INVESTIGATING THE ECONOMIC AND ENVIRONMENTAL EFFECTS OF A CARBON TAX IN A QUANTITATIVE MACROECONOMIC FRAMEWORK

Adeline Guéret
Frédéric Reynès
Gissela Landa
Paul Malliet
Meriem Hamdi-Cherif
Aurélien Saussay
Gaël Callonnec

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ABOUT THE AUTHORS

Adeline Guéret, OFCE - French economic observatory
Email Address: adeline.gueret@sciencespo.fr
Frédéric Reynès, OFCE - French economic observatory, NEO - Netherlands Economic Observatory
Email Address: frederic.reynes@sciencespo.fr
Gissela Landa, OFCE - French economic observatory,
Email Address: gissela.landa@ofce.sciences-po.fr
Paul Malliet, OFCE - French economic observatory,
Email Address: paul.malliet@ofce.sciences-po.fr
Meriem Hamdi-Cherif, OFCE - French economic observatory,
Email Address: meriem.hamdicherif@sciencespo.fr
Aurélien Saussay, OFCE - French economic observatory, LSE - London School of Economics
Email Address: aurelien.saussay@ofce.sciences-po.fr
Gaël Callonnec, ADEME - French Environment and Energy Management Agency
Email Address: gael.callonnec@ademe.fr

ABSTRACT

Climate policy uses a variety of economic instruments, such as taxes and regulations, to reduce greenhouse gas emissions by redirecting economic activity. In this article, we assess the impact of a carbon tax on both environmental and economic variables. We use a neo-Keynesian macroeconomic model (ThreeME) calibrated for France as a small open economy. We examine whether and to what extent the results vary under different model features. We find that the degree of flexibility of the economy and the degree of exposure to foreign competition are the two most influential assumptions regarding the existence and size of a double dividend. These assumptions also drive most of the dynamics following the introduction of a carbon tax. Conversely, the way in which tax revenues are redistributed to firms and the way in which wages, employment and inflation interact with each other have little impact on the outcomes. We conclude that revenue recycling is necessary but not sufficient to induce a positive economic response while striving to reduce emissions. Helping firms and consumers substitute clean energy for polluting energy and designing policies that ensure a level playing field are key.

KEYWORDS

Carbon tax, double dividend, neo-Keynesian macroeconomics, macroeconomic modeling.

JEL

E12, E17, E27, E37, E47, D57, D58.

Investigating the economic and environmental effects of a carbon tax in a quantitative macroeconomic framework

Adeline Guéret[1,2], Frédéric Reynès[1,3], Gissela Landa[1], Paul Malliet[1], Meriem Hamdi-Cherif[1], Aurélien Saussay[1,4], and Gaël Callonnec[5]

[1]OFCE - French Economic Observatory
[2]DIW Berlin - German Institute for Economic Research
[3]NEO - Netherlands Economic Observatory
[4]LSE - London School of Economics
[5]ADEME - French Environment and Energy Management Agency

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Abstract

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1 Introduction

The macroeconomic and welfare effects of transitioning to a low carbon economy are still debated. If it is widely accepted that global warming is going to lower global welfare, the economic consequences of phasing-out fossil fuels and other sources of carbon dioxide emissions are subject to a fierce debate. Is there a trade-off between economic activity and the fight against climate change? Can a carbon tax generate a double dividend (DD), i.e. an outcome where both emissions decrease and the economic activity increases? While the double dividend is not an end in itself since the absence of an economic dividend should not deter the implementation of a carbon fiscal policy, policymakers often use the existence of a double dividend as an argument for climate policy measures such as carbon taxes. Besides, examining this issue contributes to better understanding short-term constraints impeding the transition to a low-carbon economy.

The conditions under which the implementation of a carbon tax can lead to a double dividend has been discussed in the literature (see e.g. Jaeger, 2012; Freire-González, 2018; Aubert and Chiroleu-Assouline, 2019; Hafstead and Williams III, 2018). Its existence is highly sensitive to model assumptions (see Section 2). Most studies use Computable General Equilibrium (CGE) models built upon a neoclassical framework and find little to no DD. This result mostly relies on the assumption of perfectly flexible prices, which guarantees that supply is always equal to the maximum production capacity. In contrast, few studies investigate the question of the DD adopting a different theoretical framework that relaxes some key assumptions of the neoclassical framework. If they often conclude that a double dividend exists in the model, the reasons are not clearly outlined.

This paper's first objective is to perform a systematic analysis to identify the fundamental mechanisms leading to a DD. We use ThreeME (Multi-sector Macroeconomic Model for the Evaluation of Environmental and Energy policy), a dynamic macroeconomic model, to investigate the key modeling assumptions that may lead to a DD in the case of a small open economy like France. This model integrates neo-Keynesian features which are well-suited to assess short- and medium-term impacts of economic policy in addition to long-term impacts. We investigate the role of four features mentioned in the literature: (i) the degree of exposure to foreign competition where a low exposure can be seen as a proxy for trading partners implementing a joint carbon policy; (ii) the degree of flexibility of the economy, i.e., the ease with which economic agents can substitute green for brown technology; (iii) the way the carbon tax is redistributed to firms (lump-sum redistribution of tax revenues versus a reduction of the employers' social security contributions); (iv) the wage-setting and inflation dynamics, which play a crucial role in crowding out effects in a neo-Keynesian framework.

We find that the two main features leading to a DD are a low exposure to foreign competition and a high degree of flexibility of the economy. In comparison, the impacts of the carbon tax redistribution scheme and the inflation dynamics remain small.

Section 2 provides a short literature review on the double dividend in theoretical and empirical CGE and macroeconomic models. Section 3 describes the ThreeME model and its main assumptions. Section 4 presents the tested policies and assump-

tions. Section 5 outlines the main results. Section 6 concludes.

2 The double dividend in the literature

The concept of double dividend was originally connected to the debate over the acceptability of taxes as opposed to command-and-control tools, which have been widely discussed in the economic literature, in particular by Weitzman (1974). Among the pioneering works that transposed the debate to environmental economics and the carbon tax is Pearce (1991). He underlined that not only could a carbon tax help correct the distortions leading to negative environmental externalities (first dividend) but that the recycling of the proceeds of the tax could also be used to reduce other more distorting taxes, and hence lead to a second (economic) dividend[1]. The concept has then developed quickly, leading to confusion around the definition of a double dividend and, in particular how the "second dividend" should be defined and analyzed. For instance, Goulder (1995) defines several forms of double dividends - the weak, the intermediate and the strong forms - depending on whether the economic improvement is in absolute terms or relative to a specific recycling method. Others have suggested using criteria other than growth such as employment (Bovenberg, 1999).

Beyond definition considerations, the main issues regarding the double dividend remain whether it exists or not, why and for whom[2]. Recent works relied on environmental tax reforms implemented around the world to estimate whether they impacted the economy positively or not. Metcalf and Stock (2020) find that the hypothesis of the DD can not be rejected by the data. They develop an empirical identification strategy based on the last thirty years in 31 European countries and find that implementing a carbon tax could lead to a slightly positive impact on economic growth. Most importantly, their results show that the absence of a negative impact on the GDP is statistically significant. Nevertheless, such *ex-post* assessments are exceptions. Most works dealing with the existence of a double dividend consist in *ex-ante* studies, be they theoretical or empirical models such as CGE models. Even though it has been widely documented, the existence of a double dividend is still controversial.

The large majority of the theoretical studies on the DD are based on a neoclassical market-clearing Walrasian model. While first theoretical papers often concluded that there is no double dividend (see e.g. Bovenberg and De Mooij, 1994a,b; Bovenberg and van der Ploeg, 1994), many studies have later shown that this outcome is highly sensitive to the modeling assumptions. The list of the key assumptions includes the design of the recycling policy (Parry, 1995), the preexisting tax system and its distor-

[1] The existence of a DD from an environmental policy should not been seen as a necessary condition of implementing it since important non-economic benefits from environment preservation are also at play.

[2] In recent years, studies have put forward the issues of equity and horizontal redistribution (highlighted during the *Yellow Vests Protests*), (see e.g. Fullerton and Monti, 2013; Berry, 2019; Pizer and Sexton, 2019). Adopting a multi-agent framework in the analysis may relativize conclusions on the existence of DD, highlighting the heterogeneity of impacts and by corollary, the need to implement redistribution measures. In this paper, we design a representative agent setting, bearing in mind the redistributive implications that an environmental policy might have.

tionary features (Babiker et al., 2003), the specification of the wage and price setting process (Marsiliani and Renström, 1997), the possibilities of substitution between labor supply and environmental quality (Kahn and Farmer, 1999) or between labor and energy (Koskela et al., 1998), the presence or not of a fixed factor in the production process of the polluting good (Bento and Jacobsen, 2007). Studies using applied empirical models also led to diverging conclusions(Patuelli et al., 2005). For a survey on the different modeling frameworks used for the study of the energy transition, refer to (Hafner et al., 2020). Among the empirical studies finding a DD with a CGE model, one finds Takeda (2007); Glomm et al. (2008); Sancho (2010); Ciaschini et al. (2012); Orlov et al. (2013); Fraser and Waschik (2013).

Within the neoclassical framework, the existence of a DD is largely supply-driven. The assumption of perfect price flexibility guarantees that production is always equal to the maximum production capacity, which is characterized by the full use of production factors. In other words, Say's law (Say, 1836), where a product always finds its demand, holds. Under such an assumption, a DD is possible only if the available production factors increase. Since the capital stock is fixed and generally predefined by previous savings, the key mechanism goes through labor supply. A neoclassical CGE model may conclude that a DD exists when the implementation of the carbon tax is such that, through various mechanisms, it leads to an increase in labor supply. For this reason, the assumptions regarding the elasticity of substitution between leisure and consumption or the importance of fossil consumption in consumers' utility function are of great importance in the theoretical and empirical studies previously reviewed.

Say's law has been criticized by Keynesian theories for ruling out demand constraints and situations where production factors are under-utilized (e.g. involuntary unemployment). It is also in contradiction with empirical findings showing that most companies rationally choose not to produce at their full production capacity. Indeed, the capacity utilization ratio fluctuates historically around eighty percent, with some heterogeneity across production sectors[3]. Neo-Keynesian macroeconomic models account for demand constraints. In comparison to the neoclassical literature, there is little research on the DD performed within a neo-Keynesian framework. "Neo-Keynesian" models are different from the so-called "new Keynesian" models as defined in the Dynamic Stochastic General Equilibrium (DSGE) literature (see e.g. Clarida et al., 1999; Galí, 2008; Goodfriend and King, 1997; Goodfriend, 2007; Woodford, 2011). The term "new Keynesian" is misleading since most of the model assumptions are more of classical than of Keynesian influence. Among others, we can cite perfect information, perfectly rational and forward-looking agents, the absence of involuntary unemployment as well as a Ramsey rule defining the optimal climate trajectory that maximizes the inter-temporal utility. The assumption of slow price adjustment - modeled as frictions in the price setting process - is one of the only Keynesian features of these models. Combined with other neoclassical features, this does not lead to results that are much different from CGE models' results in terms of DD. For instance,

[3]See for instance the historical data for various US industries: https://fredblog.stlouisfed.org/2019/01/capacity-utilization/ or http://myf.red/g/1I8W.

this framework has been used to study the impact of climate policy by Annicchiarico and Di Dio (2015, 2017) and results do not show a DD. Nevertheless, new Keynesian models have been criticized in recent years for their lack of practical applications (see e.g. Mankiw, 2006; Solow, 2010; Romer, 2015; Stiglitz, 2018).

Contrary to new Keynesian models, neo-Keynesian macroeconomic models conclude that a DD might exist (see e.g. Landa Rivera et al., 2016; Lee et al., 2018; Callonnec et al., 2025). Pollitt and Mercure (2018) and Meyer and Ahlert (2019) identify and discuss important assumptions that could explain this difference in results. In particular, assumptions about the financial system where investment can only be financed by previous savings leads to "crowding out" investment in the neoclassical framework. The role of the bank system in neo-Keynesian frameworks make "crowding in" effects possible. However, to the best of our knowledge, no research has performed a systematic analysis confronting various key assumptions that lead to or preclude a DD in a neo-Keynesian macroeconomic framework. This is the main objective of this paper.

3 The ThreeME model

ThreeME is an open-source country-level, multi-sector macroeconomic model developed to support policymakers in the design and evaluation of decarbonization pathways in France (Callonnec et al., 2013, 2016, 2025; Malliet et al., 2020)[4]. Since its first release, it has been adapted to other countries, in particular Mexico (Landa Rivera et al., 2016), Indonesia (Malliet et al., 2017) and the Netherlands (Bulavskaya and Reynès, 2018). ThreeME is specifically designed to evaluate the short- and medium-term impacts of environmental and energy policies at the macroeconomic and sectoral levels, assuming a steady-state equilibrium in the long-term as in standard CGE models. The model combines several important features:

- Its sectoral disaggregation makes it possible to analyze the impacts of activity transfers from one sector to another in particular in terms of employment, investment, energy consumption or trade balance[5].
- The detailed representation of energy flows through the economy enables analyses on changes in economic agents' energy consumption. Sectors can arbitrage between capital and energy when the relative price of energy increases and substitute energy carriers one for another. Consumers can substitute across energy carriers, transportation modes and consumption goods.

ThreeME fully considers feedback between supply and demand. Demand (consumption and investment) drives the supply (production). Symmetrically, supply

[4]The full documentation of ThreeME can be found on `www.threeme.org`. The version used in this study can be retrieved from the GitHub repository `https://github.com/fosem/ThreeME_V3-open`, Branch FRA-DDIVIDEND-OFCEWP2024.

[5]For this study, we used a version of the model with 10 sectors: Agriculture and other industries, Manufacture of motor vehicles, trailers and semi-trailers, Construction of buildings and Civil engineering, Rail transport, Road transport, Services, Fossil energy, Transmission and distribution of electricity, Green and blue electricity generation, Fossil fuel electricity generation. The calibration of the base year (2010) is based on data from WIOD National Supply and Use Table (SUT) for France 2010 (`www.wiod.org`).

drives demand through incomes generated by production factors (labor, capital, energy products, and materials). Compared to bottom-up energy models such as MARKAL (Fishbone and Abilock, 1981; Heaps, 2008), ThreeME goes beyond the mere description of the sectoral and technological dimensions by integrating these within a comprehensive macroeconomic model.

ThreeME is a demand-driven macroeconomic model. Standard neoclassical CGE models are largely supply-driven since the so-called "Walrasian closure assumption" ensures that prices and quantities adjust instantaneously to clear all markets. Instead, ThreeME relies on a "neo-Keynesian closure assumption", meaning that prices and quantities adjust slowly and producers adjust their supply to the demand. In such a framework, market disequilibria can arise, which allows to better describe short- and medium-term macroeconomic dynamics such as the presence of involuntary unemployment. This framework is well-suited for policy analysis in the short-term and transition phases, which is particularly relevant when assessing the implementation of climate policies. Besides, it also provides information on the long-term.

In a neoclassical framework, supply is always at its full production capacity. A policy increasing public spending or public investment hurts the economy: it has an eviction effect on private consumption and investment because it is not possible to increase production. Macroeconomic models as ThreeME do not assume full utilization of available production factors, which can be interpreted as either spare production capacities or unemployment. By including slow adjustment on capital and labor, the relationship defined by the production function between the levels of labor and capital and the level of production is more a long-term optimum than a binding constraint. Hence, a positive multiplier effect can appear following an increase in public spending. The eviction effect is limited and spreads over time via inflationary pressure generated by a higher utilization rate of available production factors. Compared to a standard neoclassical framework, a neo-Keynesian model therefore accounts for important effects supported by empirical evidence such as demand-side Keynesian multipliers, that may be an additional mechanism leading to a DD.

4 Tested settings and assumptions

To understand whether and to what extent a double dividend can exist in a neo-Keynesian macroeconomic setting, we focus on both policy measures and specific equations and parameters of the model. By policy measures, we refer to the way policies are implemented, e.g., whether the carbon tax is redistributed or not and how. On the other hand, we analyze to what extent some modeling assumptions and parameters might impact the outcomes. More precisely, we investigate the wage equation specification as well as the degree of flexibility of the economy and the degree of exposure to foreign competition.

4.1 Policy measures

Macroeconomic studies dealing with the double dividend aim to understand whether the implementation of a specific policy leads to positive impacts on both the economy and the environment. We study the introduction of a carbon tax of 55 € in France which corresponds *ex ante* to an increase in fiscal revenues of one percent GDP point. All the receipts of the tax are recycled in the economy [6]. We test two types of redistribution mechanisms. While we keep the redistributive scheme to households unchanged (a lump-sum transfer), we design two types of redistribution schemes to firms:

- ◇ *Lump-sum redistribution*: the redistribution to each firm is proportional to its labor share;
- ◇ *Employers' social security contributions*: the redistribution corresponds to a decrease in the labor tax proportional to the labor share;

The lump-sum strategy reduces firms' costs, which could lead to lower retail prices and increase firms' competitiveness. The decrease in the employers' social security tax rate also leads to lower costs. Compared to the lump-sum strategy, it additionally distorts the relative prices between inputs, which provides an incentive to reallocate production factors. In particular, labor becomes cheaper compared to capital and energy. Hence, a lower labor tax for firms could incentivize them to replace polluting capital with labor especially since the decrease in tax is proportional to their labor share. It creates an incentive for firms to hire more people after the introduction of the carbon tax, not only because it is less polluting (hence they will be less taxed) but also because it is more profitable (they will get a bigger transfer *ex-post*).

4.2 Modeling assumptions and parameters

Next to policy measures, we investigate to what extent the existence and magnitude of a double dividend in ThreeME depend on some modeling assumptions.

4.2.1 Functional assumptions: wage curve

Wage formation has significant implications for inflation dynamics and, consequently, for the transmission of transition costs within the economy. It is likely to amplify the negative economic effects of the low-carbon transition by reducing competitiveness or diminishing households' real incomes. The modeling of wages has sparked technical, theoretical, and empirical debates that remain challenging to resolve (L'horty and Thibault, 1998; Le Bihan and Sterdyniak, 1998; Blanchard and Katz, 1999; Chagny et al., 2002; Reynès, 2006; Heyer et al., 2007; Reynès, 2010). We tested three competing specifications from the literature. Each specification typically results in different

[6] In this study, we do not explore in detail scenarios where tax revenues are solely used to reduce the public deficit (without being redistributed to households and firms), as such cases, except in very specific circumstances, result in negative economic impacts, and therefore fail to produce a double dividend.

long-term properties for a macroeconomic model, driven by different long-term equilibrium unemployment rates (*NAIRU*, Non-Accelerating Inflation Rate of Unemployment)[7]:

- ◇ *Wage-Setting (WS) curve* assumes that wage levels depend negatively on the unemployment rate. This implies that changes in taxation on labor and commodities may have a permanent impact on the NAIRU;
- ◇ *Phillips curve with constant NAIRU* assumes that the growth rate (rather than the level) of wages depends negatively on the unemployment rate. In this case, changes in the structure of taxation have only a transitory effect on the NAIRU. Moreover the NAIRU is independent from the level of actual unemployment rate;
- ◇ *Phillips curve with Time-Varying (TV) NAIRU*, which relies on the same assumptions as previously described, the main difference being that the level of the long term NAIRU is time-dependent and varies with the level of the actual unemployment rate. Compared to the previous specification, this curve is less inflationary when the unemployment rate decreases.

Investigating wage equation specifications derives from the intuition that job creation is an important part of the DD narrative. More generally, it is also a good indicator of economic activity dynamics. Choosing one specification rather than another comes along with implicit assumptions on the functioning of the labor market, which have in turn implications on the general economic activity and, hence, on the existence or/and magnitude of a double dividend.

4.2.2 Parametric assumptions: elasticities

On the other hand, results can also be influenced by the parameters that are chosen for some equations, in particular elasticities. Changing some parameters allows to see to what extent the results depend on specific characteristics of the economy, which could in turn serve as an exploratory analysis for public policy recommendations. In particular, we investigate two parameters:

- ◇ *Degree of flexibility of the economy*: in the flexible (resp. rigid) case, the elasticities of substitution between energy and capital, clean and dirty energy, clean and dirty transports are high (2 ; resp. low: 0.2). If the elasticity between clean and dirty energy is high, introducing a carbon tax will most probably shift production towards cleaner processes without hurting the economy. On the other hand, a low elasticity means that firms will most likely face greater difficulties to cope with short-term constraints.
- ◇ *Degree of exposure to foreign competition*: in this case, a high elasticity (Armington elasticity of 2) corresponds to a high substitution between domestic and foreign products, that is to say, a high exposure of domestic production to the direct competition of products produced abroad and imported. This can impact

[7] Unemployment rate below which an inflationary spiral begins to take hold.

the DD since the introduction of a carbon tax might increase the price of domestic production, which is likely to spur imports and pull down exports in an open economy, leading to a deterioration of the trade balance. On the contrary, it is likely that less open economies (we set the value of the Armington elasticity to 0.6) are more protected from these trade balance shifts, leading more probably to a DD.

The study of these modeling hypotheses aims at investigating limit cases. We use them as a way to explore the range of possible outcomes and understand to which extent these sensitivity analyses can help interpret the results of our model in general.

5 Main results

All possible combinations between the type of redistribution, the wage equation specification, the flexibility of the economy and its exposure to foreign competition amount to 24 settings. For each of them, we analyze how the GDP and the emissions evolve, both in the short-run (see Tables 1 and 5) and in the long-run (see Figure 1 and Table 2)[8]. As the implementation of a carbon tax leads in all cases to a reduction of carbon emissions in the short and long run, the existence of a DD only depends on the evolution of the GDP following the shock and over time.

5.1 A double dividend can exist both on the short- and long-term

Table 1 summarizes the different cases and shows for each of them if there is a short-term DD. We can first underline that the combination of a high degree of flexibility and a low degree of exposure to foreign competition always leads to the existence of a DD in the short-term. On the contrary, combining a low degree of flexibility and a high degree of exposure to foreign competition results in the absence of a short-term DD, irrespective of the type of redistribution and wage equation specification.

Table 1: Overview the existence of a short-term double dividend depending on various model settings

		Lump-sum			**Social security contributions**		
		Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low	*Low exp.*	No	Yes	Yes	No	No	No
flexibility	*High exp.*	No	No	No	No	No	No
High	*Low exp.*	Yes	Yes	Yes	Yes	Yes	Yes
flexibility	*High exp.*	Yes	No	No	Yes	No	No

Notes: This table summarizes the 24 possible settings with regard to whether they lead or not to the existence of a double dividend in the short-run. For instance, when redistributing the carbon tax as a lump-sum transfer to firms, with a WS equation, low flexibility and low exposure to foreign competition, the model does not lead to a short-term double dividend. All other things being equal, switching the flexibility parameter from low to high will result in the existence of a short-term double dividend.

[8] Hereafter we mean by "short-run" up to ten years and by "long-run" up to fifty years after the carbon tax was implemented.

In total, 10 cases out of 24 lead to a short-term DD. When it comes to the long-term, the number of DD cases rises up to 12 (Table 7). Not only does it show that implementing a redistributed carbon tax does not necessarily trigger a DD, but it also confirms that chosen assumptions do play a role in such a computable general equilibrium framework.

5.2 The combined degrees of flexibility and exposure to foreign competition drive the dynamics

Looking only at the binary output of the existence of a DD ten years following the implementation of a carbon tax can lead to over-simplistic conclusions. Overall dynamics can also shed light on regular patterns across the settings.

Figure 1: Long-term evolution of the GDP (in volume) following the implementation of a carbon tax (24 scenarios)

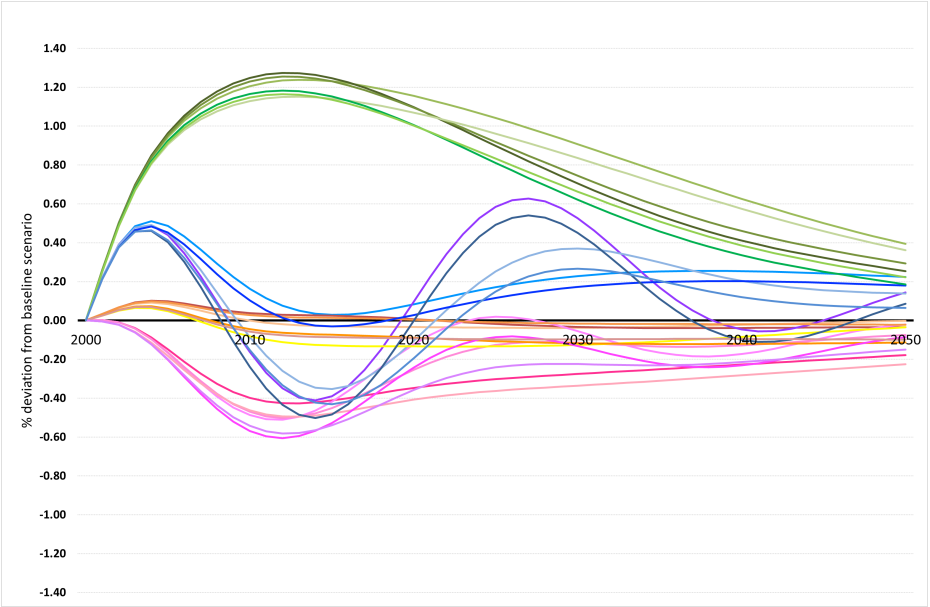


Figure 1 shows the evolution of the GDP in volume following the implementation of a carbon tax for the 24 settings and up to 50 years after introducing the new policy. It depicts four distinct clusters of trajectories:

- ◇ A strong and long-lasting increase of the GDP (green)
- ◇ A moderate short-term increase of the GDP followed by strong oscillations (blue)
- ◇ A small short-term increase of the GDP followed by a smooth return to the equilibrium (orange)

- ◇ A moderate decrease of the GDP during the first fifteen years followed by a return to the equilibrium (pink)

Each cluster gathers six settings. Within each cluster, all settings have the same flexibility and exposure parameters. Hence, the green lines correspond to scenarios where a high degree of flexibility of the economy is combined with a low degree of exposure to foreign competition. The blue cluster gathers settings with a high degree of flexibility and a high degree of exposure. The orange cluster is made of settings combining a low degree of flexibility and a low degree of exposure. Finally, the settings of the pink group are all characterized by a low degree of flexibility and a high degree of exposure to foreign competition. This result strengthens our conclusions drawn from the analysis of short-term impacts. It puts emphasis on the importance of the flexibility and exposure parameters in shaping the evolution of the GDP following the implementation of a carbon tax.

The existence of a redistribution mechanism is essential for achieving a DD. This is illustrated in Figure 12 in the appendix, where tax revenues are not redistributed to households and firms, resulting in negative economic impacts in most scenarios. The only exceptions are optimistic cases where the widespread availability of low-cost technological alternatives within the national territory (indicating a high degree of economic flexibility) is paired with low exposure to foreign competition (represented by the green curves in Figure 12).

However the type of redistribution or the specification of wage equation only play a minor role regarding the macroeconomic outcome in specific settings. For instance, it is possible to distinguish between three types of oscillations in the "blue" group. These distinct subgroups correspond to the different wage specifications (the lines oscillating the less correspond to settings with the WS specification; the ones oscillating the most to settings with a Phillips curve with constant NAIRU). One can also distinguish two subgroups in the "orange" cluster, one being slightly above the other. This difference is driven by the type of redistribution assumed. A lump-sum transfer combined with low exposure and low flexibility leads to a smaller short-term GDP increase than a decrease of the employers' social security contributions. The two other clusters (green and pink) show almost no variation across settings due to the type of redistribution or the wage equation specification.

From the analysis of trajectories, we conclude that a high degree of flexibility and a low degree of exposure to foreign competition entail a very high likelihood that a DD will appear. On the contrary, with a low degree of flexibility and a high degree of exposure to foreign competition, it is very likely that there will be no DD, irrespective of the other assumptions made. This result highlights differentiated priorities for policymaking. The design of the redistribution scheme cannot drive in a decisive way the economy's pathway following the implementation of a carbon tax. Policymakers should first ensure that firms are easily able to switch from dirty to clean production means and that there exists international cooperation (corresponding to a low level of foreign competition) when it comes to climate policies. It is all the more relevant as a high degree of flexibility and a low degree of exposure to foreign competition also

lead to a higher drop in carbon emissions, as shown in Table 2.

Table 2: Overview of the CO_2 emissions deviation from baseline scenario fifty years after the introduction of a carbon tax

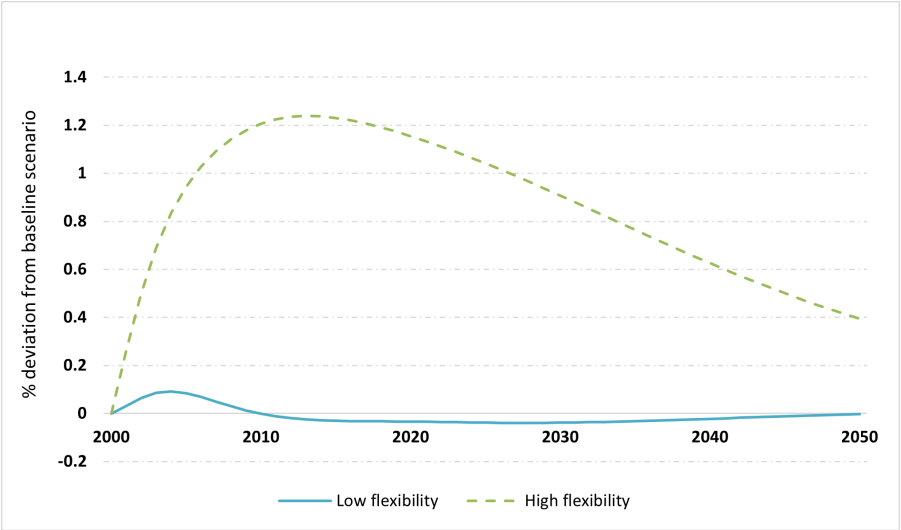
		Lump-sum			**Social security contributions**		
		Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low	*Low exp.*	-1.36	-1.42	-1.43	-1.47	-1.59	-1.64
flexibility	*High exp.*	-1.66	-1.54	-1.59	-1.79	-1.70	-1.78
High	*Low exp.*	-5.60	-4.97	-5.29	-5.68	-5.05	-5.37
flexibility	*High exp.*	-6.39	-6.83	-6.78	-6.49	-6.95	-6.93

Notes: This table summarizes the 24 possible settings with regard to the deviations from the baseline in terms of CO_2 emissions fifty years after implementing a carbon tax. For instance, when redistributing the carbon tax as a lump-sum transfer to firms, with a wage-setting equation, high flexibility and low exposure to foreign competition, the emissions deviate from the baseline by -5.60% fifty years following the shock.

5.3 The more flexible the economy, the higher the likelihood of a double dividend

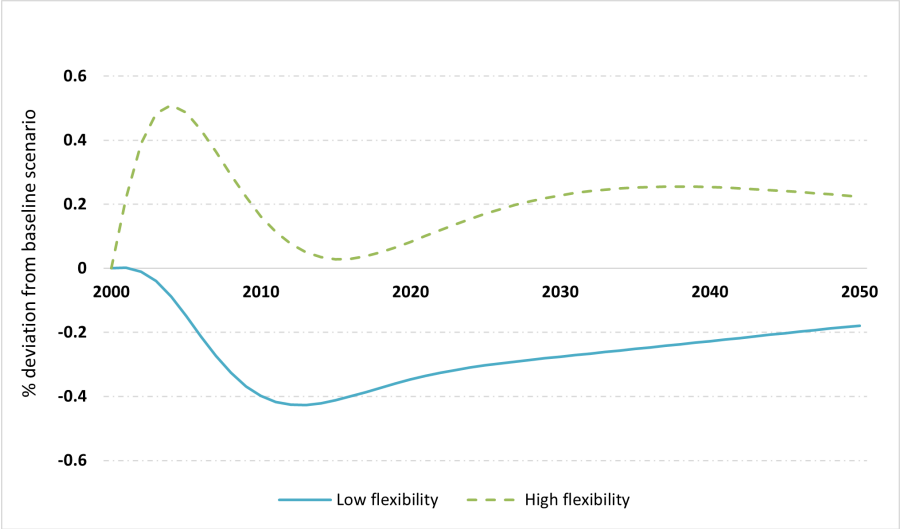
Everything else remaining constant, considering a high degree of flexibility rather than a low degree of flexibility changes the DD outcome for half of the settings (Table 1). More precisely, a higher flexibility increases the likelihood that a DD will exist in the short-run: about eight (resp. two) out of twelve settings show a DD in the short-run when considering a high (resp. low) degree of flexibility. Besides, when a DD exist with a low degree of flexibility, switching to a high degree of flexibility makes the DD even larger (see Table 6).

Figure 2: Evolution of GDP (in volume) following the introduction of a carbon tax with WS, lump-sum redistribution and **low** exposure to foreign competition



A high degree of flexibility allows to shift production processes and consumption patterns quickly from dirty energy to clean energy and from energy to capital. For instance, a higher degree of flexibility means that firms are more reactive to invest in more energy-efficient capital when energy becomes more expensive. Firms can also more easily switch from energy to labor. To this extent, the increase in employment is bigger when elasticities of substitution are high, hence inducing a greater demand shock that sustains the economic activity. Nonetheless, this implies that the exports also deteriorate more in a flexible framework since higher wages following a higher employment level leads to higher production prices, almost entirely transferred to retail prices. On the other hand, imports follow a short decrease before increasing greatly again in the flexible case, while they only decrease a little and go back to the previous level in the rigid case. This is driven by a substitution of national goods with foreign goods in a setting where foreign competition is low. This substitution happens due to the greater substitution between factors in the first place. This explains why imports react more strongly when the degree of flexibility of the economy is high. The changes in imports and exports result nonetheless in an improved trade balance compared to the baseline. The improvement is bigger in the case of a high degree of flexibility. The economic activity generated with high elasticities of substitution is sufficiently high to result in an overall short-run increase of the GDP volume. The increase is twelve times bigger in the case of a high degree of flexibility compared to the case where the flexibility of the economy is low (see Figure 2).

Figure 3: Evolution of GDP (in volume) following the introduction of a carbon tax with WS, lump-sum redistribution and **high** exposure to foreign competition



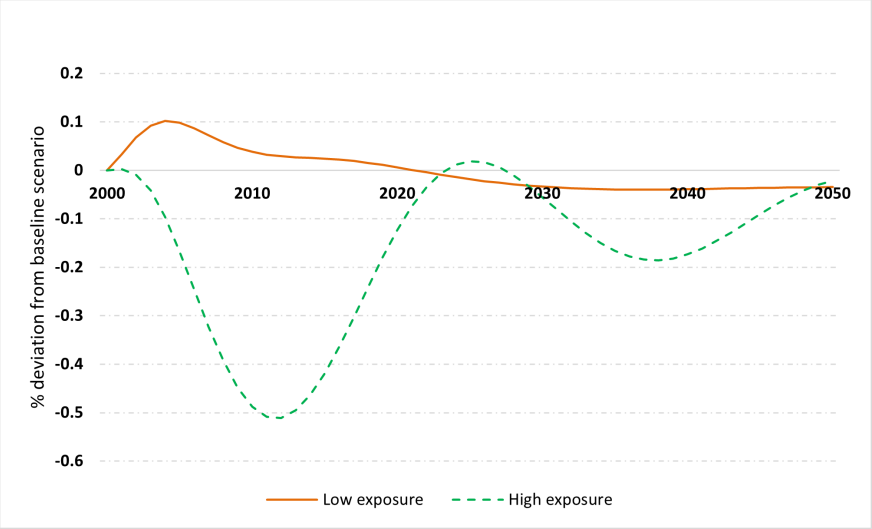
When considering a high level of foreign competition instead (Figure 3), the same drivers are at stake. Nonetheless, the overall positive impacts on the economic activity are smaller in size, leading the short-term DD to disappear if the degree of flexibility is low. When it comes to dynamics, we observe a greater volatility of the evolution

of the GDP mainly driven by the volatility on the labor market.

5.4 In an economy more exposed to foreign competition, the existence of a double dividend is less likely

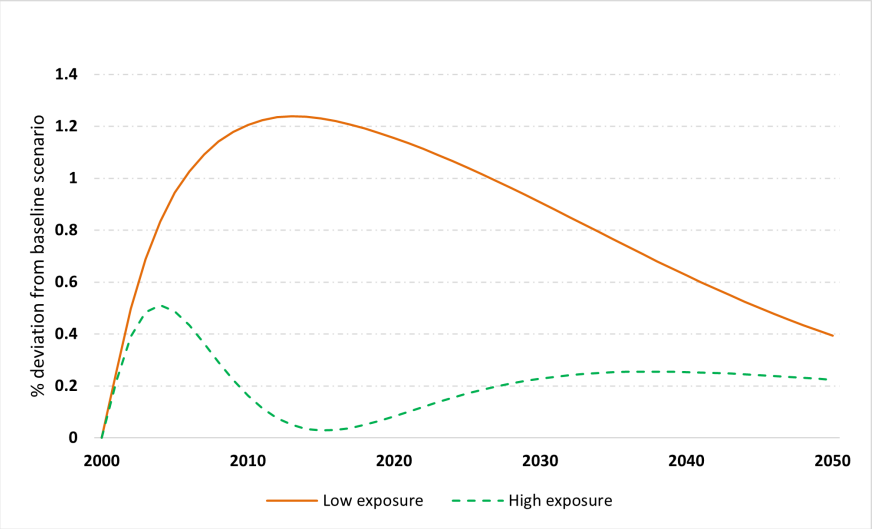
The degree of exposure to foreign competition alone is not a determining factor. However, in a state of high exposure to foreign competition, it is not likely that a DD would appear. According to Table 1, only two settings out of twelve lead to a short-term dividend when exposure to foreign competition is high. These two settings feature both a high degree of flexibility of the economy and a WS specification, no matter the type of redistribution considered. Beside, the degree of exposure to foreign competition can discriminate between no short-term DD and a short-term DD when the wage equation is specified following a Phillips curve (constant or time-varying NAIRU). In these cases, increasing the economy's exposure to foreign competition leads to no DD while it exists when the economy is protected from foreign competition (Figure 4).

Figure 4: Evolution of GDP (in volume) following the introduction of a carbon tax with constant NAIRU, lump-sum redistribution and low flexibility of the economy



When considering the WS specification for the wage equation, switching the degree of exposure to foreign competition from low to high does not impact qualitatively the outcome in terms of short-term DD. The reason is that this specification is less inflationary than the Phillips curve specifications. Still, Figure 5 shows that the economic dividend is quantitatively smaller with a WS specification in the case of a high degree of exposure to foreign competition.

Figure 5: Evolution of GDP (in volume) following the introduction of a carbon tax with WS, lump-sum redistribution and high flexibility of the economy



5.5 Redistribution mechanisms to firms do not play a decisive role

The way the carbon tax is redistributed to firms is not a determining factor regarding the existence of a DD. When analyzing how settings with a lump-sum redistribution change when assuming a redistribution via contribution cuts instead, we find that the results for ten out of twelve settings remain unchanged. Only in two settings does the type of redistribution considered influence the existence of a DD. More precisely, when we opt for a Phillips wage specification (be it with constant or time-varying NAIRU), low flexibility and low exposure to foreign competition, a lump-sum transfer to firms leads to the existence of a DD. In contrast, there is no DD when the carbon tax is redistributed via a decrease in employers' social security contributions. Even though there is a DD in both cases in the very short-term, the increase of GDP following the introduction of a carbon tax only lasts 4 years before declining and ending up being negative when redistributing via employers' social security contributions (Figure 6).

The difference between these two trajectories is driven by investment dynamics. In the case of the lump-sum transfer, firms' investment decreases less (Figure 7) because the lump-sum transfer does not induce an increase in the relative cost of capital, contrary to the reduction of employers' social security contributions. This difference in investment levels between the two cases explains why there is still a DD ten years after the carbon tax was introduced in the lump-sum transfer case and not in the other (Figure 6).

Figure 6: Evolution of GDP (in volume) following the introduction of a carbon tax with Phillips curve, low flexibility and low exposure to foreign competition

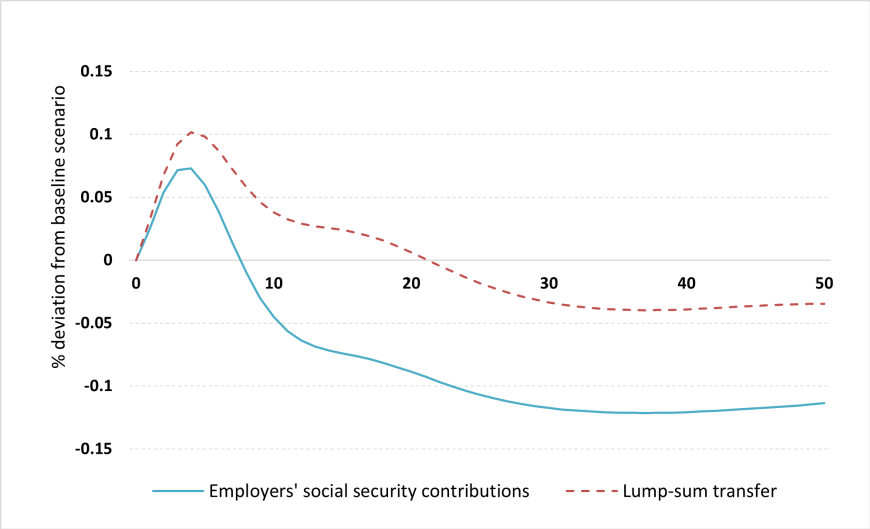
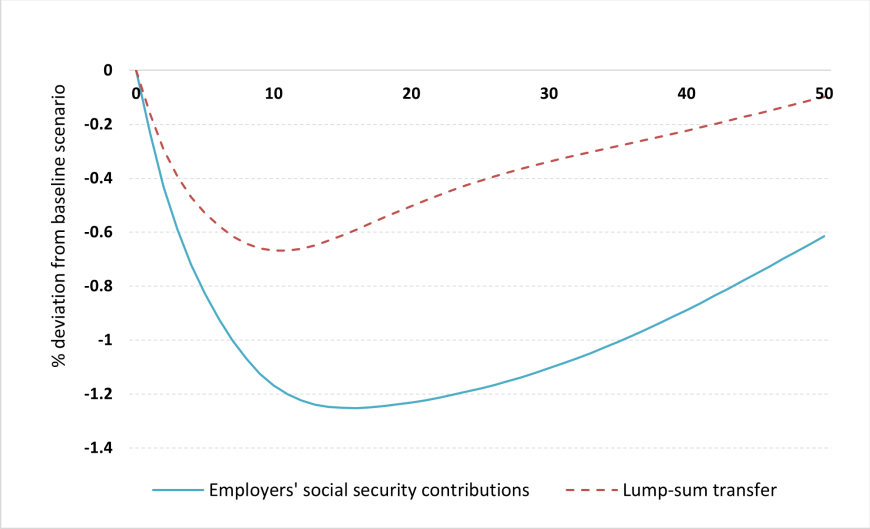


Figure 7: Evolution of firms' investment following the introduction of a carbon tax with Phillips curve, low flexibility and low exposure to foreign competition



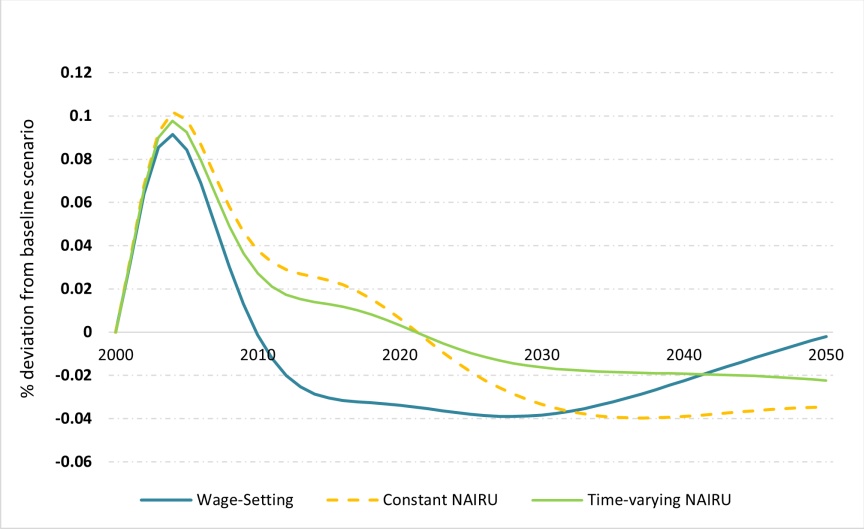
5.6 Wage specifications only influence marginally the DD dynamics

All other parameters remaining constant, considering various wage equation specifications leads to eight different settings. Out of these settings, there is no difference in

outcomes between the two considered Philips curve (with constant or TV NAIRU). When comparing a wage-setting specification to a Philips specification shows differences in three out of the eight possible cases (see Table 1).

However, when looking at the evolution of GDP over time, differences remain small. For instance, when parameters are set to low flexibility, low exposure to foreign competition, and a lump-sum redistribution of the carbon tax, the WS specification leads to no short term DD contrary to a Phillips curve specification (as indicated in Table 1). Still the dynamic reported in Figure 8 show that in all cases there is an increase in GDP in the very short run, peaking four years after the carbon tax implementation. This increase is followed by a decrease, which is a bit steeper with the WS specification. This difference in speed explains why, ten years following the introduction of a carbon tax, a DD appears in one case and not in the other. Except for this slight difference, the overall trajectory of the GDP in both cases is very similar. In the long-run, the WS specification leads to a GDP level slightly higher than before the introduction of the carbon tax, while the opposite holds for the Phillips curve specification.

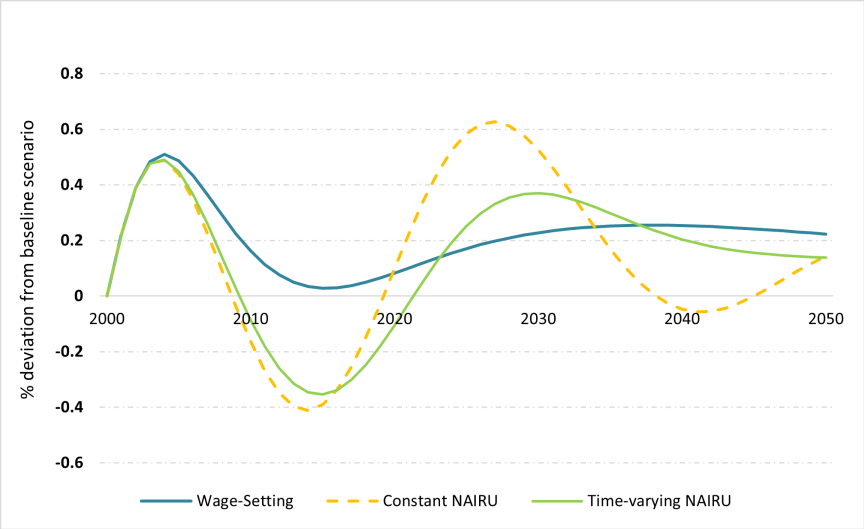
Figure 8: Evolution of GDP (in volume) following the introduction of a carbon tax with low flexibility, low exposure to foreign competition and lump-sum redistribution



The wage equation specification plays also a role in the existence of a DD in the short-run when setting parameters to high flexibility and high exposure to foreign competition, no matter the type of redistribution considered: as indicated in Table 1, the DD appears only with a WS curve. But here as well the very short run dynamic is similar with a GDP increase in all cases (Figure 9).

The impact of the wage equation appears mainly in the medium- to long-run dynamic especially in the cases where one assumes a high degree of flexibility and

Figure 9: Evolution of GDP (in volume) following the introduction of a carbon tax with high flexibility, high exposure to foreign competition and lump-sum redistribution



of exposure to foreign competition (see Figure 9 and the blue curves in Figure 1). The least oscillating lines correspond to scenarios with the WS specification. Those that oscillate the most correspond to scenarios with a Phillips curve featuring a constant NAIRU, which is more inflationary (respectively deflationary) during periods of growth (respectively recession). In this configuration, the high degree of flexibility initially has a positive impact on the economy. However, the subsequent inflation counteracts this effect by significantly degrading competitiveness and activity due to the assumption of strong exposure to foreign competition. When the recessionary effect dominates, a deflationary dynamic takes over, restoring competitiveness and setting the stage for the next recovery phase. This set of assumptions reproduces an endogenous economic cycle reminiscent of the properties of the model proposed by Goodwin (1967). This explains why focusing on a specific year, we can observe significant differences in terms of DD depending on the wage specification.

5.7 The magnitude of the double dividend also needs to be considered

Beyond the existence of a positive economic response after implementing a carbon tax, it is important to consider the magnitudes at stake. To quantify the influence of each feature on short-term GDP, we calculate the spread between the results obtained for two distinct values of a given feature while keeping all other features constant. For instance, in the case of the degree of exposure to foreign competition, we compare the short-term GDP deviation from the baseline under a low degree of exposure with that under a high degree of exposure, holding all other features constant. By "spread", we

refer to the difference between these two deviations. The larger the spread, the more sensitive the model is to the tested feature.

The analysis of spreads confirms previous conclusions, as the largest spreads are associated with the degree of exposure to foreign competition and the degree of flexibility of the economy. The average spread for the degree of exposure to foreign competition is 0.86 (percentage point of GDP), while for the flexibility of the economy it is 0.82. This indicates that switching from high to low exposure results in, on average, a 0.86 percentage point of GDP improvement across scenarios.

Table 3: Spread of GDP deviations from baseline for the factor of exposure to foreign competition

	Lump-sum			**Social security contributions**		
	Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low flexibility	0.40	0.53	0.50	0.38	0.52	0.48
High flexibility	1.04	1.41	1.32	1.03	1.41	1.30

Notes: This table shows the difference between the short-term (10 years) GDP deviations from the baseline scenario following the implementation of a carbon tax when setting a low degree of exposure to foreign competition as compared to a high degree of exposure to foreign competition, all other settings being equal.
Key: When settings are "lump-sum redistribution", "constant NAIRU" and "high flexibility of the economy", the difference between the short-term (10 years) deviations from the baseline of the GDP when comparing a low degree of exposure to foreign competition and a high degree of exposure is 1.41. In other words, the economic activity is better off by 1.41 percentage point of GDP in the case of a low degree of exposure to foreign competition compared to a high degree of exposure.

More specifically, the spreads for the degree of exposure to foreign competition range from 0.38 to 1.41, and two clusters can be identified depending on the degree of flexibility of the economy (cf. Table 3). When the flexibility of the economy is kept at a low level, the average spread for the exposure to foreign competition parameter is approximately 0.47. In contrast, the average spread increases to 1.25 when flexibility is set to a high level.

Table 4: Spread of GDP deviations from baseline for the factor of flexibility of the economy

	Lump-sum			**Social security contributions**		
	Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low exposure	1.21	1.21	1.20	1.21	1.21	1.20
High exposure	0.56	0.32	0.38	0.57	0.33	0.39

Notes: This table shows the difference between the short-term (10 years) GDP deviations from the baseline scenario following the implementation of a carbon tax when setting a low degree of flexibility of the economy as compared to a high degree of flexibility, all other settings being equal.
Key: When settings are "lump-sum redistribution", "constant NAIRU" and "low exposure to foreign competition", the difference between the short-term (10 years) deviations from the baseline of the GDP when comparing a high degree flexibility and a low degree of flexibility is 1.21. In other words, the economic activity is better off by 1.21 percentage point of GDP in the case of a high degree flexibility of the economy compared to a high degree flexibility.

A similar conclusion can be drawn from the analysis of the spreads for the degree of flexibility of the economy. While there is significant heterogeneity across spreads, it can be reduced to two main clusters based on the degree of exposure to foreign competition. Table 4 shows the improvement of the economic activity when the degree of flexibility of the economy is increased. The average spread is around 1.21 when the economy is not highly exposed to foreign competition, compared to an average

spread of 0.43 when it is highly exposed. This confirms the previous conclusion that the combination of the flexibility and exposure to foreign competition parameters determines whether a double dividend happens following the implementation of a redistributed carbon tax. In contrast, the type of redistribution and the specification of the wage equation have no significant impact on the magnitude of deviations from the baseline (see Appendix, Table 9 and Table 10).

Nevertheless, the magnitude of the double dividend does not only depend on the magnitude of the reaction of the economic activity but is also impacted by the magnitude of the emission reduction itself. All other things being equal, the greater the emission reduction, the larger the DD. Our estimates for emission reductions following the implementation of the same policy vary a lot in the short-run. Table 5 shows that the emission reduction ranges from 13.60 to 2.75 percents. Settings that lead to the biggest emission reductions feature a high degree of flexibility of the economy as well as a high degree of exposure to foreign competition. Since settings that lead to the biggest reduction in emissions do not coincide with the ones leading to the biggest economic activity response, our results indicate that a trade-off between emission reductions and economic activity exist.

Table 5: Overview of the CO_2 emissions deviation from baseline scenario 10 years after the introduction of a carbon tax

		Lump-sum			**Social security contributions**		
		Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low flexibility	*Low exp.*	-2.75	-2.77	-2.81	-2.98	-3.02	-3.07
	High exp.	-3.33	-3.47	-3.46	-3.54	-3.71	-3.69
High flexibility	*Low exp.*	-11.06	-10.68	-10.93	-11.25	-10.85	-11.11
	High exp.	-13.03	-13.43	-13.39	-13.18	-13.60	-13.55

Notes: This table sums up the 24 possible settings with regard to the deviations from baseline scenario in terms of CO_2 emissions 10 years following the implementation of a carbon tax. For instance, when redistributing the carbon tax as a lump-sum transfer to firms, with a wage-setting equation, high flexibility and low exposure to foreign competition, the emissions deviate from the baseline scenario by -11.06% ten years following the shock.

6 Conclusion

In this paper, we perform a systematic analysis to understand how modeling features impact the existence and dynamics of a double dividend in a neo-Keynesian framework. We use a multi-sector macroeconomic model (ThreeME) calibrated on French data.

We investigate the role of (i) the degree of exposure to foreign competition where a low exposure can be seen as a proxy for trading partners implementing a joint carbon policy; (ii) the flexibility of the economy, i.e., the ease with which economic agents can substitute green for brown technology; (iii) the type of redistribution of the carbon tax revenues (lump-sum redistribution vs. reduction of employers' social security contributions); (iv) the wage equation and inflation dynamics specification (Wage-Setting versus Phillips curve with constant or time-varying NAIRU).

We conclude that not all features play an equal role. Among the ones analyzed,

the degree of economic flexibility and the level of exposure to foreign competition emerge as the most decisive factors. However, no single factor alone can fully explain the presence or absence of a DD. It is the interplay of multiple features that must be considered. Specifically, the combination of low economic flexibility and high exposure to foreign competition consistently prevents the occurrence of a DD, irrespective of other parameters. Conversely, a high degree of flexibility coupled with low exposure to foreign competition ensures a DD. This is due to the fact that greater economic flexibility or lower exposure to foreign competition quantitatively improves the economic position of net fossil fuel-importing countries like France, thereby mitigating the adverse economic effects of a carbon tax. While the type of redistribution of carbon tax revenues to firms and the specification of the wage equation are less critical, the interaction between wage specification and exposure to foreign competition provides additional insights.

These findings have two key policy implications. First, enhancing economic flexibility requires fostering the ability to substitute between energy sources, which underlines the importance of R&D investment policies aimed at developing low-carbon technologies. Such policies not only increase the potential to reduce emissions, but also reduce the associated economic costs. Second, given the costs inherent to a low-carbon transition, an economic dividend can only be achieved if the economy is protected from environmentally unfair competition. A global cooperative agreement on carbon reduction remains the most promising approach to address this point but is difficult to achieve. A carbon border adjustment mechanism (CBAM) could also provide such a protection, while making it more profitable to relocate some industrial production in Europe. The latter aspect seems all the more desirable as several recent crises (COVID-19, the 2022 energy crisis, the 2025 threat of a globalized trade war) have exposed the vulnerability of globalized supply chains and underscored the need for European countries to reduce their dependence on imports. Finally, a CBAM could also incentivize foreign countries to decarbonize their production processes in the medium term, at least those whose products they want to export to Europe, potentially further reducing global emissions.

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Appendix: additional results

With redistribution of the receipts of the carbon tax to households and firms

Table 6: Overview of the GDP (in volume) deviation from baseline scenario 10 years after the introduction of a carbon tax

		Lump-sum			**Social security contributions**		
		Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low	*Low exp.*	0.00	0.04	0.03	-0.08	-0.05	-0.06
flexibility	*High exp.*	-0.40	-0.49	-0.47	-0.46	-0.57	-0.54
High	*Low exp.*	1.21	1.25	1.23	1.13	1.17	1.15
flexibility	*High exp.*	0.16	-0.68	-0.09	0.10	-0.24	-0.15

Notes: This table sums up the 24 possible settings with regard to the deviations from baseline scenario in terms of GDP (in volume) 10 years following the implementation of a carbon tax. For instance, when redistributing the carbon tax as a lump-sum transfer to firms, with a wage-setting equation, high flexibility and low exposure to foreign competition, the GDP (in volume) deviates from the baseline scenario by 1.21% ten years following the shock.

Table 7: Overview the existence of a long-term dividend depending on various model settings

		Lump-sum			**Social security contributions**		
		Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low	*Low exp.*	No	No	No	No	No	No
flexibility	*High exp.*	No	No	No	No	No	No
High	*Low exp.*	Yes	Yes	Yes	Yes	Yes	Yes
flexibility	*High exp.*	Yes	Yes	Yes	Yes	Yes	Yes

Table 8: Overview of the evolution of the GDP (in volume) 50 years after the introduction of a carbon tax

		Lump-sum			**Social security contributions**		
		Wage-Setting	Constant NAIRU	TV NAIRU	Wage-Setting	Constant NAIRU	TV NAIRU
Low	*Low exp.*	0.00	-0.03	-0.02	-0.04	-0.11	-0.10
flexibility	*High exp.*	-0.18	-0.02	-0.07	-0.22	-0.09	-0.15
High	*Low exp.*	0.39	0.25	0.29	0.36	0.19	0.22
flexibility	*High exp.*	0.22	0.14	0.14	0.18	0.09	0.06

Table 9: Spread of GDP deviations from baseline for the factor of type of redistribution

		Wage-Setting	Constant NAIRU	TV NAIRU
Low flexibility	*Low exp.*	0.08	0.08	0.08
	High exp.	0.06	0.08	0.07
High flexibility	*Low exp.*	0.08	0.08	0.08
	High exp.	0.06	0.08	0.07

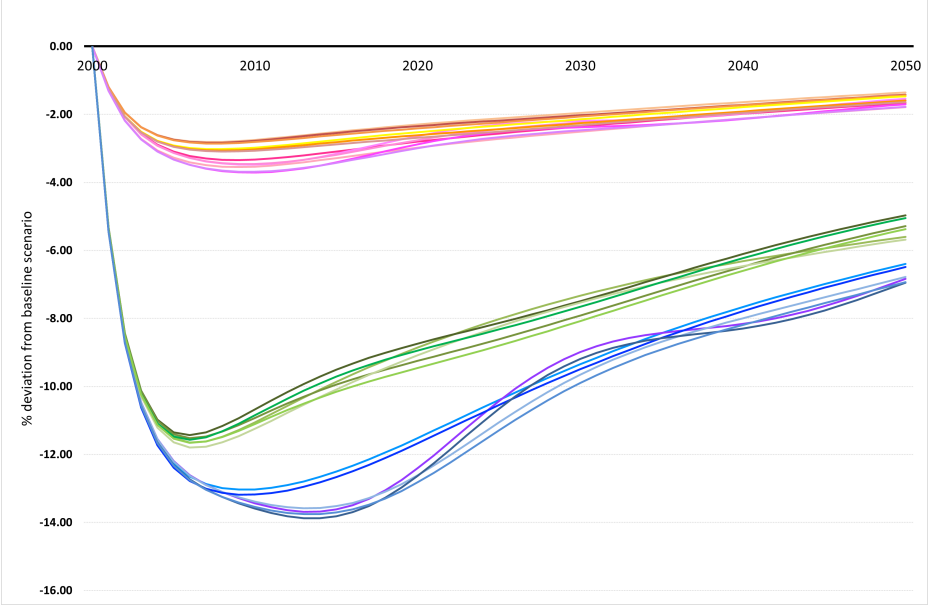
Notes: This table shows the difference between the short-term (10 years) GDP deviations from the baseline scenario following the implementation of a carbon tax when setting a lump-sum transfer as compared to decrease of employers' social security contribution, all other settings being equal.
Key: When settings are "wage-setting curve", "low flexibility" and "low exposure to foreign competition", the difference between the short-term (10 years) deviations from baseline of the GDP when comparing a lump-sum transfer and a decrease of employers' social security contribution is 0.08.

Table 10: Spread of GDP deviations from baseline for the factor of wage specification

		(1)		**(2)**		**(3)**	
		Lump-sum	SSC	Lump-sum	SSC	Lump-sum	SSC
Low flexibility	*Low exp.*	-0.04	-0.04	-0.03	-0.02	0.01	0.01
	High exp.	0.09	0.11	0.07	0.08	-0.02	-0.03
High flexibility	*Low exp.*	-0.04	-0.04	-0.02	-0.02	0.02	0.02
	High exp.	0.33	0.34	0.25	0.26	-0.08	-0.09

Notes: This table shows the difference between the short-term (10 years) GDP deviations from the baseline scenario following the implementation of a carbon tax when setting different wage curve specifications: WS as compared to Philips curve with constant NAIRU (1) or WS as compared to Philips curve with time-varying NAIRU (2) or Philips with constant NAIRU as compared to Philips with time-varying NAIRU (3), all other settings being equal.
Key: When settings are "lump-sum redistribution", "low flexibility" and "low exposure to foreign competition", the difference between the short-term (10 years) deviations from baseline of the GDP when comparing a wage-setting curve (WS) and a Philips curve with constant NAIRU is -0.04.

Figure 10: Long-term evolution of the CO2 emissions following the implementation of a carbon tax (24 scenarios) **with** redistribution



<u>Without</u> redistribution of the receipts of the carbon tax to households and firms

Figure 11: Long-term evolution of the CO2 emissions following the implementation of a carbon tax (24 scenarios) **without** redistribution

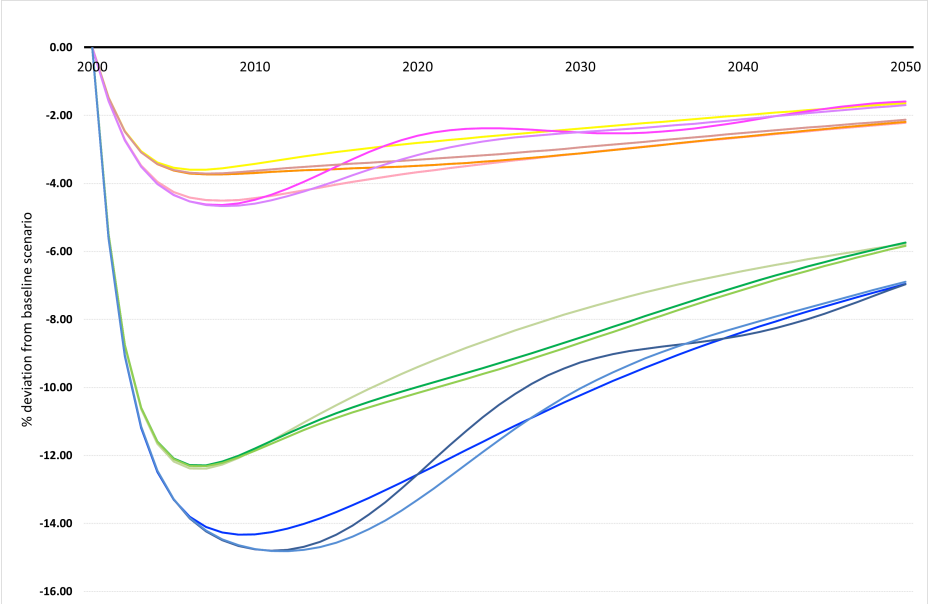
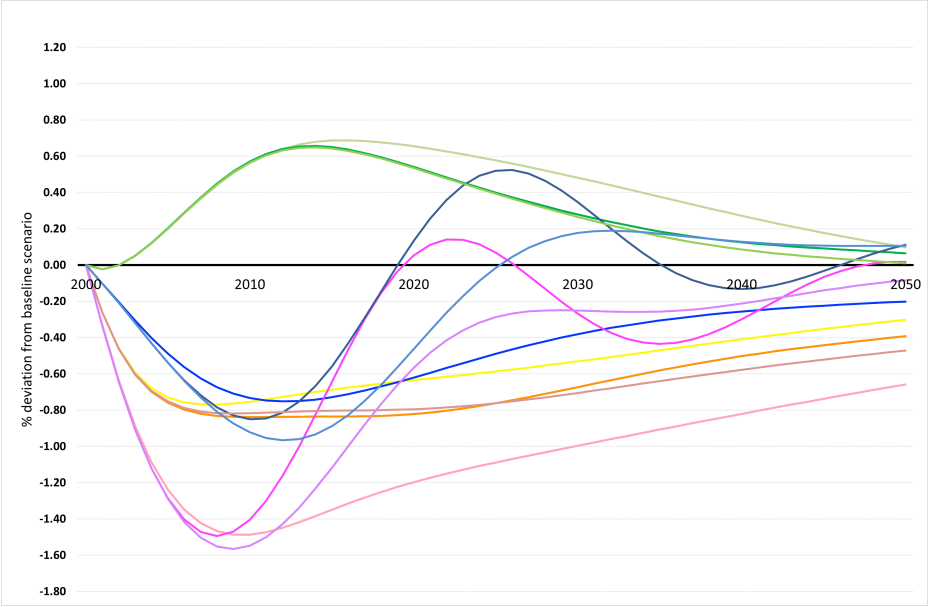


Figure 12: Long-term evolution of the GDP (in volume) following the implementation of a carbon tax (24 scenarios) **without** redistribution



ABOUT OFCE

The Paris-based Observatoire français des conjonctures économiques (OFCE), or French Economic Observatory is an independent and publicly-funded centre whose activities focus on economic research, forecasting and the evaluation of public policy.

Its 1981 founding charter established it as part of the French Fondation nationale des sciences politiques (Sciences Po) and gave it the mission is to "ensure that the fruits of scientific rigour and academic independence serve the public debate about the economy". The OFCE fulfils this mission by conducting theoretical and empirical studies, taking part in international scientific networks, and assuring a regular presence in the media through close cooperation with the French and European public authorities. The work of the OFCE covers most fields of economic analysis, from macroeconomics, growth, social welfare programmes, taxation and employment policy to sustainable development, competition, innovation and regulatory affairs.

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Its research community includes over two hundred twenty members and three hundred fifty PhD candidates. Recognized internationally, their work covers a wide range of topics including education, democracies, urban development, globalization and public health.
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