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Analysis

Farm-level Autonomous Adaptation of European Agricultural Supply to Climate Change

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ABSTRACT

The impact of climate change on European agriculture is subject to a significant uncertainty, which reflects the intertwined nature of agriculture. This issue involves a large number of processes, ranging from field to global scales, which have not been fully integrated yet. In this study, we intend to help bridging this gap by quantifying the effect of farm-scale autonomous adaptations in response to changes in climate. To do so, we use a modelling framework coupling the STICS generic crop model to the AROPAj microeconomic model of European agricultural supply. This study provides a first estimate of the role of such adaptations, consistent at the European scale while detailed across European regions. Farm-scale autonomous adaptations significantly alter the impact of climate change over Europe, by widely alleviating negative impacts on crop yields and gross margins. They significantly increase European production levels. However, they also have an important and heterogeneous impact on irrigation water withdrawals, which exacerbate the differences in ambient atmospheric carbon dioxide concentrations among climate change scenarios.

1. Introduction

The impacts of climate change on agriculture have come under scientific scrutiny for more than two decades, but are still shadowed with uncertainty. Agriculture is fundamentally of an intertwined nature, involving agronomic, environmental and socio-economic dimensions. Studies set out to disentangle what is at stake from these points of views (Parry et al., 2007), but the estimates and the tools used to carry them out varied greatly.

Recent studies on this matter covering at least the European continent (Alcamo et al., 2007; Audsley et al., 2006; Fischer et al., 2005; Hermans et al., 2010; Parry et al., 2004; Rounsevell et al., 2005; van Meijl et al., 2006) generally appraise the impact of *global change* on agriculture, achieving significant prospective insights on the state of future agriculture. Indeed, they pay much attention to accounting for the evolution of the main determinants of agriculture other than climate itself. More specifically, they include technological progress, climate change, and land use change (affecting future agricultural supply), and global-wide demography and its food diets, trade regimes, and economic growth rates (affecting the future demand for agricultural goods). On the one hand, global-scale partial and general equilibrium models endogenously model changes in technological progress, demand for agricultural goods and land use consistently across the given spatial domain, and dynamically over time (Fischer et al., 2005; van Meijl et al., 2006). On the other hand, finer-scale land-use models (Audsley et al., 2006; Hermans et al., 2010; Rounsevell et al., 2005) use downscaled and static versions of these determinants (Abildtrup et al., 2006; van Vuuren et al., 2007). No matter the means, these studies suggest that climate change may be a relatively minor driving force behind the evolution in the European agricultural supply (Audsley et al., 2006; Ewert et al., 2005; Hermans et al., 2010; van Meijl et al., 2006).

We have reasons to believe that in these recent studies the complexity of agricultural systems is not fully reflected in the way the impact of future climate on agriculture is accounted for, from both conceptual as well as methodological points of view.

The most commonly found patterns of adaptations refer to rather long-term structural changes: a reduction in the agricultural share in European land use (as a result of technological progress), and a global spatial redistribution of agricultural supply (through dynamic trade regimes). To better understand the various facets of adaptation, the Intergovernmental Panel on Climate Change (IPCC) has defined a conceptual framework. It separates the *potential impacts* of climate change on a particular system from the *residual impacts*, including the *effective adaptation* (defined by *adaptation options* and the ability of the system to implement them, i.e. the *adaptive capacity*). Adaptation is further differentiated (Füssel, 2007) according to various criteria, including its purposefulness (autonomous vs. planned), planning horizon (short-term or long-term), form (technical, institutional, financial, behavioral or

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educational), and the actors involved. In the above-mentioned studies the adaptation possibilities of holdings at the farm-scale were only partially accounted for, such as changes in management practices, or in the crop portfolio at the farm-scale (Antle et al., 2004; Bindi and Olesen, 2010; Olesen et al., 2011; Smit and Skinner, 2002). These adaptations are of an *autonomous* nature, defined as the ongoing implementation of existing knowledge and technology by farmers themselves, in response to experienced changes in climate. They are known to have played an important role in Europe (Reidsma et al., 2010), and have been identified as a key uncertainty in climate change impact assessments (Easterling et al., 2007).

From the methodological point of view, the tools used to assess the effects of changes in climate alone may not be able to fully capture the spatially heterogeneous link between outcomes of the agricultural supply and its physical, technical and socio-economic environment. Firstly, the atmospheric variables (such as atmospheric carbon dioxide level and weather) have impacts on several processes of the soil-plant system (DaMatta et al., 2010). Furthermore, their net effects as well as their spatial variability are heavily dependent on the species under consideration and on the distribution of the physical (climate and soil) and technical (management practices) environment. In this respect, tools such as the Agro-ecological Zones (AEZ) methodology used in (van Meijl et al., 2006), the ROIMPEL agro-climatic model used in (Audsley et al., 2006), or the Environmental Strata method (Metzger et al., 2008) used in (Hermans et al., 2010; Rounsevell et al., 2005), have a relatively coarse representation of this link. Secondly, this link has been measured across Europe as spatially heterogeneous, and as very dependent on the socio-economic context of agricultural systems (e.g., farm economic size and production orientation, see (Reidsma et al., 2007)). This latter context also strongly influences the farm-scale adaptations (Reidsma et al., 2010), and has not been accounted for in the above-mentioned studies.

In this paper, we propose to quantify the specific role of short-term autonomous adaptations in the European agricultural supply response to climate change, with a supply-side approach. We rely on the coupling at the farm-scale of a micro-economic European agricultural supply-side model (AROPAj, (De Cara et al., 2005; Galko and Jayet, 2011)) with a generic crop model (STICS, (Brisson et al., 2003, 2008)). This modeling framework is designed to perform a quantitative analysis of the European agricultural supply, through the diagnosis of agricultural supply outcomes at the farm to continental-wide aggregated level. It models the behavior of a distribution of economic agents, who optimizes the use of resources and the agricultural activities at the farm scale by maximizing profit. The effects of changes in climate and management practices for various crops are accounted for by the coupling to the crop model. Moreover, the model has a regional spatial resolution and a fine accounting for the infra-regional heterogeneity in the physical and socio-economic determinants of agricultural activities. It consequently provides an adequate tool to address autonomous adaptations, and it opens the door to addressing the following set of questions under a supply-side point of view:

- How do farm-scale adaptations alter the projected changes in yields, production levels, gross margins and environmental impacts of the European agricultural supply?
- Do they alter the north–south geographical gradient generally associated with climate change impact on agriculture over European?
- Would they alter the place of climate change in the ranking of the determinants of future European agricultural supply?

In the next section, we detail the modelling framework and the scenarios under consideration. In Section 3, we present our results. In Section 4, we discuss them with respect to any limit in the modelling framework, and to the literature. We then derive their implications for future climate and global change impact assessments on European agriculture.

2. Material and Methods

We first briefly detail the modelling framework, and then the scenarios constructed to assess the effects of both climate change and farm-scale autonomous adaptations.

2.1. The Modelling Framework

The European agricultural production is represented by AROPAj, a supply-side model belonging to the ‘agricultural input-output models’ category identified by van der Werf and Peterson (2009). It is based on a micro-economic approach applied to a distribution of virtual farm-types representative of real-world farms (excluding horticulture, wine and grapes, and arboriculture). This distribution is constructed against the Farm Accountancy Data Network (FADN) census data, a harmonized annual survey sample of accountancy information regarding most agricultural holdings in the European Union. For each of the FADN regions (Fig. 1), the FADN sampling methodology selects holdings in order to be representative of all targeted agricultural holdings, in terms of production orientation and economic size. The regional farm-type distributions in AROPAj are delineated by regrouping FADN farms in homogeneous elevation, economic size and production orientation classes of a minimal sample size. Here we use a version of the model covering the former 15 Member European Union (hereafter referred to as EU-15), including 1074 farm-types delineated after 2002 FADN census data, distributed across 101 regions.

Each farm-type is considered as an autonomous price-taker economic agent, fed with FADN data (total agricultural land, animal capital, existing activities and related variable production costs, yields, prices, and policy bindings). Each agent k organizes his production activities to maximize his gross margin, this behavior being modeled by the following mixed integer linear mathematical program (P_k):

$$(P_K)\begin{cases} \max_{x_k}[\pi_k(x_k)] = g_k \cdot x_k \\ \quad s.t.\begin{cases} A_k \cdot x_k \le z_k \\ \forall i, x_{k,i} \ge 0 \end{cases} \end{cases} \tag{1}$$

where π_k denotes gross margin, x_k and z_k respectively denote activities and resources vectors, and g_k and A_k respectively denote the gross margin operator and the matrix of technical constraints.

Each agent can thus react to changes in demand (via prices) or policies (via premiums or other incentives) by adjusting his activities (e.g. land allocation to different uses, adjustment in animal capital and its feed sources, allocation of on-farm grain production to market or animal feed, of on-farm sources of manure as fertilizer, etc …). De Cara et al. (2005) developed an additional module that computes a detailed accountancy of non-CO_2 GHG emissions related to the various activities. More information on the technical description of the AROPAj model can be found in (De Cara et al., 2005; Galko and Jayet, 2011).

In order to be able to account for changes in crop yields due to changes in either climate or crop management practices, we extended to EU-15 the methodology developed by (Godard et al., 2008). We thereby replaced observed FADN crop yields and nitrogen inputs by simulated ones (Leclère et al., submitted for publication). As shown on Fig. 1, we simulate for each AROPAj agent the yield of nine European major crops[1] with the STICS generic crop model (Brisson et al., 2003, 2008) using spatialized inputs for soil, weather and management practices. STICS is a detailed generic crop model, working at daily time-step and simulating the interaction of the soil-plant system, including management practices. In this procedure, we first simulated the response of crop yields to nitrogen input for a large range of nitrogen values, and then interpolated it as *production functions* $Y_{C,k}$ for each crop C of each

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[1] Namely bread wheat, durum wheat, barley, maize, rapeseed, sunflower, soybean, potato and sugarbeet.