applies to domestic consumption taxes. This is important: because the VAT rate is now set at 20%, a rise of 10% in DCT actually represents a rise of 10 x (1 + 20%) = 12% of the price including tax.

Regional adjustment of DCTEP

In the context of decentralization, possible regional adjustment of DCTEP rate on petrol and diesel was introduced, within the limits set by law. As of 1 January 2007, an initial adjustment tranche was implemented: each region may decrease, compared to the amount designated by the state financial legislation, the DCTEP rate by up to €1.77/hl for premium grade fuel and by up to €1.15/hl for diesel. As of 1 January 2010, a new adjustment tranche was introduced allowing the regions to increase DCTEP rates, compared to the amount designated by the state financial legislation, by €0.73/hl for premium grade fuel and €1.35/hl for diesel. Thus the total possible adjustment is €2.5/hl for premium grade fuel and diesel. Moreover, as of 2017, a price increase was introduced in Ile de France: €1.02/hl for premium grade fuel and €1.89/hl for diesel. Lastly, special provisions also apply to Corsica and the French overseas territories.

Table 1: 2018 DCT tariffs for major forms of energy. Source: Customs Code

Petrol	Diesel	Heating fuel	Natural gas
€68.29/hl [8]	€59.40 euros /hl [9]	€15.62/hl	€8.45/MWh PCS

As the proceeds from DCTC are very small[10], we will focus mainly on DCTNG and DCTEP, and more particularly on petrol, diesel and domestic fuel within DCTEP.

2. The 2014 reform: the introduction of a carbon component into DCTs

After two attempts, in 2000 and in 2010, both of which ended in censure by the Constitutional Council, the carbon tax was finally introduced in France in 2014. This very specific institutional and legal context is not unimportant, because it largely accounts for the choices made during the introduction of the tax.

The aborted reform of 2010

The system envisaged[11]

In line with the Grenelle Environment Forum and the work of the Rocard Commission, the government decided in late 2009 to create a carbon tax in the draft budget for 2010. Two options were then discussed.
The first was to institute **a differential tax** on the consumption of fossil fuels, that is to say, to increase in a differentiated way already existing taxes (DCTs) depending on greenhouse gas emissions.
The second option was to create **an additional tax** on the consumption of fossil fuels and thus to clearly separate the carbon component from the other taxes applying to these products. At the time, it was this second solution that was adopted, because it provided the best legibility in terms of the price signal. For the first year, the price per tonne of CO_2 was set at 17 euros.
This reform was accompanied by the creation of an income tax credit in order to redistribute some of the proceeds from the carbon tax to households. Moreover, so as not to harm the competitiveness of certain sectors of the French economy, several total or partial exemptions were planned. The most important concerned industries subject to the European emissions trading scheme, the reasoning being that these companies were in fact already subject to a carbon-price signal.

Censure by the Constitutional Council[12]

Following referral of the draft budget to the Constitutional Council, it rejected all the provisions relating to the carbon tax. The main reason for this censure was the existence of too many exemptions which, according to the Council, constituted a violation of the principle of equality with regard to public burdens. The exemption of companies subject to the ETS allowances market was singled out by the Constitutional Council (see Appendix 2 for more details).

The paradoxical consequences of the Constitutional Council's decision

Ultimately, the Council criticized the carbon tax because it covered only 48% of the country's greenhouse gas emissions and was therefore inadequate for meeting the objective of combatting climate change.

This decision had paradoxical consequences. In view of the legal, economic and political difficulties involved in extending the carbon tax to companies subject to the ETS, the government subsequently dropped the tax. Justified by the objective of combatting climate change, the decision by the Constitutional Council led from a situation where 48% of French emissions would have been taxed to one where no emissions were taxed.

In late 2013, the government therefore decided to increase the amount of DCT. As part of this reform, it was also decided to introduce a Pigouvian component into DCT by adjusting, for the various types of energy, the increases according to the amount of CO_2 emitted. The new rates were thus broken down into two parts: an "energy" part (corresponding to the "traditional" DCT) and a "carbon" part based on a standardized carbon content of energy products. This time the carbon tax introduced was a differential tax and no longer an additional tax (see previous box). The calculation formula is as follows:

$$Rate\ in\ year\ N = (\text{"}Energy\text{"}\ share\ in\ year\ \ N) + (Carbon\ content\ ) * (Rate\ of\ carbon\ in\ year\ \ N)$$

a. The tax base

As in Ireland, where a tax was introduced in 2009, the solution adopted in France for the carbon tax was to target all CO_2 emissions resulting from the use of fossil fuels not covered by the European allowances trading system, in order to avoid double charging. In Sweden, where the carbon tax pre-existed this system, the same solution was adopted, with total exemption from the carbon tax for industrial installations subject to the EU ETS.

Although in theory DCTs should apply to all energy consumption, there are many exemptions and these reduce the carbon tax base. DCT derogation regimes that existed prior to the introduction of the carbon component are still in place and offer total or partial exemption and reimbursement schemes. For example, freight road hauliers (with vehicle mass greater than 7.5 tonnes) may claim reimbursement of the proportion of the DCTEP on diesel in excess of 43.19 euros.[13]

b. The carbon component rate

In concrete terms, the carbon component of DCTs is calculated from the carbon content of the energy product and the price of carbon.

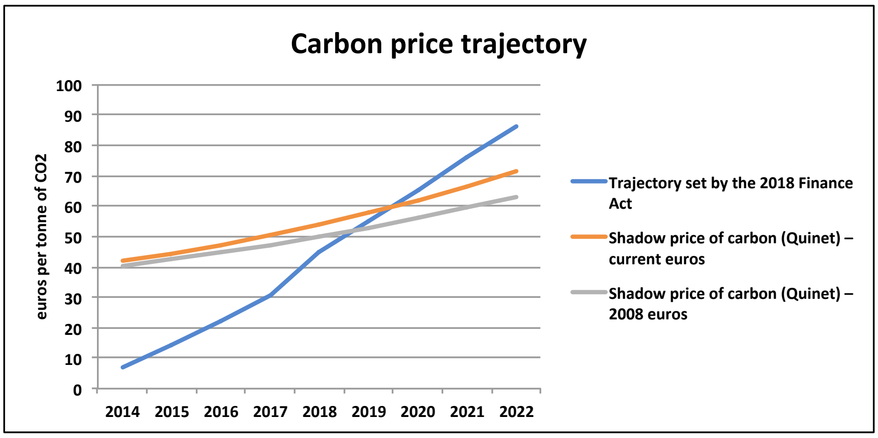
For the carbon content, the emission factors used correspond solely to the combustion of energy products and do not include the “upstream” part (i.e. the production of these products). Table 2 below shows the emission factors for the different types of energy considered in our study.

Table 2: Emission factors used to calculate the carbon component of DCTs. Source: Preliminary evaluation by the Articles of the draft finance law for 2018 for petrol and diesel; CEC estimate for heating oil and natural gas

Energy	Amount of the tax	Unit
SP95 and SP98 petrol	0.2287	tCO_2/hl
Diesel for road transport	0.2651	tCO_2/hl
Heating oil	0.2651	tCO_2/hl
Natural gas	0.1817	tCO_2/MWh PCS

The price of carbon was defined when the reform was introduced in 2014, as follows: 7 euros per tonne in 2014, 14.5 euros in 2015 and 22 euros in 2016. For 2017, the price was set at 30.5 euros. Article 1 of Act No. 2015-992 of 17 August 2015 on the energy transition for green growth anticipated a target of €56 in 2020 and €100 in 2030. Under the 2018 Finance Act, this trajectory has been revised: the price of carbon is now set at €44.60 per tonne of carbon in 2018, €55 in 2019, €65.40 in 2020, €75.80 in 2021 and €86.20 in 2022. The graph below traces the tax trajectory and compares it to trajectory of the “shadow price” of carbon calculated in 2009 by the Quinet Commission.

Figure 1: Carbon price trajectory from 2014 to 2022. Source: Customs Code and Quinet report, 2009



c. *A parallel reform: petrol-diesel convergence*

With the aim of combatting fine particle air pollution, another reform was added to the introduction of the carbon tax. Concerned with the "energy" part of the carbon tax, this reform aims at the convergence of taxation on petrol and diesel. Thus the "energy" part of diesel and unleaded petrol has changed since 2014 and will continue to do so until 2021 in order to make the tax on these two fuels converge.

C. Transmission of the price signal to consumers

1. The price impact of introducing the carbon tax

In 2014, the introduction of a carbon component into the DCTEP had negligible effect on household energy bills. Indeed, for petrol, diesel and heating oil, the introduction of the carbon tax was fully offset by an equivalent drop in the "energy" part and the amount represented by the DCTNG was low.

This is no longer the case today. With regard to "transport", the increase in the carbon component of the DCTEP since 2014 amounts to 7.5 euro cents for petrol and 10 cents for diesel (9 and 11.2 cents including VAT) per litre of fuel. At the end of the five-year period, the increase in the carbon component since 2014 will represent more than 17 cents for petrol and 21.2 cents for diesel (20.4 and 25.5 cents with VAT). Compared to the average price for 2013, and given that the entire increase in taxation is passed on to consumers (see II.B), the introduction of the carbon component represents a rise of 5.8% in the price of petrol (and 8% in the price of diesel) between 2013 and 2018. At the end of the five-year period, these percentage increases will amount to 13.2% and 18.2% respectively. Moreover, these figures do not take into account petrol-diesel convergence. As can be seen from Figure 3 below, this measure is far from being without consequence for diesel, as the total price increase compared to 2013, taking into account the carbon tax and petrol-diesel convergence, could be more than 30%.

Figure 2: Cumulative change in DCTEP on petrol since 2014. Source: CEC calculations from "Preliminary Finance Act Evaluations 2018"

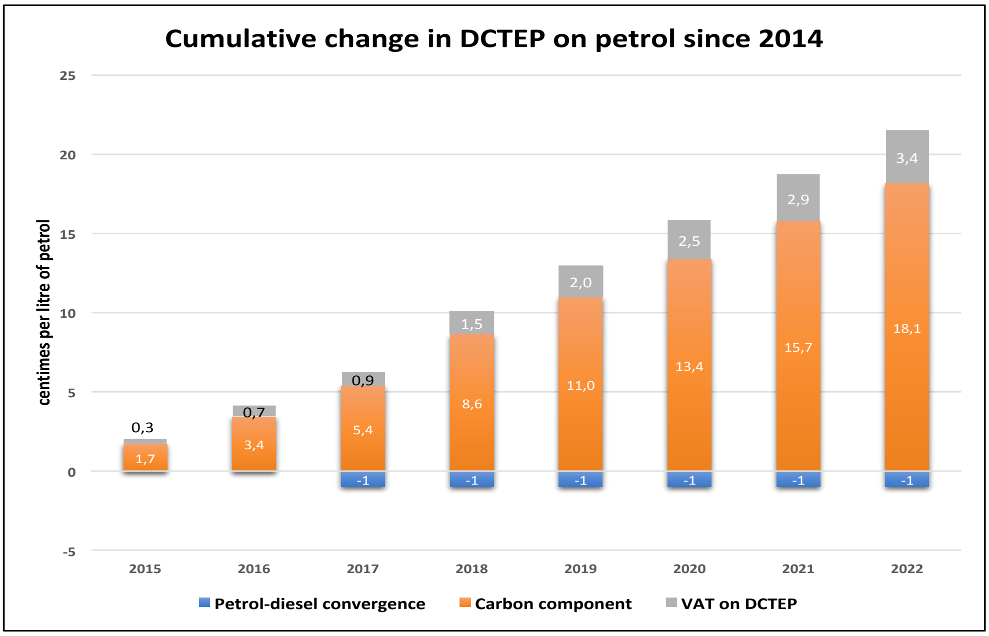
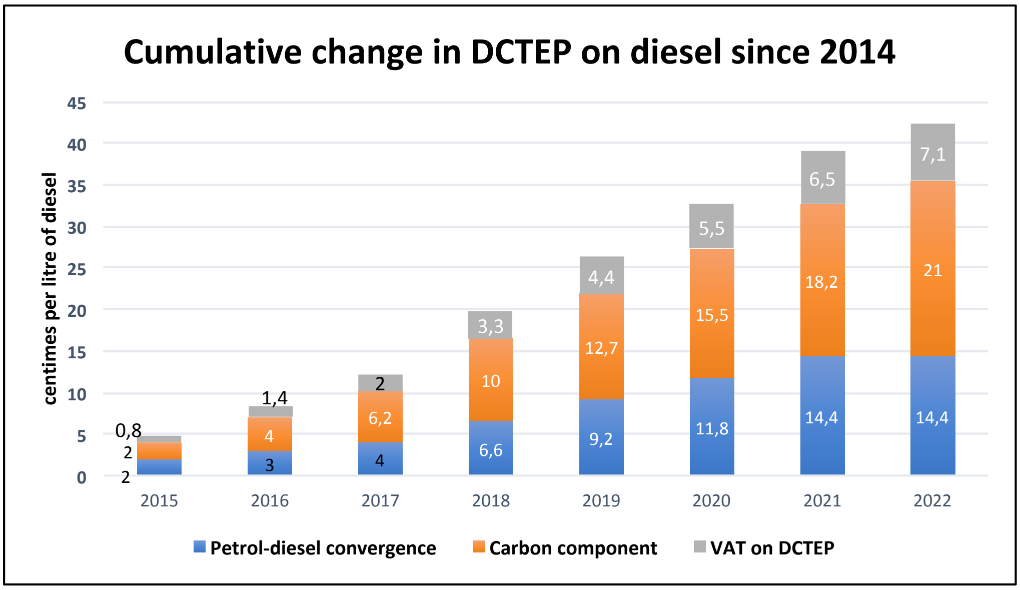


Figure 3: Cumulative change in DCTEP on diesel since 2014. Source: CEC calculations from "Preliminary Finance Act Evaluations 2018"



For "heating", we will consider a poorly insulated, 120 sq. metre, older house, whose annual consumption for heating is estimated at 25,000 kWh (including losses related to the operation of the boiler). For a household occupying a house heated by gas, the additional cost related to this reform was approximately 35 euros a year in 2014, nearly 210 euros a year in 2018 and is likely to be nearly 400 euros a year at the end of the five-year period. For a household occupying house heated by oil, the additional cost related to this reform was zero in 2014, about fifty euros in 2015, about 240 euros a year in 2018, and is likely to be nearly 500 euros a year at the end of the five-year period.

Figure 4: Cumulative change in DCTNG since 2014. Source: CEC calculations from "Preliminary Finance Act Evaluations 2018"

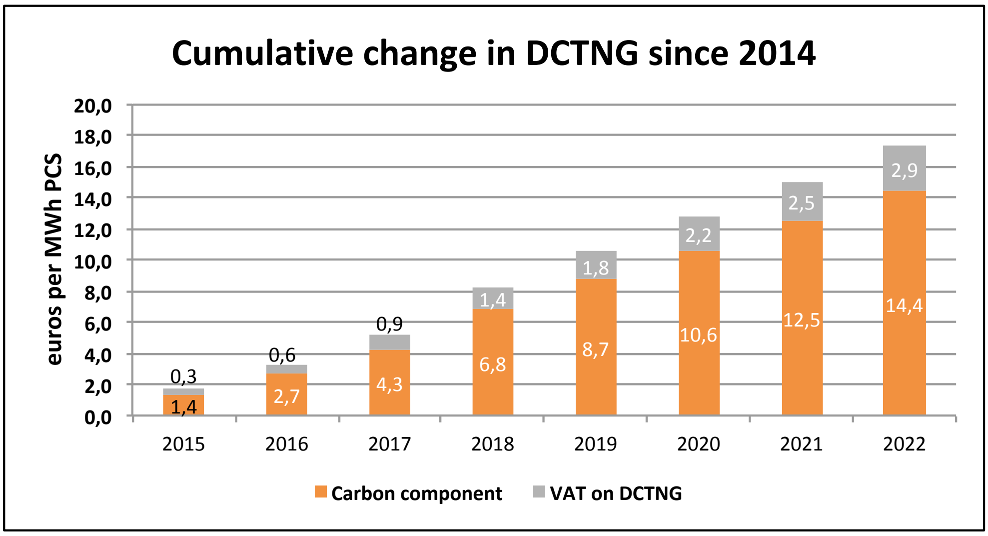
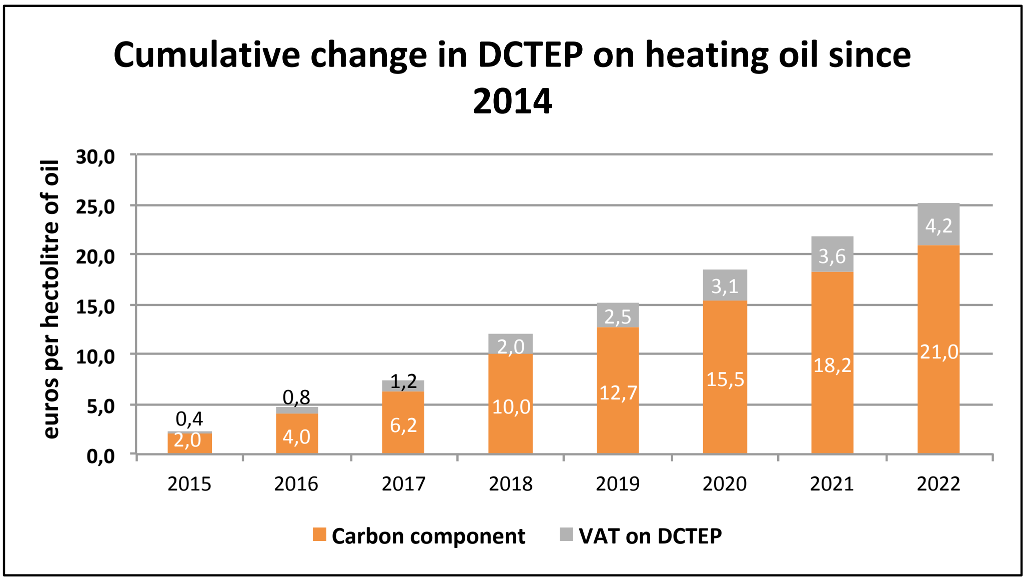


Figure 5: Cumulative change in DCTEP on heating oil since 2014. Source: CEC calculations from "Preliminary Finance Act Evaluations 2018

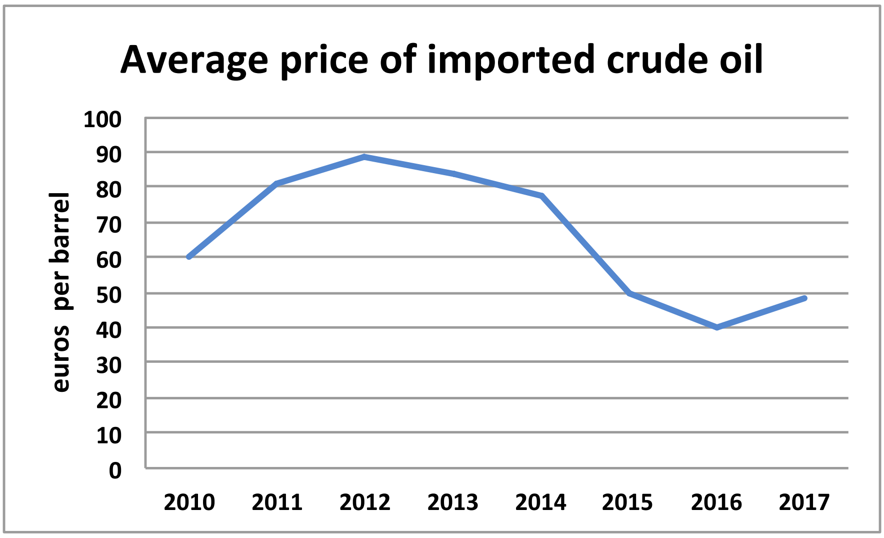


2. <u>A price signal clouded by the fall in the price of raw materials</u>

In point of fact, during the first years of implementation of the reform, the expected increases in the price of these energies did not occur. Concomitantly, the price of commodities in the world markets, especially oil, fell sharply. Between 2014 and 2016, the price of oil declined by nearly 50%, from around 80 euros per barrel to 40 euros. The fall in oil prices more than compensated for the increase in DCT and, in the end, the reform went completely unnoticed in terms of energy bills.

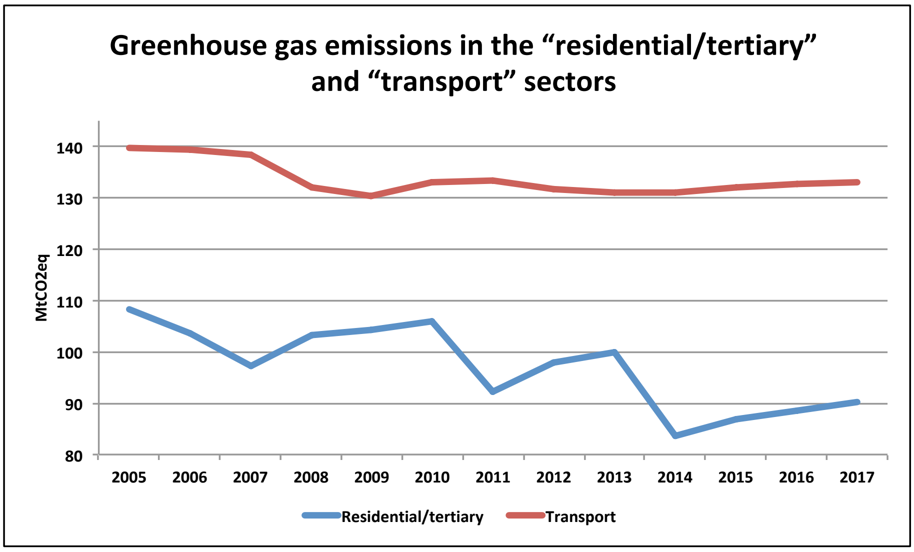
At the same time, for political reasons, the government was initially silent on the subject. We can therefore legitimately raise the question of the real environmental impact of the carbon tax. Is this measure, conceived as a preferred instrument for combatting climate change, really effective in reducing greenhouse gases?

Figure 6: Change in oil prices since 2010. Source: OECD



Answering this question is far from easy. At first glance, the instrument is ineffective since emissions in the “residential/tertiary” and “transport” sectors have been on the rise since 2014.

Figure 7: Changes in greenhouse gas emissions in the transport and residential/tertiary sectors. Source: CITEPA, total emissions UTCATF



However, simply noting the difference between emissions before and after the reform is not really relevant. We should rather compare the situation actually observed, that is, with the implementation of the 2014 reform, with the fictitious situation where there would have been no carbon tax in France, a situation that obviously cannot be observed. In short, constructing the counterfactual of greenhouse gas emissions in France since 2014 is the focus of this study.

II. An ex ante evaluation method through calculating price elasticities

An initial way of assessing the impact of the carbon tax is to evaluate the price elasticities of energy consumption. By definition, these measure the variation in consumption induced by a change in the price. If we assume that energy taxes are fully borne by consumers, each tax increase translates into an equivalent price increase. Through the elasticities that have been calculated, we can then derive, all other things being equal, the decrease in energy consumption induced by the increase in DCT and therefore the greenhouse gas emissions avoided.

The topic of energy-price elasticities has extensively discussed in the literature. Many methods have already been explored and a large number of estimates are available. Dahl and Sterner (1991)[14] carried out a meta-analysis of the elasticity estimates made for OECD countries and classified the results obtained according to the time horizon concerned (short or long-term elasticity) and the methods used. This exercise was recently repeated by Labendeira, Labeaga and Xiral López-Otero (2016).[15]

In this study, we will estimate these elasticities for France, using simple models based on linear regression estimates, with or without instrumental variables. The models used will be static (that is, all the data used in the model are contemporary). According to Dahl and Sterner, the elasticities calculated will be short-term if monthly data is used and medium-term in the case of annual data.

In the second stage, we will take the analysis further and investigate a less studied area, namely the difference in consumer behaviour in response to price changes, depending on the origin of the price variation. We will attempt to corroborate or refute the hypothesis that consumers react more to a tax change than to an equivalent change in the price of raw materials or the distributor's margin.

In the case of fuel, a number of studies have in some cases confirmed this intuition. For British Columbia, Rivers and Schaufele (2012)[16] estimate that consumers' response to the tax is 4.9 times greater. Andersson (2017)[17] finds the ratio for Sweden to be 3, while Li, Linn and Muehlegger (2012)[18] find a ratio of 8 for the United States.

Several theories have been proposed to explain this phenomenon:

- Li, Linn and Muehlegger (2012) argue that the price change induced by a tax variation is more visible for consumers because it is often the subject of debate and therefore of extensive media coverage.
- Li, Linn and Muehlegger (2012) also suggest that consumers perceive tax increases as more permanent and less volatile than increases in oil prices. Their decisions, and in particular long-term decisions (purchase of a vehicle or heating system), are thus influenced to a greater extent.
- Congdon, Kling and Mullainathan (2009)[19] consider "non-standard preferences" and introduce the idea that the environment can be integrated into the utility function. Nicholas and Schaufele use this idea to show that a carbon tax can eliminate the problems of free-riding. Take the example of two drivers, one of whom is conscious of environmental issues and the other is not. Suppose also that the road used is congested. If the environmentally-aware driver tries to reduce the pollution he emits, he frees up space on the congested road, which may encourage the other driver to drive more. The efforts of the environmentally-aware driver are partly nullified by this free-riding problem, and this in turn may cause him to reduce his efforts. With a carbon tax, the environmentally-aware driver knows that no matter what happens, the other driver will pay for the environmental externalities he causes, and hence the first driver will not reduce his efforts.

In our study, we are interested only in fuel and heating oil. The situation with regard to natural gas is very different and cannot be studied here. Indeed, the setting of the price of natural gas has long been fully regulated and today still nearly 43% of gas consumed in the residential sector is charged at the regulated rate.[20] The particularly complex formula for calculating this rate makes it difficult to study its various components. Moreover, prior to 2014, households were not subject to DCTNG. The limited data available makes it difficult to study the response of gas consumers to DCTNG.

After briefly presenting the data used, we will then present the evaluation process used in three stages.

- Firstly, we will test the central hypothesis on the tax impact of DCTs. Are changes in tax entirely passed on in the tax-inclusive price?
- Secondly, we will calculate the elasticities of consumption for the tax-inclusive price and we will deduce the counterfactual.
- Thirdly, we will determine whether or not consumers react differently to price changes stemming from price variations in raw materials.

A. The data used

In this study, we focus on the following types of energy: fuel for passenger cars and light commercial vehicles (diesel, SP95, SP98, ARS super fuel,[21] regular petrol) and heating oil consumed by households. We will use price, DCT, VAT and consumption data for each of the energies. For domestic heating oil, consumption is corrected for climatic variations. For passenger cars and light commercial vehicles, we reconstruct a weighted synthetic "fuel" price based on consumption and the prices of each fuel. As we are not interested in the road transport of goods, which has a partial DCTEP exemption, we remove the volume consumed by heavy goods vehicles from the consumption of diesel fuel. The following additional variables are also used: the average price of imported oil, the consumer price index, gross disposable household income, the proportion of oil-heated dwellings, and the unemployment rate.

We work on both monthly and annual data. For monthly data, the time period used is from September 2002 to March 2018 for heating oil and fuel. Data were available from January 2000 but it was decided to exclude from the sample the period when the floating TIPP (domestic tax on petroleum products) was introduced. For annual data, the time period used is from 1980 to 2017 for fuel and 1983-2017 for heating oil. These choices were guided by the availability of data. The details of the data sources and their processing can be found in Appendix 3.

B. Tax impact

Before turning to the calculations of elasticity, the central hypothesis of the tax impact of DCTs needs to be tested. Theoretical arguments support the hypothesis that DCTs apply solely to consumers. Indeed, it can be legitimately supposed, given the structure of the market, that market power lies more on the producer side rather than the consumer side. This hypothesis can also be checked by econometric tests. The following model used in this part:

$$\Delta p_t^{Excl.VAT} = \alpha + \beta \Delta Oil_t + \gamma \Delta DCTEP_t^{Excl.VAT} + \varepsilon_t$$

where t is the period of time considered temps, $p_t^{Excl.VAT}$ is energy price considered excluding VAT, Oil_t is the average price of imported oil and $DCTEP_t^{Excl.VAT}$ is the amount of DCTEP excluding VAT. All amounts are expressed in nominal prices. Δ is the difference operator. When monthly data is used, indicators for the different months of the year are added to take into account the possible seasonality of the data.

If, in accordance with intuition, any increase or decrease in DCTEP is passed on to prices, the coefficient γ should be close to 1.

With the monthly data (N = 187), after seasonal adjustment, we obtain the following results:
- 1.02 for fuel (95% confidence interval of [0.19, 1.85])
- 1.10 for heating oil (95% confidence interval of [0.38, 1.83])

With the annual data (N = 37 for fuel, N = 34 for heating oil), the following results are obtained:
- 1.03 for fuel (95% confidence interval of [0.73; 1.33])
- 1.40 for heating oil (95% confidence interval of [0.73, 2.07])

With both monthly and annual data, the standard deviation is calculated with the Newey-West estimator, which is robust to heteroscedasticity and autocorrelation of the residuals. In accordance with intuition, the coefficients obtained are not statistically different from 1. The hypothesis that the changes in DCTEP are fully passed on to consumers cannot therefore be rejected.

C. Price elasticity (tax included)

We now seek to evaluate the tax-inclusive price elasticity of the consumption of different energies. For this, we use two types of model.

Model (1) reasons in terms of level:

$$\log(C_t) = \alpha + \beta \log\left(p_t^{incl.tax}\right) + \gamma \log\,(X_t) + \delta\tau_t + \varepsilon_t$$

where C_t is per capita consumption at time t, $p_t^{incl.\ tax}$ is the tax-inclusive price deflated by the consumer price index, τ_t is a temporal tendancy and X_t is a vector comprising several control variables (according to the energy considered: gross disposable income per capita, unemployment rate, proportion of oil-heated dwellings). For the monthly data, month dummies are added to take seasonality in account.

Model (2) reasons in terms of variation:

$$\Delta \log(C_t) = \alpha + \beta\Delta \log\left(p_t^{incl.\ tax}\right) + \gamma\Delta\log\,(X_t) + \varepsilon_t$$

Model (1) will generally be preferred. However, the second model allows for robustness tests and will also be useful when the level variables are not stationary or when the residuals are auto-correlated.

Our parameter of interest is the coefficient β, which corresponds exactly to the tax-inclusive price elasticity of energy consumption.

For each type of energy, estimates were made using the following methodology:

- test for the presence or absence of unit roots in the variables in order to avoid fallacious regressions
- carrying out simple linear regression (OLS) by gradually adding control variables[22]
- carrying out linear regressions with instrumental variables (IV).

The results of linear regressions may in fact be biased because of omitted variables or because of the endogeneity of the price of energy: if the price of energy influences consumption, the reverse may theoretically also be the case.

However, France is a small country and the different energy markets are global. We can therefore legitimately suppose that the impact of French energy demand on world prices is negligible. Nevertheless, there is still a problem as energy providers in France may adjust their margins in response to variations in demand in the French market.

The price of imported crude oil will therefore be chosen as an instrument for the tax-inclusive price of energy. The latter price confirms the condition of relevance, since the price of oil is an integral part of the tax-inclusive price of the various types of energy. It also confirms the condition of validity, because it may be legitimately assumed that the price of oil is exogenous to energy consumption in France. Rivers and Schaufele (2012), Andersson (2017) and Li, Linn and Muehlegger (2012) have used the same instrument in a similar context.

Several tests will be carried out during the IV regressions.

- An F-statistic is calculated to ensure that there is a strong correlation between the instrument and the problem variable (condition of relevance)

- The Wu-Hausman test is implemented. This test reveals whether or not performing an IV regression provides additional information compared to an OLS regression. The null hypothesis is that the OLS estimate and the IV estimate are both convergent, but that the IV estimate is less effective. Rejection of the null hypothesis implies that only the IV estimate is convergent. Non-rejection implies that the OLS estimate is more effective than the instrumental variable estimate.

1. For fuel

a. Monthly data

For model (1) the results of the two simulations are presented in Appendix 4. These consist of an OLS regression (Table 1) and an IV regression (Table 2) with the same control variables (GDP per capita and the unemployment rate). Other simulations were also carried out: without a control variable, with a single control variable, or by replacing GDP per capita with gross disposable income. The results obtained are similar. We get a slightly lower elasticity at -0.10. Our preferred estimate is the IV estimate presented in Table 2. The signs of price elasticity and of GDP per capita elasticity are consistent. The sign of the unemployment rate elasticity is not, but the coefficient is not significantly non-zero. The IV estimate will be preferred to the corresponding OLS estimate, because the p-value of the Wu-Haussman test is rather low (rejection of the null hypothesis at 10%).

For model (2), the value obtained is greater: -0.48 with the OLS regression (Table 3) and -0.25 with the IV regression (Table 4). The low p-value of the Wu-Hausman test in Table 4 prompts us to reject the null hypothesis and to prefer the IV estimate to the OLS estimate.

In this last estimate, the standard deviation of the estimated price elasticity is high. We can therefore express some reservations about its significance.

We will finally retain only the values obtained with the model (1.

b. Annual data

For model (1), the OLS estimates are presented in Appendix 4 (Tables 5 to 8). It can be seen that the value of the estimated elasticity varies between -0.30 and -0.40 except for Table 8, where the value is -0.24. We can also see that, for Table 8, the sign of the unemployment rate elasticity is not consistent, since it is positive (note, however, that the standard deviation is high).

Two IV regressions are also presented in Tables 9 and 10. Table 9 presents the IV regression carried out with the same variables as Table 7, and the results obtained are very similar. On the other hand, the result of the Wu-Hausman test shows that the IV regression does not add anything to the OLS regression. This is not the case with Table 10, which presents the IV regression with the same variables as Table 8. The estimated elasticity is higher: -0,27. In addition, the Wu-Hausman test (rejection of the 10% null hypothesis) makes us prefer the IV regression.

For model (2), we do not present the results in the appendices, but all the simulations carried out (OLS and IV by varying the variables of interest) give an elasticity equal to or very close to -0.10. The coefficient of determination (R^2) is, however, relatively small compared to the estimates made in the framework of model 1.

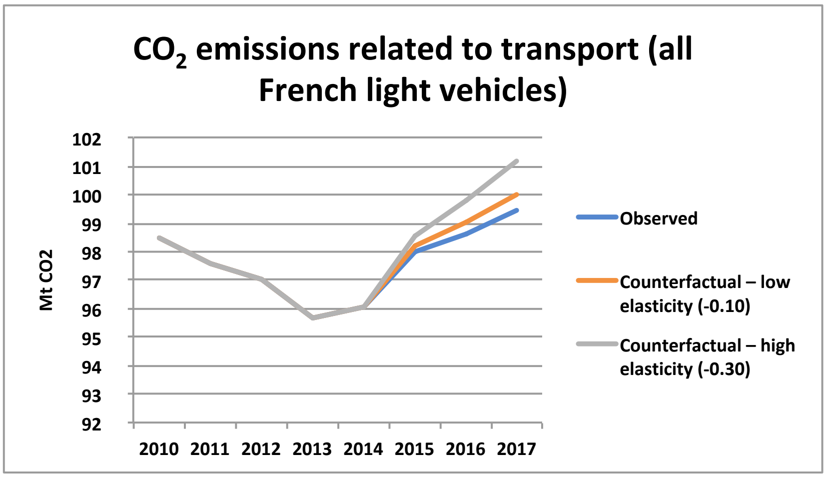
c. Summary

In short, we will here use model 1, which seems more robust. Thus values of -0.10 for the monthly data and of -0.30 for the annual data will be used. The difference between annual and monthly elasticity can easily be explained: the adjustment of consumption to price is more pronounced in the case of data with longer periodicity. By way of comparison, Andersson (2017) finds, with a similar method and annual data, a price elasticity of -0.51 for Sweden. The meta-analysis by Dahl and Sterner (1991) provides a value of -0.53 with annual data and -0.29 with monthly data. In a more recent meta-analysis, Labendeira, Labaega and Xiral López-Otero (2016) find a short-term elasticity of -0.249 for petrol (compared to -0.213 for diesel) and a long-term elasticity -0.720 for petrol (-0.620 for diesel). The values found for France would therefore be rather low compared to these estimates, thus suggesting that the carbon tax produces a more limited effect.

d. *Impact in terms of greenhouse gas emissions*

In the absence of the 2014 reform, the prices of petrol and diesel would have been lower. Through the elasticities that we have just calculated and the price and consumption data that we possess for the last few years, we can reconstruct the counterfactual for consumption and for greenhouse gas emissions.[23] In 2017, without the reform, France would have emitted between 0.6 and 1.7 $MtCO_2$ more, that is, between 0.6% and 1.7% more on the perimeter "emissions related to transport by car". At the end of the five-year period, if the carbon price trajectory is adhered to, and all other things being equal (especially that the population and the price excluding DCTEP will not vary from 2017), the carbon tax could reduce emissions by between 1.3 and 4 $MtCO_2$ a year compared to 2017.

Figure 8: CO_2 emissions related to light vehicle transport in France (observed and counterfactual trajectories). Source: CEC calculations



2. For domestic heating oil

a. *Monthly data*

For model (1), the OLS and IV simulations are similar, with or without control variables. In each case we find a low elasticity (of around -0.03 to -0.07), but this result is not statistically significant. Moreover, none of the coefficients of the control variables are significant.

For model (2), we present the result of two estimates (Tables 11 and 12): an OLS regression and an IV regression with the unemployment rate, GDP per capita and the proportion of oil-heated dwellings as control variables. In both cases, the coefficients associated with the control variables are not significant. However, the price elasticity is significant in both regressions: estimated at -0.67 with the OLS regression and -0.52 with the IV regression. The R^2 coefficients of determination are equivalent (around 0.47). The non-rejection of the null hypothesis for the Wu-Hausman test suggests we should prefer the OLS regression.

b. Annual data

With the model (1), the OLS and IV estimates, carried out with the same control variables as previously, are presented in Tables 13 and 14.

This time the tax-inclusive price elasticities are significant and equal in both cases to -0.13. Among the control variables, only the proportion of oil-heated dwellings is significant, with a sign consistent with intuition. The coefficient of determination is very high (around 0.97) in both cases. The Wu-Hausman test shows that the IV regression provides no additional information with respect to the OLS regression. Other estimates, not presented in the appendices, where only the significant variables (proportion of oil-heated dwellings and tax-inclusive price) were kept, give an elasticity of around -0.20 with an almost unchanged coefficient of determination. For what follows, we will take this latter estimate to be the most robust.

With model (2), there are no significant results and the coefficient of determination is extremely poor. As was the case with fuel, model (2) is therefore less relevant with annual data. An explanation for this result may be that when the period of time considered is a year, households react more to current prices than to price changes compared to the previous year.

c. Summary

In conclusion, with the monthly data, it would be more appropriate to choose the value of -0.67 for the tax-inclusive price elasticity, and with the annual data, the preferred value would be -0.20.

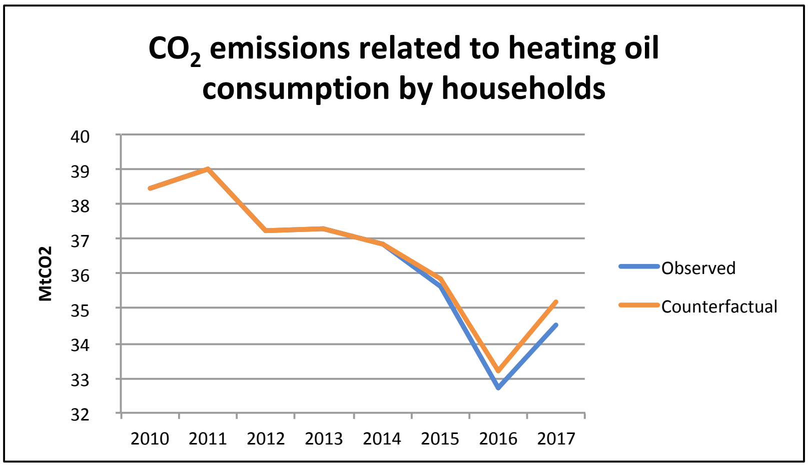
This result may seem strange, because the elasticity calculated with the annual data is smaller than with the monthly data. An explanation may be that the result with the monthly data comes from the variation model: we thus estimate the change in consumption following a price change, a reaction that with monthly data may be strong immediately but only very temporary.

Comparing the results with the meta-analysis by Labendeira, Labaega and Xiral López-Otero (2016), who for heating oil found a short-term elasticity of -0.242 and a long-term elasticity of 0.747, and given the better coefficient of determination obtained with the annual data, we will choose the value of -0.20 for the remainder of the study.

d. Impact in terms of greenhouse gas emissions

As in the case of fuel, we evaluate the impact of the introduction of the carbon tax on greenhouse gas emissions.

Figure 9: CO_2 emissions related to heating oil consumption by households (observed and counterfactual trajectories). Source: CEC calculations



In 2017, in the absence of the reform, France would have emitted an additional 0.7 $MtCO_2$, or nearly 2% more. At the end of the five-year period, if the carbon price trajectory is adhered to and all other things are equal (in particular assuming that the population, the proportion of oil-heated dwellings and the price excluding DCTEP do not vary compared to 2017), the carbon tax would save nearly 1.7 $MtCO_2$ over a year compared to 2017 (a decrease of 5% compared to 2017).

D. Elasticity to tax changes

We make use here of the method followed by Rivers and Schaufele (2012) and Andersson (2017) to determine whether or not consumers react more strongly to a tax change than to an equivalent change in the price of raw materials or the distributor's margin.

The tax-inclusive price is broken down into two parts: a non-DCT component to which VAT is applied and a DCT component to which the VAT rate is also applied:

$$Price\ tax\ included = Price\ tax\ excluded * (1 + VAT) + \ ICT * (1 + VAT)$$

As before, we will make estimates using two models: one in terms of level and the other in terms of variation. However, this time we will favour log-linear models and will express prices in euro cents per litre. This type of specification allows us to obtain semi-elasticities whose interpretation is easier and, above all, allows us to test the separability of the tax-inclusive components.

The model in terms of level is as follows:

$$\log(C_t) = \alpha + \beta_1 p_t^{excl.tax+VAT} + \beta_2 p_t^{ICT+VAT} + \gamma X_t + \delta \tau_t + \varepsilon_t$$

and in terms of variation:

$$\Delta \log(C_t) = \alpha + \beta_1 \Delta p_t^{excl.tax+VAT} + \beta_2 \Delta p_t^{ICT+VAT} + \gamma \Delta X_t + \varepsilon_t$$

The interpretation of the β coefficients is as follows: if the price varies by Δp cents, the consumption will vary by 100βΔp per cent.[24] We can thus genuinely compare the reaction of consumers to the same price variation with a different cause: variation in the price of raw materials or variation in the tax. We proceed in the same way as for the evaluation of tax-exclusive price elasticity: testing the stationarity of variables; OLS regression with or without control variables; IV regression.

1. For fuel

With the monthly data, we here use only model (2). Indeed, the variable "DCTEP, VAT included" is not stationary in levels. With unemployment rate and gross disposable income per capita as the control variables (Tables 15 and 16), we obtained with the OLS regression (the IV regression respectively) a semi-elasticity at the price excluding DCTEP of -0.0038 (-0.0026) and a semi-elasticity at DCTEP of -0.0279 (-0.0259). Due to the non-rejection of the null hypothesis from the Wu-Hausman test, our preferred estimate is one made with the OLS regression.

Thus, an increase of 1 cent in DCTEP (including VAT) would cause a 2.7% fall in consumption, nearly 7 times more than an increase in the price of raw materials (including VAT). The 95% confidence intervals are [-0.0061; -0.0016] for semi-elasticity to the price excluding DCTEP and [-0.0423; -0.0136] for semi-elasticity to DCTEP. The ratio between the two semi-elasticities should be used with caution as the standard deviation for semi-elasticity to DCTEP is high. Moreover, the semi-elasticity to DCTEP seems very high and cannot be reasonably accepted: for example, it would mean that an increase in DCTEP of 10 cents, roughly what happened between 2014 and 2017, would lead to a 27% reduction in consumption, which is hardly credible. As previously when calculating the elasticity of fuel consumption to the tax-inclusive price, working with a variation model certainly leads to an overestimation of consumers' reaction. However, the fact that the confidence intervals do not overlap is an interesting point: it means that consumers react more strongly to an increase in DCTEP than to an equivalent increase in the price of raw materials or the producer's margin.

With the annual data, both with model (1) and model (2), either no significant and robust results are found or, when they are significant, the confidence intervals overlap.

For British Columbia, Rivers and Schaufele found similar results. The authors also use monthly and annual data: with the annual data, they find that the confidence intervals overlap but do not with the monthly data. With the monthly data, they estimate that consumers' reaction to the tax is 4.9 times greater. For Sweden, Andersson finds that the semi-elasticity to the tax is 3 times greater. Finally, Li, Linn and Muehlegger (2012) find a ratio of 8.1.

2. Domestic heating oil

As with fuel, with the monthly data we only use model (2). Indeed, the variable "DCTEP, VAT included" is not stationary in levels. With the unemployment rate and gross disposable income per capita as the control variables (Tables 17 and 18), we obtained with the OLS regression (the IV regression respectively) a semi-elasticity to price excluding DCTEP of -0.0087 (-0.0082 respectively) and an elasticity to DCTEP of -0.0706 (-0.0705 respectively). Due to the non-rejection of the null hypothesis from the Wu-Hausman test, our preferred estimate will be that made with the OLS regression. Thus, a 1 cent increase in DCTEP (including VAT) would lead to a 7% fall in consumption, almost 8 times more than an increase in the price of raw materials (including VAT). This figure should again be treated with caution because the confidence interval for the semi-elasticity to DCTEP is large and the values of the semi-elasticities seem much too high. However, here too, it is important to emphasize that the confidence intervals of the two semi-elasticities do not overlap: [-0.0152; -0.0021] for semi-elasticity to price excluding DCTEP and [-0, 1232; -0.0180] for the semi-elasticity to DCTEP. We can therefore say that the latter are statistically different.

With the annual data, the model (1) gives, with the same control variables as before, a value of -0.0020 for the semi-elasticity to price excluding DCTEP and a value of -0.012 for the semi-elasticity to DCTEP. We find the same ratio as before, but the values of the semi-elasticities are lower, which makes them more credible. Moreover, the confidence intervals overlap, making it impossible to say whether the two semi-elasticities are statistically different. With model (2), there are no significant results and the coefficient of determination is extremely poor.

E. Conclusions

Two main points stand out from this econometric evaluation.

- The calculation of the elasticities to the tax-inclusive price makes it possible to construct the counterfactual until the end of 2017 and thus to evaluate the impact of the implementation of the carbon tax. For households' "heating oil" and "transport", the savings in terms of emissions would be between 1.3 and 2.4 $MtCO_2$ in 2017.
- Consumers seem to react more to an increase in DCTEP than to an equivalent rise in the price of raw materials. As explained above, the excessive uncertainty about the values obtained for the semi-elasticities to the tax does not reasonably allow us to use them to calculate the emissions avoided. However, we can still say that the estimate presented below is a minimum estimate.

Figure 10: Summary of the results of the study based on calculations of elasticities (the percentages are in relation to the emissions of the sector considered: transport or heating buildings with oil). Source: calculations CEC

	Tax inclusive price elasticity	Emissions avoided in 2017 (compared to the counterfactual)	Forecasts: emission reductions in 2022 compared to 2017
Fuel	-0.30 to -0.10	0.6 to 1.7 $MtCO_2$ (between 0.6 and 1.7 %)	1.3 to 4 $MtCO_2$ (between 1.3 and 4 %)
Domestic heating oil	-0.20	0.7 $MtCO_2$ (2 %)	1.7 $MtCO_2$ (5%)

The stronger reaction by consumers to a tax change than to an equivalent change in another price component is an important finding. It legitimizes the carbon tax as an effective instrument for reducing greenhouse gas emissions. Two main consequences follow from this. First, in order to avoid unpleasant budgetary surprises, the calculation of the tax yield must take into account this stronger reaction to the tax than to a "classical" variation in price. Second, the importance of having a clear and legible price signal is underlined. Accordingly, the carbon component must be more visible and the carbon price trajectory over the long term must be credible.

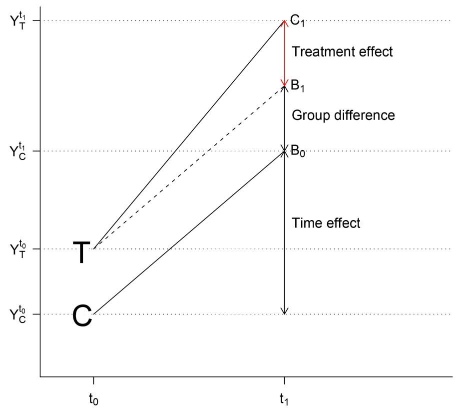
III. An ex-post evaluation method: "synthetic control"

In this section, we present a second method for estimating the effects of the carbon tax. Similar to an ex post evaluation, this approach uses empirical data to determine the impact of the carbon tax in terms of reducing greenhouse gas emissions.

A. The difference-in-differences method

The difference-in-differences method is conventionally used to evaluate the effect of a "treatment" by public policy. It involves comparing changes in the variable of interest (in this case, greenhouse gas emissions resulting from the combustion of fossil fuels) before and after the treatment is implemented (here, the carbon tax) in two different groups: the group that underwent the treatment and a control group. The effect of the treatment is then the difference in the changes observed in the two groups. With this type of method, the control group is used to develop the counterfactual (see graph). This method is nevertheless based on a core hypothesis: the two groups, without the implementation of the treatment, would have undergone exactly the same process of change (often referred to as the "common trend assumption"). Having a control group is therefore essential. However, it is by construction impossible to verify this hypothesis by observation. It is therefore necessary to rely on economic arguments or common sense to confirm or disconfirm it.

Figure 11: Principle of the difference-in-differences method



In our study, the treatment group comprises only one element: France. In order to use this method, it is necessary to find a relevant control group. This control group should comprise another country that does not have a carbon tax in place and which is sufficiently similar to France in its economic and energy structure, in order to confirm the "common trend assumption" (that is, the evolution of that country's emissions before and after 2014 is identical to what France would have experienced without the carbon tax).

It is in practice impossible to find such a country. However, this does not mean that the difference-in-differences method should be abandoned. To overcome the obstacle of the impossibility of finding the "right" control country, the solution is to construct this comparable country (which we will now call "synthetic France") from a linear combination of several other countries that have not introduced a carbon tax and are relatively similar to France. This so-called "synthetic control method" was developed by Alberto Abadie, Alexis Diamond and Jens Hainmueller, in particular to assess the effect of anti-smoking policies in California,[25] the impact on GDP of terrorism in the Basque country[26] and the impact of reunification in Germany.[27]

The method has already been used to assess the impact of the carbon tax in Sweden.[28] Andersson finds that the Swedish carbon tax reduced greenhouse gas emissions in the transport sector by 10.9% a year between 1990 and 2005 (or 2.5 $MtCO_2$ a year). For British Columbia, Elgie and McClay (2013)[29] used the difference-in-differences method because Canada's federal structure allowed for a consistent control group: all the other provinces in Canada. They estimate that the carbon tax reduced greenhouse gas emissions per capita by 8.9% between 2008 and 2011 over the all the sectors subject to the carbon tax.

B. The synthetic control method: principle and formalization

To understand this method, certain notations need to introduced.

- We thus consider N + 1 countries, which will be indexed by i. The country for i = 1 is France and the remaining N countries constitute the control group
- The data cover a period of time going from 1 to T
  - the pre-treatment period goes from t = 1 to t = T_0
  - the post-treatment period goes from t = T_0 + 1 to t = T
- our variable of interest here will be emissions per capita and will be denoted by Y_{it} (i denotes the country, t denotes time)
  - For France, for t > T_0, we will denote the emissions actually observed by Y_{1t}^{Obs}
  - For France, for t > T_0, we will denote the counterfactual emissions by Y_{1t}^{Cf}

The ultimate aim of the method is therefore to evaluate the difference $Y_{1t}^{Cf} - Y_{1t}^{Obs}$. To do this, we need to construct the counterfactual emissions from a linear combination of the N countries of the control group: $Y_{1t}^{Cf} \approx \sum_{i=2}^{N+1} w_i Y_{it}$. The challenge now is to find the "best" combination $(w_{2,} \dots, w_{N+1})$ of the N other countries, where w_i are the weights/percentages given to the countries used to construct synthetic France (which gives $\sum_{i=2}^{N+1} w_i = 1$).

In order to find this combination, it is therefore necessary to define "quality criteria" that will allow us to choose between two combinations. A good combination $(w_{2,} \dots, w_{N+1})$ is one that satisfies the following criteria.

- Before the introduction of the carbon tax (therefore before T_0), the emissions trajectory of synthetic France must be similar to that of real France.
- Synthetic France must be similar to real France in terms of a certain number of variables, termed "predictors". These predictors are evaluated before T_0 and are chosen as relevant explanatory variables of the variable of interest Y_{1t}. We will denote Z_i as the vector of the predictors observed for each country i.

Mathematically, this means that we must find$(w_{2,} \dots, w_{N+1})$ such that for all $t \leq T_0$,

- $\sum_{i=2}^{N+1} w_i Y_{i1} = Y_{11}, \sum_{i=2}^{N+1} w_i Y_{i2} = Y_{12}, \dots, \sum_{i=2}^{N+1} w_i Y_{iT_0} = Y_{1T_0}$ (1)
- $\sum_{i=2}^{N+1} w_i Z_i = Z_1$ (2)

In general, it is impossible to find such a combination of w_i that satisfies all of these constraints. We will therefore settle for getting as close as possible to this ideal case (see 5). In practice, this "best combination" will be determined by means of the Synth Package for R, developed by Alberto Abadie, Alexis Diamond and Jens Hainmueller.[30]

C. The main stages of the method

The implementation of the synthetic control method involves making a number choices that we detail below:

- choice of the variable of interest Y
- choice of the period of time (pre-treatment and post-treatment)
- choice of the control group
- choice of the right predictors of the variable of interest

These choices are guided by theoretical considerations, but also by practical considerations (availability of data).

1. Choice of the variable of interest and the period of time

Our variable of interest is CO_2 emissions per capita. The use of inter-country comparisons implied by this method requires reasoning per capita and not in absolute terms. For this type of variable, only annual data are available.

Choosing the scope of emissions considered is trickier. At first glance, it seemed logical to consider all the country's emissions. However, since the French carbon tax base is relatively small, we decided to focus only on sectors directly affected by the tax (transport by car and heating by gas and oil).

For the time period, it is necessary to have as much post-tax data as possible and a relatively large number (between 20 and 30) of pre-tax data.

After looking at the different databases available, we decided to use the UN national inventory database (UNFCCC). At the time of writing, this study contains data from 1990 to 2016, with a detailed breakdown by sector. To get as close as possible to the tax base, two study perimeters were defined on the basis of this breakdown.

- Emissions related to transport by car
- Emissions related to fossil fuel combustion by households, the commercial sector and the institutional sector.

2. Choice of the control group

For the choice of the countries of the control group, two basic criteria must be satisfied.

- They must be countries that are relatively similar to France in economic terms. This implies that all non-OECD countries are excluded and, within the OECD, Mexico, Chile, South Korea and Turkey are excluded.
- They must be countries that have not introduced a carbon tax. Within the OECD, therefore, Ireland, the United Kingdom, Denmark, Portugal, Sweden, Finland, Slovenia, Iceland, Norway and Switzerland are excluded.

Other, more secondary, criteria were then added.

- Small countries (Luxembourg, Baltic states) were excluded, in particular because fuel consumption could be associated with cross-border transport.
- Countries that have had unusual economic trajectories, such as Greece, were also excluded.

A final question arose on the relevance of including only those countries, such as France, that have adopted the European carbon market. As the answer to this question has not yet been settled, two control groups were defined.

If all these criteria are adhered to, including the one on the European allowances market, we obtain the following control group (control group 1): Austria, Belgium, Czech Republic, Germany, Italy, Netherlands, Poland and Spain.

If the final criterion is not adhered to, which can be justified since we is interested in economic sectors that are little or not affected by the allowances market, we obtain the following control group (control group n ° 2): same as before, plus Australia, Canada, USA, Japan and New Zealand.

3. Choice of predictors of the variable of interest

The predictors chosen vary according to the scope of the emissions taken into account. Some are common to both areas, while others are specific.

The following predictors are common to both areas:

- GDP per capita (average 2005-2013)
- Percentage of urban population in the total population (average 2005-2013)
- Energy intensity of GDP (average 2005-2013)
- Amounts of CO_2 emissions per capita in 1995, 2005 and 2013.

The predictors specific to “transport by car” are:

- Number of vehicles per 1000 inhabitants (average 2005-2013)
- Fuel consumption per capita (average 2005-2013)

The predictors specific to “household, commercial and institutional energy consumption” are:

- Share of nuclear energy in the electricity mix (average 2005-2013)
- Climate indicator based on the number of degree-days of heating a year (average 2005-2013).

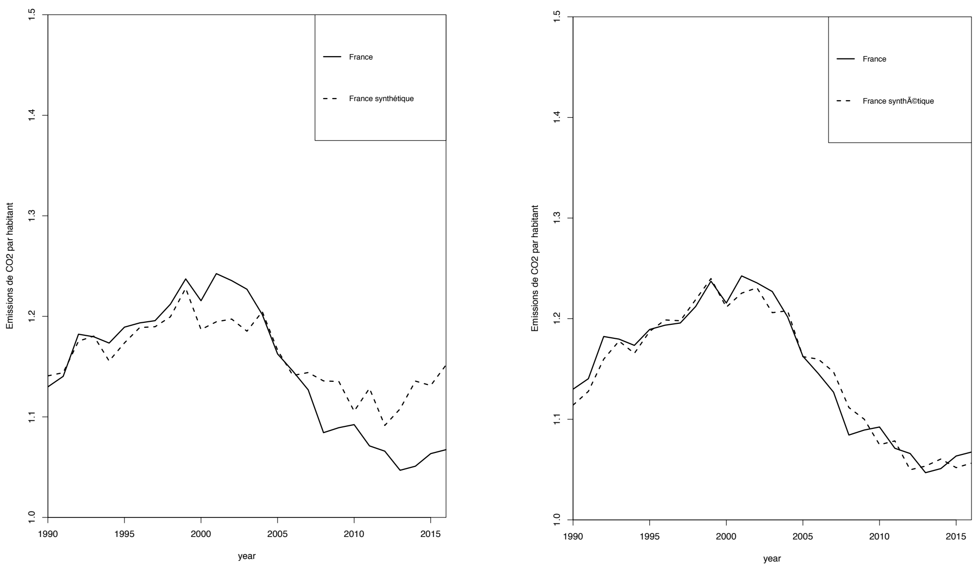
D. Findings

1. “Transport by car”

The graphs below show the results obtained with this method with regard to “Transport by car” for control group 1 and control group 2. The solid line represents the emissions trajectory actually observed and the dotted line represents the emissions trajectory for synthetic France.

For the two control groups, it can be seen that over the pre-treatment period (1990-2013) the trajectories are similar or very similar to control group 2. This is a good indicator of the relevance of the combination $(w_{2,} \dots, w_{N+1})$ that was calculated. Over the post-treatment period (2014-2016), and for control group 1, there is a slight divergence between the emissions trajectory of synthetic France and the emissions trajectory actually observed. Consistently with intuition, the synthetic France emissions are higher than those of the “real” France. However, the gap is still small and is not significant, in particular because it is of the same order of magnitude as the gap observed in the first decade of the century. But the gap appears to widen from 2012 onwards, that is, even before the introduction of the carbon tax. For control group 2, no gap is evident. The tests carried out with control group 2 could have served as robustness tests if the results had been observed with control group 1. The absence of a gap with control group 2 is therefore a further argument for the non-significance of the difference obtained with group 1.

Figure 12: Emissions related to transport by car for France and for synthetic France with control group 1 (left) and control group 2 (right)



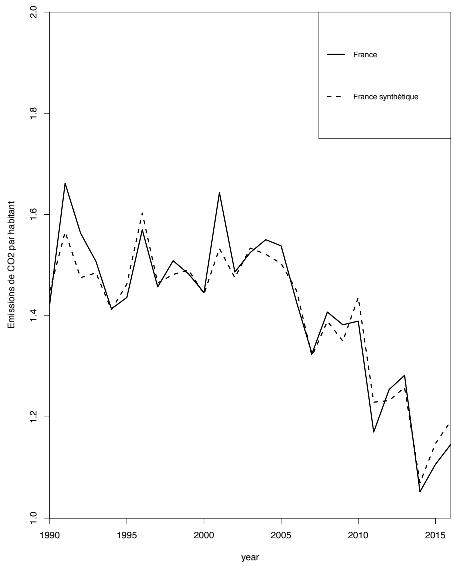
2. Household, commercial and institutional energy consumption

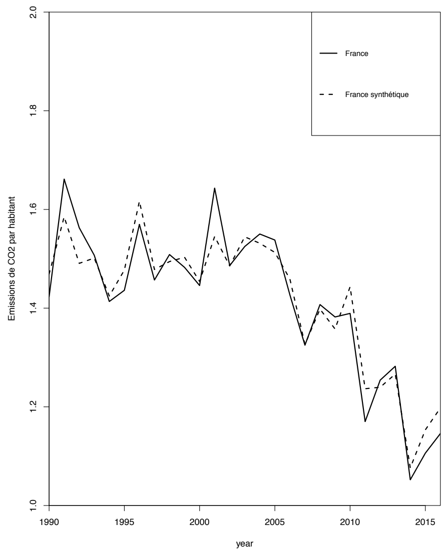
The graphs below show the results obtained with this method with regard to "Households, the commercial sector and the institutional sector" for control groups 1 and 2.

We see first of all fairly strong year-on-year variations in real France's emissions. These variations are due to climatic variations and are fairly well reproduced in the emissions trajectory of synthetic France. When we look at the countries that have the most weight in synthetic France (combination W), we see that the countries geographically close to France are heavily weighted, no doubt because they generally have the same climatic conditions as France.

We then see, as with the first graph above, a slight widening of the gap between the emissions of synthetic France and real France at the end of the period. Although this divergence is consistent with intuition, it is not significant for the moment. It would require a rather greater temporal distance to determine whether this shift persists and grows.

Figure 13: Emissions related to energy combustion by households, the commercial sector and the institutional sector of real France and synthetic France with control group 1 (left) and control group 2 (right)





E. Interpretation

Unlike in the study on Sweden, the synthetic control method does not allow us to draw conclusions as to the impact of the carbon tax on greenhouse gas emissions in France. Several factors account for this lack of results for France.

Firstly, the study only covers the period up until 2016. The carbon tax was introduced in 2014 and, with regard to fuel, it was fully offset in the first year. Furthermore, the amount of the tax was initially very low. The amount of data and the extent of the treatment are therefore far too low to reasonably expect to see any effect..

Secondly, in the Swedish study, the post-treatment period is 1992-2005. The amount of data is greater and in particular, during this period, few countries had implemented policies to fight against climate change. The control group selected for the study was therefore particularly coherent. For the control group in our study, we admittedly selected countries that have not introduced a carbon tax. But these countries have nevertheless not been inactive in combatting climate change. This last consideration might affect our estimate.

Finally, it may be necessary to recall the particular context of the introduction of this carbon tax. As mentioned above, the introduction of the carbon tax in France was concomitant with a fall in the price of oil, while at the same time the reform was very little publicized. Moreover, fear of further censure by the Constitutional Council led to the creation of a legally stronger but much less readable and transparent system, which affected the quality of the price signal.

IV. Conclusion

Through the evaluation of tax-inclusive elasticities in part II, we showed that at the very least the carbon tax made it possible to avoid 1.3 to 2.4 $MtCO_2$ of emissions in 2017. In 2022, all other things being equal, the carbon tax should reduce emissions by an additional 3 to 5.7 $MtCO_2$ compared to 2017. Compared to the 453 $MtCO_2$ emitted in 2017 (excluding LULUCF), these amounts may seem modest. This last comment, however, calls for a number of qualifications.

In the first place, these estimates are estimates from below. Part II has shown that in France, as in other countries, an increase in the cost of energy by way of a tax leads to higher elasticities than in the case of an increase in the price excluding tax. But given the wide range of confidence intervals, we are not able to take this parameter into account in our analysis.

Secondly, these figures do not take into account the use of gas by households, which is the component of energy consumption where the tax has had the greatest impact because of the initial exemption of this product from the DCT.

Thirdly, the elasticities that have been used are short-run elasticities. The study does not address this point, but it is likely that in the long term the rise in energy prices resulting from the carbon tax will lead to structural changes, such as modernization of heating installations, purchase of more efficient vehicles, the adoption of more moderate heating or mobility habits, and so on.

Finally, it should also be noted that the many total or partial exemptions from the DCT significantly reduce the carbon tax base. If excluding industries subject to the European allowances market is legitimate from an economic standpoint – provided that the market transmits a price signal of an amount comparable to the tax –, other exemptions such as those concerning road freight transport or agriculture cloud this signal.

Section III, based on an ex post evaluation method, does not, however, reveal a statistically significant effect of the carbon tax on greenhouse gas emissions. The lack of temporal distance, since the tests could only be implemented up until 2016, makes any conclusion premature, and it will be interesting to see whether this method will yield results in the future when we can work on a larger amount of data. In addition, a major technical difficulty is that the carbon tax is only one of the instruments used to reduce emissions. Moreover, the use of the synthetic control method may encounter problems if the countries used to construct the counterfactual put in place other emissions-reducing instruments at the same time as the introduction of the carbon tax in France.

The conclusions we have drawn are sufficiently robust to put forward some implications for public policy. We have found significantly lower impacts from the tax than work that has used comparable methods in other countries or provinces, even though the rate of introduction of the tax is somewhat faster and should continue at least until 2022.

Two factors seem to have been in play, and these could be corrected by the authorities in the coming years.

The first concerns the scope of the carbon tax. Indeed, due to the presence of numerous exemptions and exonerations, we were obliged to restrict the number of sectors looked at in our study. Automatically, the effect in terms of tonnes of CO_2 avoided is reduced. Some of these exemptions are not justified by the EU CO_2 trading scheme, responding to sector support logics that we not have time to discuss here. But this type of support introduces very damaging distortions for reductions in greenhouse gas emissions. While there are good reasons pertaining to the public interest for maintaining such support, the government should find channels other than exemption from the carbon tax for directing it towards the sectors concerned.

The second concerns the complexity and lack of visibility of the system that has been in place since 2014. The very principle of a distinction between the “carbon component” and the “fixed part”, together with the amounts and methods of calculation of these different components, is not explicitly stated either in the Customs Code or the financial legislation. These latter documents indicate only the total amount of DCT. Only certain documents appended to the draft finance law[31], as well as Article L100-2 of the Energy Code[32] in an allusive manner, mention the existence of the carbon component in DCT. If these choices were made to circumvent the risk of unconstitutionality of the system, they unfortunately nonetheless affect the quality of the price signal.

It seems desirable, therefore, to change the system so as to give greater clarity and transparency.

The evolution of the system could aim at increasing its transparency through:

- inclusion in the Customs Code of the existence of a carbon component in the DCT
- inclusion of calculation methods in the legislation, including the calculation of the emission factors used
- explicit specification of the amount of each of the two components of the DCT in the Customs Code and in the financial legislation, so that elected representatives may have full information during parliamentary debates on the Finance Act.

Lastly, these institutional changes should be accompanied by information to citizens and economic actors, so as to speed up the behavioural changes needed to switch to a low-carbon society in which the tax base has shrunk to next to nothing.

Appendix 1: Proceeds from DCT

In 2016, the DCTEP yield amounted to 28.5 billion euros, of which about 16 billion for the state budget,[1] the rest being paid to departments, regions and the Financing Agency for French Transport Infrastructure.
The proceeds from the DCTNG have risen sharply since 2014. Up until then, individuals did not pay this tax. In 2016, the DCTNG brought in 1.1 billion euros (1.4 billion in 2017 and 1.8 billion forecast for 2018).
The DCTC brings in very little in terms of proceeds (11 million euros in 2017).

[1] Since 2017, a proportion of the state's DCTEP revenues have been allocated to the "Energy Transition" trust account (this amount was €6.9 billion in 2017),

Appendix 2: The legal arguments motivating the decision of the Constitutional Council in 2010.[2]

Following the referral to the Constitutional Council of the draft budget laws, the Constitutional Council censured all the provisions relating to the carbon tax. The main reason for this decision was that there were too many exemptions which, in the Council's opinion, were a violation of the principle of equality with regard to public burdens.

Article 6 of the Declaration of the Rights of Man and the Citizen of 1789 lays down the principle of equality: "The law [...] must be the same for all, whether it protects or punishes." In general terms, this principle does not preclude the legislator from settling different situations in different ways, or from derogating from equality on the grounds of public interest, provided that in both cases, the resulting difference in treatment is directly related to the purpose of the law.

Thus, in tax affairs, the principle of equality with regard to tax does not prevent the adoption of environmental taxes. These taxes aim to encourage taxpayers to adopt behaviour consistent with public interest objectives. However, the rules laid down for that purpose must be justified in the light of those objectives.

The very principle of the carbon tax, which could have been seen as an infringement of the principle of equality since different energies are taxed according to their carbon content, is therefore absolutely not called into question by the Constitutional Council. What justified the censure were various partial or total exemptions accompanying the reform project.

Some partial exemptions have been accepted (such as agricultural or fishing activities or road transport of goods) by the Council, on the basis that the exemptions were justified by reason of public interest aimed at preserving the competitiveness of economic sectors exposed to international competition. Moreover, their transitional nature, which was referred to during the parliamentary debates, did not call into question the overall aim of the reform, which was to combat climate change. The Council also considered that total exemptions were possible if the economic sectors concerned were specifically made use of by a particular scheme.

According to the Council, the total exemption of enterprises subject to the European carbon market did not fall within this framework, in particular because the initial allocation of allowances was at that time free of charge and would have become payable only from 2013 and progressively increased until 2027. Such an exemption was therefore contrary to the general objective of the reform, which was the fight against climate change. It therefore constituted a breach of the principle of equality in relation to public burdens.

The Constitutional Council's reasoning was purely legal in nature. As such it caused profound misunderstanding among economists, who consider that the European emissions trading system is indeed a price signal and that although the initial allocation of allowances was free, the allowances themselves were not. The industries belonging to the ETS market therefore really do participate in the fight against climate change. Moreover, from an economic standpoint, the superimposition of two systems (tax and market) is not relevant and would not bring any environmental benefit. In economic terms, the Council's decision was therefore unfounded.

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[2] DC decision, 2009-599 DC // Commentary on the decision 29 November 2009 // Information reports 300 by Fabienne Keller

Appendix 3: Data sources for econometric methods

❖ Annual data

➢ Fuel consumption (period: 1980-2017)

Data sources:

- Consumption for the period 1980-1989: transport accounts for the years 1983, 1985, 1990 and 1991 (http://www.statistiques.developpement-durable.gouv.fr/donnees-densemble/1924/874/ensemble-comptes-transports.html)
- Consumption for the period 1990-2016: transport accounts 2016 (http://www.statistiques.developpement-durable.gouv.fr/donnees-densemble/1924/874/ensemble-comptes-transports.html)
- Consumption for 2017: reconstitution from the monthly Pegasus database (http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/r/pegase.html)
- Average annual population in metropolitan France: INSEE (https://www.insee.fr/fr/statistiques/serie/000067671)

Comments. We obtain consumption data for diesel and gasoline. Through demographic data, we reduce total consumption to per capita consumption. For diesel, we only use consumption by light vehicles (passenger cars, motorcycles and light commercial vehicles). For petrol, consumption is the sum of consumption for all petrol categories (SP 95, SP 98, ARS premium petrol, regular petrol). Consumption by category of petrol is useful for the construction of the synthetic price. The figures are approximated through the “2016 network study” by UFIP.

➢ Fuel prices (period: 1980-2017)

Data sources:

- Price with and without VAT for the period 1980-1989: transport accounts for the years 1983, 1985, 1990 and 1991 (http://www.statistiques.developpement-durable.gouv.fr/donnees-densemble/1924/874/ensemble-comptes-transports.html)
- Price with and without VAT for the period 1980-1989: transport accounts http://www.statistiques.developpement-durable.gouv.fr/donnees-densemble/1924/874/ensemble-comptes-transports.html)
- Price VAT included for 2017: Pégase annual database (http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/r/pegase.html)
- Consumer Price Index: OECD (Base 2010, all households and products: https://data.oecd.org/fr/price/inflation-ipc.htm)
- DCTEP rate: Customs Code on www.legifrance.gouv.fr (Article 265) and www.douanes.gouv.fr (for regional rates)

Comments. For diesel and each category of petrol, the prices provided by the transport accounts are VAT-included and VAT-excluded. From the VAT rates over the period, the amount of the DCTEP is reconstructed for each year until 2016. This value does not always correspond to the amount set in the budget law, in particular because of the floating TIPP between 2000 and 2002 and because of regional adjustment.

For 2017, the Pégase database gives only the tax-included price. An estimate of DCTEP, including regional adjustment, is made from regional rates provided by the General Directorate of Customs and Indirect Taxes and regional populations. The tax-excluded amount is then calculated using this estimate and the VAT rate.

A synthetic “fuel” price is obtained by weighting the price of each fuel category by the corresponding consumption. All prices are deflated by the consumer price index.

➢ Consumption of domestic heating oil (period: 1983-2017)

Data source:

- monthly Pégase database, oil consumption corrected for climatic variations

Comments. Annual consumption is obtained by summing monthly consumption

➢ Price of domestic heating oil: Pégase data (period: 1983-2017)

Data sources:

- Price with and without VAT for the period 1983-2013: transport accounts for the years 1983, 1985, 1990 and 2014 for the prices with and without VAT (http://www.statistiques.developpement-durable.gouv.fr/donnees-densemble/1924/874/ensemble-comptes-transports.html)
- Price including VAT for the period 2014-2017: annual Pégase database (http://www.statistiques.developpement-durable.gouv.fr/donnees-ligne/r/pegase.html)
- Consumer Price Index: OECD (Base 2010, all households and products: https://data.oecd.org/fr/price/inflation-ipc.htm)
- DCTEP rate: Customs Code on www.legifrance.gouv.fr (Article 265)

Comments. Over the period 1983-2013 the prices provided by the transport accounts are with and without VAT. From the VAT rates over the period, we reconstruct the amount of DCTEP. We then confirm that it corresponds to figures set in the finance law of, except for the years 2000 to 2002 because of floating TIPP. Over the 2014-2017 period, the Pégase database only gives the price including VAT. The amount of DCTEP is based on the value given by the Customs Code. The amount excluding VAT is then calculated using this estimate and the VAT rate.

➢ Control variables (period: 1980-2017 except for oil-heated housing units: 1983-2017)

Data sources:

- Current GDP and gross disposable income: INSEE - annual national accounts 2017
- Unemployment rate: INSEE, employment surveys
- Urbanization rate: World Development Indicators
- Average price of imported crude oil: OECD
- Proportion of oil heated dwellings: estimated from the CEREN survey

Comments. Current GDP and gross disposable income are deflated by the CPI and per capita values are then calculated. The average price of imported crude oil is converted into euros and then deflated by the CPI.

❖ Annual data

➢ Consumption of fuel and domestic heating oil (September 2002 - March 2017)

Data sources:

- Petrol, diesel and domestic fuel consumption: Pégase monthly database
- Share of diesel fuel consumed by light vehicles: transport account 2016
- Average annual population in metropolitan France: INSEE (https://www.insee.fr/fr/statistiques/serie/000067671)

Comments. Monthly consumption figures for diesel cover all consumption. We must therefore remove consumption by road freight. To do this, we use annual transport account data which enable us to calculate the share of diesel fuel consumed by light vehicles. From these annual data, monthly ratios are estimated by linear interpolation. Similarly, the monthly population, which allows us to calculate per capita consumption, is estimated from the annual population by linear interpolation.

➢ Prices of fuel and domestic heating oil (September 2002 - March 2017)

Data sources:

- VAT-inclusive of petrol, diesel and heating oil: monthly Pégase database
- DCTEP of heating oil: annual finance law
- DCTEP of petrol and diesel: estimation of real rates, including regional adjustment, from data calculated using transport accounts
- CPI: INSEE (2015 database - All households - Metropolitan France - All products)

Comments: the tax-excluded price of heating oil is calculated from the price including tax, the VAT rate and the amount of DCTEP given by the finance laws. For petrol and diesel, the amount of DCTEP comes from the amounts calculated from the transport accounts to take account of regional adjustment. The price is then calculated from the tax-inclusive price, the VAT rate and these DCTEP amounts. All prices are deflated by the CPI.

➢ Control variables (period: 1980-2017, except for the share of oil-heated dwellings: 1983-2017)

Data sources:

- Current GDP and gross disposable income: INSEE - 2nd estimate of the quarterly account for the first quarter of 2018 (current price, CVS-CJO data)
- Unemployment rate: Eurostat, seasonally adjusted
- Price of Brent dated in euros per barrel: INSEE
- Share of oil heated dwellings: interpolation from annual data estimated by the CEREN survey

Comments. Current GDP and gross disposable income are deflated by the CPI and then per capita values are calculated. The average price of imported crude oil is also deflated by the CPI.

Appendix 4: Result tables of the econometric estimates of the ex-ante evaluation

Table 1: OLS estimation of fuel-price (tax inclusive) elasticity with monthly data

Variable	Coefficient	(Standard deviation
log(tax-inclusive price)	-0.0774433**	(0.01924792)
Tendency	-0.0003742**	(0.00010176)
log(unemployment rate)	0.0281699	(0.04658839)
log(GDP par capita)	0.4662442**	(0.14748578)
Indicator January	-0.0910401**	(0.01602894)
Indicator February	-0.1056269**	(0.01127636)
Indicator March	0.0104303	(0.01168720)
Indicator April	0.0196092	(0.01096156)
Indicator May	0.0142037	(0.01450016)
Indicator June	0.0446073**	(0.01232331)
Indicator July	0.0954868**	(0.01194085)
Indicator August	0.0149849	(0.01297393)
Indicator September	0.0255202*	(0.01126249)
Indicator October	0.0457995**	(0.01301753)
Indicator November	-0.0467162**	(0.01574018)
Constant	-0.5559000	(1.9585061)
Observations	187	
Adjusted R^2	0.737	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 2: IV estimation of fuel-price (tax inclusive) elasticity with monthly data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.0907919**	(0.0197602)
Tendency	-0.0003615**	(0.0001298)
log(unemployment rate)	0.0247203	(0.0598741)
log(GDP per capita)	0.4694341*	(0.1883811)
Indicators	[...]	[...]
Constant	-0.5756201	(1.8098238)
Observations	187	
Adjusted R^2	0.7366	
F-statistique	2135.523 (p<2e-16)	
Wu-Hausman	3.333 (p=0.0697)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 3: OLS estimation of fuel-price (tax inclusive) elasticity with monthly data

Variable	Coefficient	(Standard deviation)
Δlog(tax-inclusive price)	-0.487365**	(0.1242335)
Δlog(unemployment rate)	-0.214940	(0.3053500)
Δlog(GDP per capita)	-2.387013	(1.6712430)
Indicators	[...]	[...]
Constant	0.039986**	(0.0125992)
Observations	186	
Adjusted R^2	0.571	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 4: IV estimation of fuel-price (tax inclusive) elasticity with monthly data

Variable	Coefficient	(Standard deviation)
Δlog(tax-inclusive price)	-0.25191†	(0.13899)
Δlog(unemployment rate)	-0.06704	(0.35575)
Δlog(GDP per capita)	-1.67811	(1.54014)
Indicator January	-0.11990**	(0.03299)
Indicator February	-0.06329**	(0.01587)
Indicator March	0.06495**	(0.02033)
Indicator April	-0.03199	(0.02137)
Indicator May	-0.04968**	(0.02185)
Indicator June	-0.01185	(0.02427)
Indicator July	0.01764	(0.01905)
Indicator August	-0.12847**	(0.02553)
Indicator September	-0.02823†	(0.01683)
Indicator October	-0.02194	(0.02098)
Indicator November	–0.13390**	(0.02668)
Observations	186	
Adjusted R^2	0.5638	
F-statistique	267.46 (p<2e-16)	
Wu-Hausman	4.61 (p=0.0332)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 5: OLS estimation of fuel-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.33922361**	(0.04747823)
Tendency	0.00474139**	(0.00096829)
Constant	6.33262400**	(0.01658987)
Observations	38	
Adjusted R^2	0.7294	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 6: OLS estimation of fuel-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.40021505**	(0.05569364)
Tendency	0.00569412**	(0.00082551)
log(unemployment rate)	-0.01427972†	(0.00771218)
Constant	6.44359436**	(0.00082551)
Observations	38	
Adjusted R^2	0.7563	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 7: OLS estimation of fuel-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.311113**	(0.038436)
Tendency	-0.004306*	(0.001728)
log(GDI per capita)	0.813039†	(0.150511)
Constant	-1.423743	(1.435901)
Observations	38	
Adjusted R^2	0.8501	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 8: OLS estimation of fuel-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.2394282**	(0.0554482)
Tendency	-0.0087702**	(0.0026866)
log(GDI per capita)	1.1288618**	(0.2133368)
log(unemployment rate)	0.0142267†	(0.0078058)
Constant	-4.5472407*	(2.0665467)
Observations	38	
Adjusted R^2	0.8612	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 9: IV estimation of fuel-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.325432**	(0.049918)
Tendency	-0.004204†	(0.002179)
log(GDI per capita)	0.805447**	(0.186077)
Constant	-1.349975	(1.771615)
Observations	38	
Adjusted R^2	0.8495	
F-statistique	496.412 (p<2e-16	
Wu-Hausman	2.091 (p=0.158)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 10: IV estimation of fuel-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.271432**	(0.065136)
Tendency	-0.007655*	(0.003072)
log(GDI per capita)	1.049636**	(0.236162)
log(unemployment rate)	0.011039	(0.008440)
Constant	-3.765158	(2.294194)
Observations	38	
Adjusted R^2	0.8596	
F-statistique	257.476 (p<2e-16)	
Wu-Hausman	3.096 (p=0.0881)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 11: OLS estimation of heating oil-price (tax inclusive) elasticity with monthly data

Variable	Coefficient	(Standard deviation)
Δlog(tax-inclusive price)	-0.67222**	(0.228671)
Δlog(unemployment rate)	0.35850	(0.869382)
Δlog(GDP per capita)	0.99203	(6.793973)
Δlog(proportion of oil heated dwellings)	5.97983	(4.945241)
Indicators	[...]	[...]
Constant	0.18537**	(0.039363)
Observations	186	
Adjusted R^2	0.4696	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 12: IV estimation of heating oil-price (tax inclusive) elasticity with monthly data

Variable	Coefficient	(Standard deviation)
Δlog(tax-inclusive price)	-0.52874*	(0.25536)
Δlog(unemployment rate)	0.54170	(0.83020)
Δlog(GDP per capita)	1.85041	(6.46875)
Δlog(proportion of oil heated dwellings)	5.49432	(4.80062)
Indicators	[...]	[...]
Constant	0.18854**	(0.04122)
Observations	186	
Adjusted R^2	0.4685	
F-statistique	232.630 (p<2e-16)	
Wu-Hausman	0.503 (p=0.479)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 13: OLS estimation of heating oil-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.1314117*	(0.0474550)
Tendency	-0.0047394	(0.0056370)
log(GDP per capita)	0.7177903†	(0.3733474)
log(unemployment rate)	0.1159811	(0.1067222)
log(proportion of oil heated dwellings)	0.8688774**	(0.0943110)
Constant	-0.0393966	(4.0480380)
Observations	35	
Adjusted R^2	0.9729	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 14: IV estimation of heating oil-price (tax inclusive) elasticity with annual data

Variable	Coefficient	(Standard deviation)
log(tax-inclusive price)	-0.136617**	(0.041399)
Tendency	-0.004118	(0.005015)
log(GDP per capita)	0.689716*	(0.327850)
log(unemployment rate)	0.109060	(0.104134)
log(proportion of oil heated dwellings)	0.875667**	(0.092072)
Constant	0.284036	(3.565293)
Observations	35	
Adjusted R^2	0.9729	
F-statistique	216.57 (p<2e-16)	
Wu-Hausman	3.096 (p=0.766)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 15: OLS estimation of fuel-price elasticities with monthly data

Variable	Coefficient	(Standard deviation)
ΔPrice (excluding DCTEP)	-0.00389672**	(0.00114073)
ΔDCTEP (including VAT)	-0.02794383**	(0.00724823)
ΔUnemployment rate	-0.01861337	(0.03680012)
ΔGDI per capita	-0.00014125	(0.00020389)
Indicators	[...]	[...]
Constant	0.04109199**	(0.01557609)
Observations	186	
Adjusted R^2	0.5871	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 16: IV estimation of fuel-price elasticities with monthly data

Variable	Coefficient	(Standard deviation)
ΔPrice (excluding DCTEP)	-2.680e-03*	(1.317e-03)
ΔDCTEP (including VAT)	-2.590e-02**	(7.389e-03)
ΔUnemployment rate	-9.207e-03	(4.076e-02)
ΔGDI per capita	-5.561e-05	(2.369e-04)
Indicators	[...]	[...]
Constant	4.330e-02**	(1.576e-02)
Observations	186	
Adjusted R^2	0.5841	
F-statistique	344.921 (p<2e-16)	
Wu-Hausman	2.205 (p=0.111)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 17: OLS estimation of heating oil-price elasticities with monthly data

Variable	Coefficient	(Ecart-type)
ΔPrice (excluding DCTEP)	-0.0086891*	(0.0033640)
ΔDCTEP (including VAT)	-0.0706417*	(0.0311793)
ΔUnemployment rate	0.0604665	(0.1366903)
ΔGDP per capita	0.0003384	(0.0006344)
ΔProportion of oil heated dwellings	10.4515917	(51.2224792)
Indicators	[...]	[...]
Constant	0.1896856**	(0.0437759)
Observations	186	
Adjusted R^2	0.4769	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Table 18: IV estimation of heating oil-price elasticities with monthly data

Variable	Coefficient	(Standard deviation)
ΔPrice (excluding DCTEP)	-0.0082723*	(0.0040280)
ΔDCTEP (including VAT)	-0.0705942**	(0.0267300)
ΔUnemployment rate	0.0642860	(0.1137774)
ΔGDP per capita	0.0003598	(0.0006325)
ΔProportion of oil heated dwellings	10.0171703	(26.7929046)
Indicators	[...]	[...]
Constant	0.1903261**	(0.0387690)
Observations	186	
Adjusted R^2	0.4768	
F-statistique	308.102 (p<2e-16)	
Wu-Hausman	2.205 (p=0.868)	

Significance : † : 10% ∗ : 5% ∗∗ : 1%

Appendix 5: Optimization programme for the synthetic control method

Let the vector $X_1 = (Z_1', Y_{11}, \dots, Y_{1T_0})'$ contain, for France, all the predictors as well as the values of the variable of interest Y before the introduction of the tax carbon.[3] X_0 will designate the matrix containing the same variables for each country in the control group.
Let the vector $Y_1 = (\,Y_{11}, \dots, Y_{1T_0})'$ contain, for France, the values of the variable of interest Y before the introduction of the carbon tax. Y_0 will desigate the matrix containing the same variables for each country in the control group.
With these notations, equations (1) and (2) are rewritten: $X_1 = X_0W$ avec $W = (w_{2,} \dots, w_{N+1})$
Since the equation $X_1 = X_0W$ has no solution, our goal is to minimize the distance between X_1 and X_0W. It is therefore necessary to define a metric on this Euclidean space. We thus call V the positive semi-definite matrix which makes it possible to define the following norm:

$$\|X_1 - X_0W\|_V = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)}$$

V is a positive semi-definite matrix (in practice diagonal). This matrix makes it possible to give a differentiated weight to each of the predictor variables included in X_0 et X_1. The determination of V is included in the optimization programme.
The latter allows us to find the right combination $W^* = (w_{2,} \dots, w_{N+1})$ and takes place in two stages:
- in the first stage, we look for W^* which minimizes $\|X_1 - X_0W\|_V$ at fixed V. We thus determine a vector W* which depends on the matrix V: $W^*(V)$.
- in the second stage, we look for V^* which minimizes $(Y_1 - Y_0W^*(V))'(Y_1 - Y_0W^*(V))$ and from this we deduce the best combination: $W^*(V^*)$
This second step consists in minimizing the difference between the variable of interest of real France and of synthetic France over the pre-treatment period.

[3] Only certain pre-treatment values or a linear combination of these values can be used

Appendix 6: Data used for the synthetic control method

For greenhouse gas emissions: UNFCCC data portal (https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2018)

For the predictors,

- World Bank database (https://data.worldbank.org/) for:
  - Percentage of urban population in the total population
  - Energy intensity of GDP
  - Population per country
  - Share of nuclear in the energy mix
- OECD database (https://stats.oecd.org) for:
  - GDP per capita (in constant prices, constant PPPs, OECD base year)
  - Number of vehicles per 1000 inhabitants
  - Per capita fuel consumption
- Eurostat for the heating degree days indicator for control group 1
- World Average Degree Days Database, KAPSARC database for the heating degree days indicator for control group 2 (https://datasource.kapsarc.org/explore/dataset/world-average-degree-days-database-1964-2013/information/?disjunctive.temperature&disjunctive.country)

[1] Report of the Commission chaired by Alain Quinet, *La valeur tutélaire du carbone*, French documentation, CAS, 2009

[2] Lawrence H. Goulder, *Environmental taxation and the double dividend: A reader's guide,* 2005, International Tax and Public Finance, vol 2(2), pages 157-183

[3] On April 1, 2018, the rate was raised to $35 and will increase again by $5 a year to $50 in 2021

[4] British Columbia Ministry of Finance, *Myths and Facts about the Carbon Tax*

[5] Brian Murray and Nicholas Rivers, *British Columbia's Revenue-Neutral Carbon Tax: A Review of the Latest "Grand Experiment" in Environmental Policy*, Duke Nicholas Institute W.P. 15-04, May 2015

[6] For DCT, European Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity

[7] Articles 265, 266d, 266d B and 266d C

[8] As a result of regional adjustment, the real rate is €67.29 in Corsica, €70.04 in Ile de France and €69.02 in the other regions

[9] As a result of regional adjustment, the real rate is €59.40 in Corsica, €62.64 in Ile de France and €60.75 in the other regions

[10] The reader can refer to Appendix 1 on the returns of the different DCTs

[11] *Evaluations préalables des articles du projet de loi,* Annex to the draft budget law for 2010

[12] The reader can refer to Appendix 2 as well as to the following documents: Decision by the Constitutional Council 2009-599 DC; Commentary on the decision of 29 December 2009; Information Report No. 300 by Fabienne Keller, made on behalf of the Senate Finance Committee

[13] Article 265f of the Customs Code

[14] Carol Dahl and Thomas Sterner, *Analysing gasoline demand elasticities: a survey,* Energy Economics, 1991

[15] Xavier Labandeira, José M.Labeaga and Xiral López-Otero, *A meta-analysis on the price elasticity of energy demand*, European University Institute, Robert Schuman Centre for Advanced Studies, Florence School of Regulation Climate, 2016

[16]Nicholas Rivers and Brandon Schaufele, *Carbon Tax Salience and Gasoline Demand*, University of Ottawa, 2012

[17] Julius Andersson, *Cars, carbon taxes and CO_2 emissions,* Grantham Research Institute on Climate Change and the Environment, Centre for Climate Change Economics and Policy, 2017

[18] S.Li, J.Linn and E.Muehlegger, *Gasoline Taxes and Consumer Behaviour*, American Economic Journal: Economic Policy, 2014

[19] W.J Congdon, J.R Kling and S.Mullainathan, *Behavioral Economics and Tax Policy,* National Tax Journal, 2009

[20] Energy Regulatory Commission, Observatory for Electricity and Natural Gas Retail Markets, 1st quarter 2018 (as of 31/03/2018)

[21] Formerly called “super leaded”

[22] The standard deviation is calculated using the Newey-West estimator, which is robust to the heteroscedasticity and autocorrelation of residuals

[23] Emissions are calculated from consumption reconstructed from elasticities and the emission factors are those used to calculate the CEC amounts

[24] In fact the variation is $100(e^{\beta\Delta p}-1)$ per cent, but if the coefficient β is small, the approximation is valid

[25] Alberto Abadie, Alexis Diamond and Jens Hainmueller, *Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program*, Journal of the American Statistical Association, 2010

[26] Alberto Abadie and Javier Gardeazabal, *The Economic Costs of Conflict: A Case Study of the Basque Country,* American Economic Review, 2003

[27] Alberto Abadie, Alexis Diamond and Jens Hainmueller, *Comparative Politics and the Synthetic Control Method,* American Journal of Political Science, 2015

[28] Julius Andersson, *Cars, carbon taxes and CO_2 emissions,* Grantham Research Institute on Climate Change and the Environment, Centre for Climate Change Economics and Policy, 2017

[29] Dr. Stewart Elgie, Jessica McClay, *BC's carbon tax shift after five years: results “An Environmental (and Economic) Success Story”*, University of Ottawa, 2013

[30] Alberto Abadie, Alexis Diamond and Jens Hainmueller, *Synth: An R Package for Synthetic Control Methods in Comparative Case Studies,* Journal of Statistical Software, 2011

[31] For example, in the annex (“Preliminary Assessments” of PLF 2018)

[32] Amendment introduced by Article 1 of the article on the energy transition of 2015

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