Are subsidies for "green" R&D better to fight climate change than a carbon tax?

Climate change, a consequence of excess greenhouse gas emissions (GGE) into the atmosphere, may seriously disrupt the world economy in future decades. In a 2006 report, the results of which have been widely publicised, economist Nicholas Stern considered that in the absence of coordinated intervention by the international community, the average temperature could rise more than 3°C by the end of the century, which would cost the planet's inhabitants the equivalent of 5% of gross world product each year (Stern, 2007). We study and compare two types of tools at the disposal of the public authorities to encourage a reduction in carbon emissions: a carbon tax and subsidies for "green" research and development (R&D). We show that the two policies are not antagonistic but in fact complementary, with each reinforcing the role of the other in the correction of the externality justifying its implementation.

From a strictly economic point of view, GG emissions are like a negative environmental externality that should be corrected with the help of economic tools, like any other form of pollution. Regarding CO_2[1] emissions, a carbon tax is part of a package of available tools. By making the price of fossil energy more expensive, it aims to reduce its use, thereby favouring substitution by alternative forms of non-carbon energies.

Improving the efficiency of non-carbon technologies or "decarbonisation" helps fight against GGE. Technical progress plays a dominant role in systems of emission reduction. However, t aking account of technical progress from research implies the emergence of a second type of distortion of the economy: externalities linked to R&D activity, such as the transmission of knowledge beyond its originator, the phenomena of imitation, and so on…They prevent innovators from capturing all the income associated with their innovation, so much so that they innovate less than would be optimal for society. Empirical studies show that taking all sectors together, the merchant value of an innovation remains 3 to 4 times lower than its optimal value, thus explaining under-investment in R&D. These externalities may also be corrected by subsidies to R&D, for instance. However, by cutting the running cost of alternative energies, these subsidies are also liable to have effects on fossil energy consumption and therefore on CO_2 emissions.

Which tools to fight GG emissions?

Connecting these two types of externalities, climate and R&D, therefore supposes the emergence of complex interactions. The objective of this study is to identify the main lines followed by combined carbon tax and green R&D subsidies and analyse their joint effects. We use a endogenous growth model of the "top-down" type showing two sources of

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[1] The CO_2 representing more than 70% of the GG of anthropic origin, we limit ourselves to that sole emission source in that study

externalities linked to climate and research, respectively corrected by a carbon tax and a system of subsidies, to simulate several scenarios (see frame). These scenarios are mentioned in table 1.

Methodological frame: description of the model

The model used is of the top-down type, that is to say that it includes all the interactions between economic growth and climate on a global scale. It is derived from the Nordhaus' DICE model (2008) and is illustrated by figure 1.

Figure 1: Description of the model
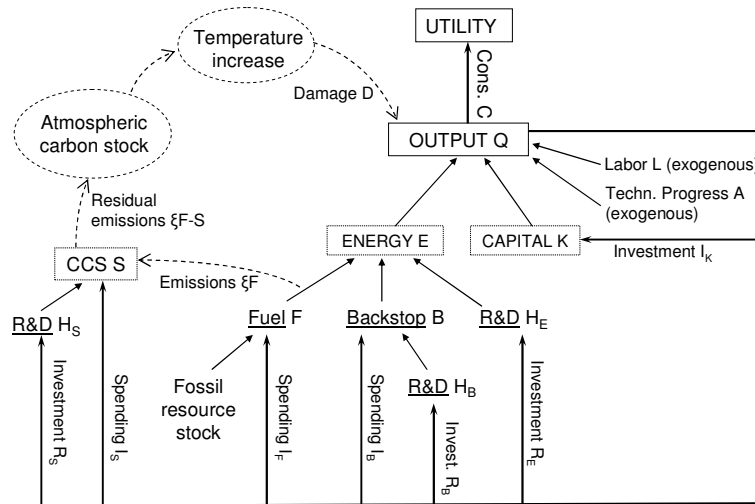
We consider a competitive economy in which a final consumption good (Q) is produced from Capital (K) and Energy (E), itself produced from two imperfectly substitutable sources of primary energy: a fossil energy (F) coming from a non-renewable stock of resources and a non-carbon renewable resource (B). The CO_2 emissions from fossil resource combustion may be sequestered and stockpiled in geological reservoirs (CCS). The residual emissions accumulate in the atmosphere, causing a rise in average temperature. These variations in temperature affect the economy through a damage function which reduces the production level. This synthetic function includes both gradual weak to medium damage and catastrophic and irreversible damage, requiring the setting of a maximum of atmospheric CO_2 concentration ceiling that must not be exceeded. There are three sectors of endogenous R&D, respectively dedicated to energy effiency (H_E), renewable production of energy (H_B) and sequestration (Hs). Final production is divided between consumption (C), direct investments in capital (I_k) production of primary energies (I_B and I_F), sequestration (I_S) and investments in specific R&D (R_B, R_E and R_S).

The climate externality is corrected by a tax on residual CO_2 emissions and the distortions linked to research by the subsidies in each R&D sector. Next, we analytically determine all the equilibria of the economy, with each one corresponding to a particular combination of economic policies. The numerical analysis of the model, however, limits this spectrum to a selection of scenarios (see table1).
Next, the model is calibrated using world data from existing models (DICE, ENTICE-BR, DEMETER) or reports from independent bodies (AIC, IPCC).

Scenarios A and D represent the two extreme situations of laissez-faire (no distortion correction) and first-order optimal (optimal correction of both distortions). Their comparison allows the joint effects of both tools to be assessed. Between them, 2 second-order B and C scenarios each correct one of the two sources of externalities unilaterally with the help of the appropriate tool. They therefore enable the assessment of both policies' separateed effects on the economy. Finally, E and F are forced optimal "scenarios" in which R&D subsidies are set at the same levels as in D, but the carbon tax is fixed so as to stabilize atmospheric CO_2 concentration below a definite ceiling, in an optimal way.
These thresholds are set at 550ppmv (parts per million volume) for E and 450ppmv for F, which corresponds to 2°C or 3°C temperature rises or so compared with the 1990 levels, respectively.

Table 1: Scenarios

Scenario	Carbon tax	R&D subsidy	Description
A	no	No	Laisser-faire
B	yes	No	2nd order optimal with carbon tax and without R&D subsidy
C	no	Yes	2nd order optimal with R&D subsidy and without tax
D	yes	Yes	1er order optimal
E	yes	Yes	Optimal with 550ppmv ceiling
F	yes	Yes	Optimal with 450ppmv ceiling

Carbon tax

Figure 2 shows the paths of the various carbon taxes that would have to be implemented to maximize social welfare in each scenario.

The first-order optimal tax (scenario D) starts from an initial level of $49/tC (dollars per ton of carbon) and increases continuously to reach $256 in 2015. The lack of an R&D support policy implies a slightly higher second-order tax level than the first-order one, chiefly over the very long term. On the second hand, the stabilization objectives of 550 and 450ppmv require quite high tax levels. They start at $73 and 172$ respectively, next increase quickly to reach their respective optimums of $550 and $735 in 2075 and 2055, before decreasing once the concentration ceilings are reached. The more restrictive the ceiling, the faster the tax increases in the short term and the sooner it reaches its peak.

Investments in R&D

Figure 3 shows the R&D investment intensity in each sector (that is to say the share of research efforts in production) for each scenario. In the absence of regulation (scenario A), these investments are very small, as is also the case when the sole environmental externality is corrected (scenario B). In order to really stimulate R&D, the correction of the externalities linked to research by specific subsidies is necessary (scenarios C and D).
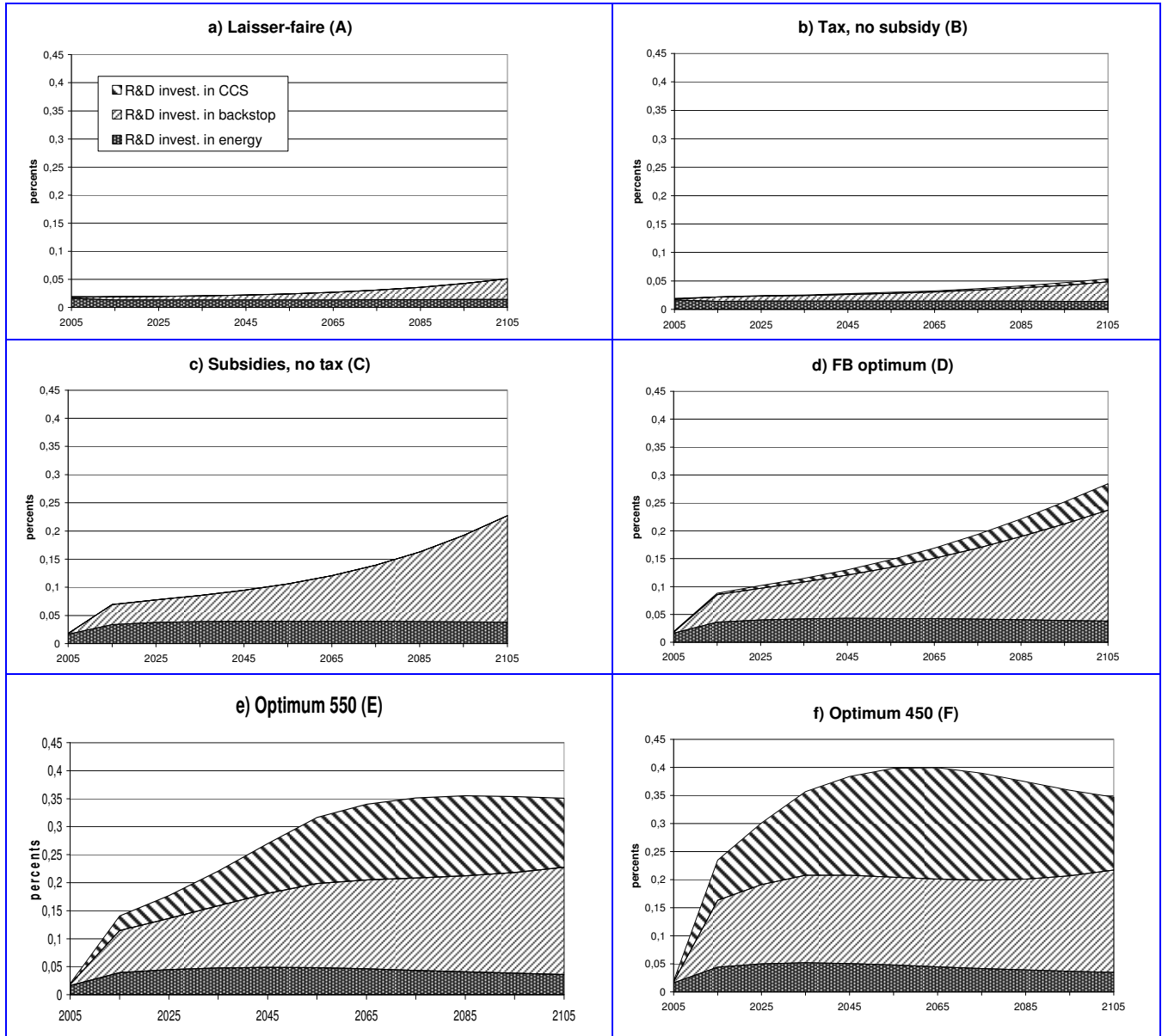
Figure 2: The various optimal taxes
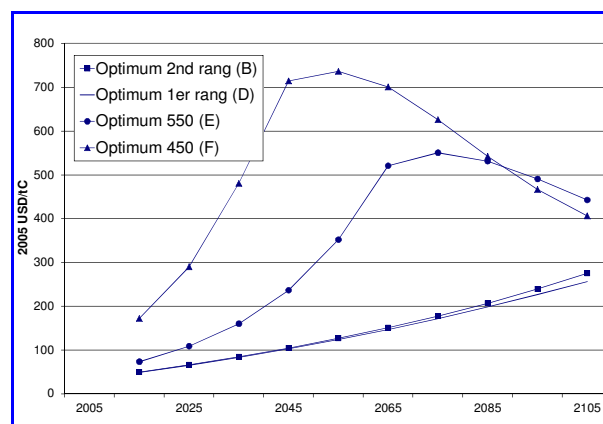
However, the use of subsidies without carbon tax turns out to be ineffective in concentrating research on CCS (Carbon Capture and sequestration (scenario C), the backstop renewable energy sector being the only one to benefit from the correction. To really increase research efforts in CCS, it would seem necessary to turn to a carbon tax in addition to R&D subsidies (scenario D). This combination of tools raises R&D expenditure in CCS to nearly 17% of global expenditure by 2100. This result is boosted by adding the concentration ceilings implying higher tax levels (scenarios E and F).

To sum up, implementation of a carbon tax alone is not enough to stimulate research, whatever the sector considered. In order to create effective incentives, a system of subsidies dedicated to each of the three sectors must be added.

Figure 3: Investment intensity in R&D

a) Laisser-faire (A)

Legend:
- R&D invest. in CCS
- R&D invest. in backstop
- R&D invest. in energy

b) Tax, no subsidy (B)

c) Subsidies, no tax (C)

d) FB optimum (D)

e) Optimum 550 (E)

f) Optimum 450 (F)

The composition of the energy mix

Figure 4 illustrates the energy mix trend over the century to come, according to various scenarios. We distinguish consumption of fossil energy without turning to CCS, consumption of fossil energy coupled with CCS and consumption of renewable not- carbonated energy.

Scenario A results in global energy consumption which should increase fivefold by the end of the century in the absence of restrictive policies (this laissez-faire consumption is shown on the other graphs by the dotted curve). Moreover, CCS is not used at all and renewable energy consumption remains low. The introduction of a carbon tax alone (passing from A to B) has no effect on use of renewable energy while it considerably reduces consumption of fossil energy and only provides very little incentive to sequester carbon. This is translated by a substantial fall in global energy consumption. Symmetrically, the unilateral introduction of subsidies for R&D (passing from A to C has an effect neither on the use of fossil energies nor on use of CCS). On the other hand, it implies a greater penetration of renewable energy in the energy mix, which increases global consumption of energy. The simultaneous use of both types of policies (passing from A to D) clearly shows an

additional effect between each one of them. This scenario strengthens the unilateral tax effect on the consumption of fossil energy and the sequestration of emissions (up to 4% in 2010).

Moreover, it also strengthens the subsidy effect on the use of renewable energy.

Figure 4: Composition of the global energy consumption according to the sources of primary energies
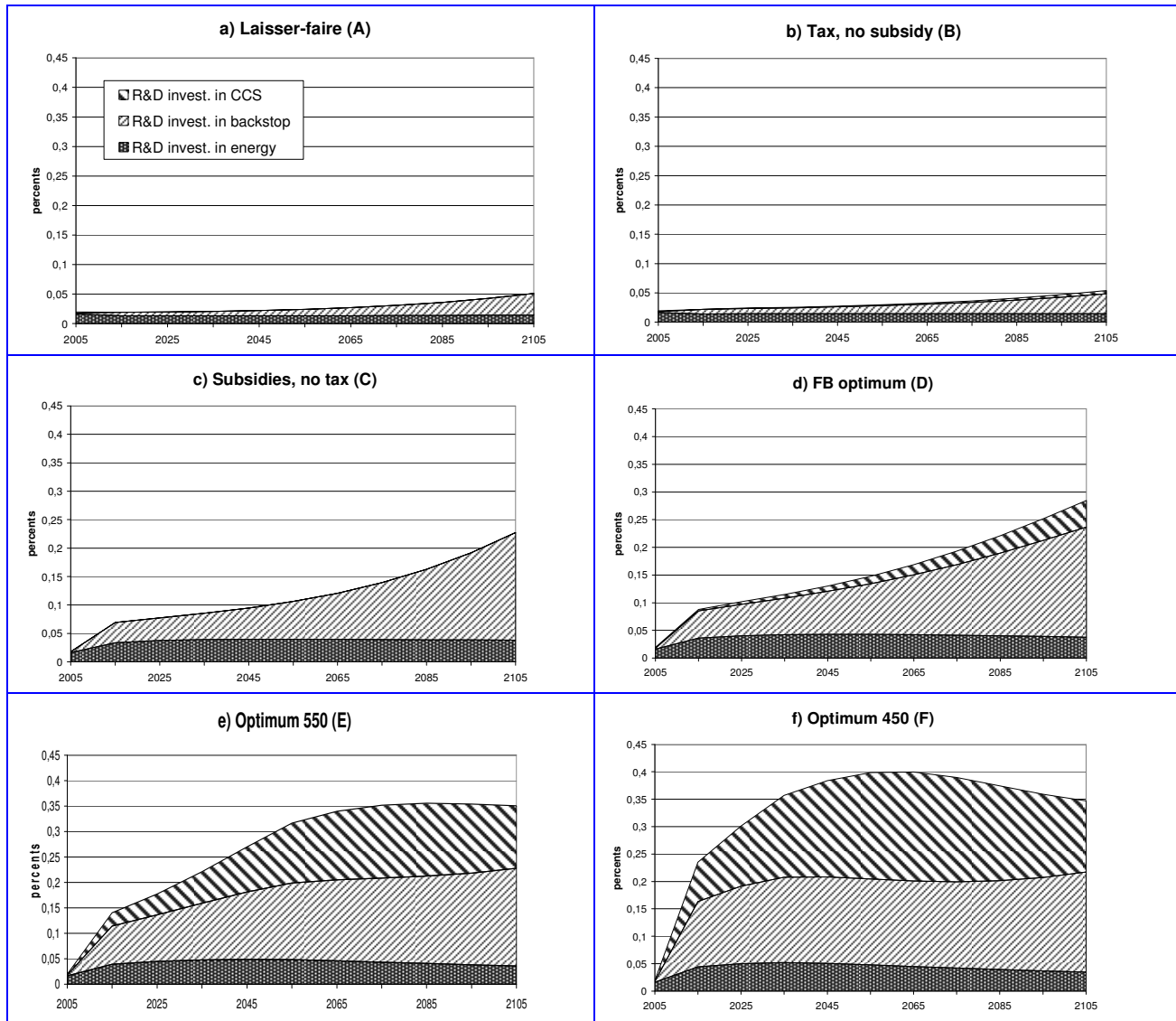
Last, both scenarios with stabilization constraints (E and F) imply radical changes in the energy mix, due to the sharp rise in fossil energy costs. Fossil energy is sharply reduced in the short term, before the substitution potentialities really become effective. This involves a 47% fall in global demand for energy in 2050 in scenario E and 60% in scenario F compared with scenario A. As investments in R&D, substantial in both scenarios as we already mentioned, make the production technologies of renewable energy and sequestration competitive, the global consumption of energy has a tendency to grow again. It is driven by a major development of

renewable energy (from 42 to 46% of global energy in 2010 according to ceiling levels) and by increasing use of fossil energy coupled with a sequestration device (from 40 to 49% of global energy in 2010, depending on the ceiling).

The impact on climate and economy

The consequences of the various scenarios in terms of emissions are represented in figure 5-a. The highest curve of atmospheric CO_2 concentration and the one which grows the quickest is obtained in scenario A, in which neither regulation is applied. At the end of the century, this reaches 1000ppmv, a critical

threshold according to the International Panel on Climate Change and which corresponds to an average temperature rise of more than 6°C. The unilateral use of research subsidies hardly helps to reorientate this tendency (scenario C). On the other hand, the implementation of a carbon tax proves to be more efficient in reducing these concentrations, which then reach no more than 850ppmv in 2100 (scenario B). The combination of both policies (scenario D) boosts the unilateral effect of the carbon tax since it enables the reduction of concentrations to 800ppmv by the end of the century. Last, the lowest concentration levels are observed in the two restricted scenarios E and F.

The repercussions on the economy must be connected directly with these concentration curves (see graph in Grimaud et al., 2010). The cost of inaction (scenario A) can amount to 5% of World Gross Product (WGP) in 2010. The simultaneous implementation of both types of optimal policies enables this cost to be kept to 3.5% of WGP by the same horizon. Imposing ceilings of 550ppmv and 450ppmv, respectively, limits these losses to 1.8% and 1% of the WGP.

Last, the intergenerational social cost of each combination of economic policies may be assessed by comparing the WGP path obtained in each regulated scenario with the laissez-faire scenario. The resulting changes are given in figure 5-b. The conclusions of these comparisons are the following: i) Carbon tax involves wealth losses for the first generations and gains for the future ones. The more restrictive the tax the greater the amplitude of the difference between short-term losses and long-term gains, meaning even greater economic growth for the future generations. ii) Subsidies to R&D only imply gains for society, which increase with the generations. On the other hand, long-term gains offered by these subsidies remain lower than those of the carbon tax, at least in scenarios D, E, and F. The simultaneous use of both types of tools therefore enables a better intergenerational distribution of the costs of policies to fight climate change.

More complementary than antagonistic

This research consisted in studying the policy effects of an environmental tax and a support policy for green research in the fight against climate change. We therefore developed an endogenous growth model of the "top-down" type presenting two externality sources linked to climate and research, respectively corrected by a carbon tax and a subsidy system. Once graded, apart from the standard comparison of the laissez-faire and first-orderoptimum options, the model calculated a certain number of second-order optima.

Figure 5: Impact on climate and economy
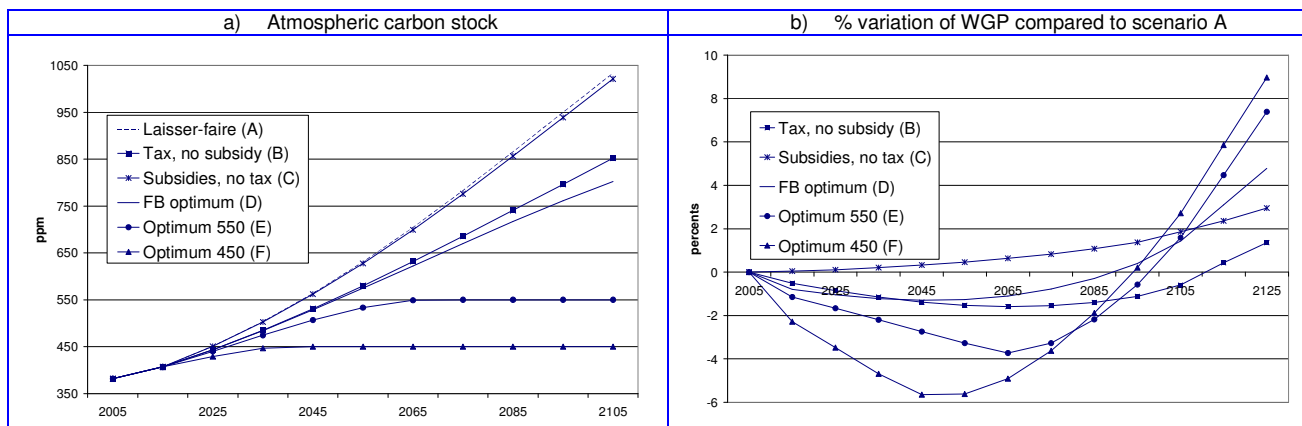
The main results of this study are the following:

i)   The indirect effects of each policy are not very significant. The use of a carbon tax only provides a small incentive to develop research while granting green research subsidies only very slightly modifies CO_2 emission paths.

ii)   Simultaneous use of both types of tools boosts the individual effect of each in correcting the externality for which it was implemented, thus revealing some complementarity between carbon tax and subsidies for green R&D.

iii)   Geological carbon sequestration does not appear a competitive option as long as no really restrictive atmospheric CO_2 concentration ceilings are set. Conversely, like renewable energies, it becomes an effective medium term solution in the fight against climate change.

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For further information:

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