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The optimal carbon sequestration in agricultural soils: Do the dynamics of the physical process matter?

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ABSTRACT

The Kyoto Protocol, which came into force in February 2005, allows countries to resort to 'supplementary activities', consisting particularly in carbon sequestration in agricultural soils. Existing papers studying the optimal carbon sequestration recognize the importance of the temporality of sequestration, but overlook the fact that it is an asymmetric dynamic process. This paper takes explicitly into account the temporality of sequestration. Its first contribution lies in the modelling of the asymmetry of the sequestration/de-sequestration process at a micro level, and of its consequences at a macro level. Its second contribution is empirical. We compute numerically the optimal path of sequestration/de-sequestration for specific damage and cost functions, and a calibration that mimics roughly the world conditions. We show that with these assumptions sequestration must be permanent, and that the error made when sequestration is supposed immediate can be very significant.

1. Introduction

The Kyoto Protocol, ratified by the European countries in 2002 and in force from February 2005, allows countries to resort to 'supplementary activities', consisting in the sequestration of carbon in forests and in agricultural soils (Articles 3.3 and 3.4). The emissions trapped by such voluntary

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activities, set up after 1990, can be deduced from the emissions of greenhouse gas. They can be the result of afforestation projects (Article 3.3) or of changes of practices in the agricultural and forestry sectors (Article 3.4). As far as this last Article is concerned, the list of eligible activities proposed by the IPCC (2000) gives appreciable opportunities of reduction of emissions to countries possessing significant surfaces of agricultural land. For example, gross French emissions of greenhouse gas were estimated at 148 MtC in 2000. France emits low levels of GHG per capita and will encounter difficulties in further reducing its emissions, in part because of the importance of French nuclear energy generating capacity. Given the area of land devoted to agriculture, the prospects opened by Article 3.4 may be of interest for the French policy of greenhouse gas mitigation. The French National Institute for Agricultural Research has estimated the potential additional carbon storage for the next 20 years, between 1 and 3 MtC/year, for the whole of mainland France (INRA, 2002). This potential is equivalent to 1%–2% of annual French greenhouse gas emissions, a large proportion of the efforts required to comply with the commitments to the Kyoto Protocol. At the European level, this potential is estimated at 1.5%–1.7% of the EU-15 anthropogenic CO_2 emissions during the first commitment period (European Climate Change Programme, 2003).

The Bonn Agreement (COP6bis) in July 2001 clarifies the implementation of Article 3.4: eligible activities in agriculture comprise 'cropland management', 'grazing land management' and 'revegetation', provided that these activities have occurred since 1990 and are human-induced. Carbon sequestration can occur either through a reduction in soil disturbance (zero tillage or reduced tillage, set-aside land, growth of perennial crops…) or through an increase of the carbon input to the soil (animal manure, sewage sludge, compost…). Switching from conventional arable agriculture to other land-uses with higher carbon input or reduced disturbance can also increase the soil carbon stock (conversion of arable land to grassland or woodland, organic farming…).

Lal et al. (1998) provide estimates of the carbon sequestration potential of agricultural management options in the USA. A few studies present estimations of agricultural soil carbon sequestration potentials for EU-15 (see European Climate Change Programme, 2003), and one study does the same for France (INRA, 2002). They all show that soil carbon sequestration is a non-linear process. Increases in soil carbon are often greatest soon after a land use or land management change is implemented. There is also a sink saturation effect: as the soil reaches a new equilibrium, the rate of change decreases, so that after 20 to 100 years a new equilibrium is reached and no further change takes place. Moreover, by changing agricultural management or land-use, soil carbon is lost more rapidly than it accumulates (Smith et al., 1996; INRA, 2002). Carbon de-sequestration is far faster than sequestration or, to put it differently, carbon storage in agricultural soils takes far more time than carbon release (the unit of measure of the storage time is tens of years, the one of release is years, see INRA, 2002).

The aim of this paper is to study the optimal policy of carbon sequestration in agricultural soils. While many technical papers try to quantify the potential of carbon sequestration, very few study the optimal path of sequestration. To the best of our knowledge, the paper by Feng et al. (2002) is the only one. But their dynamic representation of the process is limited by the assumption that the sequestration potential of a unit of land on which a change in land use or land management takes place is instantaneously obtained. Technical papers recognize the importance of the temporality of sequestration, and we take here this temporality explicitly into account. Moreover, we also take into account the fact that sequestration is an asymmetric dynamic process, which most experts in the field of agriculture consider determining (INRA, 2002).

We adapt the Feng et al. (2002) model to take into account explicitly the dynamics of the sequestration process. The main characteristics of our model are the following. Economic activity causes exogenous carbon emissions that accumulate into the atmosphere. Damages are associated to the atmospheric carbon stock. Carbon sequestration in agricultural soils has a cost, depending on how much land is devoted to it. When a change of practice occurs on a unit of land in order to enhance its carbon sequestration, it stores its potential gradually; when the unit of land returns to the usual practice, it releases carbon more rapidly than it has stored it. The total amount of land on which a change of practice can take place is bounded from above. In the same way, at each date, the amount of new land that can be used to store carbon is bounded from above, as well as the amount of land that can go back to the usual practice. This assumption expresses in a simple way the existence