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CLIMATE CHANGE, AGRICULTURE, AND DEVELOPING ECONOMIES

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ABSTRACT

The impact of global climate change on the less developed countries is analyzed using archetype CGE-multimarket models for three economies representing the poor cereal importing nations of Africa, Asia, and Latin America. The objective is to predict the differential impact of climate change across continents on macroeconomic variables, sectoral responses, and household income and food consumption effects, particularly among the poorest. Results show that all these countries will lose and that their agricultural outputs will fall, but that Africa will be by far the most severely affected. Countervailing policies to mitigate negative effects should focus on the production of food crops in Africa and of export crops in Latin America and Asia..

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1. Introduction

Analyses of the effects of global climate change suggest that the overall world capacity to meet future food demands will not be severely threatened and that economy-wide impacts on developed countries will be modest. There is, however, general agreement that climate change will lead to significant reductions in agricultural productivity in developing countries[2]. Attributable to these global yield changes, world prices of traded agricultural commodities are expected to adjust to alterations in world supply and demand. Due to linkages with the agricultural sector, these yield and price effects will result in economy-wide adjustments. In this paper, we model these adjustments to predict the disparate repercussions of climate change on the macroeconomic performance, sectoral resource allocation, and household income levels of developing economies. Since low income, net cereal-importing economies of Africa, Asia, and Latin America are most vulnerable to environmental and world market changes, it is these countries on which we focus.

Using three regional archetype multisectoral and multiclass computable general equilibrium (CGE) models for Africa, Asia, and Latin America, we analyze the contrasted impacts of global warming across continents, sectors of economic activity, and social groups.[3] Simulations help identify those underlying structural features of an economy which are the primary determinants of the magnitude of economy-wide, sectoral, and household impacts of climate change. These determinants are in turn suggestive of policy instruments that could be used to countervail undesirable effects, particularly on the poorest household categories.

The paper is divided into five sections. In Section 2, we discuss the methodology used to predict the effects of climate change on a subset of developing economies. The section focuses on the archetype approach, on the channels through which climate change directly affects agricultural sectors, and on the use of CGE models. Section 3 analyzes the consequences of climate change on

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[2] See Rosenzweig and Parry (1993), Reilly et. al. (1993b), Cline (1992), Schelling (1992), and Nordhaus (1991).

[3] The archetype approach to policy analysis was pioneered by de Melo and Robinson (1982). Here, we rigorously construct the archetypes from the national accounts for the corresponding economies.

macroeconomic variables, sectoral responses, and household income and food consumption. In Section 4, alternative policy interventions to mitigate the negative effects of warming are explored. Conclusions are drawn in Section 5.

2. Methodology and Data

2.1. Archetype economies

Climatologists often use the doubling of carbon-dioxide-equivalent gases above pre-industrial concentrations as a benchmark to study climate change (Houghton et. al, 1992). Differences in existing estimates of the date at which doubling will occur depend on assumptions about the collective impact of industrial policies on global carbon dioxide concentrations. We have retained a prediction of expected doubling by the year 2050.[4] Most climate change impact studies base their assessment on the structures of current economies.[5] Departing from this norm, we modify current (1985) social accounting matrices (SAMs) to be archetypal of economies around the year 2050.

The current archetype models developed for Africa, Asia, and Latin America are based on SAMs which have been designed to represent the defining structural features of low income, cereal-importing countries from the three regions (for details see Winters et. al., 1995). They replicate the average levels of the macro aggregates in 1985 for the countries grouped in each archetype.[6] These current SAMs were modified to allow for predicted economic growth and structural change until the year 2050. Predicted growth rates in GDP per capita were computed for each archetype based on projections by the Intergovernmental Panel on Climate Change (1990) and on past growth rates reported in the World Bank Tables (various years).[7] The corresponding

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[4] Parry (1990) argues that carbon-dioxide-equivalent doubling above pre-industrial levels will be reached in 2025 under a business-as-usual scenario; under an optimistic scenario this will be delayed until 2070. In Rosenzweig and Iglesias (1993), agricultural shocks from a carbon-dioxide-equivalent doubling are assumed to occur in 2060, while in the MINK study (Crosson, 1993) the shocks occur in 2030.

[5] All impact studies reviewed in Sonka (1991) study the effects of climate change on current economies as do more recent studies (e.g. Reilly et al, 1993b; Mendelsohn et al., 1994)

[6] The following countries are represented in each archetype: *Africa:* Benin, Burkina Faso, Central African Republic, Ethiopia, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Mali, Mauritania, Mozambique, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Tanzania, Togo, and Zaire. *Asia:* Bangladesh, Indonesia, Pakistan, Papua New Guinea, Philippines, and Sri Lanka. *Latin America:* Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, and Peru.

[7] These calculations suggest that while Asia and Latin America will experience significant growth, African population growth will outweigh economic growth leaving the economy virtually unchanged over

structural changes were based on the 'normal patterns of growth' established by Chenery and Taylor (1968).[8]

Table 1 summarizes characteristics of the future archetype SAMs for Africa, Asia, and Latin America. Agricultural sectors will generate over 38% of total income in Africa while for Asia and Latin America the corresponding figures are only 18% and 7.6%, respectively. Other important contrasted features are: the high share of total exports derived from agriculture in Africa (69%); the high share of agricultural income in total household income in Africa (61%) and the high share of non-agricultural income in Latin America (83%); for the income of the rural poor, a high share coming from agricultural profit in Africa (65%) compared to a high share coming from labor income in Latin America (70%); large farmers' income high dependency on export crops, particularly in Africa (22%) and Asia (18%); and a high degree of cereal self-sufficiency among small farmers/landless in Africa (97%) compared to zero self-sufficiency for this group in Asia.

2.2. Agricultural shocks

Climate change is expected to impact several aspects of multi-sectoral economies. However, for developing nations, the impact on agriculture is expected to be predominant. Two direct effects on agriculture are anticipated. First, a reduction in overall crop yields which will depend on individual crop productivity changes (as predicted by climate and crop models) as well as on the composition of agriculture in the country--i.e., on the importance of specific crops in total production and how these are individually affected by climate change. Second, since climate change is a global phenomenon, there will be an effect on global supply and demand for agricultural commodities and therefore, on world prices. As with yields, the transmission of world price shocks into an economy will depend on the relative importance of different crops in the export and import portfolios.

Climate change can affect crop yields via changes in temperature, precipitation, soil

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this period.

[8] These normal patterns predict a diminishing size of the agricultural sector relative to the industrial and service sectors, urbanization of the labor force, decrease in the share of cereal consumption in total consumption, and increase in international trade as GDP per capita rises.

moisture and soil fertility, changes in the length of the growing season, and an increased probability of extreme climatic conditions (Parry, 1990). To simulate these climatic effects of carbon dioxide-equivalent doubling, several research centers have developed global climate models (GCMs). Based on three GCM warming scenarios, Rosenzweig and Parry (1993) have, in turn, used crop modeling techniques to estimate the crop- and region-specific impact of climate change on average crop yields.

Changes in crop yields due to climate change depend on both technological considerations as well as on- and off-farm responses to the new environment. Rosenzweig and Parry (1993) identify three levels of response: no adaptation; level 1 adaptation with positive carbon dioxide (CO_2) effects, which allows for on-farm responses to climate change; and level 2 adaptation with positive CO_2 effects, which incorporates substantial changes to agricultural systems beyond the farmer's means such as investment in irrigation infrastructure, and in research and extension services. With adaptation, farmers reduce yield loss by harnessing positive fertilization effects on plant production from the additional CO_2 in the atmosphere (Wolfe and Erickson, 1993).

We use a subset of crop yield change data from the Rosenzweig and Parry study.[9] The data are based on the climatic predictions of the Goddard Institute of Space Studies GCM (GISS) for the three response levels identified above. Since our archetypes represent a chosen cluster of countries, and the cereal and export crop sectors comprise several crops, the yield data had to be aggregated in such a way as to make the two sectoral yield shocks (cereal and export crops) applicable to each archetype economy.[10] Aggregation of the data emphasizes that the impact of

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[9] We thank Dr. Cynthia Rosenzweig of the Goddard Institute of Space Studies and Professor Martin Parry of Oxford University for providing data for use in this study. For results with the GFDL and UKMO warming scenarios, see Winters et. al. (1995).

[10] The first step in this process is to make the crop specific data represent production patterns in each archetype. To do this, individual country yield shocks to each crop, for example maize, were aggregated using weights equal to the proportion of individual country maize production in total maize production in the archetype. To compute the cereal and export crop yield shocks, the individual crop shocks were weighted by their relative value for the archetype. That is, $S_A^j = \sum_i \left(\sum_C S_C^i W_C^i \right) W_A^i$, where j = {cereal, export crop}, i = {maize, rice, wheat, other coarse grains, soybeans} if j = cereal and i = {cotton, tobacco, sugar, oilseeds, coffee, cocoa, tea, bananas} if j = export crop, A = {African, Asian, Latin American archetypes}, C= {countries of archetype A}, S_A^i is the shock to crop i for archetype A, S_A^j is the shock to aggregate crop j for archetype A, W_C^i is the share of country C production of crop i in total production of i

climate change on production is not simply a function of the size of yield shock to a particular crop, but also the relative value of that commodity in an economy. The aggregate cereal and export crop shocks for the three archetypes and three response levels are presented in Table 2. Negative yield shocks are generally larger on cereals than on export crops. For each archetype, the magnitude of shocks also decreases with each level of adaptation.

Climate change will affect agriculture through its effect on world prices as well; individual crop price changes are due to global changes in production and are important since the archetype economies import cereals and export other crops at prevailing world prices. Global reductions (or increases) in production, in turn, depend on farmer and government responses to cope with new climatic conditions. Rather than presuming no adaptation or widespread adaptation (level 2) for all countries, we use price shocks data based on an intermediate position of level 1 adaptation with positive CO_2 effects for all countries. These world price changes for each crop are drawn primarily from a study by Reilly et. al. (1993) which also uses the Rosenzweig and Parry yield loss estimates.[11] Since the composition of cereal imports and crop exports varies by archetype, the aggregate price shock is different for each archetype. All experiments in this paper are based on the price and yield shocks reported in Table 2.

2.3. Computable general equilibrium (CGE) model

To trace the effects of crop yields and price shocks on the archetype economies, a CGE model with

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in archetype *A*, and W_A^i is the ratio of the value of crop *i* production to the value of producing all *j* crops in archetype *A*.

[11] Their results suggest greater price shocks for cereal crops than for export crops. Contrary to the adverse yield shocks developed for our simulations, global warming may increase total world yields and therefore decrease prices if warmer temperatures allow production of certain crops where it was previously impossible, particularly in northern countries such as Canada and Russia (Reilly et al., 1993b). To make the price effects correspond to the cereal and export crop sectors of each archetype, world price shocks for each crop are weighted by their relative value as a net export for that region. That is, $P_A^j = \sum_i P_A^i V_A^i$, where *j* = {cereal, export crop}, *i* = {maize, rice, wheat, other coarse grains, soybeans} if *j* = cereal and *i* = {cotton, tobacco, sugar, oilseeds, coffee, cocoa, tea, bananas} if *j* = export crop, *A* = {archetypes}, P_A^i is the world price shock to crop *i*, P_A^j is the world price shock to aggregate crop *j* for archetype *A*, and V_A^i is the ratio of the net value of crop *i* imports to the net value of imports of all *j* crops in archetype *A*.

a multimarket agricultural sector specification was constructed for each archetype.[12] The models used in this paper are largely neoclassical,[13] in which agents respond to relative prices as a result of profit maximizing and utility maximizing behavior in determining levels of production and consumption, and markets reconcile endogenous supply and demand decisions with adjustments in relative prices. General equilibrium modeling which emphasizes linkages between sectors on the demand and supply sides allows to trace the effects of agricultural shocks on the macroeconomic makeup of the economy, sectoral structure and prices, and the welfare of different classes of households.

Embedded in the CGE, the multimarket representation specifies a joint production function for the three agricultural sectors. It includes complementarities and substitutions among export crops, cereals, and other agriculture, along with reallocations across sectors of different types of labor. In general, the supply elasticities which encapsulate the joint production function, particularly the own price elasticities, are lower for Africa than for both Asia and Latin America.[14] Underlying these values is the observation that African agriculture is not as responsive as the other two regions to external changes due to a variety of institutional factors such as limited access to credit, inefficiency of marketing channels, and shallow labor markets.

Archetype response to world price shocks and adverse yield shocks depends substantially on the ability of economies to offset some of the burden of domestic adjustment by participating in international markets. It concurs with Reilly and Hohmann (1993) who argue that trade adjustments may play an important role as a mitigating factor against global warming. Yet, the degree to which this occurs depends on an individual country's degree of integration into the world market. Integration is largely summarized by the elasticities of substitution between domestic and foreign goods both on the consumption and the production sides. In particular, an increase in the international price of cereals will have relatively small effects on the domestic producer price of

[12] The CGEs used here were developed by Sadoulet, Subramanian and de Janvry (1992).
[13] All commodity markets and unskilled/rural wages follow the neoclassical market-clearing price system. However, wage rates for urban and skilled labor are institutionally determined. The real exchange rate and investment adjust to satisfy foreign exchange and savings-investment equilibria. Total government expenditures are fixed. For a detailed discussion of sources of parameter values, see Winters et. al. (1995).
[14] The elasticities are taken from Sullivan et al. (1989).

cereals if imports are a poor substitute for domestic production, if the share of imports is small, and/or if the elasticity of cereal supply is large. For the Asian archetype a high degree of substitutability characterizes the observed high degree of competitiveness between imports and domestic cereal crops.[15] This is captured by a value of 30 for the elasticity of substitution between imported and domestic cereal crops in Asia. Correspondingly, Africa has a low degree of substitutability with an elasticity of 0.3, while Latin America is an intermediate case with an elasticity of 1.2.

Most of the impact of climate change will only be felt in the future. Therefore, it has been necessary to make predictions about the effects of climate change and the economic structure of future economies. This combination of data derived from several economic and scientific models cannot be avoided and potential discrepancies should be borne in mind as the results are interpreted. Consequently, the focus of the paper is not on specific absolute values obtained by simulations, but rather on the identification of structural features and processes that determine which countries, sectors, and social groups will be relatively more or less severely affected by climate change.

3. Responses to climate change

The four main factors that influence the impact of climate change on an economy are: the relative and absolute magnitude of yield and price shocks, the importance and composition of agriculture in the economy, the responsiveness of the agricultural sector, and the relationship between the domestic and international economy.

As the magnitude of yield and price shocks increases, the economic impact of climate change will clearly be greater. Of our three sets of shocks, it will then be the case that no adaptation will have the largest economy-wide effects while level 2 adaptation will have the smallest impact. The realized shocks for a given economy will depend on how climate change influences global and local weather patterns as well as on the composition of production in that

[15] For the analysis of the degree of substitutability between imported and domestic cereals which underlies this choice of elasticities, see Sadoulet and de Janvry (1990).

economy. For instance, an economy reliant on a cereal that is particularly susceptible to climate change will suffer more severe effects. The shocks to cereals, particularly the yield shock, are expected to have more impact than the export crop shocks since cereals are domestically important as both a producer and consumer good.

Since we have focused on the impacts of climate change on agriculture, it is expected that countries with large shares of GDP in agriculture will be most impoverished. The implication is that Africa will be most affected, then Asia, and finally Latin America.

When shocks are not uniform across agricultural commodities, the impact of climate change-induced shocks may be mitigated by reallocating production towards commodities that are less affected. In our model, supply responsiveness of the agricultural sector is embodied in the multimarket elasticity specifications within agriculture. For simplicity, all cereals and all export crops have been aggregated into two sub-sectors. Therefore, substitution possibilities among cereals and among export crops that may have allowed greater flexibility in responding to climate change have been eliminated. The responsiveness of the agricultural sector depends on several factors such as human capital, technological capabilities, credit market access, and infrastructure. Based on these factors, Africa will be most severely affected by climate change, followed by Asia and Latin America.

An alternative means of mitigating the effect of climate change is via participation in international commodity markets. A negative shock to domestic cereal production will have only mildly deleterious consequences if domestic cereals are readily substitutable by imports. In effect, domestic shocks may be exported to world markets. Integration into world markets depends on domestic preferences for commodities easily accessible via trade, regional market integration within the economy, infrastructure supporting trade links, etc. Based on the relevant elasticities for each archetype, Africa is again expected to suffer the most, but Asia is expected to do better than Latin America.

3.1. Macroeconomic effects

Agricultural shocks due to climate change have an overall negative effect on per capita income for all the archetype economies under each adaptation scenario. GDP per capita reductions range from -6.1% to -0.4% for Asia and -9.2% to -0.8% for Latin America according to levels of adaptation (Table 3). Africa suffers the most with a decrease in per capita income ranging from -11.1% to -2.2%. Negative yield shock effects are attenuated to some degree when the world price of the composite agricultural import to an archetype falls (all archetypes are net importers of cereals) and/or the world price for export crops rises. This is particularly true for Asia which faces the most favorable set of price shocks and least true for Africa since it faces a negative price shock for its exports.

Africa responds particularly poorly to climate change since it is largely agrarian, suffers an adverse price shock to its exports, has a low ability to adjust agricultural portfolios, and has a low elasticity of substitution between domestic and imported cereals. The orientation towards cereal self-sufficiency prevents the economy from taking advantage of lower world cereal prices by shifting consumption towards imported cereals.[16] Unfavorable yield shocks to cereal production can be attenuated by sectoral shifts in production away from the cereal sector towards export crops, livestock, and other sectors. Due to a limited ability to respond with resource reallocation, meeting the demand for cereals is expensive and difficult for the African archetype.

Interestingly, Asia suffers relatively smaller reductions in GDP per capita relative to Latin America for all three levels of adaptation, even though yield shocks to Asia were generally larger than Latin America and Asia's economy relies more heavily on agriculture. The conventional arguments among critics of policy efforts to slow global warming (see Schelling, 1992) rely on the expected tendencies for developing economies to be less dependent on agriculture, and hence less vulnerable to climate change. Our analysis suggests that the degree of dependence of an economy on agriculture is important, but an equally relevant consideration is the ability of an economy to adapt or respond to agricultural yield shocks by integrating into the international market. Development of the agricultural sector must be complemented with an outward orientation.

[16] This corresponds to Reilly et al. (1993b) who state that, "subsistence agricultural systems are most at risk because they cannot avail themselves of the risk pooling value of markets."

Absorption (equal to domestic consumption) is everywhere less affected by climate change-induced agricultural shocks than income per capita. The more open an economy, as embodied in the elasticity of substitution between domestic and international cereals, the greater the ability to import cereals and to maintain cereal consumption levels when the world price of cereals falls. Asia, with the highest substitutability, is able to maintain consumption, and therefore absorption through enhanced cereal imports. In contrast, Africa with low substitutability is forced to reduce absorption. Latin America lies between these two.

The dramatic increase in cereal imports in Asia and Latin America leads to a high demand for foreign currency. Balance of trade equilibrium is achieved by currency depreciation, by 3.5% in Asia and 1% in Latin America. For Africa, an appreciation of the real exchange rate reduces further the degree of openness of the African economy. There is a 5% appreciation of the currency in response to a complex of changes, but primarily due to a large decline in demand for imports. The cereal sector yield shock of -17% cannot be compensated by an increase in cereal imports. In response, the domestic price of cereals rises which induces resource reallocation towards cereal production. Import demand for cereals and industry declines, since real incomes of all households decrease, leading to a lower demand for foreign exchange. The supply of foreign currency falls as export crop production decreases both because productivity falls and in order to allow a shift towards cereal production. The depreciating effect from lower supply of foreign currency is overwhelmed by the significant decrease in industrial imports, which are much larger in value terms than export crops, causing a net appreciation.

3.2. Sectoral effects

Although yield and price shocks directly influence only the cereal and export crop sectors, all sectors will be affected indirectly through linkages with agriculture. The linkages range from substitution possibilities between sectors, household income and consumption, industrial inputs in agriculture, to the use of agricultural outputs in food processing. These effects will vary across the archetypes depending on the relative sizes of the different sectors, the substitution possibilities between factors and outputs within the agricultural sectors, and the relationship between agriculture and other sectors.

Climate change-induced changes in the sectoral composition of the economy are also enumerated in Table 3. Comparison of Tables 2 and 3 shows that the yield shocks lead to lower cereal production in the economy, but the decrease is less than the yield shocks themselves in Africa and Latin America. Essentially, lower yields are mitigated by resource movement into cereal production in response to higher domestic cereal prices. In Africa and Latin America, this price rise is more pronounced because of a relatively low elasticity of substitution between imported and domestic cereals. In Asia, since domestic cereal supply reductions are easily replaced by imports, the cereal price effect is much lower. In fact, the 17% decline in the world price (Table 2) induces a decline in the domestic cereal price ranging from -2.9% to -13.5%. This contributes to cereal production falling by more than the yield shock for all three levels of adaptation.

Input reallocation into cereal production comes at the expense of other sectors. The degree of responsiveness depends on the friction in input adjustment across and within sectors as specified by elasticities in the multimarket. Africa, with low elasticities, is again the most negatively affected archetype. In some cases, movement of resources out of the export crop sector leads to production levels which are lower than levels dictated solely by the export crop yield shock. In Africa and Asia, substitution towards cereal production may come from either other agriculture or from export crops. Whether the factors of production that are reallocated to cereal production come from other agriculture or export crops depends on both relative prices and cross-price elasticities as well as on the world price shock to export crops.

We have modeled climate change so there is no direct effect on the non-agricultural sector. As can be seen from Table 3, there are indirect effects which may for the purpose of exposition be classified into a demand effect and a substitution effect. The demand effect is a result of higher cereal prices and consequent lower real incomes of consumers. Reduced demand for the non-agricultural sectors is evident in the lower relative prices for industry and services in Africa and Latin America. The substitution effect is related to the agricultural terms of trade. In most simulations, the change in cereal price, along with the reduction of non-agricultural commodity prices, leads to an increase in the agricultural terms of trade. Therefore, factors of production shift from the non-agricultural to the agricultural sectors, leading to a lower supply of non-agricultural goods.

If each shock is examined in isolation (results not presented), the cereal yield shock has the most profound impact, particularly for Africa and Latin America. This is because the cereal sector is larger than the export crops sector in each archetype, and cereals are important both as a consumer and a producer good while export crops are produced mainly for international markets. The situation is somewhat different in Asia because of greater sensitivity to world prices. The cereal yield shock has the dominant impact on production, but not on prices.

In summary, total cereal production is lower in all archetypes, but it does not decrease by as much as the yield shock since domestic cereal prices increase (except in Asia due to world price changes). Production of export crops decreases by more than its yield shock in Africa which faces a negative price shock to this sector. In Africa and Asia, both the price and production of other agriculture (mostly livestock) tends to fall. Finally, the agricultural terms of trade increase in all cases, most substantially in Latin America.

3.3. Household effects

While aggregate incomes systematically fall, not all social groups lose. Net sellers of cereal and export crops benefit from warming when the domestic prices of these commodities increase by more than the fall in yield. However, "producer-consumer" peasant households suffer a loss in real income since they also purchase cereals. Linkage effects emanating from the shocks to the cereal and export crop sectors also lead to changes in the domestic prices of other sectors such as livestock and industry, and factor prices. The overall social impact depends on the distribution among household classes of net buyers and net sellers of cereal and export crops, the proportion of income derived from wage payments and agricultural profits, and the share of cereals in total expenditure. Table 3 presents the percentage changes in real incomes of rural and urban households for each archetype and changes in food consumption for poorer income groups.

In Africa, global warming has negative real income effects on all classes and regressive income distribution effects with richer income groups in both the rural and urban areas suffering relatively less than other classes. Incomes of rural households decrease despite the increase in cereal prices due to the lower prices of livestock and export crops, and the lower wages for unskilled labor. In addition, small farmers are net buyers of cereals (although almost self-sufficient) and they are slightly hurt by rising cereal prices. Medium farmers are hurt more since a larger percentage of their nominal income is derived from wages and livestock. Income losses for urban households (from lower unskilled labor wages and payments from firms) are counteracted to a large degree by the fall in prices of agricultural processing, industry, and services which account for the bulk of their expenditures.

In contrast to Africa, income distribution changes in Asia are progressive. The size of marketed surplus of cereals is very unequal in Asia. The small farmer group buys most of their cereals, and medium farmers 74% of their cereals, while larger farmers are net sellers. Thus, when the world price of cereals falls and is transmitted to the domestic market, small farmers gain in real income terms.

The Latin American social structure lies between that of Asia and Africa. Small farmers buy 72% of their cereals while both medium and large farmers are net sellers. With higher cereal and export crop prices, the income effect is regressive among rural households. In the urban sector, rising cereal prices depress real incomes, with the urban poor losing more as they have a higher budget share for cereals.

To summarize, the effects of climate change on income distribution are generally regressive. All social classes in Africa will be hurt by climate change which is essentially a productivity shock since world prices are not transmitted to the domestic market. In Asia and Latin America, certain groups may experience real income gains if they allocate a large proportion of their budget to cereal consumption and the price of cereal falls, or if they are net sellers of commodities whose prices rise in the domestic market.

Much of the literature on climate change is concerned with possible increases in hunger in developing countries (Rosenzweig and Parry, 1993). Results reported here are in agreement with this concern in the African and Latin American context where all low income groups have lower food consumption. However, food consumption levels for the poor in Asia increase with warming due to reductions in cereals prices. Required to protect the African and Latin American poor from the impact of warming are either greater integration in to world food markets, or development programs to raise the supply response of agriculture to allow import substitution, or compensatory food aid to shelter them from rising domestic food prices.

4. Policy analysis

The analysis has thus far identified factors which explain the impact of climate change on developing economies. The results hinge on the relationship of each archetype economy to the international market, the responsiveness of the agricultural sector to price changes, the importance and composition of agriculture in the economy, and the relative and absolute magnitude of yield and price shocks. Policies to alleviate the impact of climate change can focus on altering the first two of these factors. For each of the relevant structural parameters, the base model and the yield and price shocks at level 1 adaptation are taken as given, and parameter values higher than in the base run are examined. Alternatively, compensatory measures may be targeted directly at facilitating adaptation of the agricultural sector to climate change. Adaptive responses can occur at the farm level (level 1 adaptation) or via government investment in infrastructure, research into new technologies, and agricultural extension services (level 2 adaptation). We should bear in mind that these simulations provide information only on the potential benefits of policy interventions. Benefits must be weighed against the cost of these interventions to fully evaluate the merits of compensatory measures.

On-farm and off-farm adaptation measures help reduce the losses in per capita income in all archetypes relative to a scenario of no adaptation to climate change: GDP per capita losses under level 2 adaptation compared to no adaptation are reduced by 80% in Africa, 91% in Latin America, and 93% in Asia (Table 3). These adaptations systematically benefit most the Asian countries and least the African. Thus, even if farmers and governments were fully capable of implementing the opportunities to adapt to warming in Africa, this poorest continent would still benefit least from these efforts.

Experiment 1 in Table 4 examines policies such as investment in infrastructure to reduce transactions costs in imports, changes in trade policy such as the elimination of quantity restrictions, and domestic market integration, which increase the elasticity of substitution between domestic and imported cereals. These policies are aimed at helping the fall in the international price of cereals better transmit to the domestic market, thus benefiting net buyers of cereals. They are important for Africa and Latin America where low elasticities of substitution imply that the domestic price of cereals rises sharply in spite of a falling international price. Results show that these measures reduce the overall income losses due to warming in both archetypes and help mitigate the domestic rise in the price of cereals by improving substitution of imported for domestic production. Greater market integration increases trade as it allows economies to further specialize on the basis of comparative advantages. Greater trade induces an upward movement in the real exchange rate. The result is a smaller decline (Africa) or a rise (Latin America) in the price of export crops, inducing a smaller decline in the production of these crops. By contrast, cereal production shrinks further in the two archetypes as the elasticity increases since easier importation of cereals in a context of a falling international price lowers the domestic price, making cereal production less profitable and inducing a reallocation of resources toward export crops. The smaller decline in cereal production in Africa is due to the lower supply response of its agriculture as embodied in the multimarket specification.

There is considerable diversity in the responsiveness of small farmers' incomes. In Latin America, a large portion of small farmers’ income is from labor, not cereal production, so the decrease in the price of cereals that occurs as cereal imports increase has a positive real income effect on them. Medium farmers, since they are net sellers of cereals, are worse off as the elasticity increases. In Africa, small farmers are largely self-sufficient cereal producers and livestock herders, with the latter being the more important income source. As the elasticity increases and cereals are more easily imported, cereal prices fall and there is a movement towards production of livestock which suppresses the price of livestock and depresses their incomes. Medium farmers are net buyers of cereals and sellers of export crops, and therefore benefit from both the decrease in cereal price and the increase in export crop price as the elasticity is increased.

This strategy of greater international market integration helps ease the cost of climate change on the urban poor. Since the price of cereals continues to rise in Africa and Latin America even with higher elasticities of substitution, the policy implication for agriculture is to focus agricultural development efforts on the production of cereals in order to take advantage of rising domestic prices and further import substitute. This includes technological change in the production of food crops and policies to increase the price responsiveness of the sector, an experiment to which we now turn.

In experiment 2, increased responsiveness to price incentives is examined by three sets of multimarket elasticities classified as low, medium, and high responsiveness.[17] Price responsiveness can be increased in Africa and Asia, helping amplify the impact of domestic price movements on production. In Africa, where domestic cereals prices rise and domestic export crops prices fall, higher elasticities allow a greater reallocation of resources toward food crops at the expense of export crops. Higher price responsiveness is thus an important element of a strategy to boost the production of food crops. This allows import substitution in cereals and reduces the negative pressures on the real exchange rate and GDP. In Asia, the domestic price of export crops increases while cereal prices decrease. With a high elasticity of substitution in consumption, cereal requirements are met by imports. With greater price responsiveness in the agricultural sector, resources are reallocated from the production of cereals to the production of export crops. In this case, agricultural development efforts should thus be directed at facilitating the production of export crops.

[17] The low elasticity set was the initial values for Africa, the medium for Asia, and the high for Latin America. The direct price elasticities were taken as given and the cross price elasticities were recalibrated for each archetype to satisfy the appropriate constraints.

5. Conclusions

General equilibrium analysis of the consequences of global warming conducted on the future structure of archetype African, Asian, and Latin American cereal importer nations shows that these countries will suffer global income losses. Agricultural production will fall in all these countries, both cereals and export crops. As incomes fall, there will be a global shrinkage of trade, particularly of the demand for manufactured imports, which will have negative repercussions worldwide. These overall negative effects will be highly differentially felt across sectors and classes of households in the three groups of countries.

The negative effect will be largest on Africa, already the poorest set of countries, and least detrimental on Asia. The reasons why Africa will be the most negatively affected are because it has the largest share of its GDP in agriculture, the lowest substitution possibilities between imported and domestically produced cereals, it is the only continent subjected to a negative shock in the price of its export crops, and it has the lowest elasticities of supply response. Because of the low elasticity of substitution between domestic production and imports, the international cereals price shock created by climate change leads to an appreciation of the real exchange rate and hence to a fall in the domestic price of export crops. By contrast, the price of cereals rises, giving incentives to import substitute in food crops, and hence creating a logic to target development efforts at increasing the elasticity of supply response of food crops. Policies to improve integration in the international market on the import side also help ease the rise in the domestic price of cereals. The long overdue Green Revolution for Africa will become all the more pressing, particularly in the food crops for which imports are poor substitutes. In Asia and Latin America, increasing international prices for the crops they export and depreciation of the real exchange rate create sharp domestic price increases and a strong logic to focus development efforts on the production of export crops, in part to generate the foreign exchange that will be necessary to meet rising cereals import bills. In Latin America, cereal import bills can be reduced by greater international market integration on the import side.

Africa also fares worst in terms of impact on the rural and urban poor as the domestic price of cereals rises. Given the extreme poverty that already characterizes the African landless and small farmers, rural development programs and food aid programs should be part of the international community's assistance to Africa to help it cope with climate change. The same applies to Latin America, although to a lesser extent. In Asia, by contrast, falling cereals prices on the world market carries to domestic prices and creates real income gains for the rural and the urban poor. In that populous continent, global warming may turn out to be a benefit to the poor.

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Table 1. Characteristics of the archetype economies, year 2,050

	Africa	*Asia*	*Latin America*
General Indicators			
GDP/Capita in year 2,050 (1985 US$)	243	901	3047
Structure of Production (% of GDP)			
Agriculture	38.1	18.0	7.6
Industry	20.8	36.3	39.9
Services	41.1	45.7	52.5
International Trade			
% domestic supply of cereals from imports	13.9	8.8	12.6
% of total exports from agriculture	69.0	24.5	23.3
Households Income			
% of rural income in total households income	61.1	57.3	16.6
% of urban income in total households income	38.9	42.7	83.4
% of poorest group in rural income	19.2	30.3	58.0
% of poorest group in urban income	59.4	55.4	49.4
Sources of Income of Rural Poor			
% from agricultural profit	64.5	5.3	6.6
% from labor income	34.0	58.2	70.4
% from other sources	1.5	36.6	23.1
Sources of Income for Urban Poor			
% from unskilled/rural labor	18.8	0.0	48.6
% from skilled/urban labor income	25.4	71.2	9.9
% from public labor income	31.4	7.9	0.0
% from other sources	24.4	20.9	41.5
Share of income from Export Crops (%)			
Small farmers / Landless	0.0	0.0	3.6
Medium farmers	14.0	0.0	8.0
Large farmers	22.2	18.0	9.9
Share of income from Labor (%)			
Small farmers / Landless	34.0	55.9	70.4
Medium farmers	30.5	39.7	54.5
Large farmers	50.7	19.2	46.7
Self-sufficiency in Cereals (other ag in LA) (%)			
Small farmers / Landless	96.5	0.0	38.1
Medium farmers	91.1	36.2	192.9
Large farmers	177.8	385.7	313.5

Notes: There is no public labor category in Latin America

Table 2. Climate change-induced agricultural shocks (GISS)

	Percentage changes in yields					
	No adaptation, w/o CO2		Level 1 adaptation, with CO2		Level 2 adaptation, with CO2	
Yield shocks	cereals	export crops	cereals	export crops	cereals	export crops
Africa	-22.4	-21.5	-17.4	-3.5	-7.2	0.1
Asia	-37.1	-35.1	-14.5	-11.6	-6.8	-4.6
Latin America	-32.0	-33.8	-13.2	-10.7	-5.2	-5.0

	Percentage changes in prices	
	Level 1 adaptation, with CO2	
Price shocks	cereals	export crops
Africa	-8.8	-2.3
Asia	-0.2	15.4
Latin America	-8.1	10.4

Source: Calculated; see text for details

Table 3. Effects of climate change shocks (GISS)

	Africa			Asia			Latin America		
Levels of adaptation	None	Level 1	Level 2	None	Level 1	Level 2	None	Level 1	Level 2
Macroeconomic effects: % changes in									
GDP per capita	-11.1	-6.5	-2.2	-6.1	-1.6	-0.4	-9.2	-2.5	-0.8
Absorption	-10.4	-6.1	-2.1	-4.8	-0.5	0.6	-9.0	-2.1	-0.3
Real exchange rate	4.7	-5.3	-2.6	12.1	3.5	1.0	8.5	1.0	-1.0
Value of Industrial Imports	-13.2	-6.7	-2.3	-8.5	-1.7	0.3	-13.8	-2.7	0.5
Value of Export Crops	-22.9	-8.3	-2.4	-37.7	-5.6	3.2	-43.9	-12.6	-3.4
Value of Cereal Imports	-9.5	-1.9	1.1	371.5	242.4	197.5	64.3	28.2	18.0
Sectoral effects: % changes in									
Total Agricultural Production	-16.5	-9.0	-3.1	-18.2	-5.8	-2.0	-25.5	-8.9	-3.6
Production of Export Crops	-22.0	-8.2	-2.4	-24.3	-3.8	2.2	-35.6	-10.8	-3.1
Production of Cereals	-17.6	-12.4	-4.8	-39.5	-19.3	-12.7	-19.3	-7.8	-3.8
Production of Other Agriculture	-8.9	-4.9	-1.5	-2.6	0.1	0.8	-	-	-
Agricultural Terms of Trade	10.3	9.1	3.1	9.7	0.4	-1.9	74.6	20.2	8.3
Price of Export Crops	3.4	-6.0	-3.4	48.1	19.7	14.5	40.3	13.7	9.2
Price of Cereals	30.5	28.0	10.3	-2.9	-11.1	-13.5	78.2	21.3	7.3
Price of Other Agriculture	-22.9	-13.0	-4.3	-2.5	-1.9	-1.1	-	-	-
Price of Industry	-5.3	-6.0	-2.1	0.8	0.5	0.4	-1.3	-0.5	-0.4
Price of Services	-6.4	-5.3	-1.8	-3.8	0.0	1.0	-6.0	-1.5	-0.4
Household effects: % changes in									
Small farmer real income	-15.9	-8.7	-2.6	-4.3	0.5	1.7	-10.3	-2.2	0.0
Medium farmer real income	-17.4	-10.1	-3.4	-7.8	-2.1	-0.7	1.6	1.3	1.1
Large farmer real income	-9.6	-4.7	-1.7	-7.3	-2.4	-0.6	6.2	2.6	1.5
Urban poor real income	-7.7	-4.9	-1.7	-3.7	0.1	1.0	-12.0	-2.7	-0.3
Urban rich real income	-7.9	-4.0	-1.4	-2.9	-0.1	0.6	-10.4	-2.4	-0.4
Small farmer food cons.	-19.5	-12.4	-4.3	-4.4	4.0	6.4	-14.0	-4.7	-1.0
Medium farmer food cons.	-22.6	-15.2	-5.7	-8.2	1.9	4.7	-11.1	-3.5	-0.6
Urban poor food cons.	-16.6	-13.5	-5.0	-3.6	5.4	8.2	-15.5	-5.4	-1.4

Source: Calculated; see text for details

Table 4. Policy experiments

	Africa			Asia			Latin America		
Experiment 1: Elasticity of substitution (e) between imported and domestic cereals									
% changes in	e=0.3*	e=0.8	e=1.2	e=1.2	e=3.0	e=30*	e=0.8	e=1.2*	e=3.0
GDP per capita	-6.5	-6.0	-5.8	-2.5	-2.2	-1.6	-2.6	-2.5	-2.2
Real Exchange Rate	-5.3	-2.0	-0.1	-1.4	0.1	3.5	0.6	1.0	2.2
Production of Export Crops	-8.2	-6.4	-5.4	-7.4	-6.3	-3.8	-11.6	-10.8	-8.3
Production of Cereals	-12.4	-13.2	-13.8	-10.2	-12.7	-19.3	-6.8	-7.8	-10.8
Price of Export Crops	-6.0	-3.1	-1.3	15.5	16.7	19.7	13.6	13.7	14.1
Price of Cereals	28.0	22.3	18.8	19.8	9.9	-11.1	24.4	21.3	12.4
Small farmer real income	-8.7	-8.9	-9.0	-3.6	-2.2	0.5	-2.2	-2.2	-2.0
Medium farmer real income	-10.1	-9.4	-9.0	-2.3	-2.2	-2.1	2.3	1.3	-1.7
Experiment 2: Agricultural responsiveness									
% changes in	low*	medium	high	low	medium*	high	low	medium	high*
GDP per capita	-6.5	-6.4	-6.3	-1.7	-1.6	-1.6	-3.0	-2.7	-2.5
Real Exchange Rate	-5.3	-2.8	-2.2	3.8	3.5	3.4	1.4	1.1	1.0
Production of Export Crops	-8.2	-9.7	-9.9	-6.7	-3.8	-3.1	-11.3	-10.8	-10.8
Production of Cereals	-12.4	-10.9	-10.3	-16.6	-19.3	-20.3	-9.7	-8.4	-7.8
Price of Export Crops	-6.0	-3.6	-3.0	21.5	19.7	19.3	14.2	13.8	13.7
Price of Cereals	28.0	21.2	18.4	-11.2	-11.1	-11.0	31.0	24.2	21.3
Small farmer real income	-8.7	-7.7	-7.2	0.1	0.5	0.5	-2.9	-2.4	-2.2
Medium farmer real income	-10.1	-9.0	-8.5	-2.2	-2.1	-2.1	3.9	2.0	1.3

* = base run

Source: Calculated