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## **“Climate Change in World Agriculture: Mitigation, Adaptation, Trade and Food Security”**

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## **The European Union's Framework for Climate Change Adaptation: Implications of Agriculture's Adaptation through Sustained Yield Growth**

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### **1. Introduction**

Governmental and nongovernmental organizations have been devising responses to climate change since the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1998, and even before then. From these efforts, a two-pronged approach to climate change has emerged, divided into: (1) mitigation—efforts to reduce the emission of greenhouse gases (GHGs) or to provide for the sequestration of those gases; and (2) adaptation—efforts to adjust to climate change, to lessen its adverse effects, and in some instances, to benefit from the new opportunities presented by a changing climate.

Adapting to changes in long-term climatic patterns and preparing in advance for potential extreme variations in short-term weather conditions are longstanding aspects of agricultural activity. In fact, many of the adaptation policies recommended for the agricultural sector closely resemble traditional governmental activities related to agriculture—such as the promotion of soil and water conservation and publicly funded research and development of new crop varieties. For the world as a whole, climate change issues present a distinct challenge, in that it is not immediately clear how existing policies and programs should be tailored in anticipation of the situations that further climate change could present. There is a sense among many persons that

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governments need to “do more” in these areas, but there are few specifics on what this actually entails.

This paper examines the efforts of the European Union (EU) to define an adaptation policy for its agricultural sector and then gauges the likely effects of differing levels of adaptation as reflected in crop yields over the next 40 years on agricultural production, consumption, and trade, both in the EU and throughout the world. The EU is selected as the paper’s focus because it is a region where governmental efforts to facilitate agriculture’s adaptation to climate change have the potential to be robust, well developed, and regionally differentiated. As a common market consisting of high-income and upper-middle-income countries, the EU possesses sufficient resources to organize and implement a strong response to climate change. Moreover, the EU has a technologically advanced agricultural sector and provides extensive public support to this sector at the supranational, national, regional, and local levels. Finally, the EU features a variety of climatic zones, ranging from the Member States of Sweden and Finland, whose territory extends north of the Arctic Circle, to the warmer and drier climates found in the seven Member States—Portugal, Spain, France, Italy, Greece, Cyprus, and Malta—that lie on or near the Mediterranean Sea.<sup>2</sup>

The extent to which adaptation efforts by the EU and other countries and regions succeed in sustaining crop yield growth in the face of a changing climate will have important impacts on agricultural production, consumption, and trade. To estimate these possible impacts, this paper relies on a prototypical application of the Dynamic Partial Equilibrium Agricultural Trade Simulator (PEATSIM). Although the PEATSIM model covers a total of 36 agricultural commodities, this paper focuses on wheat in order to provide an early opportunity to study the

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<sup>2</sup> Unless otherwise indicated, this paper examines the EU in its current configuration with 27 Member States.

model and consider ways to improve its performance. Later work will extend the paper's simulations to other crops included within PEATSIM.

The paper is organized as follows. Section 2 considers the role of government in fostering agriculture's adaptation to climate change from the standpoint of economists, climate change researchers, and persons involved in agriculture. Section 3 summarizes the EU's recent efforts to formulate an adaptation policy for its agricultural sector. Section 4 provides an overview of the PEATSIM model and the three simulations analyzed in this paper, and Section 5 reports the results from these simulations. Section 6 contains a brief conclusion.

## **2. What is the Role of Government?**

Government's role in facilitating agriculture's adaptation to climate change is not universally agreed upon. Some persons envision a substantial role for government, while others recommend a more limited role, emphasizing the uncertainties associated with climate change and the abilities of the private sector to adapt on its own. Many adaptation efforts by the agricultural sector will be market driven or "autonomous," meaning that economic agents undertake adaptation largely under their own volition in response to signals from the marketplace and not in response to government programs or policies. Mendelsohn (2006) emphasizes that markets "are likely to do most of the needed adaptation" in the agricultural and forestry sectors, and he cautions: "Markets and government should focus on the climate changes that are likely to occur in the next decade or two but they should be cautious adapting now to climate impacts far in the future." Still, an agricultural adaptation policy that addresses the climatic challenges of the next 50-100 years would require many governmental entities to adopt a much longer planning horizon than is currently the practice.

Economists who write about adaptation policy tend to identify areas where governmental involvement in the economy is believed to improve economic efficiency and increase social welfare, consistent with the theoretical and empirical lessons of their discipline. Thus, the provision of public goods, correction of negative externalities, generation of positive externalities, and addressing inadequacies in the information needed for economic decisions are all economically “safe” areas for adaptation policy. Exemplifying this type of approach is again Mendelsohn (2006), who identifies just three areas for adaptation policy in agriculture and forestry: (1) crop insurance, (2) water policy and coastal management, and (3) biodiversity.

The *Stern Review on the Economics of Climate Change* (2006) differentiates its prescription for adaptation policy according to a country’s level of economic development, but its recommendations are still carefully tied to specific market failures. In the developed countries, “Government has a role in providing a clear policy framework to guide effective adaptation by individuals and firms in the medium and long term.” The main components of this framework are:

- High-quality climate information will help drive efficient markets. Improved regional climate predictions will be critical, particularly for rainfall and storm patterns.
- Land-use planning and performance standards should encourage both private and public investment in buildings, long-lived capital and infrastructure to take account of climate change.
- Government can contribute through long-term policies for climate-sensitive public goods, such as natural resources protection, coastal protection, and emergency preparedness.
- A financial safety net may be required to help the poorest in society who are most vulnerable and least able to afford protection (including insurance) (p. 416).

In the developing countries, adaptation is viewed as “an extension of good development practice” and is aimed at reducing “vulnerability”:

- Promoting growth and diversification of economic activity.
- Investing in health and education.
- Enhancing resilience to disasters and improving disaster management.

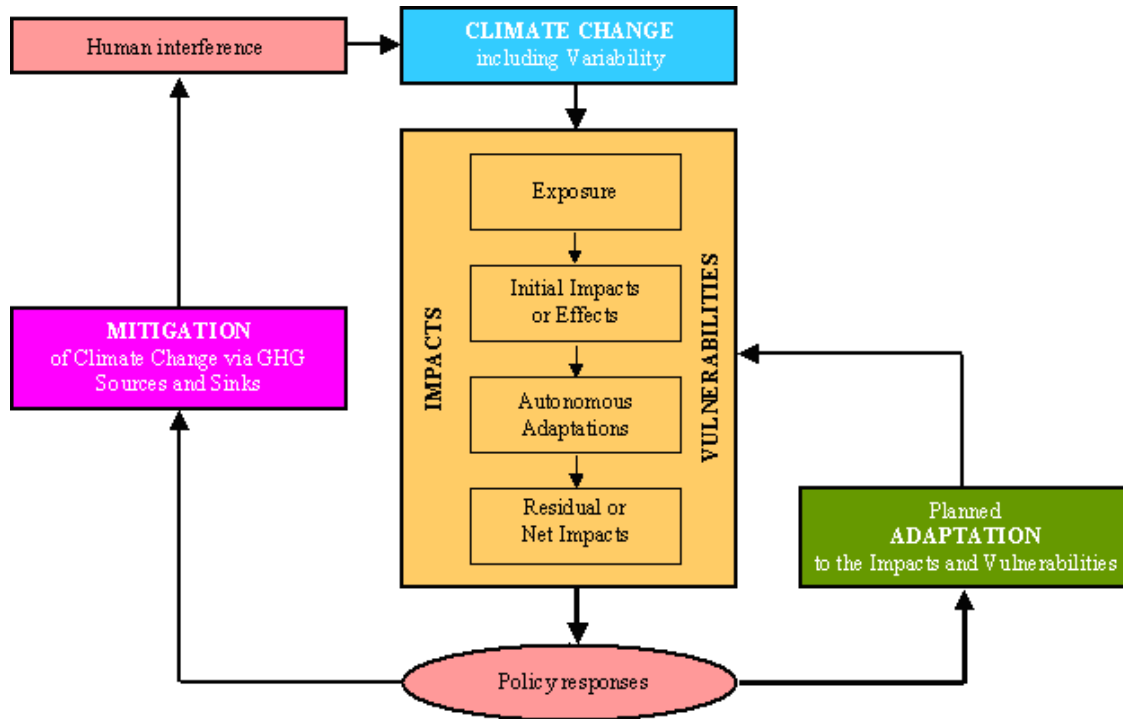
- Promoting risk-pooling, including social safety nets for the poorest (p. 430).

Overall, these recommendations target policy and program areas where governmental involvement is fairly accepted.

There are, of course, economists who deviate from this conventional approach. Weitzman (2008a, 2008b), for instance, considers the possibility of wider-than-normal tails in the distributions of climate-change predictions and the disastrous outcomes associated with the far end of those distributions. He concludes that human civilization should be prepared to respond to catastrophic changes in climate by developing the capacity to engage in planetary engineering, such as the injection of sulfur particles into the upper atmosphere, as recommended by Crutzen (2006). Such contingency planning for worst-case scenarios is consistent with the high level of pessimism among some economists regarding government's ability to solve pressing social problems, yet it probably would require substantial government involvement.

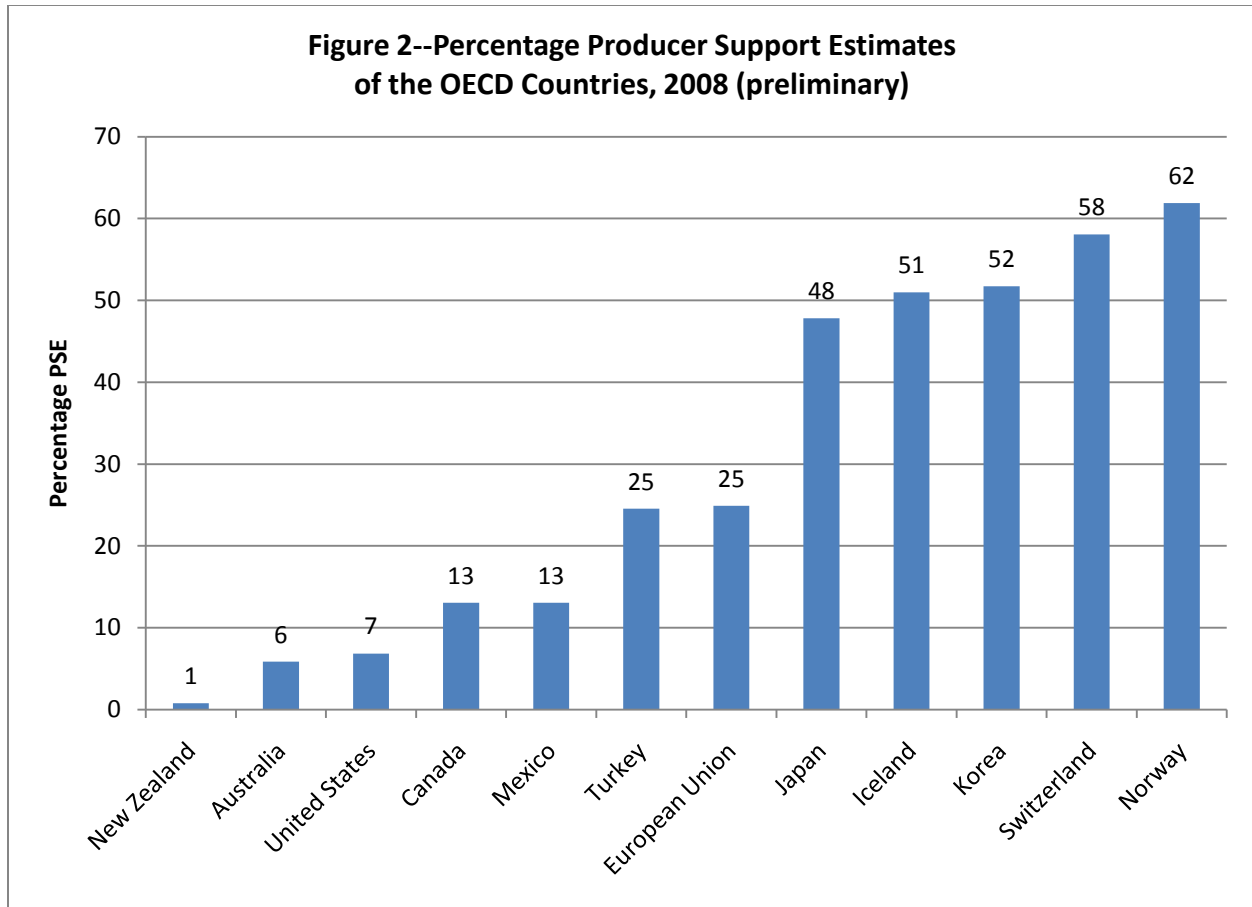
Researchers with the IPCC have worked to outline the organization and flow of adaptation policy and its interrelationship with autonomous adaptation and mitigation. Some of this research describes government as an external actor to the economic sectors where adaptation is facilitated. Figure 1 depicts the adaptation circuit as conceptualized by IPCC researchers during the 1990s. In this diagram, policy responses to climate change—which would include government efforts to facilitate agriculture's adaptation—are distinctly separate from autonomous adaptation and feed into planned adaptations to climate changes. Moreover, policy responses are represented as addressing “residual or net impacts” following autonomous adaptation.

Figure 1: Adaptation and Mitigation in the IPCC Assessment



Source: Finnish Environment Institute (SKYE) (2007), as adapted from Smit, et al. (1999).

This view of adaptation does not acknowledge the substantial role that government plays in the agricultural sectors of many countries. In the case of agriculture, it would be more accurate to describe government as embedded in many aspects of the sector. In the member countries of the Organisation for Economic Co-operation and Development (OECD), for instance, agricultural producers customarily receive a large amount of governmental support in comparison to the market value of production. In 2008, the median level of support in the OECD countries, as measured by the percentage Producer Subsidy Equivalent (PSE), was about 28 percent of gross farm receipts, as calculated as the average of the values for Turkey and the EU (fig. 2).



Source: OECD (2009b).

The Producer Subsidy Equivalent (PSE) is defined as “the annual monetary value of gross transfers from consumers and taxpayers to agricultural producers, measured at the farm gate level, arising from policy measures that support agriculture, regardless of their nature, objectives or impacts on farm production or income” OECD (2009a). The percentage PSE is calculated by dividing the PSE by gross farm receipts (including support).

An alternative approach to determining government’s role in agricultural adaptation would be to consult with practitioners in the public and private sectors and identify those areas where they believe that government’s involvement is needed. Smit and Skinner (2002) apply something along the lines of this approach in their identification of adaptation options—both autonomous and planned—for Canadian agriculture. Drawing from the literature and the experiences of individual agricultural producers and representatives of producer organizations, farm groups, and government agencies, the authors identify four main categories of adaptation



options: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management. These categories are not mutually exclusive, in that government could have a role in any of the other three categories. This consultative approach differs from the economist's approach in that it could generate ideas for adaptation policy that run contrary to economic prescriptions for efficient interventions in the economy, and it differs from the adaptation circuit depicted in Figure 1 in that the lead actors in autonomous adaptation (i.e., the private sector) are also explicitly involved in generating ideas for planned adaptations. We shall see below that the EU's approach to the formation of an agricultural adaptation policy contains elements of this consultative approach.

### **3. European Union**

The EU has devoted some attention to the design of adaptation policies for its agricultural sector, and these efforts seem to be leading in the direction of a concrete set of such policies. To date, however, most of the EU's efforts have focused on the creation of a broad framework for adaptation activities, rather than the definition and implementation of specific actions. In June 2007, the European Commission published a Green Paper entitled "Adapting to Climate Change in Europe—Options for the EU" (European Commission, 2007), and in April 2009, it published a White Paper that defines an official framework for EU action, entitled "Adapting to Climate Change: Towards a European Framework for Action" (European Commission 2009b). These papers were respectively accompanied by an external study (Iglesias, et al. 2007) that describes many of the adaptation options available to European agriculture and a staff working document on agriculture (European Commission 2009a).

The official framework specified by the White Paper is part of a two-phase approach. Overall, the plan is to “lay the ground work for a comprehensive EU adaptation strategy” during phase 1 (2009-12), which in turn will be implemented during phase 2 (2013 onward) (European Commission, 2009b: 7). The White Paper identifies four pillars of action that are to be the focus of phase 1 (table 1). These pillars resemble but do not exactly match a previous set of pillars that were identified as high priorities in the Green Paper. To a great extent, these differences are a matter of presentation. For instance, while the White Paper’s pillar on integrating adaptation into key policy areas replaces the Green Paper’s pillar on early action, the Green Paper’s section on early action in fact emphasizes the importance of incorporating adaptation within existing governmental activities. Similarly, the White Paper’s pillars on building the knowledge base and increasing international cooperation on adaptation are by and large identical to corresponding pillars in the Green Paper.

**Table 1--From Green Paper to White Paper: Evolution of the EU’s Adaptation Framework**

<b>Green Paper of 2007</b>	<b>White Paper of 2009</b>
Expanding the knowledge base through integrated climate research	Building a solid knowledge base on the impact and consequences of climate change for the EU
Early action by the EU	Integrating adaptation into EU key policy areas
Involving European society, business, and public sector in the preparation of coordinated and comprehensive adaptation strategies	Employing a combination of policy instruments (market-based instruments, guidelines, public-private partnerships) to ensure effective delivery of adaptation
Integrating adaptation into EU external actions	Stepping up international cooperation on adaptation

Sources: European Commission (2007: 5-26; 2009: 7).

Coordination with the Member States and consultation with technical experts and other members of civil society are key aspects of the adaptation framework, even though the White Paper's pillar on the employment of various policy instruments replaces the Green Paper's pillar on involving a range of social actors in the formulation of adaptation strategies. The European Commission indicates in the White Paper its intent to establish an Impact and Adaptation Steering Group (IASG), made up of representatives from the Member States who are involved in crafting adaptation programs at the national and regional levels and to be supported by various technical groups, one of which will focus on agriculture. This idea has its roots in the Green Paper's recommendation that the Commission create a European Advisory Group on Adaptation to Climate Change.

The EU's Common Agricultural Policy (CAP) is envisioned in the White Paper to play a major role in the adaptation of European agriculture. The White Paper primarily considers the CAP in its section on integrating adaptation within key policy areas, even though the CAP is clearly relevant to all of the pillars listed in the White Paper, except perhaps the one on international cooperation. Nevertheless, the White Paper's section on employing policy instruments to ensure effective delivery of adaptation does not mention the CAP, although it does discuss in general terms several agriculture-related initiatives, including payments for ecosystem services, the trading of greenhouse gas emission allowances, and improved use of insurance and other financial service products.

Two elements of the CAP directly concern adaptation: (1) the provision of decoupled farm supports and (2) the EU's rural development policy. Decoupling means that direct payments to farmers do not depend on current or future levels of production, inputs, or prices. Thus, decoupling of supports gives farmers the flexibility to change production levels, input

combinations, agronomic techniques, and even the crops that they produce in response to climate change without jeopardizing their farm support payments.

The EU's rural development policy for 2007-13 contains three thematic axes: (1) improving the competitiveness of the agricultural and forestry sector, (2) improving the environment and the countryside, and (3) improving the quality of life in rural areas and encouraging diversification of the rural economy (European Commission, Directorate General for Agriculture and Rural Development, 2008b). The White Paper encourages the Member States to incorporate adaptation within the activities of each axis, and it identifies the Farm Advisory System as a mechanism that "could be used to disseminate knowledge and encourage the adoption of new farm management methods and technologies that facilitate climate change adaptation (European Commission, 2009b: 9-10). A cursory analysis of the Rural Development Plans of the Member States (European Commission, Directorate-General for Agriculture and Rural Development, 2008a), including many plans formed at the regional level within individual Member States, reveals numerous activities with the potential to foster adaptation. Examples include: the sustainable management of water and soil resources; mitigation of desertification and soil deterioration; improving the efficiency of irrigation systems; diversification of rural economies out of agriculture; training, advisory, and extension services, including efforts to set up young farmers; modernization of production units; investments in infrastructure; and development of new products, processes, and technologies. Moreover, the plans of several Member States—including the Czech Republic, England, Germany, Ireland, Luxembourg, and Spain—formally acknowledge the role of the rural development policy in addressing the challenges of climate change.

The extent to which the EU and other parts of the world are able to sustain crop yield growth in the face of a changing climate will affect future levels of agricultural production, consumption, and trade. For this reason, the modeling scenarios and simulation results presented below consider the economic impacts of differing levels of yield growth, focusing on wheat as an initial case to probe the strengths and weaknesses of the PEATSIM model. The White Paper explicitly acknowledges that crop yields are likely to be affected by projected climatic changes, and the accompanying staff discussion paper identifies various adaptations at the sectoral level to accompany more autonomous adaptations at the farm level. Many of these suggestions could potentially affect crop yields and yield growth, including assessments of opportunities to change crops and crop varieties, the support of agricultural research related to crop selection and varietal development, investments in irrigation and water-use technologies, and the development of irrigation plans (European Commission 2009a: 7).

Through its ongoing farm supports and rural development activities, along with any new adaptation activities that are implemented and more autonomous adaptations by the private sector, the EU's approach to agricultural adaptation is likely to have tangible economic effects. Indeed, the staff discussion paper contains a certain degree of muted optimism about the prospects for EU agriculture, at least over the next 30 years, emphasizing: "Most assessments anticipate that at the overall EU level the expected changes in mean climatic variables will be beneficial for agricultural production for the next three decades" (European Commission 2009a: 4). This expectation is explained in greater detail by Iglesias, et al. (2007), the external study that accompanied the Green Paper. Their study indicates that the warmer temperatures, longer growing seasons, and higher levels of carbon dioxide in the atmosphere (through its impact on photosynthesis) brought about by climate change will initially improve opportunities for many

aspects of crop production in the agro-climatic zones of northern Europe (the zones located north of approximately 45 degrees latitude).

#### **4. PEATSIM and the Modeling Scenarios**

The Dynamic Partial Equilibrium Agricultural Trade Simulator (PEATSIM) is a dynamic, partial equilibrium model of the world's agricultural production, consumption, and trade. PEATSIM covers a total of 36 agricultural commodities, including various grains, oilseeds, vegetable oils, sweeteners, meats, dairy products, and cotton. For the purposes of this paper, however, we focus on a single commodity—wheat—in order to make a preliminary application of PEATSIM to the question of how differing levels of success in sustaining wheat yield growth as part of agriculture's adaptation to climate change would affect the world's agricultural sector. Wheat is a good starting point for this effort, given the commodity's importance to the world and the EU's role as one of the world's larger and more productive wheat growing regions. Wheat is the world's number two food grain, and when the EU's 27 Member States are considered together and compared with other countries, the EU is the world's largest wheat producer, with yields of about 5 tons per hectare in recent years and Denmark, France, Germany, and the United Kingdom customarily achieving yields in the neighborhood of 7-8 tons per hectare.

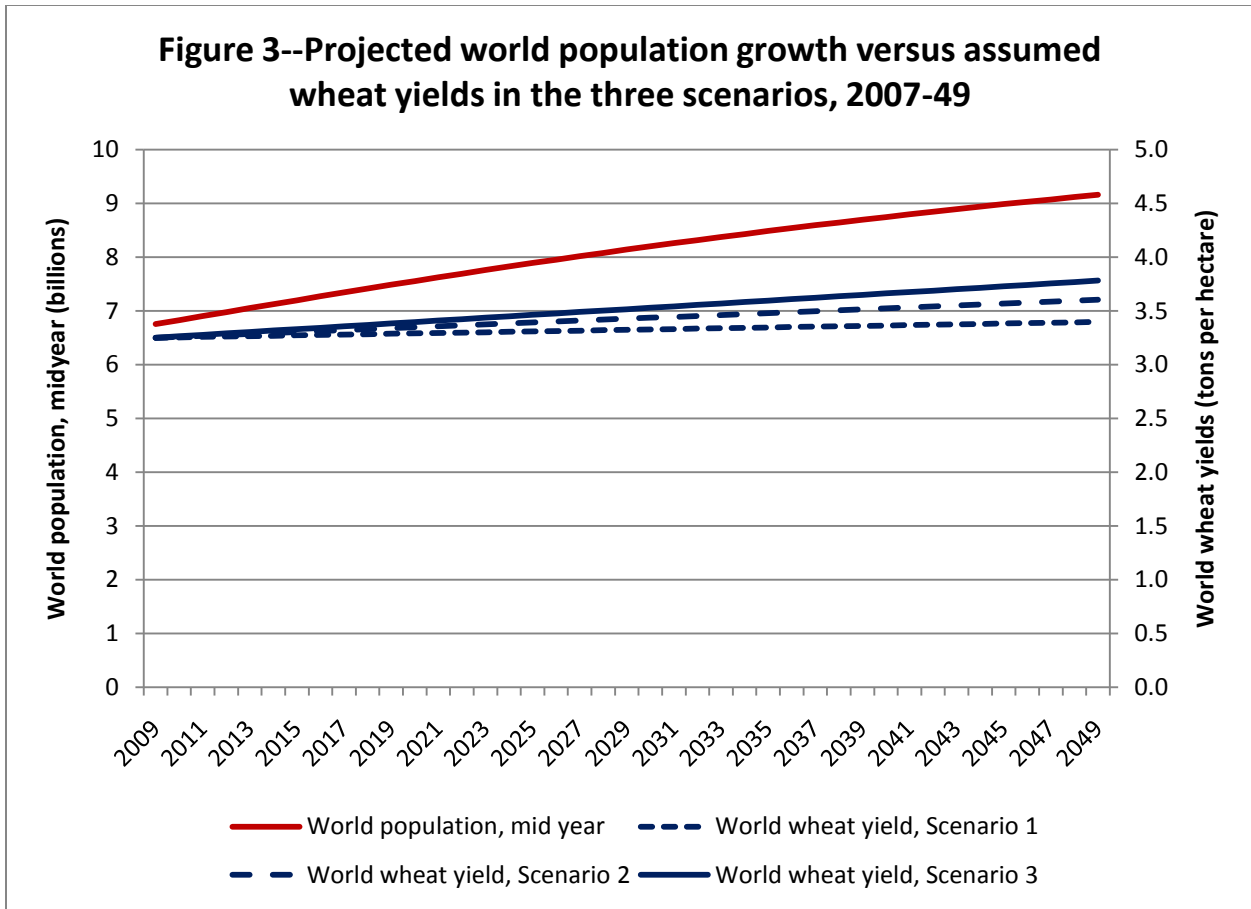
PEATSIM covers a total of 13 countries and regions. For our simulations, we divide these countries and regions into two groups and then exogenously assign specific rates of wheat yield growth to each group over the period 2009-49 (table 2). The countries in Group A are intended to correspond to regions where the wheat sector's adaptation to climate change is likely to be easier relative to Group B. Group A tends to consist of higher latitude areas with more

temperate climates and higher-than-average wheat yields, while Group B tends to consist of lower and middle latitude areas with warmer and drier climates. We conduct three separate simulations distinguished by the rate at which wheat rates are assumed to grow over the period 2009-49 in Group A and Group B. In each of these scenarios, world wheat yields grow at a slower rate than world population (fig. 3), so the simulations all present cases in which adaptation by the world’s agricultural economy is necessary.

**Table 2--Summary of modeling scenarios**

<b>Country groups</b>	
Group A:	Argentina, Canada, China, European Union, Japan, New Zealand, South Korea, United States
Group B:	Australia, Brazil, India, Mexico, Rest of World
<b>Assumed growth in wheat yields between 2009 and 2049</b>	
Scenario 1:	Group A yields increase 10% Group B yields decrease 5%
Scenario 2:	Group A yields increase 20% Group B yields decrease 5%
Scenario 3:	Group A yields increase 20% Group B yields increase 10%

Source: Authors.



Sources: U.S. Department of Commerce, U.S. Census Bureau (2010) (estimated and projected population) and authors’ analysis of PEATSIM results (assumed wheat yields).

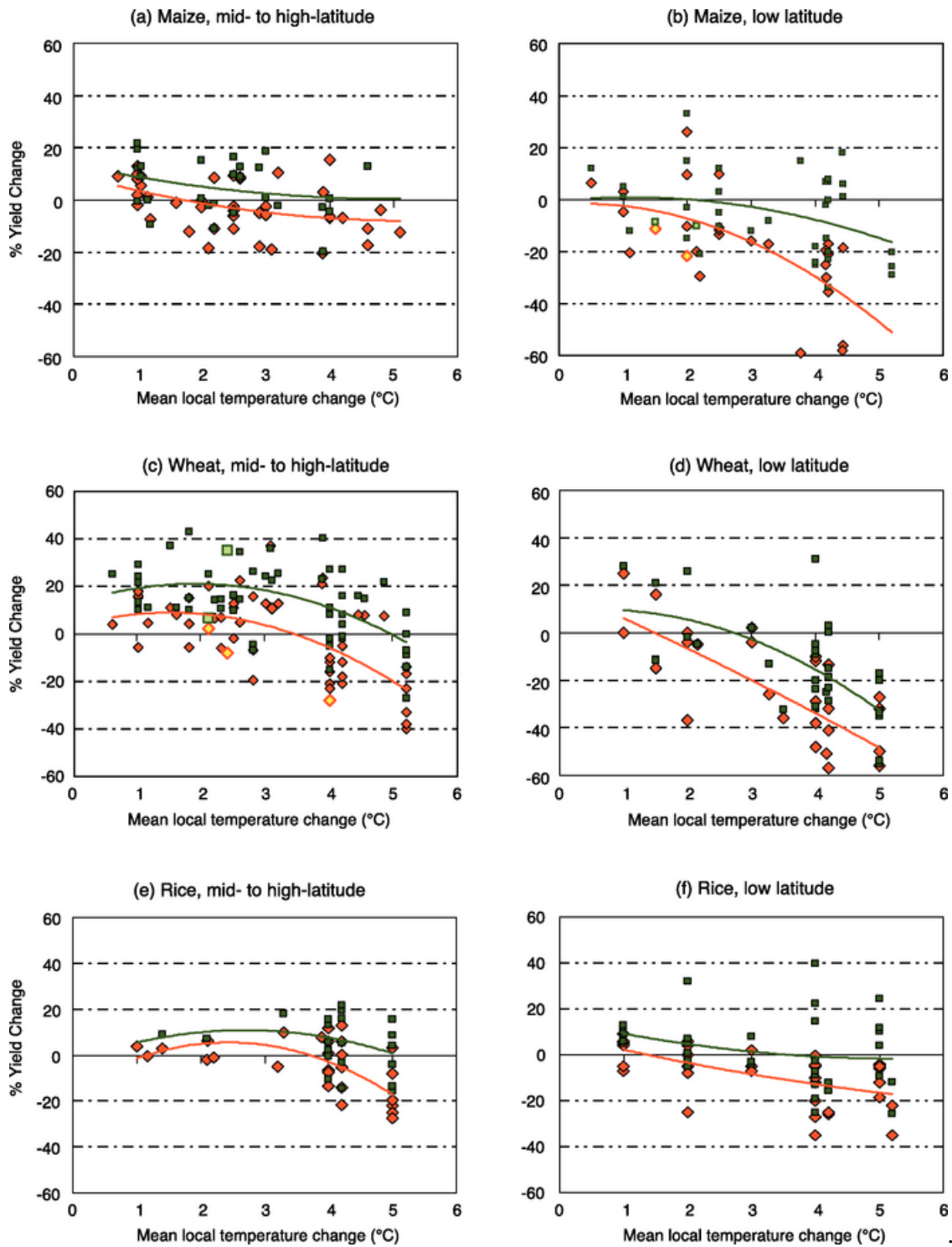
The assumed rates of wheat yield growth for the period 2010-19 are generally lower than those posited by the *USDA Agricultural Projections to 2019* (U.S. Department of Agriculture, Office of the Chief Economist, 2010). For instance, USDA’s projections assume a yield of 5.7 tons per hectare for the EU in 2019, compared with 5.6 tons per hectare in Scenario 3. With respect to macroeconomic assumptions, each simulation utilizes GDP growth rates and exchange rates from USDA’s projections, which are then extended to 2049 using predicted values from regressions whose results are not reported here.

Specification of the scenarios is guided by previous research in the life sciences about possible future wheat yields. In particular, we are influenced by the literature review conducted



by Easterling, et al. (2007) for the IPCC's Fourth Assessment Report in which they summarize a variety of yield projections for corn, wheat, and rice under various climatic conditions (fig. 4). The green dots in the figure represent cases of adaptation, while the red dots indicate cases without adaptation. Easterling and his colleagues emphasize that the green and red lines are intended to summarize the works that they reviewed rather than serve as a predictive tool. Our simulations incorporate the values of the summary lines at a mean local temperature change of 2 degrees Celsius. Thus, the projected growth levels of Group A's wheat yields (20 percent with adaptation, 10 percent without adaptation) come from Figure 5.2(c) in Easterling, et al., while the projected levels for Group B (10 percent with adaptation, -5 percent without adaptation) come from Figure 5.2(d).

**Figure 4: Graphical Representation of Literature Review by Easterling, et al. of Yield Projections for Corn, Wheat, and Rice**



Source: Reproduction of Figure 5.2 from Easterling, et al. (2007: 286).

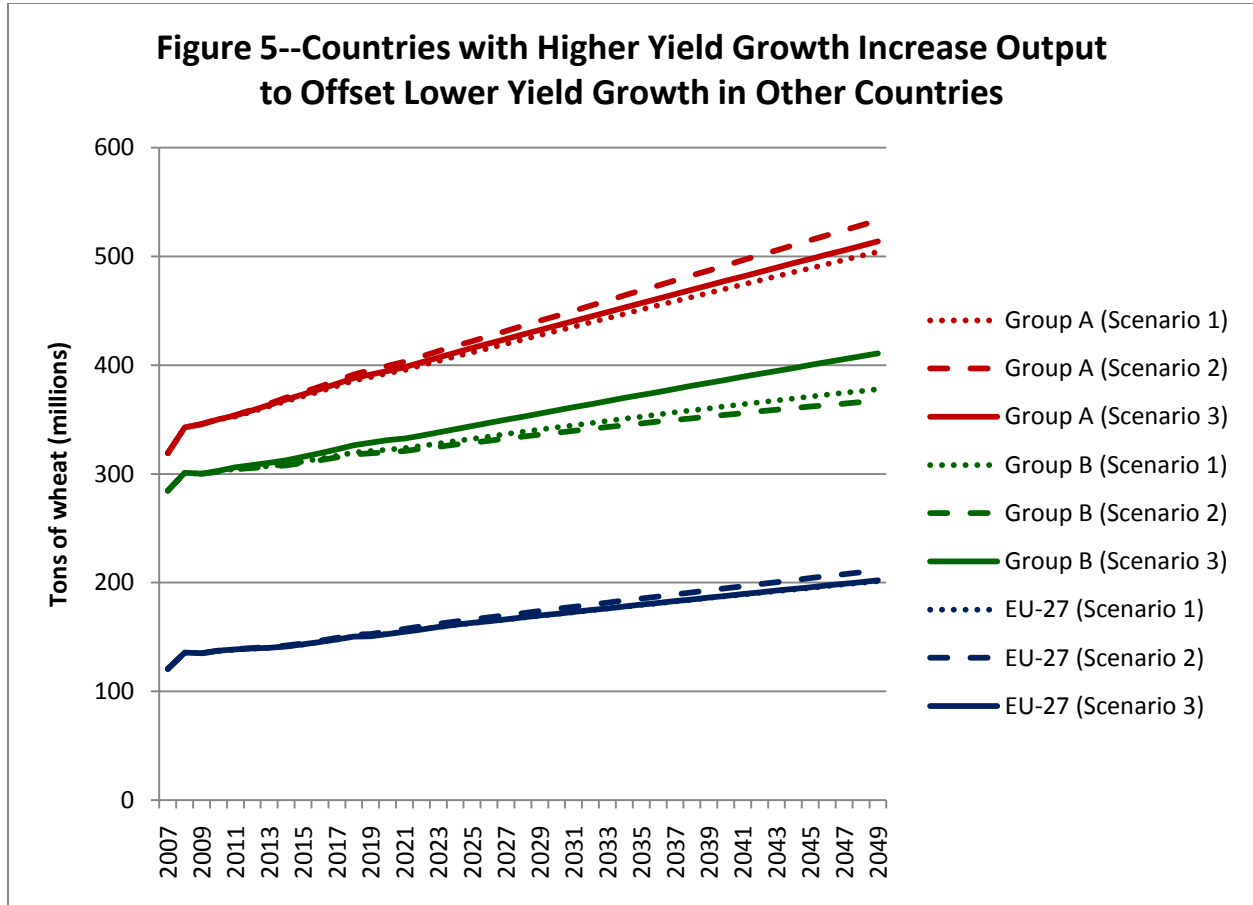
The specification of our simulations also is influenced by works published after the literature review by Easterling, et al. For instance, Ortiz, et al. (2008) indicate that the mega-environments more suitable for wheat production in India will contract and migrate northward during the course of the 21<sup>st</sup> Century, a conclusion that motivates our placement of India in Group B. Still, we are struck by the great variety of yield projections, each of which corresponds to a specific set of climatic conditions, agronomic techniques, crops, and geographical type if not a precise geographic location.

## **5. Preliminary Findings**

The three simulations in this paper constitute a first attempt to use the PEATSIM model to understand the economic impacts of varying levels of success in adapting to climate change, with those levels represented by different growth paths for wheat yields over the next 40 years. Overall, the simulations generate several findings regarding adaptation's role in agriculture, while providing insights into possible model improvements that would make future simulations more representative of the world's agricultural economy.

The main finding from the simulations is that international trade provides a channel by which yield improvements in one region can substitute for limited yield improvements in another region. While this notion is rather straightforward, it is intriguing to see how this phenomenon plays out with specific values of production, consumption, and trade under the three scenarios. As a first example, compare the production levels in Scenarios 1 and 2 (fig. 5). In both scenarios, the wheat yields of Group B, countries that are assumed not to adapt as well to climate change, decrease by 5 percent between 2009 and 2049. Meanwhile, wheat producers in the Group A countries are assumed to adapt better to climate change under Scenario 2 relative to Scenario 1,

achieving yield growth of 20 percent in Scenario 2 as opposed to 10 percent in Scenario 1. When Group A’s wheat sector is more successful at adaptation, Group B’s wheat production increases at a slower compound annual rate during 2009-49: 0.51 percent in Scenario 2, compared with 0.58 percent in Scenario 1.

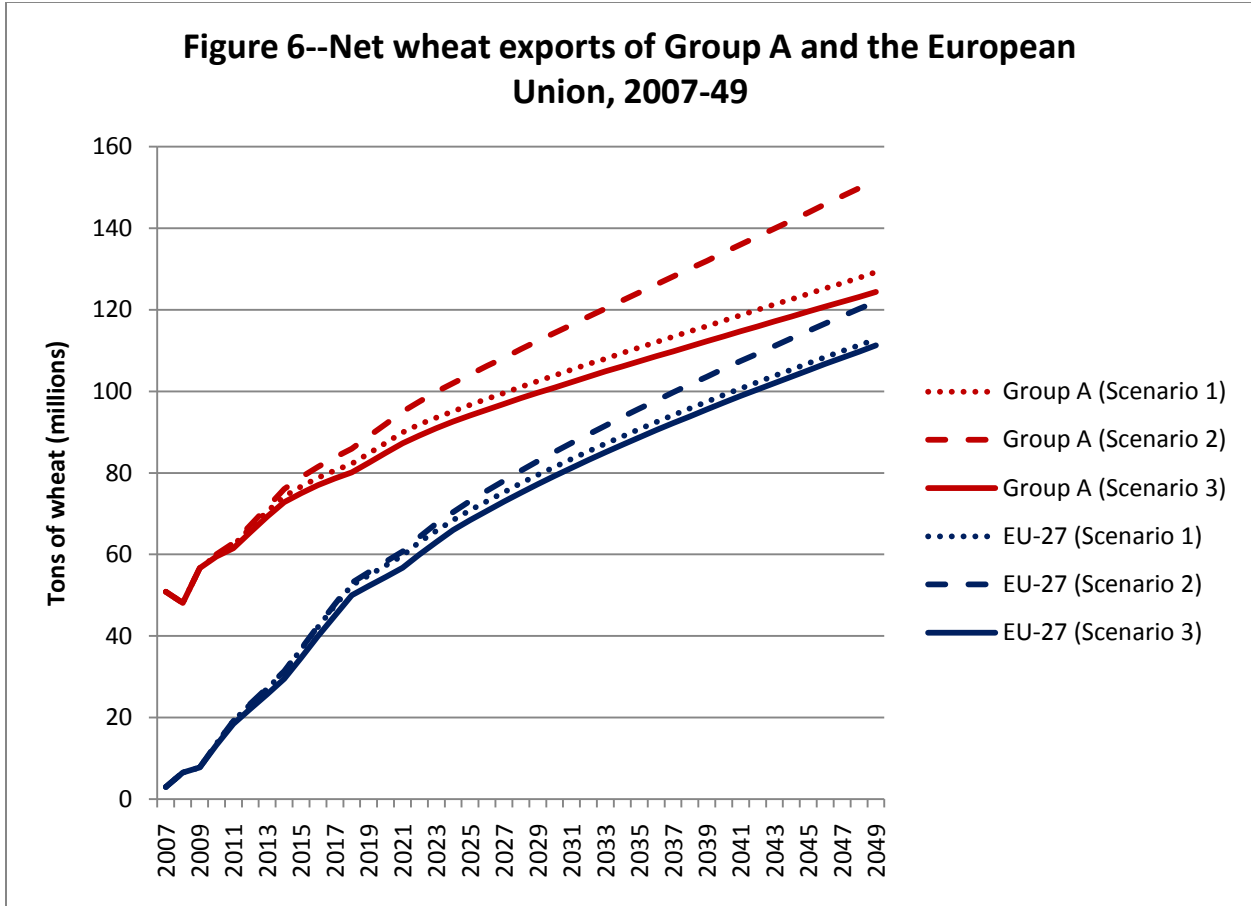


Source: Authors’ analysis of PEATSIM results.

A similar contrast is evident between Scenarios 2 and 3. Group B’s wheat producers are assumed to adapt better to climate change in Scenario 3 than in Scenario 2 (and Scenario 1), achieving yield growth of 10 percent between 2009 and 2049 in Scenario 2. Group A’s wheat yields, meanwhile, increase by 20 percent in both Scenarios 2 and 3. When Group B’s wheat

sector is more successful at adaptation, Group A's wheat production increases at a slower compound annual rate during 2009-49: 0.99 percent in Scenario 3, compared with 1.09 percent in Scenario 2. Interestingly, the path of wheat production over time in a particular country or region in one scenario can be virtually identical to its path in another, starkly different scenario. For instance, the path of the EU's wheat production during 2010-49 in Scenario 1 is almost indistinguishable from its path in Scenario 3.

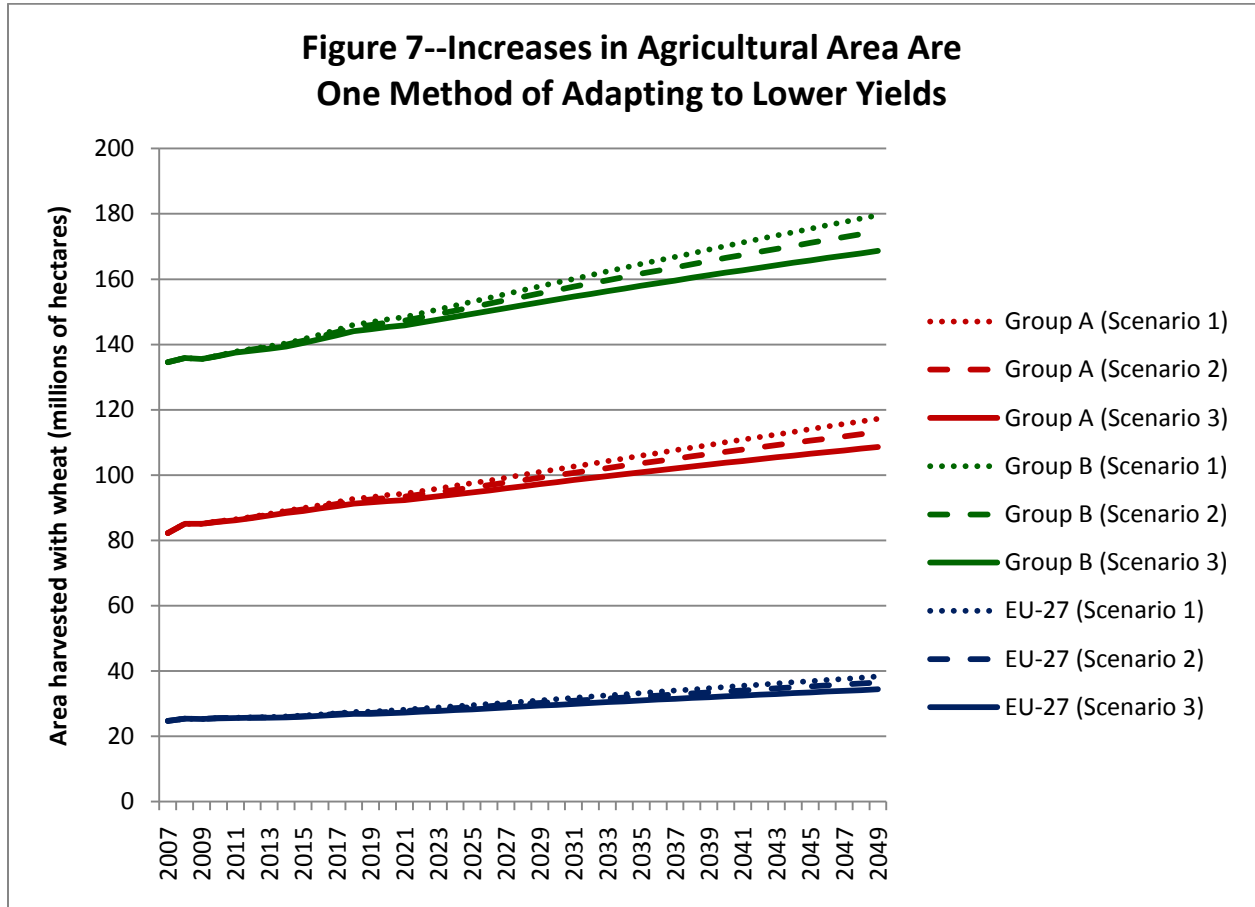
To supply wheat to the world's growing population, international wheat trade will need to expand well beyond its current levels over the next 40 years. Even in the most favorable of the three scenarios examined in this paper, net wheat exports from the Group A countries to the Group B countries will more than double, reaching at least 124 million tons by 2049 (fig. 6). The EU plays a major role in this expansion of wheat trade, with its net wheat exports reaching some 110-120 million tons by 2049. We shall see below that this massive growth of the EU's wheat exports is grounded in a substantial increase in wheat area that probably is not realistic given the way in which the scenarios were performed—particularly its implicit assumption that the intensiveness of production practices remains constant when yields or area harvested changes. Nevertheless, the slight decline that is projected for the EU's population during 2011-49 makes it more likely that the EU will have a major role as a wheat exporter over the next 40 years.



Source: Authors' analysis of PEATSIM results.

One method of adapting to lower yields is simply to devote more land to the crop, and an expansion of wheat area is an instrumental part of the process by which yield improvements in some countries are able to compensate for limited yield growth in other countries. For example, in the low-productivity world of Scenario 1, in which the Group A countries face slower yield growth and the Group B countries experience a contraction in yields, Group A's area harvested with wheat reaches 117 million hectares by 2049, compared with just 109 million hectares in Scenario 3 (fig. 7). Meanwhile, Group B's area harvested with wheat in Scenario 1 reaches 180 million hectares in 2049, compared with 169 million hectares in Scenario 3. Open trading relationships ensure that this process is fully utilized. Under conditions of restricted trade, a

country would need to shoulder the full burden of adapting to slower yield growth or declining yields.



Source: Authors' analysis of PEATSIM results.

There are, of course, limitations to devoting additional land to a particular crop, and incorporating these limitations within the PEATSIM model will require additional work. Diminishing yields can be expected as lands less suited to wheat cultivation are brought into production, and increases in area cultivated place additional demands on scarce water resources if that area is irrigated, as well as additional stresses on any waterways that receive agricultural runoffs. In the simulations presented in this paper, the exogenously specified yield for a

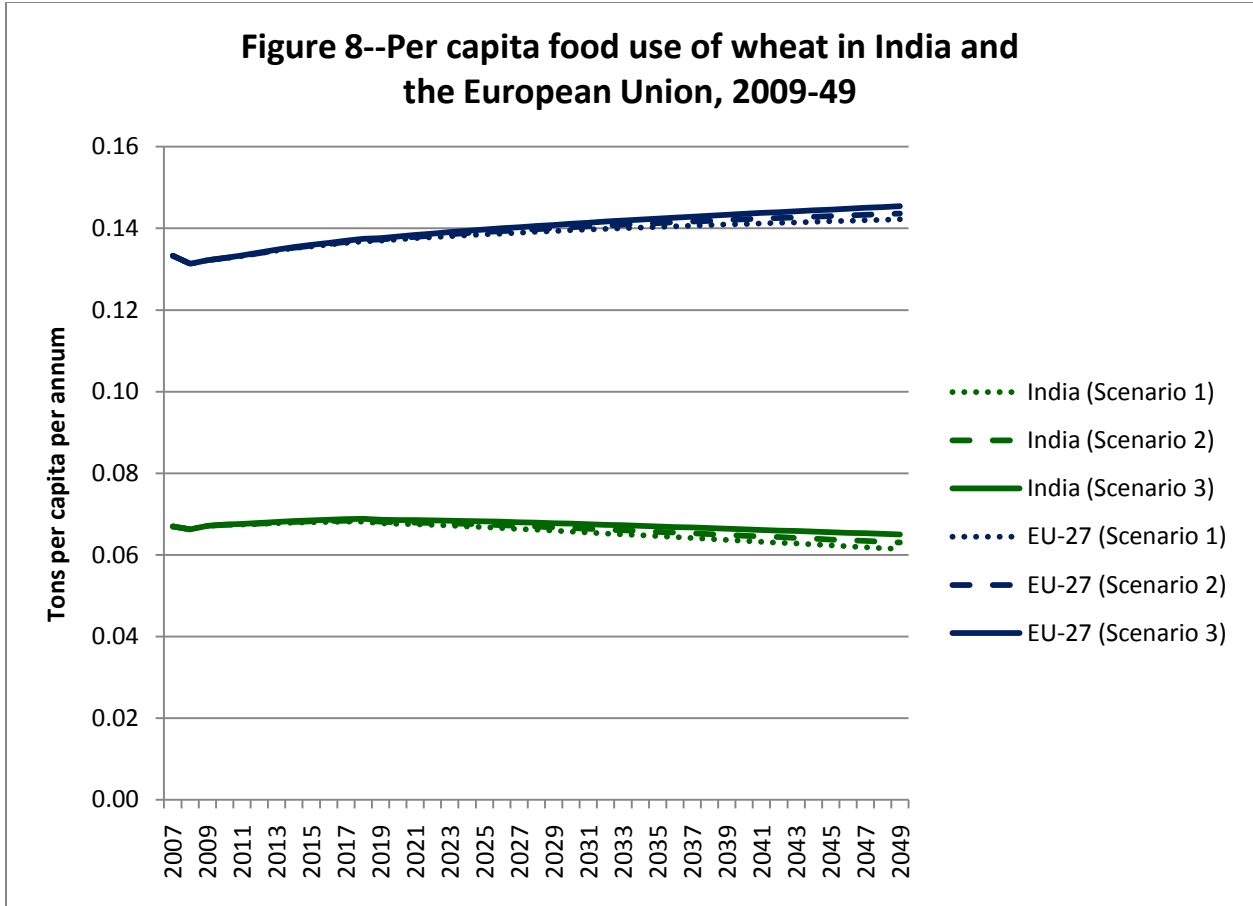
particular country or region in a given year does not vary with area planted, and there is no accounting of external costs associated with agricultural production.

Another limitation is that the sum of arable and potentially arable land is finite. In the three simulations of this paper, area harvested with wheat in the EU reaches its highest point at 38 million hectares (Scenario 1, year 2049). By contrast, the total area harvested with wheat in the 27 Member States that currently make up the EU has remained in the neighborhood of 25-27 million hectares since 1961 (Food and Agriculture Organization of the United Nations, 2010). Limiting the responsiveness of area harvested, imposing overall area constraints, and incorporating changes in production intensity within the model will almost certainly generate different results indicating that the challenge of adapting to climate change is that much greater.

Another basic method of adapting to lower yields is decreased consumption. For commodities such as wheat that can be used either as food for direct human consumption or as feed for livestock, decreased consumption can take the form of decreased feed use, decreased food use, or some combination of the two. In the scenarios examined in this paper, yields for feedstuffs other than wheat continue to grow along their currently projected paths as contained within the PEATSIM model. Accordingly, in countries that can produce large quantities of feedstuffs other than wheat—primarily the Group A countries—feed use of wheat plummets precipitously in each scenario, as those countries expand their production of those other feedstuffs. In the EU, for example, feed use of wheat falls from about 78 million tons in 2009 to around 29-33 million in 2049, depending on the scenario. This outcome will almost certainly change as the simulations' assumptions on yield growth are expanded to encompass commodities other than wheat.



The extent to which wheat producers can adapt to climate change will help to determine future levels of food use of wheat and, more broadly, the extent to which lower- and middle-income countries adopt diets similar to those in higher-income countries. For example, in each of the three scenarios, per capita food use of wheat in India increases until 2018 and then starts to taper off (fig. 8). The simulation results for the EU's per capita food use of wheat reveal that additional work is needed to ensure that PEATSIM's macroeconomic drivers are also more realistic. Substantial increases in the EU's already high levels of wheat consumption, particularly under circumstances of slower yield growth, seem unlikely. In addition, greater attention should be paid to the possible interaction between yield growth and macroeconomic growth in the future use of the model, as decreased crop yields could potentially depress GDP growth and draw resources away from non-agricultural sectors of the economy.



Source: Authors’ analysis of PEATSIM results.

## 6. Conclusion

Adaptation to climate change potentially can take on a variety of forms, and the degree of success (or failure) in one approach to adaptation influences the extent to which other approaches are taken. In this paper, we have used simulation results from a dynamic, partial-equilibrium model to illustrate how differing levels of achievement in maintaining wheat yield growth over the next 40 years in the face of a changing climate affects the production, consumption, and trade of wheat. While international trade clearly offers a mechanism by which yield improvements in one country or regions can partially offset limited yield growth in another country or region, international trade can only accomplish so much. When yield growth is slower, adaptation takes

less elegant forms—namely, an increase in the area devoted to wheat or a decrease in wheat consumption.

The EU is in the process of developing and implementing its framework for adapting to climate change. With respect to agriculture, this framework relies on existing farm income supports and rural development activities that are parts of the CAP, as well as the possibility of new activities to be defined over the next several years and implemented sometime afterwards. Many of the ongoing and contemplated activities are likely to affect crop yields and yield growth, and the EU is cautiously optimistic about its prospects to improve crop yields over the next 30 years at least, particularly in the Common Market's northern agro-climatic zones.

As the EU's adaptation framework increases in specificity, it should be possible to incorporate greater detail about these efforts within economic simulations. Modeling the interplay between different approaches to adaptation using PEATSIM, however, will require additional improvements to the model. On the supply side, there is a need to limit the responsiveness of area planted to changes in yields, to impose overall area constraints, and to account for possible changes in production intensities. On the demand side, there is a need to limit the responsiveness of consumption to increases in income for those countries and regions where per capita consumption of specific agricultural commodities is already high, and to incorporate more realistic income growth projections within the model, particularly for those scenarios where crop yields grow at less favorable rates.

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