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## Conclusion

This study has applied what might be called a consensus estimate by six climate models of changes in temperature and precipitation by 2070–99, by averaging their results as converted to a standardized grid size of 2° latitude by 3° longitude. Models relating agricultural impact to temperature and precipitation (mostly of the Ricardian variety) have then been applied to these changes at the standardized grid level and averaged to obtain agricultural impacts at the level of more than 100 countries, regions, or subzones within the largest countries. Projections of agricultural impact from a suite of alternative crop models and climate models have also served as the second framework for examining future agricultural impact of unabated global warming.

The two central results of these estimates are, first, that at least modest global agricultural damage can be expected from business as usual climate change by late in this century, with losses about 15 percent greater if the carbon fertilization effect fails to materialize; and second, the damages will be disproportionately concentrated in developing countries. The diagnosis of damage suggests that it would be a risky strategy to do nothing about global warming on grounds that some studies have estimated that there would be global agricultural gains rather than losses for the first few degrees of warming. The magnitude of global land surface warming by the 2080s under business as usual warming would be 4.4°C (weighting by farm area), and precipitation would rise only 2.9 percent (table 4.3). This combination would go far beyond optimal temperatures in the low latitudes and also in the mid-latitudes.

Table 7.1 presents an overview of the aggregate estimates of this study. The estimate for global productive capacity change including carbon fertilization is a decrease of about 3 percent. This reduction probably understates potential losses, however. If the carbon fertilization effect (already

**Table 7.1 Summary estimates for impact of global warming on world agricultural output potential by the 2080s (percent)**

	<b>Without carbon fertilization</b>	<b>With carbon fertilization</b>
Global		
Output-weighted	-15.9	-3.2
Population-weighted	-18.2	-6.0
Median by country	-23.6	-12.1
Industrial countries	-6.3	7.7
Developing countries <sup>a</sup>	-21.0	-9.1
Median	-25.8	-14.7
Africa	-27.5	-16.6
Asia	-19.3	-7.2
Middle East North Africa	-21.2	-9.4
Latin America	-24.3	-12.9

a. Excluding Europe.

Source: Tables 5.8 to 5.10.

constrained to a 15 percent increase in these estimates, lower than in some earlier estimates) failed to materialize, the losses would be estimated at about 16 percent. The Ricardian models probably err in the direction of optimism by implicitly counting on availability of more water for irrigation under circumstances in which there could easily be less water. Neither the Ricardian nor the crop models deal explicitly with increased damage from pests or more frequent and more severe extreme weather events (floods and droughts).

For several reasons, then, a prudent range for impact on global agricultural capacity by the 2080s could thus easily involve greater damage than the direct preferred estimates in this study and could perhaps lie in the range of reductions of 10 to 25 percent. Even if global productive potential were cut by only 3 percent, the results find an inequitable distribution of the effects, driven by the fact that the poor countries tend to be located in lower latitudes, where temperatures are already at or above optimal levels. On average developing countries would suffer losses of 9 percent, and median losses for these countries would amount to 15 percent. Confirming previous studies, the results here indicate that the losses would be most severe in Africa (estimated here at 17 percent average loss and 18 percent median loss in agricultural capacity) and Latin America (13 percent average and 16 percent median loss). The losses would be much larger if the benefits from carbon fertilization failed to materialize (averaging about 21 percent for all developing countries, 28 percent for Africa, and 24 percent for Latin America).

In terms of geopolitics, the results here are particularly important for the cases of China and India. China is already the second-largest emitter of carbon dioxide (after the United States but ahead of the European Union), and its cooperation will surely be crucial to effective action against global warming. Although the central estimate in this study finds China a modest gainer in agriculture under business as usual (increase in agricultural capacity by about 7 percent with carbon fertilization), the estimate turns to a loss (7 percent reduction in agricultural capacity) if carbon fertilization effects do not materialize or are offset by excluded damages. For India, there is no ambiguity: Prospective losses are massive (on the order of 30 to 40 percent).

For Australia, one of the two steadfast opponents of the principal international initiative to date against global warming (the Kyoto Protocol), the results also suggest that a more positive position on global warming abatement would be in its long-term interests. The estimates for Australia indicate losses of around 16 percent even with carbon fertilization (with potentially much larger losses suggested by the Ricardian estimates). As for the United States, the other principal opponent, although the estimates show an aggregate gain of 8 percent in the case with carbon fertilization, they indicate a comparable loss (6 percent) if carbon fertilization is excluded. Moreover, regional losses are pronounced: by about 30 to 35 percent in the Southeast and in the Southwest Plains, if carbon fertilization is excluded (and about 20 to 25 percent if it is included; table 5.8).

For an initial phase of modest global warming, average impacts on agriculture are ambiguous and may be benign globally on average, but it would be a serious mistake to infer from such a diagnosis that little should be done to curb climate change. This study has sought to sharpen analysis of agricultural impacts by bringing to bear rigorous and detailed estimates available for regional climate change and quantitative models of agricultural impact. The new estimates in this study strongly suggest that by late in the present century the global effects under business as usual global warming would turn malignant for agriculture globally and that the damages would be the most severe and begin the soonest where they can least be afforded: in the developing countries. Moreover, it would be a serious mistake to downplay the risks of future agricultural losses from global warming on grounds that technological change, for example in new seed varieties, will offset any negative climatic effects. A close look at the pace of yield increases in the past two decades, combined with attention to the prospective rise in global food demand and the conversion of a substantial portion of agricultural land from food to energy crops, suggests that there is little margin for complacency about erosion in agricultural potential from global warming.

Finally, it should be emphasized that the estimates of this study understate potential damages from another crucial standpoint: They take a snap-

shot of time at the 2080s, yet baseline damages could be expected to continue to grow throughout the following two centuries before atmospheric concentrations of carbon eventually would begin to decline once again from mixing into the deep ocean (Cline 1992). Even if carbon emissions collapsed after the 2080s back to well below today's levels, the delay of some three decades for ocean thermal lag means that the warming and impacts estimated in this study would substantially underestimate the eventual equilibrium warming and damages.