Projected Impacts of a Regional Nuclear Conflict on Global Food Supply, Consumption and Undernutrition

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Abstract

This paper examines recent suggestions that even a limited nuclear engagement in South Asia could cause yield failures in other parts of the world that would raise food prices, resulting in higher undernutrition. Building on new dynamic climate models that predict significant yield shortfalls for key crops in North America following a conflict between two South Asian governments involving 100 warheads each with a 15 kiloton payload, we extend the analysis with a global Computable General Equilibrium model to assess the likely effects of yield reductions on commodity prices, production and trade. Focusing on globally-important cereals plus soybeans, we estimate food price, trade and economic welfare effects of several scenarios that impose mild to more severe yield shocks to determine possible consumption impacts. Those estimates are in turn used to project outcomes in terms of chronic undernutrition for different regions. These combined modeling exercises suggest that a single-year shock could increase the number of undernourished in the developing world by nearly 40 million, while shocks accumulated over a 10-year horizon (repeated crop yield shortfalls at varying levels resulting from the single nuclear event) could increase the number of undernourished people by over 215 million—more than double the number estimated to have become undernourished during the global food price crisis of 2008. This would have serious impacts on human wellbeing globally, including in geographic regions far beyond the location of the conflict itself.

Key Words: Nuclear war, climatic shock, food production, prices, trade, consumption, undernutrition.

"The biggest challenge facing most developing countries is the risk of a big boost in food prices. Food accounts for a large and increasingly volatile share of family budgets for poor and urban families. When prices of staple foods soar, poor countries and poor people bear the brunt."

World Bank Group President, Robert Zoellick, February 10, 2011[1]

Introduction[2]

During the early 1980s, 300 scientists from 30 countries worked together over a 2 year period to determine the global consequences of nuclear war (Solomon and Marsden 1986). One of the key points of consensus was that "the primary mechanisms for human fatalities would likely not be from blast effects, not from thermal radiation burns, and not from ionizing radiation, but, rather, from mass starvation." (Harwell and Harwell 1986) While the direct mortality attributed to a 'large-scale nuclear war' were estimated as several hundred million people, the subsequent food and health crisis was expected to result in "the loss of one to four billion lives." (Harwell and Harwell 1986) More recent mortality estimates linked to the after-effects of limited (regional) nuclear engagements have been somewhat more conservative, such as Starr (2011) projecting "a billion people to die from nuclear famine." [3]

The calculations underpinning such eye-catching mortality estimates derive from assumptions that, a) the world would experience significant reductions in yield and output of food in the context of a post-conflict 'nuclear winter' resulting from the large-scale injection of elemental carbon into the atmosphere[4]; b) global food stocks would be insufficient to make up for harvest losses over multiple years, resulting in a collapse in food consumption; c) the first to die (those most immediately and severely affected) would be the world's *already* undernourished population of 800 to 1 billion people. Historical analogs are often elicited as a way of backing up such assumptions. For example, explosive volcanic eruptions, such as those of Tambora in 1815, Krakatau in 1883 and Mt. Pinatubo in 1991, all resulted in large aerosol clouds in the stratosphere blocking sunlight and causing average temperatures to fall, with negative impacts on agriculture. Arguing that a relatively small decline in average global temperature (around 1°C) would cause major climatic disruptions, Harwell and Harwell (1986) point to the Tambora (1815) event which is associated with a less than 1°C fall in temperature (roughly -0.7°C according to Helfand 2007), but nevertheless brought about the "year without a summer," characterized by harvest failures in the range of 75 percent across northern Europe (Post 1983),

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[1] World Bank.2011. *Food Prices: Ensuring Access to Nutritious Food*. Press Release No: 009, February 10, 2011. Washington, D.C.

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[3] For Starr (2011), the combined rainfall, sunlight and radiation (UV) effects would "shorten or eliminate growing seasons for a decade or longer."

[4] As reported by Choi (2011), "average global temperatures would drop by 2.25 degrees F (1.25 degrees C) for two to three years afterward."

widespread increases in food prices, and Europe's last multi-country famine (Webb 2002). Similarly, aerosols from the 1991 eruption of Mount Pinatubo contributed to about -0.3°C cooling over one year (Oman 2011), with global precipitation rates, river flow, and soil moisture all reduced (Robock 2009).

However, the chain of events linking a decline in crops yields to human nutritional status is complex. The impact of any yield reduction in one or more crops does not have a simple linear relationship with food supply, food prices, actual food consumption or nutrition outcomes. In seeking to derive more granular estimates of impacts on consumption and undernutrition, this paper attempts a dynamic modeling of trade and price effects that builds on past projections of food and nutrition impacts of economic and other shocks, and on the most recent modeling of climate effects on crops yields that is part of the current project; namely, the work of Ozdogan et al. (2011). We take the estimated yield effects of a nuclear exchange in South Asia involving 100 bombs each yielding 15 kilotons, or 150 KT total, on a range of crops (major cereals plus soybeans) grown around the world. Using of a global economy-wide modeling framework, the GTAP model (Hertel 1997), we estimate food price, trade and welfare effects of various scenarios that impose mild to severe yield shocks to determine potential consumption impacts. Those estimates are in turn used to project outcomes in terms of additional numbers of people facing chronic undernutrition. We estimate how many *more* people would be added to the ranks of the undernourished, but we do not make any attempt to enumerate the increased severity (depth) of undernourishment facing those already consuming too little at the time of the conflict. The former is possible to model through CGE scenarios, but the latter is not since so much depends on the dynamics of local circumstance—substitutions by households among food categories, between food and non-food consumption, drawdown of savings or buildup of debt, availability of public assistance, etc. Such analysis requires household-level survey data and a single-country focus (in contrast to the broad cross-country perspective applied in this report).

The first part of the paper considers what we know about poverty and consumption effects of high food prices on poverty and nutrition, particularly in the context of recent food crises, and these can inform estimates of the secondary (non-blast related) impacts of a nuclear exchange on human wellbeing. A second section presents the methodology and modeling approaches used. The third section presents findings from the modeling of yield impacts on trade, prices and welfare. The final section discusses implications of these findings, and lays out areas of analysis requiring further refinement.

1. Food Supply, Trade and Price Impacts on Poverty and Consumption

According to Parry et al. (2009), "world prices are the most useful single aggregate indicator of the effects of climate change on agriculture", while Habib et al. (2010) argue that "changes in the relative price of food represent the most significant source of price impact on poor or near-poor households." In other words, food prices represent a key mechanism by which any shock to the food system, be it from the supply side (agriculture) or from the effective demand side (poverty), is translated to the consumer.

Significant correlations have been shown between economic shocks and increased poverty (Gilligan et al. 2000 ; Dobie et al. 2007; Wodon and Zaman 2010)[5], impaired food consumption (Block et. al. 2004; de Pee et al. 2010), as well as with various negative nutrition outcomes (Pongu et al. 2005; Alderman et al. 2006; Skoufias et al. 2011). Indeed, much has been learned about the relationships among food supply, prices, and consumption during the series of food price crises that affected large parts of the world in the second half of the 2000s. During that period, a downward trend in real food prices came to an abrupt end when world prices suddenly rose in 2006, with further escalation in subsequent years leading to historic peaks during 2008 and again in 2010. Price hikes were especially dramatic for the world's staple grains, such as wheat, maize and rice. For example, in March 2008, global wheat prices leaped 25 percent in a single day; in the following month the price of rice rose 50 percent in just two weeks (Webb 2010). By late 2008, the price of rice was 500 percent higher than in 2003, while global wheat prices more than doubled during the second half of 2010 (Demeke et al. 2008; Brinkman et al. 2010; Ivanic et al. 2011).[6] Of course non-grain foods also contributed to pushing food price indices upwards, including soybeans, sugar, vegetable oil and dairy products (Iannotti and Robles 2011; Heady 2010).

These food prices crises caused major hardship for millions of already-poor consumers around the world, focusing the attention of policy-makers on formulating appropriate responses (UNHLTF 2008; FAO et al. 2011). However, estimates of consumption impacts and humanitarian need (to guide appropriate tailoring and targeting of responses) varied widely depending on the outcomes considered and on assumptions made when calculating the effects of the economic shocks. For example, the World Bank (2009a) determined that between the years 2005 and 2008, the number of extremely poor people increased by 130 to 155 million; or at least those people "were not able to come out of severe poverty."(World Bank 2009b) The 2008 peak in food prices was seen as pushing 100 million more people *into* poverty by Ivanic and Martin (2008)--or perhaps it was 200 hundred million, as argued by Dessus et al. (2008).

Estimates of the effects of high prices and increased poverty on food consumption also generated a range of outcomes: the Food and Agriculture Organization (FAO 2007) estimated that 75 million people joined the ranks of the chronically undernourished during 2008, while other parts of the United Nations system argued that 50 million more people were made chronically undernourished during 2008 (UNSCN 2008)--or indeed that the number was closer to 130 million (WFP 2008). The estimates produced by Tiwari and Zaman (2010) at the World Bank argued that 63 million more people made undernourished by the 2008 crisis, with an additional 41 million added in 2009 due to the economic downturn (despite falling food prices) (Tiwari and Zaman 2010).

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[5] According to FAO (2009b), poverty can increase 5 to 20 percent in a year or two after a major economic shock.

[6] These recent increases in food prices exceed those that characterized famine in Europe in 1816/17, when the index of wholesale grain prices increased 3-fold in southern Germany between 1815 and 1817, and doubled over the same period in the Netherlands (Post 1976).

One of the very few studies to use nationally representative household budget data to look at consumption effects for 7 countries in Latin American and the Caribbean found that there was a median reduction of 8 percent in calories consumed following the food price shock—with important regional and within-country differences (Robles and Iannotti 2011). In 5 of the 7 countries (Ecuador, Haiti, Nicaragua, Panama, and Peru), households fell from being above the minimum adequate calorie adequacy threshold to below it, the largest changes observed in Ecuador and Peru (falls of 13 and 7 percentage points, respectively). On the other hand, in the wealthiest quintile of many of these countries there were significant *increases* in calories consumed, exceeding 10 percent of previous year levels. In other words, the effects of the food price shocks on actual consumption were serious but non-linear and far from uniform.

This paper draws on such analyses to make a first (to our knowledge) simulation of the impact of projected yield shortfalls for major crops on food prices, exports and demand around the world, and what those effects could have on *levels* (total number of people affected) of undernourishment in developing countries. The next section describes our approach, data and modeling tools, and well as the many assumptions underlying the analysis.

2. Methodology, Data and Limitations

This paper takes as its starting point the estimated yield impacts of global cooling averaging 1.25°C on maize and soybeans grown in the mid-West of the USA as derived by Ozdogan et al. (2011) in their simulation of the climactic effects of a limited nuclear exchange in South Asia.[7] Using the Agro-IBIS crop simulation model, they find that the annual average yield reduction (over a 10 year period following the nuclear exchange) for corn is 11.3 percent with an standard deviation of 12.3; and for soybean production is 6.7 percent with an standard deviation of 16.9. Figure 1 reproduces a key result from Ozdogan et al. (2011) regarding simulated yield effects for corn over a 10 year shock horizon. Those results confirm findings of earlier studies that suggested that in the mid-latitude locations, changes in temperature and sunlight play a larger role in reducing yields than precipitation, with "important implications" for production and exports of food, livestock feed and seed (Ozdogan et al. 2011).

That said, the authors' conclusion that "the economic and societal consequences of yield changes as a result of this short-lived climatic alteration could eclipse the long-term climatic changes expected from greenhouse gas emissions" is not elaborated on. What kinds of economic consequences are to be expected with yield disruption at that level in just one country (albeit a major exporting country) in the world? What effects on societal wellbeing would result from the economic impacts?

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[7] The authors go beyond existing studies by providing a more comprehensive assessment involving a sophisticated ecological model, results from a modern climate model, and a probability-based assessment of yield change. For the assumptions underpinning their climate impact modeling refer to their paper.

There are many uncertainties and assumptions in these models.[8] As noted by Oxfam (2011), “predicting the future is a hazardous endeavour. When it comes to agricultural production and nutrition, there are many unknowns.” Uncertainties arise from different climate models, greenhouse gas emission pathways and agricultural impact models; the uncertainty of the impact projection reflects all of these combined. (Parry 2009) Much depends on the geographic dispersal of initial radiation exposure and the duration of nuclear contaminants in the soils and water. It should be noted that the effects of climate change projections are not uniform. They predict an increase of temperature, which translates into beneficial effects for temperate regions and negative effects for tropical areas. Thus, developing countries are affected doubly by the direct productivity shock and by the adverse terms of trade of beneficial conditions in temperate areas. Our scenario differs in that we are using an homogenous negative shock for all regions. The welfare effects of this yield shock are negative in *all* cases, but depending on the production and consumption structures some regions in aggregate will gain from the changed terms of trade.

While climate impacts have been modeled as shocks over a relatively short period (3 to 5 years), it was shown for the Chernobyl disaster that while the “first effective clearance half-life (1986–1989) related to exchangeable 137Cs [caesium-137] was approximately three years; the second one (1989–1994) approximately 12 years.” (IAEA 2001) The cultivated area in districts surrounding Chernobyl fell by up to 43 percent, compared with the pre-accident period, and the decrease in soil fertility due to contaminants led to a “considerable reduction in crop production, which may have the effect of increasing the radionuclide transfer to [food] produce.”(IAEA 2001) In other words, the implications of the nuclear exchange for agricultural and food systems in South Asia would be of long duration, regardless of related productivity and trade-related impacts on the economy.

Our results are thus sensitive to a wide range of assumptions at every stage in the analysis. The results presented here represent a set of judgments regarding these assumptions, but the specific numbers presented are best interpreted as illustrative rather than precise estimates of the nutritional impacts of limited nuclear war. Importantly, the limitations of data and the focus of the exercise only allow us to estimate food price impacts on the overall numbers of people considered to be undernourished (that is, how many more people will become undernourished as a result of the series of shocks compared with a baseline). We cannot, with existing data, determine the depth of consumption shortfall that would result for those already undernourished at baseline.

Our approach is as follows: We make use of a global economy-wide model, the global GTAP model (Hertel 1997), to provide a sense of the market and economic welfare effects of these estimated changes in the productivity of global agricultural resources. Following Ozdogan et al.’s (2011) yield reduction estimates for soybeans and maize in the mid-western U.S. We

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[8] “How to deal with uncertainty is a perennial problem in population and other forecasting and of the four strategies listed: ignoring it, constructing scenarios; exploring a plausible range of variation; and making fully probabilistic projections.” (Godfray et al. 2010)

assume only the most direct biophysical changes that affect agriculture as a reduction in land productivity for all crops (that is, we assume the same yield losses for *all* crops globally, not just for those modeled in the U.S. context).[9] As a foundation for our subsequent analysis of nutritional impacts, the benefit of extending the yield shock to all crops is that it mitigates the opportunities for consumer substitution away from cereals. We then concentrate on the specific price effects for cereals as the link from the CGE simulations to the nutritional analysis.

The standard GTAP model (Hertel 1997) is perhaps the world's most widely used CGE model for economy-wide global market analysis, in part due to its robust and explicit assumptions. In its simplest form, the model as used here is comparatively static; it assumes perfect competition and constant returns to scale in production. The functional forms are nested constant elasticities of substitution production functions. On the demand side there is an aggregate regional utility function which allocates net national expenditures across private, government, and saving activities. This representation provides an unambiguous indicator of economic welfare, expressed in terms of monetary equivalent. The non-homothetic nature of private consumption (non-proportional changes with respect to income changes) is captured by a Constant Difference of Elasticities functional form. International trade is handled through a specification in which products are differentiated by country of origin and treated as close but imperfect substitutes for domestic goods.

The model runs on the GTAP 7.0 global database that describes bilateral trade patterns, production, consumption and intermediate use of commodities and services (see Narayanan and Walmsley 2008). The full GTAP 7.0 database is calibrated to the year 2004, comprising 113 regions in addition to 57 sectors of economic activity/product groups. To make the model more manageable we aggregated these into 10 sectors/product groups and 27 geographic sub-regions.

As with the modeling of dynamic ecosystem processes, the modeling of economic processes is complex and depends on a range of assumptions. For example, it is important to bear in mind not just on the scale and location of the nuclear exchange, but when it happens. Most projections of impacts on food supply and demand assume 'present day' conditions. The most up to date GTAP datasets used here are calibrated to conditions that pertained in 2004.[10] Thus, projected outcomes would be different if the shock were placed in the future, say, in 2025 or 2050. That is because, a) climate changes projected for the next 50 years (warming) would have their own implications for food security at the time when the nuclear shock is assumed to take place, including different levels of global food output and stores; b) despite recent crises, global poverty is expected to continue to decline, such that the total number of undernourished people would be lower in 20 to 50 years than today, despite continued population growth[11]; c)

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[9] While this assumption of uniform yield impacts by crop and location would not hold in reality, the models of climate impact are not yet sufficiently elaborate to allow us to specify yield shocks for every cultivar and agronomic context around the globe; that is a task for future research.

[10] Hertel et al. (2010) impose their climate change shocks (for modeling of yield impacts) on a base year of 2001.

[11] According to Easterling et al. (2007), the number of people at risk of undernourishment due to climate shocks must be viewed within the overall large reductions in poverty: "Compared to 820 million undernourished today,

progressive gains in purchasing power and related urbanization globally will result in changed dietary patterns (less reliance on whole grains versus rising demand for processed foods), and in *increased* demand for food overall.[12] As such, most economic projections broadly indicate that "prices in 2050 will be higher than those of the pre-surge years, but lower than those reached in the years of price surges."(Alexandratos 2010)

Higher food prices in coming decades clearly have important implications for how a nuclear shock would play out on world agriculture, food trade and consumption. For example, Nelson et al. (2009) calculate that "real agricultural prices will likely increase between now and 2050, the result of growing incomes and population as well as the negative productivity effects of climate change." The likely price increases between the years 2000 to 2050 projected by the latter authors range from 39 percent for wheat to more than 60 percent for maize and rice--estimates that are consistent with other models that see "average wheat and coarse grain prices projected to be nearly 15–40 percent higher in real terms [by 2020] relative to 1997–2006 (OECD/FAO 2010), or "10–60 percent higher by 2030" (Hertel et al. 2010), or even 70 to 90 per cent by 2030 (Bailey 2011)—without factoring in expected effects of climate change. Similarly, Willenbockel (2011) uses a dynamic simulation of a 'business-as-usual' scenario in the absence of climate change and policy shifts. He finds that compared to 2010, the average world market export price for wheat rises by 28 percent by 2020 and by 75 percent by 2030. Thus, were a nuclear exchange to happen between 2030 and 2050 (rather than today) the baseline conditions (prices, demand for food, poverty levels) would be quite different. This means that projections of impact must be interpreted with context in mind; are frame conditions assumed to be as today or as they might be 50 years hence? In this paper, we assume conditions as they were in 2004.

Other critical factors determining outcomes *whenever* a shock may take places are the reactions of markets and national governments. These are typically less amenable to modeling, in that they are driven as much by perceptions and politics as by economic signals transmitted through food prices. Markets react to higher prices with commodity speculation, hoarding (withholding of products from the market), or by seeking to capture market share through private non-open market deals (a loss of transaction transparency), each of which contributed to higher price volatility and market uncertainty in the crises of the 2007-2011 period (Seal 2010; Heady 2010)[13].

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the IPCC Special Report on Emissions Scenarios (SRES) scenarios of socio-economic development without climate change project a reduction to 100-230 million undernourished by 2080." Scenarios *with* climate change project 100 to 380 million undernourished by 2080.

[12] Increasing demand for food is caused not only by a rise in population size but also by the increase in per capita consumption (Godfray et al. 2010). Demand growth for food has historically been 1 to 1.5 percent per year, rising in recent decades to 2 percent per year (Evans 2008). Goldman Sachs has projected that demand will rise to an annual rate of 2.6 percent after 2010 (Currie 2007).

[13] According to Pinstrup-Andersen (2010), "from a poverty and nutrition perspective, the fluctuation of the prices—or the price volatility—has the most significant impact."

Similarly, national governments respond to the actual or perceived threat of food shortages with a mix of policy responses that often exacerbates the problem (Ahmed and Martin 2009; Anderson and Nelgen 2010). The most common reactions to rising food prices have included, i) trade responses such as tariff reduction and restriction or bans on exports to reduce prices and/or increase domestic supply; ii) consumer responses in the form of food price subsidies, social safety nets, tax reductions and price control; and iii) producer-focused responses aimed at stimulating a supply response (increased production) to higher prices, such as farm input subsidies and producer price support. During the 2007/08 food crisis, the most common policy response in Sub-Saharan Africa was reducing taxes on food, while in South Asia price subsidies and domestic supply control were common (Demeke et al. 2008; Dorosh 2009; Wodon and Zaman 2010).

How would governments respond to a market shock caused by nuclear conflict? The nature of this kind of crisis would be different—not simply causing massive direct deaths in South Asia, but also disrupting markets across the region, as well as agricultural production globally. The nuclear disaster in northern Japan in 2011 had significant impacts on Asia-wide trade (due to disruption of industrial and commercial supply chains), resulting in potential GDP losses to Japan's trading partners.[14] The threat of food shortage and/or food system contamination would likely trigger not just the usual economically rational policy and market responses but also elicit panic behaviours with unpredictable consequences. It would certainly cause hoarding at household, as well as at wholesale and retail, levels; governments would likely eschew the principles of open trade and close their borders to imports of food from Asia (fearing nuclear contamination) and exports (fearing supply difficulties within their own borders as global trade slows to a trickle); much of Asia's trade would be decimated, while industrialized countries would like promote rationing, a dietary shift to essential foods, and a large investment in both large and small-scale (including urban) agriculture. In other words, business as usual would not pertain.

This represents an important limitation to the modeling of non-ecological impacts of nuclear war. Since model-based projections have to assume that prices and markets function 'normally' in order to achieve new equilibrium levels after any shock, the interpretation of how a yield shock would translate to consumption, and then nutrition outcomes, is not straightforward. On the one hand, CGE modeling a) relies on theories and observations of how macroeconomic systems function 'in normal periods' of trade and transaction, and b) depend on actual data from the recent past (rather than crisis years). On the other hand, additional modeling is required to translate equilibrium prices after a yield and supply shock to estimates of consumption outcomes -- how many people would no longer have access to even minimal levels of energy on a daily basis due to the higher prices and reduced food availability?

To model price effects on consumption and nutrition, we assume that the primary mechanism of transmission from the negative shock in cereals yields to increased undernutrition is through

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[14] For example, Behravesh (2011) points out that roughly 13 percent of China's goods imports are from Japan, especially in electronics, and that imports from Japan accounted for 3.4 percent of China's overall output in 2010.

the expected price increase in world cereals markets, transmitted to various degrees down to local market prices.[15] As noted by Ivanic et al. (2011), "food prices are likely to have the largest direct impact on poverty given the large shares of food in the expenditures of the poor, and the importance of agricultural income for many poor households." To translate the CGE model's simulated effects on cereals prices into changes in the number of undernourished, we adopt an approach similar to that developed by Senauer and Sur (2001) and extended by Tiwari and Zaman (2010). This approach is built around the relationship between caloric intake and income (commonly referred to as the Engel function).

In short, our approach combines the relationship between income and calorie consumption with estimates of subsistence levels of caloric intake and data on income distribution to derive the proportion of a country's population that is unable to afford minimum subsistence consumption levels. We then compare this baseline estimate with the proportion of the population unable to afford subsistence consumption under alternative scenarios with higher prices. This section details the methods used in each stage of that analysis.
The Engel function relates total per capita caloric intake at the national level to per capita income.[16] We estimate this relationship econometrically using cross-country panel data from low- and middle-income countries for the period 1990 – 2009. The regression model takes the form:

$$C_{it} = \alpha + \beta \log(Y_{it}) + \gamma_t + \varepsilon_{it} \tag{1}$$

where C_{it} is per capita caloric intake in country i in year t, Y_{it} is per capita income, γ_t are dummy variables for each year (to control for idiosyncratic events in a given year that effect the entire sample), and ε_{it} is a random error. This is a standard two-way fixed effects specification of the Engel function. Our estimated parameters for this Engel function are:

$$C_{it} = 176.8^{*} + 286.5^{***} \cdot \log(Y_{it}) \qquad R^2 = .52, \qquad n = 513$$

where the three asterisks indicate that these parameter estimates are statistically different from zero at greater than the 0.01-level. This semi-log specification has attractive properties vis-à-vis consumer theory (e.g., the income elasticity of demand is declining with income), and is particularly convenient for the present application due to its linearity (in logs). At a later stage in the analysis, this linearity simplifies the simulation of price shocks.

Using the estimated intercept and slope terms from this Engel function to describe caloric intake as a function of income, we then apply 2005-07 FAO estimates for subsistence-level

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[15] It is important to note that global prices are not uniformly passed through to local prices; that is, in some countries and for some crops up to 80 percent of local price is determined by a notional world market price, but for other crops and other countries the pass-through may be as low as 20 percent (Ivanic et al. 2011).

[16] We use per capita incomes from each country converted into "international" dollars (i.e., purchasing power parity corrected dollars) to ensure comparability in caloric purchasing power across countries.

caloric intake (C^*) for each country in the sample. Plugging these data for C into equation (1), we solve for the threshold level of income per capita (Y^*) required to purchase C^*.[17]

The next stage in the analysis uses data on income distribution for each country to estimate the proportion of the population with income below Y^*. This requires approximation of the cumulative density function for income. For this purpose, we use World Bank (2010) data on the share of national income earned by each population quintile. Given the Engel relationship, the proportion of the population earning less than Y^* is also the proportion of the population that must consume less than C^* -- our estimate for the proportion that is undernourished.[18]

These relationships are depicted in panels A and B of Figure 2. Panel A shows the Engel function (which is non-linear in absolute income, but linear in log income). We derive threshold income Y^* as the point on the Engel function with height C^*. Panel B shares the horizontal axis with Panel A. Panel B is the cumulative density function describing the proportion of the population (on the vertical axis) with income below any given level. This function tells us, in particular, the proportion of the population with income less than Y^* -- the proportion that is undernourished.

Food price shocks shift the relationship between caloric intake and income. If food prices increase, the income required to purchase a subsistence level of calories also increases. We simulate such shocks by a downward (outward) shift of the Engel function. This indicates the increase in Y^* required to continue to consume C^* calories. This increase in the threshold income is then translated, via the cumulative density function, into an increased proportion of the population with income insufficient to consume the subsistence level of calories. Figure 2 depicts this shock as a shift of the Engel function, which increases the income required to purchase sufficient calories from Y^* to Y^{**}. Panel B shows the resulting increase in the proportion of the population that is undernourished.[19]

The magnitude of the shift of the Engel function in response to a change in food prices is an empirical question, summarized by the price elasticity of calories (the percentage change in caloric intake given a 1 percent increase in food price, denoted as ϵ). There is a broad consensus in the literature that this parameter is approximately -0.5.[20] This suggests that a 10 percent increase in price reduces caloric intake by 5 percent. While the use of -0.5 for this key parameter is consistent with previous studies, applying it to all countries at all times is a strong assumption, and one that affects the magnitude of our estimates for changes in undernutrition.

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[17] This approach is in the tradition of Reutlinger and Solowsky (1976).

[18] The available data on income quintiles results in a piece-wise linear cumulative density function for income. We interpolate along the relevant linear segments as necessary to determine the proportion of undernourished for a given threshold level of income per capita.

[19] It is clear in Figure 2 that the magnitude of the increase in undernutrition resulting from a shift in the Engel curve will be sensitive its the estimated intercept and slope terms (α and β). These parameters are sensitive to the choice of estimator, and this sensitivity plays out in the nutrition analysis. The approach presented above represents our judgment as to the most reasonable and justifiable approach.

[20] Senauer and Sur (2001), Timmer and Alderman (1979), Pitt (1983), Tiwari and Zaman (2010).

Lacking any other basis for adjusting this parameter on a country-by-country basis, we adopt -0.5 as the mid-point of the generally accepted range for this parameter.[21]

If our price shocks pertained to all sources of calories consumed, the percentage change in calories consumed (i.e., the magnitude of the shift of the Engel function) would be given by $\Delta P * \epsilon$. In our case, however, the shocks are specific to cereals prices.[22] This requires that we scale the magnitude of the effect of price shocks by the share of basic cereals in total caloric intake in each country.[23] Taking this into account, the shift in the Engel function for a given country *i*, with cereal share of consumption ω_i, is thus $\Delta P * \omega_i * \epsilon$.

A hypothetical example, based on data for Bangladesh, is as follows: Using the parameter estimates given above for the Engel function and FAO estimates for a subsistence threshold in 2005-07 of 1,750 kilocalories per person per day, we calculate the threshold level of per capita income (in 2005 PPP) to be US$241. The proportion of Bangladesh's population falling below this level was approximately 40 percent. Suppose that the price of cereals, in response to a nuclear conflict and its consequent effects on yields, was to increase by 15 percent.[24] A 15 percent increase in cereals prices shifts the Engel function down to the point where Y^* increases from $241 to $274. Given the distribution of income in Bangladesh, we estimate this increase in threshold income to increase the undernourished proportion of the country's population from 40 percent to 44.5 percent (an increase that would exceed 7 million in absolute terms).

3. Discussion of Results

This section presents modeling results for two kinds of scenarios: single-year and cumulative. Ozdogan, et al. provide a sequence of 10 single-year shocks with mean yield reduction of -12 percent, with annual extreme ranges from -20 percent to -40 percent yield reductions. We simulate these lower-bound, upper-bound, and mean shocks to provide expected orders of magnitude for an illustrative single-year shock. In addition, we simulate Ozdogan, et al.'s sequence of 10 single-year yield shocks (using the mean yield loss by year) and calculate the cumulative effect of those shocks. The single-year scenario takes the average yield effects presented for coarse grains and soybeans across the mid-western U.S. and applies yield effects of that magnitude globally for all crops, while the 10 year scenario applies each year's annual productivity loss (or gain) to an estimated cumulative impact on welfare.[25] The single worst

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[21] Our results are also sensitive to variations in econometric approach in estimating the parameters of the Engel function. We have adopted the most justifiably estimated parameters. More generally, for our purposes, it is the changes, rather than the levels, that of primary concern.

[22] Specifically, as noted above, we simulated a shock to all crops, and focus on the resulting changes in cereals prices as the basis for the nutrition analysis.

[23] These energy source data are also available from the FAO, and range widely across countries in our sample. For instance, the cereals share of calories in Bangladesh (2005-07) was 78 percent, as compared with 37 percent for Venezuela.

[24] Bangladesh's cereals share of caloric intake was 78 percent in 2007 (FAO).

[25] The annual affects reported by Ozdogan et al. (2011) are as follows: Y1 -0.4 percent; Y2 -4.0; Y3 - 6.1; Y4 – 7.1; Y5 – 19.5; Y6 – 8.0; Y7 – 9.0; Y8 -0.6;Y9 – 7.4; Y10 +4.3 percent.

year, in terms of productivity losses is not the year following the nuclear shock, but the 5th year following, while by year 10 the yield effect returns to positive territory.

Welfare Effects

Table 1 presents GTAP model estimates of the global welfare impact of the single year productivity shock scenario.[26] These provide total welfare impacts, and those due specifically to changes in terms of trade linked to price effects, for crop yield reduction shocks of 20 percent (a lower bound worst single year effect modeled by Ozdogan et al. (2011) and 40 percent (roughly equivalent to the cumulative yield impacts over 10 years).[27] The outcomes are shown in aggregate (the whole world) as well as for specific countries and regions of interest. The welfare impacts are large at a global level--losses amounting to US$300 billion--which is more than double the US$123 billion welfare losses projected by Hertel et al. (2010) resulting from food price increases linked to climate change (warming) by 2030 under a low-productivity scenario. Even a 20 percent yield reduction carries significant implications for trade and welfare, with losses amounting to more than US$74 billion.

However, the anticipated impacts on trade and welfare (via constrained supplies and price effects) will not be manifest uniformly around the world. There is considerable evidence from the climate change and poverty projections literature to suggest that, a) developing countries will bear the brunt of adverse consequences of economic shocks to food systems, and b) among developing countries, those in Africa and South Asia are likely to see particularly serious consequences, in large part because of high pre-existing levels of poverty and undernutrition as well as high vulnerability to shocks and limited adaptive capabilities (Ringler 2010; Erickson et al. 2011). For example, Ivanic et al. (2011) estimated that 44 million people were "driven into poverty" during 2010 as a result of the second round of food price spikes (coming after 2008), "but with considerably different impacts in different countries [depending on] the wide variation in the transmission of global prices to local prices and...differences in households' patterns of production and consumption."

That impacts differ geographically is supported by Table 1. For example, the total welfare losses for Asia (aside from the direct impacts of destruction caused by the nuclear conflict) amount to almost US$139 billion (US$100 billion of those losses carried by India and China alone), in the case of the 40 percent yield loss scenario. Those national economic welfare effects come not

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[26] The term 'welfare' in economic modeling refers to an aggregate utility function specified over *per capita* private household consumption, *per capita* government spending and *per capita* savings. The percentage change in aggregate *per capita* utility for a given region, converted into a monetary equivalent, is the welfare change variable computed by the standard GTAP model during simulations.

[27] It is important to note that we do not factor into the calculation the initial decrease in South Asia endowments in capital and labor lost as a consequence of the direct impacts of the nuclear conflict. More work is needed to estimate likely endowment losses related to a limited exchange, duration of nuclear contamination of formerly productive, irrigated soils, demand re-growth, etc.

only from the detrimental factor productivity shocks themselves but also from the change in the country's international terms of trade and the impact of producer and consumer responses to them on the resource efficiency costs of distortionary policies such as tariffs and subsidies. The terms of trade effects are significant for all countries as they are larger than (and in some cases the opposite sign than) the direct crop productivity effect.

Net welfare losses for sub-regions like East Africa amount to roughly US$216 million, and for Nigeria alone they come to more than US$2.7 billion. This is important because South Asia and sub-Saharan Africa together represent regions of the world with the highest prevailing levels not only of current undernutrition and vulnerability to food-related shocks, but also of projected demand growth. The population of India, Pakistan, and Bangladesh in 2005 was 1.4 billion; by 2015, that figure is expected to increase to roughly 1.65 billion (DFID 2007). Already today, South Asia is home to most of the world's undernourished people—more than 30 percent of the world's total, or roughly 262 million people, according to Lobell et al. (2008).

Similarly, Africa's population, currently 870 million, is forecast to double by 2050 (Eastwood and Lipton 2011), and most parts of the continent have seen some of the highest prevalence rates of child wasting, and of 13 countries that saw a deterioration in child stunting rates since 2000 (stunting representing a chronic failure to growth and develop), 11 of the countries were in Africa (SCN 2010). Given these characteristics of Africa, Parry et al. (2009) projected that 65 percent of the world's people at risk of future hunger (due to potential yield reductions in the context of environmental shocks to agriculture) are in Africa.

It should also be pointed out that while North America as a whole would also gain from either level of yield loss, a big loser would be Mexico which faces US$15 billion or more in welfare losses with a 40 percent yield shock. The Europe and other high income countries also face serious economic impacts of the higher prices linked to yield losses—amounting to roughly US$ 81 billion for Europe and US$53 billion for other high income countries (at the minus 40 percent yield reduction level).

The differences in the magnitude of aggregate welfare loss across countries and regions (as well as time) are substantial. These geographic differences diminish substantially if we consider welfare losses in per capita terms (Table 1). For example, China's aggregate welfare loss (in the 40 percent scenario) of $38.8 billion translates into a per capita loss of $30, as compared with Nigeria's much smaller aggregate loss of $2.8 billion, which is still $20 per capita. For the world aggregate, per capita welfare losses are $49 in the 40 percent shock scenario and $12 in the 20 percent scenario.

While Table 1 provides orders of magnitude for yield shocks that reflect the worst single-year and cumulative 10-year scenarios, Table 2 refines this focus by providing specific welfare changes for each year of the 10-year shock horizon. This more detailed perspective demonstrates that the magnitudes of the welfare losses vary considerably across both space (as seen in Table 1) and time. Indeed, at the global level, the greatest single-year welfare loss does not occur until year 9 of the shock, when the welfare global loss reaches a value of $165.7

billion. To fix an upper bound for the magnitude of the welfare loss, if one sums the 10 years of global losses (and discounts over time at 3 percent), the welfare loss exceeds $400 billion.

Price Effects

The price effects of the yield shock are the primary determinant of the nutrition outcomes. Table 3 describes the price effects, by commodity, of representative yield reductions of 40, 20, and 10 percent. It shows that price impacts vary considerably by crop, largely depending on volume of demand globally, whether the commodity is widely traded internationally, and how the product is used in the food system (processed versus unprocessed, etc.) The price effects increase linearly from -10 percent to – 20 percent crop yield impacts, but rise considerably more from a -20 to -40 percent shock. The results show a considerable variability in crop price increases, with 4 to 6 percent across all commodities with a 10 percent yield shock, to 16 to 89 percent increases with a 40 percent yield loss. [28]

Tables 4 and 5 provide estimates of the farm price increases for each crop, by country or region, associated with -40 and then -20 percent yield impacts, respectively. At 40 percent, farm prices for rice leap up by around 200 percent for rice and wheat across South Asia, including India (Table 4). The increases are less large across most of Africa, ranging from around 50 to just over 100 percent for rice, wheat and soybeans. Increases for coarse grains are seen to be lower in most of Africa and South Asia, largely because they represent commodities that are less traded internationally, like millet and sorghum—although they do include maize. The farm price of rice, wheat and other crops is seen to rise roughly 100 percent in the United States and other high income countries, and slightly lower in Europe. Table 6 expands this analysis of price effects to distinguish effects during each of the 10 years of the shock horizon. It is clear that these price effects vary substantially over time, as well as between regions.

That farm prices increase significantly is not surprising given the expected growth in demand resulting from a large yield shock coupled with the economic and political turmoil surrounding a nuclear conflict. But it also underlines the important fact that while net consumers will inevitably feel the squeeze of higher food prices, producers may benefit as long as they can continue to produce (and respond to the higher prices). In other words, high food prices can be beneficial to some households and some countries while other face losses.

Our results are broadly consistent with other recent studies. For example, a calculation by FAO (2008) of the impact of a 10 percent increase in internationally-traded staple food prices for 10 developing countries found that while the welfare impacts for rural households were negative for 8 of those countries, they were positive for 2 of them (Vietnam and Madagascar)—

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[28] What is more, there are differences in impact relating to bulk commodity costs versus processing costs of various kinds. Prices of processed foods climb in relation to the severity of yield shocks as ingredient costs increase. This was seen in 2011 when the agribusiness conglomerate Archer Daniels Midland reported that its fiscal fourth quarter earnings fell by 15 percent as inflated maize prices offset surging revenue; that is, while the company's revenue rose to US$23 billion, profits were hampered by a 70 percent rise in maize prices in the preceding 12 months, coupled with a 34 percent increase in the price of soybeans (AP 2011).

suggesting that the ramifications of higher prices are not generic.[29] In the same exercise, the welfare effects on urban consumers were seen to be negative across the board, although at quite different levels with relatively small welfare losses in Ghana and Guatemala but sizeable negative impacts in urban Bangladesh and Malawi (FAO 2008). Parallel analyses of welfare impacts linked to yield declines due to climate warming (rather than cooling) also find an increase in poverty specifically among non-agricultural households of 20 to 50 percent in parts of Africa (Malawi, Uganda and Zambia, for example) and Asia (Bangladesh). Poverty increased faster and more seriously in non-agricultural households (than farm households) since they do not benefit from commodity price increases. Hertel et al. (2010) also showed that poverty *fell*, rather than rose, among farm households in Indonesia, the Philippines and Thailand as world prices increased in their climate shock model. Indeed, the latter authors note that when the world price of staple grains rose more than 30 percent in their model, the average impact on poverty (at the poverty line) was relatively modest at around +6 percent overall; that is, poverty increased on average 'only' 6 percent among the poor with a 30 percent increase in food prices.

By contrast, de Hoyos and Medvedev (2009) calculated that an average rise in global food prices of only 5.6 percent from 2005 through 2007 caused a 1.7 percentage point rise in extreme poverty (using the US$1.25/day benchmark); while the World Bank (2011a) argue that a "10 percent increase in global prices could drive an additional 10 million people below the $1.25 extreme poverty line. A 30 percent price hike could lead to 34 million more poor."(World Bank 2011a)

Nutrition Effects

How do these yield-to-price effects translate into availability of food for consumption across vulnerable populations? As already noted, this depends largely on the extent to which world prices are transmitted to local markets, the structure of the economy (largely agricultural versus largely non-agricultural), and the pre-existing depth of food insecurity. At the end of the 2000s, around 20 percent of the world's total population were considered to be undernourished--some 925 million people (FAO 2010b). These people were vulnerable on an ongoing basis to volatility in food prices and to local constraints in food supplies and income-earning opportunities.[30] Around 166 million of them were in countries classified as being in 'protracted crisis'—representing roughly 20 percent of the world's undernourished people, or more than a third of the global total if China and India are excluded from the calculation (FAO 2010b). In other words, very large numbers of people today are already either undernourished or very vulnerable to price shocks and it is these people who first feel the impact of price-mediated agriculture shocks: "households already at risk for calorie inadequacy were the ones further impacted by the food prices crisis." (Iannotti and Robles 2011)

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[29] For simplicity's sake, the simulation assumes that price changes were transmitted equally to all types of households, whether urban-based consumers or smallholder farmers.

[30] Sibrian (2009) documents a strong statistically significant relationship (R2 =>0.7) between undernourishment (the proportion of a population below a minimum level of dietary energy consumption) and extreme poverty (<$1.25 per day PPP). That is, there is a strong, albeit non-linear, correlation between a country's level of undernourishment and its extreme poverty--although actual patterns differ by region of the world and by wealth stratification of households within countries.

Just how vulnerable they are depends to some extent on inter-annual fluctuations in national food availability and on the income distribution which together determine what share of population can access food that is available—the 'depth' of undernourishment that pertains to each developing country.[31] It is estimated that currently the diets of most of the "chronically hungry people lack 100-400 kilocalories per day" (FAO 2009), and that as a result, "the average consumer in low-income developing countries today obtains only two-thirds of the calories available in the developed countries."(Nelson et al. 2010) When prices rise steeply, the poor are able to command an even smaller share of the energy (kilocalories) that they require to maintain a healthy, physically active life—which results in undernutrition.[32]

Undernutrition is currently the single largest contributor to the global burden of disease. It accounts for 35 percent of disability-adjusted life-years lost by children under 5 years old—up to 4 times greater than the global burden of disease due to HIV/AIDS, malaria, diarrhea and pneumonia in the general population combined (Pelletier et al. 2011). Recent estimates of the effects of price increases on nutrition all point to significant problems. According to Tiwari and Zamman (2010) , a 5 percent rise in food prices decreases net undernourishment due to economic growth and rising average incomes making up for food price increases.[33] However, a 50 percent rise in food prices results in a 16 percent increase in undernourishment…but only if global prices are fully passed through to domestic prices. Assuming a 35 percent price increase with 80 percent transmission of global prices to local, undernourishment rises around 7 percent over previous year (63 million people, using their baseline assumptions) (Tiwari and Zamman 2010). Only looking at Latin America and the Caribbean, Iannotti and Robles (2011) found a median reduction in kilocalories consumed of 8 percent (ranging from 1 to 15 percent) following the 2006-2008 price crisis. That range is broadly consistent with the finding of Brinkman et al. (2009) on price and income changes in the 2006 to 2010 period which resulted in a decline in intake of around 16 percent for the same region. Indeed, Brinkman et al. (2009) calculated that an average 48 percent increase in food prices globally in 2008 (compared with the previous 5 years), ranging from 20 percent in West Africa to 68 percent in Southern Africa depending on market conditions, resulted in an energy consumption decline in all developing

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[31] The 'depth' of undernourishment is a measure of the per capita food deficit of the undernourished population by country (FAO 2000). Measured by comparing the average amount of dietary energy that undernourished people get from the foods they eat with the minimum amount of dietary energy they need to maintain body weight and undertake light activity. Most of the countries with the most extreme depth of hunger (more than 300 kilocalories per person per day) are located in Africa; others are found in the Near East (Afghanistan), the Caribbean (Haiti) and Asia (Bangladesh, the Democratic People's Republic of Korea and Mongolia).

[32] The modeling of Liu et al. (2009) on future per capita availability of calories by 2030 suggests that countries like Ethiopia, Uganda, Rwanda, Burundi, Niger, and Madagascar will still be hotspots of food insecurity in the future, with lower capacity to import food and per capita calorie availability 30 percent lower than today.

[33] De Hoyas and Medvedev (2010) note that "for the segment of the population whose income depends --directly or indirectly-- on agricultural markets, i.e. self-employed farmers, wage workers in the agricultural sector, and rural land owners, the rise in food prices represents an increase in their monetary income. For each household, the net welfare effect of an increase in food prices will depend on the combination of a loss in purchasing power (consumption effect) and a gain in monetary income (income effect)."

regions during the 2006 to 2010 period that caused roughly 457 million people to become undernourished (in addition to the 848 million people already undernourished at that time).

Our own estimate of price effects on undernourishment (kilocalorie availability), building on our GMAP model and the yield impact climate model behind it, are broadly consistent with previous studies. It is important to note, however, that we address a slightly different question. Three key differences between ours and these previous studies are: 1) our price increases specifically refer to cereals (rather than all foods), 2) the shock we model persists (and fluctuates in magnitude) over time, and 3) we abstract from income growth in order to highlight the shock of primary interest.

The yield effects of the nuclear exchange evolve over a 10 year horizon, with the largest single-year effects not occurring until year 5. To capture these different dimensions of the event, we report our nutrition simulations from three perspectives. First we illustrate the effects of a one-year shock, for which we take the average of the ten year-by-year price changes described in Table 6. The average (world) increases in cereals prices applied in this case is 8.5 percent, though the magnitude differs significantly by country and region. Next, we examine the nutritional impacts of the largest of the single year shocks (year 5). The world average cereals price increase in year 5 is 26.5 percent, which also varies widely across countries and regions. Finally, we then demonstrate the cumulative aspect that distinguishes our shock by summing the year-by-year price changes over the 10 year horizon. The world average price increase for cereals accumulated over this decade-long shock is 117 percent -- more than a doubling of cereals prices relative to baseline.

We regard this latter illustration as defining the upper bound of potential nutrition effects, as it entails the rather strong assumption that the price change for each year of the shock starts from the price level that pertains as a result of the previous year's shock. That is, we treat each individual year's shock as persistent, so that the price increases accumulate over the 10 year horizon to form a step function.

We use the nutrition analysis methodology described above to simulate the increases for each region of the developing world in the proportion of the population that is unable to afford the minimum caloric requirements recommended for each country by the FAO. As our country coverage is not exhaustive, we apply the population-weighted average increase in the prevalence of undernutrition, based on available countries, to each region. To calculate absolute increases in undernourished population for each region, we then apply region-specific proportional increases to the 2007 baseline estimates of population and undernutrition for each region provided by FAO (2010).

Table 7 summarizes our results. We estimate that undernutrition across all included regions would increase by 4.8 percent, scaled to the 2007 baseline, adding 39.7 million people to the baseline total of 833.4 million undernourished. These increases are not evenly distributed across regions. In relative terms, the greatest impact in percentage point increase and absolute numbers are in South Asia, where the average single-year shock increases the prevalence of undernutrition by nearly 2 percentage points, or approximately 30 million people. Part of the difference across regions derives from the share of cereals in total caloric intake across countries. Nutritional consequences for other regions include an additional 3.4 million undernourished in Sub-Saharan Africa, 4.5 million in East and South-East Asia, 0.8 million in Latin America, and 1 million in the Middle East and North Africa.

The effects of the largest (year 5) single-year shock are substantially greater. In this case, the total number of undernourished people in the included regions increases by 66.7 million, or 8 percent of the 2007 baseline number of undernourished. As with the average single-year shock, the largest impacts occur in South Asia, where the prevalence of undernutrition increases by 2.5 percentage points, accounting for just over 38 million people. This shock would also add to the list of undernourished 13.8 million in East and Southeast Asia, and nearly 9.4 million in sub-Saharan Africa. Effects in the other regions are smaller.

The cumulative effects over a 10-year horizon (e.g., our upper-bound impact estimates) swamp these single-year effects. Table 7 describes the total increase in the number of undernourished people of 215.5 million, an increase of 26 percent over the 2007 baseline. In this scenario, the largest proportional increase occurs in sub-Saharan Africa (with an almost 7percentage point increase), while the largest absolute (and second largest proportional) increases remain in South Asia. We estimate that a price increase for cereals of the magnitude that accumulates over this 10-year horizon would increase the number of undernourished in sub-Saharan Africa by 48.5 million, the number of undernourished in East and Southeast Asia by 63.5 million, and the number of undernourished in South Asia by 75.4 million. Significant increases also occur in Latin America (12.3 million) and the Middle East and North Africa (13.7 million), with smaller absolute increases in Central Asia.

Specific country experiences are illustrative. For example, India dominates the results for South Asia. The year 5 shock increases the prevalence of undernutrition in India by 3 percentage points (equivalent to nearly 35 million people, scaled from India's 2010 population). Yet, the cumulative 10-year shock increases undernutrition in India by 5.5 percentage points (equivalent to 63.8 million people, scaled from India's 2010 population). For Ethiopia, the year 5 shock increases the prevalence of undernutrition by 2.2 percentage points, or nearly 1.8 million people (scaled from Ethiopia's 2010 population). The cumulative 10-year shock, however, increases Ethiopia's prevalence by nearly 13 percentage points, or 10.7 million people. By contrast, for Haiti defined that the year 5 shock increases the prevalence of undernutrition by only 1.5 percentage points (or nearly 150,000 people), while the cumulative 10-year shock would increase the prevalence of undernutrition by 6.2 percentage points (or just over 620,000 people, based on Haiti's 2010 population).

The addition of such large numbers of people to the ranks of the undernourished would put considerable strain on national government safety nets as well as international humanitarian systems. The immediate impact of nuclear conflict in South Asia would be a human tragedy; given the already high number of undernourished adults as well as children in India, Pakistan, Nepal and Bangladesh one would reasonably expect a huge increase in nutritional (as well as health) problems among those surviving the nuclear exchange. Disruption of roads, markets, agricultural infrastructure, health systems and governance would be catastrophic for large swaths of the region's population, while predicted harvest shortfalls over a 10-year period after the immediate shock would add huge pressures to local food prices.

How many people would die of nutritionally-mediated diseases and food consumption shortfalls is hard to estimate with any precision. It should be pointed out that there were no reported starvation deaths among the 800 million people already classified as chronically undernourished during the peak food price crisis years of 2008 and 2010, although considerable hardship certainly resulted, including increased levels of macro and micronutrient malnutrition (de Pee et. al. 2010). Similarly, when harvested output collapsed by 50 to 70 percent across 11 countries of southern Africa during a severe drought in the early 1990s (affecting 100 million people), no famine emerged (Rook 1997). That widespread starvation did not occur among the *already* undernourished in either of these cases was mainly due to large-scale humanitarian action that responded to extreme need quickly, and to the ability of affected households to cope with rising prices by reducing consumption of both food and non-food essentials--with predictable longer-term negative impacts on individual and household welfare (Callihan et al. 1994). However, in the context of trade disruption following a nuclear conflict it remains to be seen how effective an international humanitarian response to rising undernutrition globally would be, and the coping mechanisms of vulnerable households would be stretched beyond breaking point if a crisis were to accumulate over the period of a decade.

Importantly, even if minimal (life-sustaining) energy consumption could be assured for all of those people undernourished, energy alone does not suffice to support sound nutrition outcomes. Diet quality matters as much as minimal diet quantity. As noted by Harwell and Harwell (1986) any shock that leads to a sole reliance on a single staple food quickly "leads to nutrient deficiencies." Reduced consumption of nutrient-rich foods increases the prevalence and severity of micronutrient deficiencies, while exacerbating chronic undernutrition. This is because people who reduce the size or number of meals will likely suffer deficiencies in macronutrients and energy, which leads to thinness among adolescents and adults, child underweight, and increased risk of acute malnutrition among young children (de Pee et al. 2010). For example, in the Horn of Africa that when annual food output falls below the long-term average food production (in drought years) rates of child undernutition (low weight-for-age) rise 5 to 12 percentage points (Mason et al. 2010).

Webb and Thorne-Lyman (2007) point out that "as food prices rise in the context of crisis, poor households typically (i) allocate a relatively higher share of their total expenditure on food in order to maintain current levels and composition of consumption (and hence spend less on other necessary goods; (ii) shift their consumption to 'less desired' (cheaper) staple foods, such as moving away from rice consumption to eating sorghum, or tubers such as cassava; (iii) spend relatively more on staples and less on 'quality' foods (which tend to be micronutrient rich, including meat, eggs, vegetables, etc.), and/or (iv) reduce their overall consumption of food (often adults skipping meals to protect the consumption level of their children)." A recent manifestation of such behaviours was documented by a World Bank (2009c) survey in

Bangladesh after the 2008 price hikes; it found that 95 percent of households were adversely affected, resulting in negative coping strategies such as reducing food intake (76 percent), and switching to lower quality food (88 percent).

The specific impacts of reduced diet quality as well as quantity include a rise in wasting among children under 5, maternal undernutrition (low body mass index) which can also cause irreversible damage to the fetus and a rise in rates of low birth weights, and outbreaks of micronutrient deficiency diseases that may be killers in their own right (UNSCN 2008). For example, during the Indonesian economic crisis of 1997, when prices of food rose and incomes declines sharply, most households responded by reducing their intake of animal products to maintain rice (their staple food) consumption (Klotz et al 2008). During the crisis, actual rice consumption did not fall in any socioeconomic strata despite the fact that maintaining consumption levels required an increase in absolute and relative expenditure on rice (Bloem et al. 2005). To offset the higher expenditure on rice, large numbers of families decreased expenditure on non-staple foods such as eggs, cooking oil, dairy products, fruit and vegetables (foods with high micronutrient qualities). As a result, the economic crisis triggered high rates of child anemia and maternal vitamin A deficiency even if children's weights did not suffer (Block et al. 2004).

This relationship between expenditure (as a proxy for consumption) on *non*-staple foods and child nutrition was also shown in Bangladesh, where expenditures on any food other than rice increases as the share of total expenditure on rice falls, resulting in a reduced prevalence of child undernutrition (Torlesse et al. 2003). It has also been noted in Zimbabwe when, as a result of the price hikes of 2008, a UNICEF/Government of Zimbabwe survey found that the share of households with 'poor' dietary diversity climbed steeply from 19 percent in 2007 to around 30 percent in 2008 (UNICEF 2008).

Based on such experiences, one can assume that any large food price increases attendant on a nuclear shock would result in similar shifts in household consumption globally (not only in South Asia) away from nutrient-rich, higher cost foods towards core staples (with a view to buffering at least a minimum energy intake). There are insufficient data to allow for the more complex modeling required to estimate resulting nutrition outcomes in terms of increased micronutrient deficiencies, maternal nutritional compromise or low birth weight. However, it is clear that the human impacts would be huge—with impaired growth and development of children, increased morbidity (due to failing immune functions caused by malnutrition), and a rise in excess mortality.

4. Conclusions

Yield shocks resulting from a sudden climate cooling associated with even a limited nuclear engagement located in South Asia would compound the pressures that have been building on food availability of vulnerable people since the mid-2000s, resulting in increased problems in nutrition, health and mortality. The projections constructed here of trade, economic welfare, consumption and nutrition impacts linked to yield losses due to a limited nuclear conflict suggest that the number of people becoming undernourished (added to pre-existing numbers) would be more than double the effect of the historic food price increases seen in 2008. Many of these would be in countries outside of Asia—demonstrating the global reach of a limited regional conflict of this kind. In addition to reduced energy consumption resulting from higher food prices, there would arguably be large scale compromise of diet quality, leading to micronutrient deficiency diseases, impaired immune functions, and higher mortality among the nutritionally vulnerable. The effects would be compounded inter-generationally because a 10-year period of food system 'aftershocks' (repeated yield shortfalls) would impact maternal nutrition and birth outcomes year after year. This would have serious consequences for added morbidity and mortality linked to nutritional compromise. While we cannot make any firm statements about impacts on those already undernourished prior to the nuclear engagement, it is likely that the food price hikes projected here would have significant deleterious effects on their already compromised consumption levels and nutritional status, representing a huge challenge for national and international humanitarian systems.

References

Acton Contre la Faim (ACF) and Medecins Sans Frontieres (MSF). 2009. *One Crisis May Hide Another: Food Price Crisis Masked Deadly Child Malnutrition*. Briefing Paper prepared for the Madrid Food Summit, 26-27 January 2009. Paris, France and Geneva, Switzerland.

Ahmed, A. and W. Martin. 2009. *Climate Change, Trade and Poverty*. Powerpoint presentation. Development Research Group. Washington, D.C.: World Bank.

Alderman, H., J. Hoddinott and B. Kinsey. 2006. Long Term Consequences of Early Childhood Malnutrition. *Oxford Economic Papers*. 58 (3): 450-74.

Alexandratos, N. 2010. *Critical Evaluation of Selected Projections*. Paper prepared for an expert meeting on “How to feed the world in 2050”, Rome, 24-26 june 2009. Mimeo.

Anderson, K. and S. Nelgen. 2010. Trade Barrier Volatility and Domestic Price Stabilization: Evidence from Agriculture. Policy Research Working Paper 5511. Washington, D.C.: World Bank.

AP (The Associated Press). 2011. A.D.D Earnings Fall 15%, Hit by Corn Prices and Taxes. *New York Times*, August 3, 2011, p. B7.

von Braun, J. 2009. Climate Change and Food Security. Presentation made at the IPC and ICTSD Seminar on *Climate Change, Agriculture, and Trade: Promoting Policy Coherence.* Washington D.C., October 29, 2009. [powerpoint presentation]

2008. *Food and financial crises: implications for agriculture and the poor*. Washington, D.C.: International Food Policy Research Institute.

Bailey, R. 2011. *Growing a Better Future: Food justice in a resource-constrained world.* London, UK: OXFAM International.

Behravesh, N. 2011. Global Economic Impact of the Japanese Earthquake, Tsunami, and Nuclear Disaster. IHS Global Insight: Country & Industry Forecasting. IHS Perspectives: 3/16/2011. Information Handling Services. http://www.ihs.com/products/global-insight/industry-economic-report.aspx?ID=1065929196 (last accessed August 24, 2011).

Block, S. L. Keiss, P. Webb, S. Kosen, R. Moench-Pfanner, M. W. Bloem, and C. Peter Timmer. 2004. Did Indonesia's Crises of 1997/98 Affect Child Nutrition? A Cohort Decomposition Analysis of National Nutrition Surveillance Data. *Economics and Human Biology*. 2: 21-44.

Bloem, M., S. de Pee, and I. Darnton-Hill. 2005. Micronutrient deficiencies and maternal thinness: first chain in the sequence of nutritional and health events in economic crises. In Bendich, A. and R. Deckelbaum (eds). *Preventive nutrition: the comprehensive guide for health professionals*. 3rd ed. Totowa, NJ: Humana Press,pp. 689-710.

Brinkman, H-J., S. de Pee, I. Sanogo, L. Subran and M. Bloem. 2009. High food prices and the global financial crisis have reduced access to nutrition food and worsened nutritional status and health. *Journal of Nutrition*. 140: 153S-161S.

Bussolo, M., R. De Hoyos, R. and D. Medvedev. 2009. *Global Income Distribution and Poverty in the Absence of Agricultural Distortions.* Policy Research Working Paper 4849. Washington, D.C.: World Bank.

Callihan, D., J. Eriksen and A. Herrick. 1994. *Famine Averted: The United States Government Response to the 1991/92 Southern Africa Drought: Evaluation Synthesis Report*. Management Systems International. Report for the US Agency for International Development.

Carpenter, J. 2011. Climate to wreak havoc on food supply, predicts report. 2 June 2011. http://www.bbc.co.uk/news/science-environment-13628374 (Accessed July 19, 2011)

Choi, C. 2011. *Small Nuclear War Could Reverse Global Warming for Years.* http://www.earth-issues.com/tag/american-association-for-the-advancement-of-science/ *[last accessed July 15, 2011]*

Cooke, B. and M. Robles. 2009. *Recent Food Prices Movements: A Time Series Analysis*. IFPRI Discussion Paper 00942. Washington, D.C.: International Food Policy Research Institute.

Currie J. 2007. Food, feed and fuels: an outlook on the agriculture, livestock and biofuels markets. http://www.gceholdings.com/pdf/GoldmanReportFoodFeedFuel.pdf

Das Gupta, S., T. Reardon, B. Minten and S. Singh. 2010. *The Transforming Rice Value Chain in India: The Rice Road from a Commercialized-Agriculture Zone in Western Uttar Pradesh to Delhi*. International Food Policy Research Institute/Michigan State University report. New Delhi, India. Mimeo.

De Hoyos, R., and D. Medvedev. 2009. *Poverty Effects of Higher Food Prices: A Global Perspective*. Policy Research Working Paper 4887. Development Prospects Group. Washington, D.C.: World Bank.

de Pee, S. H-J. Brinkman, P. Webb, S. Godfrey, I. Darnton-Hill, H. Alderman, R. Semba, E. Piwoz and M. Bloem. 2010. Why and How Nutrition Security Should Be Ensured in the Global Economic Crisis. *Journal of Nutrition*. 140 (1):138S-42S.

Demeke, M., G. Pangrazio and M. Maetz. 2008. *Country responses to the food security crisis: Nature and preliminary implications of the policies pursued.* Agricultural Policy Support Service. Rome, Italy: the Food and Agriculture Organization of the United Nations.

Dessus, S., S. Herrera and R. De Hoyos. 2008. The Impact of Food Inflation on Urban Poverty and its Monetary Cost: Some Back of the Envelope Calculations. *Agricultural Economics*. 39: 417-29.

DFID (Department for International Development). 2007. *Dimensions of Crisis Impacts: Humanitarian Needs by 2015*. A report prepared by the Humanitarian Futures Programme for the Department for International Development. London, UK: King's College, London/UK government.

Dobie, P., B. Shapiro, P. Webb and M. Winslow. 2007. *How do Poor People Adapt to Wealth Variability and Natural Disasters Today?* Occasional Paper 2007/24. Human Development Report Office. New York.

Dorosh, P. 2009. Price stabilization, international trade and national cereal stocks: world price shocks and policy response in South Asia. *Food Security*. 1:137–149.

Easterling, W., P. Aggarwal, P. Batima, K. Brander, L. Erda, S. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F. Tubiello. 2007. *Food, fibre and forest products*. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In M. Parry, O. Canziani, J. Palutikof, P. van der Linden and C. Hanson (Eds.), Cambridge University Press, Cambridge, UK, pp: 273-313.

Eastwood, R. and M. Lipton. 2011. Demographic transition in sub-Saharan Africa: How big will the economic dividend be? *Population Studies*, (3): 9-35Ericksen, P., P. Thornton, A.

Notenbaert, L. Cramer, P. Jones, and M. Herrero. 2011. *Mapping hotspots of climate change and food insecurity in the global tropics*. CCAFS Report no. 5. (Advance Copy). CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org.

Evans A. 2008. *Rising food prices: drivers and implications for development*. Chatham House Briefing Paper 08/01. London, UK: Chatham House.

FAO (Food and Agriculture Organization of the United Nations), with IFAD, IMF, OECD, UNCTAD, WFP, the World Bank, WTO, IFPRI and the UN/HLTF. 2011. *Price Volatility in Food and Agricultural Markets: Policy Responses.* Report prepared for the G20. Mimeo.

FAO (Food and Agriculture Organization of the United Nations). 2011. *The State of Food Insecurity 2010*. Rome, Italy: FAO.

2010a. *Crop Prospects.* Rome.

2010b. *State of Food Insecurity 2010*. Rome.

2009a. *More People Than Ever Are Victims of Hunger.* Press release. Rome.

2009b. *State of Food Insecurity 2009*. Rome.

2008. *High food prices and food security - threats and opportunities: The State of Food Insecurity in the World 2008.* Rome.

2007. *The State of food insecurity in the world 2007*. Rome: FAO.

GHF (Global Humanitarian Forum). 2009. *Human Impact Report: Climate Change: The Anatomy of a Silent Crisis*. Geneva, Switzerland.

Gilligan, D., H. Jacoby, and J. Quizon. 2000. *The Effects of the Indonesian Economic Crisis on Agricultural Households: Evidence from the National Farmers Household Panel Survey (PATANAS)*. Unpublished Working Paper, Center for Agro-Socioeconomic Research and the World Bank.

Godfray, C., I. Crute, L. Haddad, D. Lawrence, J. Muir, N. Nisbett, J. Pretty, S. Robinson, C. Toulmin and R. Whiteley. 2010. The future of the global food system. *Phil. Trans. R. Soc. B.* 365: 2769–77.

Gross, R. and P. Webb. 2006. Wasting time for wasted children: severe child undernutrition must be resolved in non-emergency settings. *Lancet.* 367: 1209–11.

Habib, B., A. Narayan, S. Olivieri and C. Sanchez-Paramo. 2010. *Assessing Ex Ante the Poverty and Distributional Impact of the Global Crisis in a Developing Country: A Micro-simulation Approach with Application to Bangladesh.* Policy Research Working Paper 5238. Poverty Reduction and Economic Management Network. Washington, D.C.: The World Bank.

Harwell, M., and C. Harwell. 1986. Nuclear Famine: The Indirect Effects of Nuclear War. In, Solomon, F. and R. Marston (Eds.). *The Medical Implications of Nuclear War*. Washington, D.C.: National Academy Press, pp. 117-35.

Hazell, P. and S. Wood. 2008. Drivers of change in global agriculture. *Phil. Trans. R. Soc. B.* 363: 495–515.

Headey, D. 2010. *Rethinking the Global Food Crisis the Role of Trade Shocks*. Discussion Paper 00958. Development Strategy and Governance Division. Washington, D.C.: International Food Policy Research Institute.

Helfand, I. 2007. *An Assessment of the Extent of Projected Global Famine Resulting from Limited, Regional Nuclear War*. Paper presented to the Royal Society of Medicine, London, UK, October 2007.

Hertel, T. (Ed.) 1997. *Global Trade Analysis: Modeling and Applications*. Cambridge, UK: Cambridge University Press.

Hertel, T., M. Burke, and D. Lobell. 2010. The poverty implications of climate induced crop yield changes by 2030. *Global Environmental Change*. GTAP Working Paper 59. West Lafayette, Ind.: Global Trade Analysis Project.

HFP (Humanitarian Futures Programme). 2007. *Dimensions of Crisis Impacts: Humanitarian Needs by 2015*. A report prepared for the Department for International Development. London; HFP/King's College, London.

Hulme, M., J. Mitchell, W. Ingram, T. Johns, M. New and D. Viner. 1999. Climate Change Scenarios for Global Impacts Studies. *Global Environmental Change.* 9 (4): S3–S19.

IAEA (International Atomic Energy Agency). 2001. *Present and future environmental impact of the Chernobyl accident*. IAEA-TECDOC-1240. Study monitored by an International Advisory Committee under the project management of the Institut de Protection et de Sûreté Nucléaire (IPSN), France. Vienna, Austria: IAEA.

IOM (Institute of Medicine of the National Academies*). 2010. Mitigating the Nutritional Impacts of the Global Food Price Crisis: Workshop Summary*. Washington, D.C.: The National Academies Press.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge, United Kingdom: Cambridge University Press.

IPPNW (International Physicians for the Prevention of Nuclear War). 2008. *Nuclear Famine: Climate and Health Effects of Regional Nuclear War*. IPPNW Fact Sheet.

Ivanic, M., W. Martin and H. Zaman. 2011. *Estimating the Short-Run Poverty Impacts of the 20100-11 Surge in Food Prices*. Policy Reseearch Working Ppaer 5633. Development Research Group. Washington, D.C.: World Bank.

Ivanic, M. and W. Martin. 2008. Implications of Higher Global Food Prices for Poverty in Low Income Countries. *Agricultural Economics*. 39: 405-16.

Joyce, C. 1987. Nuclear 'autumn' would bring seeds of disaster. *New Scientist*. June 4: 31.

Klotz, C., S. de Pee1,2, A. Thorne-Lyman, K. Kraemer, and Martin Bloem. 2008. Nutrition in the Perfect Storm: Why Micronutrient Malnutrition will be a Widespread Health Consequence of High Food Prices. *Sight and Life*. 1: 6-13.

Liu, J., S. Fritz, C. van Wesenbeeck, M. Fuchs, L. You, M. Obersteiner, and H. Yang. 2008. A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change. *Global and Planetary Change* 64: 222–235.

Lobell, D., M. Burke, C. Tebaldi, M. Mastrandrea, W. Falcon and R. Naylor. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science.* 319 (5863): 607–10.

Mason, J., S. Chotard, A. Bailes, S. Mebrahtu and P. Hailey. 2010. Impact of drought and HIV on child nutrition in Eastern and Southern Africa. *Food and Nutrition Bulletin*. 31 (3) S209-

18.

Moon B-K. 2008. The new face of hunger. *Washington Post*. March 12, 2008, p.19.

Narayanan, G.B. and Walmsley, T.W. (eds.) (2008). *Global Trade, Assistance, and Production: The GTAP 7 Data Base*. West Lafayette IN: Center for Global Trade Analysis, Purdue University, downloadable at www.gtap. org.

Nelson, G., M. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. Sulser, C. Ringler, S. Msangi and L. You. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options.* Washington, D.C.: International Food Policy Research Institute.

Nelson, G., M. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. Valmonte-Santos, M. Ewing and D. Lee. 2009. *Climate Change: Impact on Agriculture and Costs of Adaptation*. Food Policy Report. Washington, D.C.: International Food Policy Research Institute,

Ozdogan, M., A. Robock and C. Kucharik. 2011. *Consequences of a Regional Nuclear Conflict for Crop Production in the Midwestern United States*. Draft paper. Mimeo.

OECD/FAO (Organization for Economic Development and Co-operation/Food and Agriculture Organization). 2010. *Agricultural Outlook 2010-2019.* Paris/Rome.

Oman, L. (2011) interview at http://www.nasa.gov/topics/earth/features/nuclear-climate.html

Parry, M., C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer. 2004. Effects of Climate Change on Global Food Production under SRES Emissions and Socio-Economic Scenarios. *Global Environmental Change.* 14 (1): 53–67.

Parry, M., A. Evans, M. Rosegrant and T. Wheeler. 2009. *Climate Change and Hunger: Responding to the Challenge.* Rome: World Food Programme, International Food Policy Research Institute, New York University Center on International Cooperation, Grantham Institute at Imperial College London, and the Walker Institute, University of Reading.

Pelletier, D., P. Menon, T. Ngo, E. Frongillo and D. Frongilllo. 2011. The nutrition policy process: The role of strategic capacity in advancing national nutrition agendas. *Food and Nutrition Bulletin*. 32 (2): S59-S69

Pinstrup-Andersen, P. 2010. The Recent and Current Food Price Crisis and Future Perspectives. In, IOM (Institute of Medicine of the National Academies*). 2010. Mitigating the Nutritional Impacts of the Global Food Price Crisis: Workshop Summary*. Washington, D.C.: The National Academies Press, pp. 14-20.

Pitt, M. 1983. Food Preferences and Nutrition in Rural Bangladesh. *The Review of Economics and Statistics*. LXV: 105-114.

Pittock, A., T. Ackerman, P. Crutzen, M. MacCracken, C. Shapiro and R. Turco. 1986. *Environmental Consequences of Nuclear War, Volume I: Physical and Atmospheric Effects*. SCOPE 28. Chichester, U.K.: John Wiley & Sons.

Pongou, R., J. Salomon and M. Ezzati. 2005*. Economic Crisis and Declining Child Nutrition in Cameroon During the 1990s: The Mediating Role of Household Effects*. Working Paper Series 15 (2). Harvard Center for Population and Development Studies. Cambridge, MA: Harvard University.

Post, J. 1983. Climatic change and subsistence crises. *Journal of Interdisciplinary History*. 14: 153–160.

1976. Famine, mortality, and epidemic disease in the process of modernization. *Economic History Review*. 29: 14–37.

Reardon, T. B. Minten, M. Punjabi Mehta, S. Das Gupta, S. Rajendran, A. Sarawgi and B. Beohar. 2011. *Survey Findings in Madhya Pradesh Informing Rural Business Hub Innovations and Policymakers to benefit Poor Farmers: IFPRI/USAID-PIKA Project*. Report to USAID/New Delhi, India. Mimeo.

Reutlinger, S., and M. Selowsky. 1976. *Malnutrition and Poverty: Magnitude and Policy Options*. World Bank Occasional Paper No. 23. Baltimore, MD: Johns Hopkins University Press.

Ringler, C., T. Zhu, X. Cai, J. Koo and D. Wang. 2010. *Climate Change Impacts on Food Security in Sub-Saharan Africa: Insights from Comprehensive Climate Change Scenarios*. IFPRI Discussion Paper 01042. Environment and Production Technology Division. Washington, D.C.: International Food Policy Research Institute.

Robock, A. 2009. *Nuclear Winter*. The Encyclopedia of the Earth. http://www.eoearth.org/article/Nuclear_winter#gen3. (Accessed July 20, 2011)

Robock, A., L. Oman, G. Stenchikov, O. Toon, C. Bardeen and R. Turco, 2007, Climatic consequences of regional nuclear conflicts. *Atm. Chem. Phys*., 7: 2003-12.

Robles, M. and L. Iannotti. 2011. *Nutritional Impacts of Rising Food Prices.* Forthcoming in the *Food and Nutrition Bulletin* (http://www.foodsecurityportal.org/nutritional-impacts-rising-food-prices?print).Rook, J. 1997. The SADC Regional Early Warning System: Experience Gained and Lessons Learnt from the 1991-92 Southern Africa Drought. *Internet Journal of African Studies*. 2 (3). http://ccb.colorado.edu/ijas/ijasno2/rook.html (last accessed August 31, 2011).

Senauer, B. and M. Sur. 2001. Ending Global Hunger in the 21st Century: Projections of the Number of Food Insecure People. *Review of Agricultural Economics*. 23 (1): 68-81.

Sibrian, R. 2009. *Undernourishment and critical food poverty: Indicators at national and sub-national levels*. Working Paper No. ESS/ESSG/014e. Statistics Division. Rome, Italy: Food and Agriculture Organization of the United Nations.

Skoufias, E., S. Tiwari and H. Zaman. 2011. *Can We Rely on Cash Transfers to Protect Dietary Diversity during Food Crises? Estimates from Indonesia*. Policy Research Working Paper 5548. Poverty Reduction and Economic Management Network, Washington, D.C.: World Bank

Solomon, F. and R. Marston (Eds.). *The Medical Implications of Nuclear War*. Washington, D.C.: National Academy Press.

Starr, S. 2011. *Nuclear Darkness, Global Climate Change and Nuclear Famine*. (http://www.nucleardarkness.org/index2.php, last accessed July 15, 2011)

Stern, N. 2007. *The Economics of Climate Change: The Stern Review Report*. Cambridge, UK: Cambridge University Press.

De Pee S., M. Bloem, M. Sari, D. Soekarjo, R. Tjiong, and S. Kosen. 2000. Indonesia's crisis causes considerable weight loss among mothers and adolescents. *Malaysian Journal of Nutrition*. 6: 203-214.

Timmer, C. and H. Alderman. 1979. Estimating consumption parameters for food policy analysis. *American Journal of Agricultural Economics*. 61(5): 982-987.

Tiwari, S. and H. Zaman. 2010. *The Impact of Economic Shocks on Global Undernourishment*. Policy Research Working Paper 5215. Poverty Reduction and Economic Management

Network. Washington, D.C.: World Bank.

Torlesse H., L. Kiess and M. Bloem. 2003. Association of household rice expenditure with child nutritional status indicates a role for macroeconomic food policy in combating malnutrition. *Journal of Nutr*. 133: 1320-25.

UNSCN (United Nations Standing Committee on Nutrition). 2010. *Progress in Nutrition: Sixth Report on the World Nutrition Situation*. Geneva, Switzerland.

2008. *The Impact of High Food Prices on Maternal and Child Nutrition*. Background paper for the SCN Side Event at the 34th Session of the Committee on World Food Security, Rome, 14-17 October 2008. Mimeo.

UNHLTF (United Nations High-Level Task Force on the Global Food Crisis). 2008. *Comprehensive framework for action*. New York, NY: United Nations.

UNICEF. 2008. *Combined Micronutrient and Nutrition Surveillance Survey: Summary of Main Findings*. Harare, Zimbabwe: The Food and Nutrition Council of Zimbabwe.

Vanhaute, E. 2011. From famine to food crisis: what history can teach us about local and global subsistence crises. *Journal of Peasant Studies*. 38 (1): 47-65.

Webb, P. 2010. Medium- to Long-Run Implications of High Food Prices for Global Nutrition. *Journal of Nutrition*. 140 (1): 140S-47S.

Webb, P. and A. Thorne-Lyman. 2007. Entitlement Failure from a Food Quality Perspective: Vitamins and Minerals in Humanitarian Crises. In Guha-Khasnobis, B., S. Acharya and B. Davis (eds.) *Food Insecurity, Vulnerability and Human Rights Failure*. London, UK: Palgrave MacMillan/ World Institute for Development Economics Research, pp 243-65.

Willenbockel, D. 2011. *Exploring Food Price Scenarios Towards 2030 with a Global Multi-Region Model*. Oxfam Research Reports. Sussex, UK: Institute of Development Studies/OXFAM.

World Food Programme (WFP). 2008. *WFP completes $755 million appeal with Saudi pledge* – Press Release. Rome, 23 May 2008.

Wodon, Q. and H. Zaman. 2010. Higher Food Prices in Sub-Saharan Africa: Poverty Impact and Policy Responses. *World Bank Research Observer*. 25 (1):

World Bank. 2011a. *Food Price Watch.* April 2011. Poverty Reduction and Equity Group Poverty Reduction And Economic Management Network. Washington, D.C.: World Bank.

2011b. *Rising Food and Energy Prices in Europe and Central Asia.* Washington, D.C.

2010. *World Development Indicators* 2010. Washington, D.C.: World Bank.

2009a. *Global economic prospects 2009*. Washington, D.C.: World Bank.

2009b. *Global Economic Monitor*. Washington, D.C.: World Bank.

2009c. *Welfare Impact of Rising Food Prices in South Asian Countries*. Policy Note, South Asia Economic Policy and Poverty Unit. Washington D.C.

2008a. *Poverty Assessment for Bangladesh: Creating Opportunities and Bridging the East-West Divide.* Report No. 44321-BD. Washington D.C.

2008b. *Agriculture for Development*. World Development Report. Washington D.C.

Figure 1. Mean relative changes in maize yields across four sites over a period of 10-years following the 5 Tg nuclear conflict. Negative values indicate a decrease from the control run. Each black bar represents the average of 30 realizations of the model run for a given year while the whiskers indicate the +/- one standard deviation across experiments. The minimum and maximum yield changes across 30 model runs are given in black dots. A missing black dot means it was placed outside of the range of Y-axis limits.

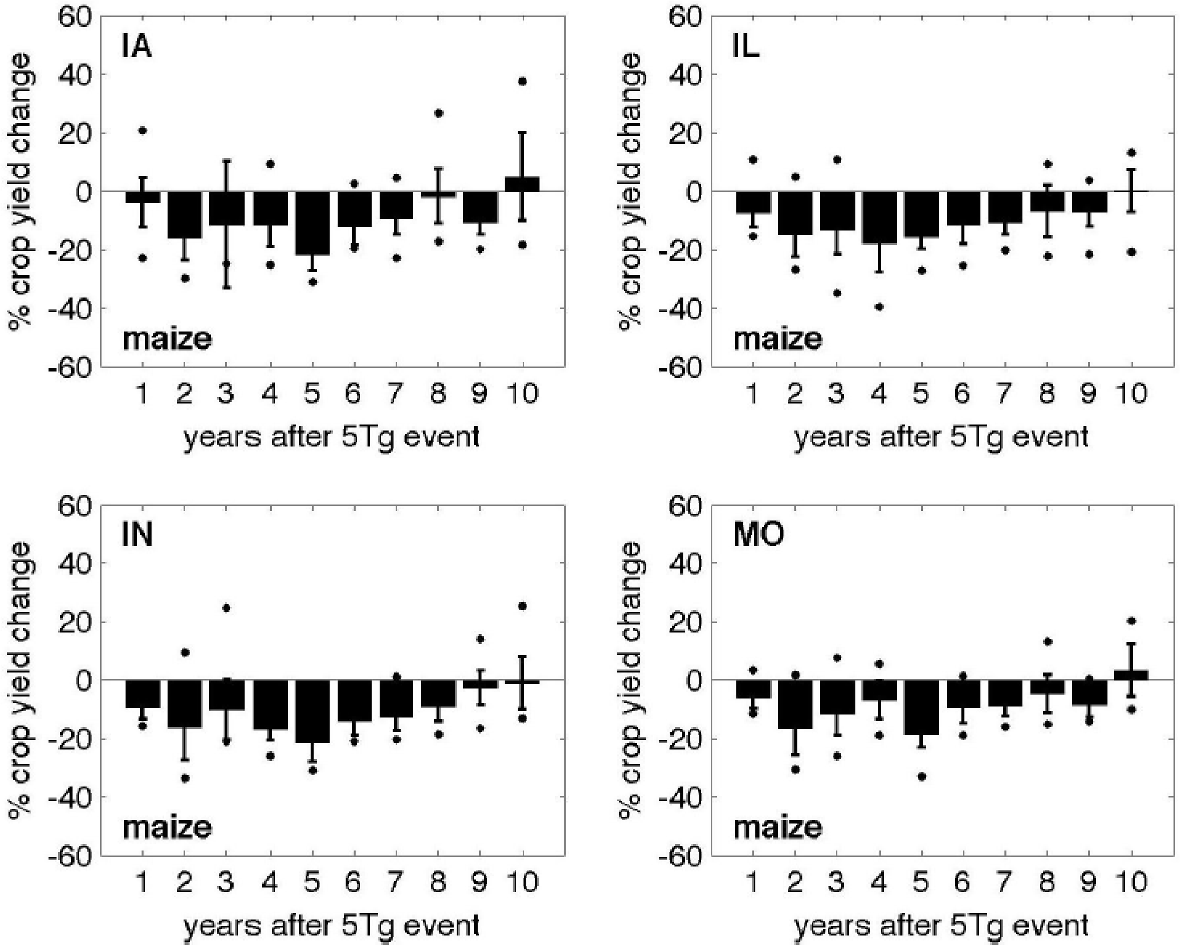

Figure 2. Relationship Between Engel Function and Income Distribution

(Panel A)

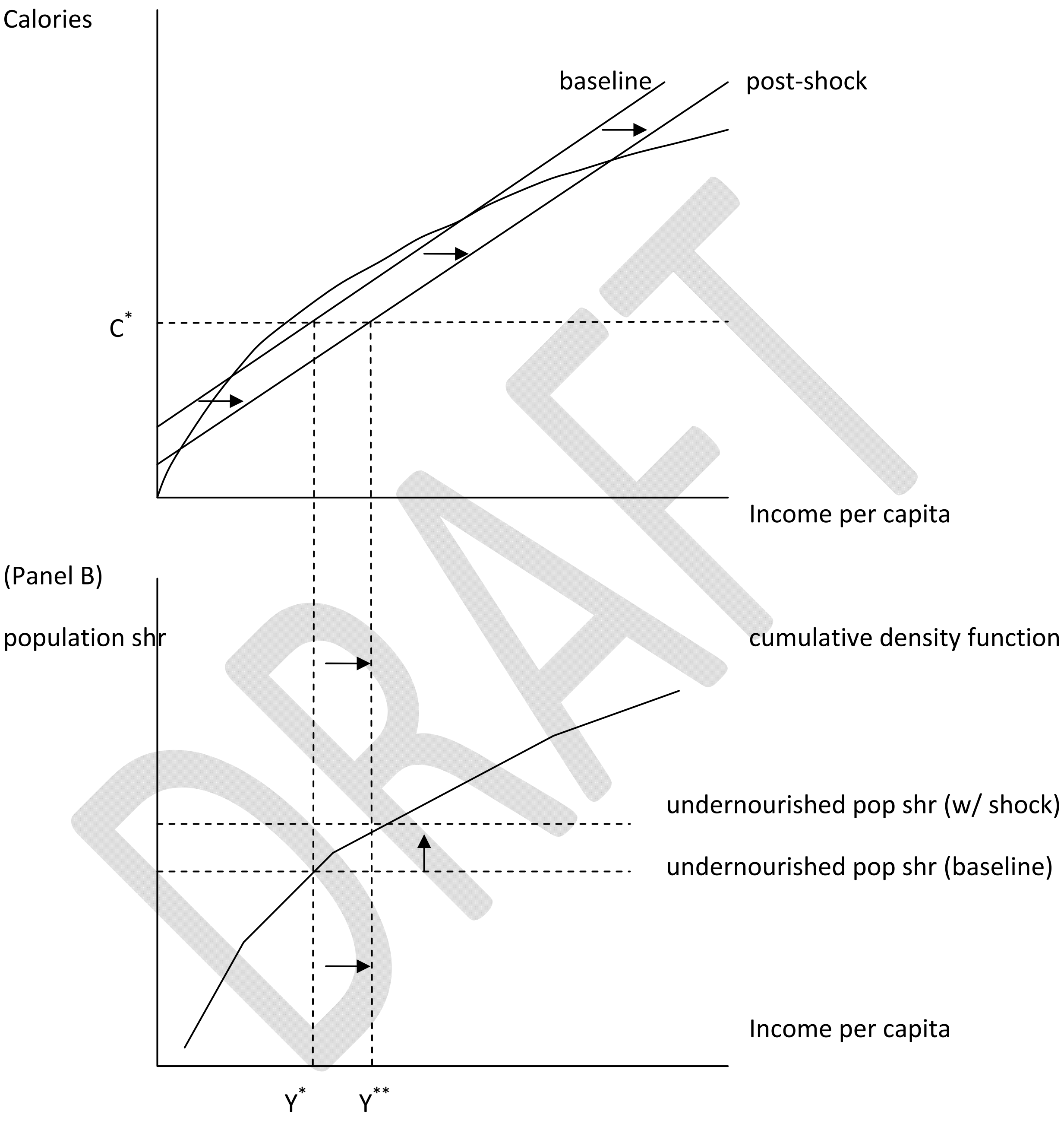

Table 1: Effects of crop yield changes due to nuclear conflict, on global welfare (equivalent variation of income in 2004 US$ million)

	-40% yield reduction			-20% yield reduction		
	Total welfare US$ million (dollar per capita in brackets)		That due to terms of trade changes	Total welfare US$ million (per capita in brackets)		That due to terms of trade changes
Australia-New Zealand	**8666**	**(361)**	**11988**	**1464**	**(61)**	**2203**
Europe	**-80640**	**(-157)**	**-20462**	**-17804**	**(-35)**	**-4005**
East Central Asia	**-18963**	**(-22)**	**-1470**	**-4923**	**(-6)**	**-701**
North America	**-10644**	**(-25)**	**30313**	**-3018**	**(-7)**	**6519**
United States	4660	(16)	34990	466	(2)	7511
Canada	58	(2)	3204	-189	(-6)	471
Mexico	-15362	(-146)	-7880	-3295	(-31)	-1462
Rest of High Income countries	**-53383**	**(-219)**	**-31219**	**-11312**	**(-46)**	**-5800**
South East Asia	**-63270**	**(-35)**	**-9610**	**-15216**	**(-8)**	**-650**
China	-38869	(-30)	-7048	-9072	(-7)	-1078
Rest of South East Asia	-24402	(-46)	-2561	-6144	(-11)	428
South Asia	**-75551**	**(-52)**	**-11924**	**-18780**	**(-13)**	**-2028**
India	-61106	(-57)	-6879	-15056	(-14)	-955
Rest of South Asia	-14445	(-39)	-5046	-3723	(-10)	-1073
Middle East & North Africa	**-20033**	**(-76)**	**-12087**	**-5005**	**(-19)**	**-3292**
West Africa	**40**	**(0)**	**3038**	**-238**	**(-1)**	**557**
Nigeria	-2757	(-20)	-1346	-709	(-5)	-354
Rest of West Africa	2796	(26)	4384	472	(4)	912
East Africa	**-216**	**(-1)**	**3857**	**-271**	**(-1)**	**679**
Ethiopia	167	(2)	431	22	(0)	86
Mozambique	-250	(-13)	-6	-67	(-4)	-9
Tanzania	-144	(-4)	546	-64	(-2)	100
Uganda	-98	(-4)	326	-47	(-2)	59
Zambia	35	(3)	270	-1	(0)	51
Zimbabwe	354	(28)	546	76	(6)	117
Rest of E Africa	-280	(-9)	1745	-189	(-6)	275
South/Central Africa	**254**	**(2)**	**2690**	**-298**	**(-2)**	**181**
South Africa	2088	(47)	3087	194	(4)	357
Rest of South/Central Africa	-1835	(-23)	-396	-492	(-6)	-176
South/Central America	**11972**	**(29)**	**33602**	**1114**	**(3)**	**6288**
Argentina	5167	(133)	8158	941	(24)	1702
Brazil	9843	(55)	15551	1329	(7)	2562
Rest of S/C America	-3039	(-15)	9893	-1156	(-6)	2024
World	**-301771**	**(-49)**	**-1283**	**-74286**	**(-12)**	**-48**

Source: Authors' simulations

Table 2: Effects of modeled annual crop yield changes on global welfare over 10 years (after Year 0 nuclear event)
(Equivalent variation of income in 2004 US$ million)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Australia-New Zealand	**16**	**177**	**339**	**537**	**3403**	**2856**	**5420**	**455**	**7292**	**-4362**
Europe	**-225**	**-2445**	**-4389**	**-6359**	**-32730**	**-23331**	**-41287**	**-3368**	**-54296**	**32013**
East Central Asia	**-65**	**-701**	**-1239**	**-1750**	**-8101**	**-4986**	**-7638**	**-574**	**-8487**	**4891**
Russia	-41	-444	-798	-1156	-5834	-4013	-6763	-535	-8236	4812
Rest of ECA	-24	-256	-441	-594	-2267	-973	-874	-39	-250	79
North America	**-44**	**-467**	**-788**	**-1044**	**-4324**	**-2575**	**-4440**	**-364**	**-6256**	**3657**
United States	0	14	73	195	1911	1679	2749	196	2389	-1236
Canada	-4	-41	-60	-59	1	140	332	29	447	-259
Mexico	-40	-440	-801	-1180	-6235	-4394	-7521	-589	-9093	5152
Other High Income countries	**-141**	**-1533**	**-2768**	**-4050**	**-21454**	**-15755**	**-28405**	**-2332**	**-37697**	**22214**
South East Asia	**-199**	**-2150**	**-3809**	**-5411**	**-26213**	**-17580**	**-29639**	**-2363**	**-37009**	**21755**
China	-117	-1262	-2254	-3237	-16065	-10952	-18597	-1487	-23377	13748
Rest of South East Asia	-83	-888	-1555	-2175	-10148	-6628	-11041	-876	-13632	8006
South Asia	**-237**	**-2583**	**-4665**	**-6776**	**-32929**	**-21306**	**-32960**	**-2514**	**-36078**	**21166**
India	-188	-2048	-3724	-5454	-26810	-17454	-26941	-2062	-29582	17461
Rest of South Asia	-50	-534	-941	-1322	-6120	-3853	-6019	-452	-6496	3705
Middle East/North Africa	**-65**	**-702**	**-1250**	**-1784**	**-8518**	**-5392**	**-8395**	**-636**	**-9427**	**5446**
West Africa	**-5**	**-48**	**-72**	**-74**	**13**	**290**	**680**	**67**	**912**	**-652**
Nigeria	-9	-101	-178	-253	-1184	-739	-1120	-83	-1178	679
Rest of West Africa	5	52	106	179	1197	1029	1801	150	2089	-1331
East Africa	**-4**	**-47**	**-77**	**-93**	**-177**	**97**	**404**	**41**	**686**	**-435**
Ethiopia	0	2	5	8	66	64	118	10	134	-81
Mozambique	-1	-10	-17	-24	-109	-69	-107	-8	-121	74
Tanzania	-1	-11	-18	-23	-67	-24	-27	-2	-37	26
Uganda	-1	-7	-13	-17	-53	-11	14	2	46	-32
Zambia	0	-1	-1	0	11	17	40	4	58	-37
Zimbabwe	1	10	18	28	147	108	188	15	234	-142
Rest of E Africa	-3	-31	-52	-66	-171	11	178	21	372	-243
South Central Africa	**-6**	**-57**	**-89**	**-99**	**-22**	**315**	**904**	**86**	**1523**	**-930**
South Africa	1	13	35	76	781	793	1590	136	2198	-1318
Rest of S/Africa	-6	-70	-124	-175	-803	-478	-686	-49	-675	387
South and Central America	**6**	**76**	**203**	**438**	**4390**	**4592**	**9442**	**815**	**13097**	**-7896**
Argentina	11	118	222	342	2040	1646	3067	257	4035	-2444
Brazil	12	139	287	498	3769	3492	6843	581	9301	-5578
Rest of S/C America	-17	-181	-306	-402	-1419	-546	-468	-22	-239	126
World	**-970**	**-10480**	**-18604**	**-26465**	**-126662**	**-82777**	**-135913**	**-10686**	**-165742**	**96867**

Source: Authors' simulations

Table 3: Effects of crop yield changes due to nuclear conflict on international prices (percent change)

Sectors	-40% yield reduction shock	-20% yield reduction shock	-10% yield reduction shock
(percent price change)			
Coarse grains	33.0	10.4	4.4
Soybeans	82.0	15.1	5.5
Rice	88.9	15.8	5.7
Wheat	75.1	13.7	5.0
Other crops	84.8	15.8	5.8
Animal products	16.6	4.0	4.4
Extraction	-5.0	-1.1	1.6
Processed Food	11.0	2.2	-0.4
Manufacturing	-3.1	-0.6	0.8
Services	-3.1	-0.6	-0.2

Source: Authors' simulations

[a] Yield changes derived from Ozdogan et al (2011) and implemented as land biased productivity shocks of -40%, -20% and -10% for all crops.

Table 4: Effects of -40 percent crop yield changes due to nuclear conflict, on farm prices (percent change)

	Coarse grains	Soybeans	Rice	Wheat	Other crops	ALL Crops
Australia-New Zealand	**7.6**	**92.0**	**97.9**	**94.5**	**102.5**	**96.9**
Europe	**15.4**	**80.6**	**95.8**	**74.5**	**82.4**	**82.1**
East Central Asia	**22.3**	**79.0**	**85.5**	**91.1**	**78.1**	**78.3**
Russia	49.0	90.3	99.6	94.6	89.7	**92.1**
Rest of ECA	19.6	73.9	74.2	89.9	74.8	**73.4**
North America	**28.1**	**91.1**	**98.6**	**108.2**	**114.5**	**106.9**
United States	27.7	93.5	99.1	111.0	118.9	**109.9**
Canada	63.2	88.9	74.3	90.7	100.4	**92.1**
Mexico	21.6	77.5	101.9	63.7	101.6	**100.9**
Other High Income countries	**57.5**	**80.4**	**121.6**	**118.7**	**124.2**	**91.3**
South East Asia	**57.3**	**73.4**	**113.5**	**117.5**	**118.1**	**98.0**
China	38.8	72.4	91.8	95.5	110.3	**91.3**
Rest of South East Asia	75.5	97.7	157.6	137.8	144.0	**111.7**
South Asia	**29.9**	**146.2**	**196.9**	**207.9**	**186.4**	**140.6**
India	30.0	152.6	199.5	211.1	207.3	**159.6**
Rest of South Asia	29.9	88.0	107.4	92.4	113.1	**72.7**
Middle East & N. Africa	**31.2**	**65.9**	**65.3**	**72.3**	**69.5**	**66.7**
West Africa	**45.1**	**81.8**	**99.7**	**101.9**	**95.7**	**93.0**
Nigeria	37.5	85.9	71.6	76.0	71.2	**69.7**
Rest of West Africa	47.5	77.7	113.8	108.5	107.0	**103.4**
East Africa	**39.4**	**79.4**	**80.0**	**92.8**	**91.8**	**85.0**
Ethiopia	38.8	77.7	83.1	89.6	97.1	**91.1**
Mozambique	46.6	89.1	95.0	69.3	94.4	**91.9**
Tanzania	50.4	79.1	104.3	112.7	97.4	**95.5**
Uganda	45.8	84.7	86.3	84.6	85.1	**84.2**
Zambia	23.6	84.9	75.5	101.7	98.9	**90.7**
Zimbabwe	16.5	83.0	115.1	157.6	106.8	**106.7**
Rest of SS-SE Africa	36.3	79.5	66.5	85.2	88.5	**77.9**
South/Central Africa	**24.1**	**71.4**	**69.6**	**82.0**	**85.5**	**80.0**
South Africa	41.4	65.8	72.6	82.0	89.8	**85.5**
Rest of S/C Africa	20.5	77.2	68.2	82.0	80.9	**75.3**
South/Central America	**38.7**	**94.4**	**101.0**	**90.1**	**109.8**	**96.6**
Argentina	34.2	93.4	95.6	93.6	112.5	**97.2**
Brazil	34.8	78.3	83.3	84.1	90.9	**81.6**
Rest of S/C America	41.1	99.2	114.3	105.7	117.3	**106.4**
World	**47.0**	**95.4**	**100.0**	**121.2**	**110.2**	**98.7**

Source: Authors' simulations

Table 5: Effects of -20 percent crop yield changes due to nuclear conflict, on farm prices (percent)

	Coarse grains	Soybeans	Rice	Wheat	Other crops	ALL Crops
Australia-New Zealand	**1.8**	**17.1**	**17.1**	**17.5**	**17.0**	**16.4**
Europe	**4.4**	**13.6**	**16.0**	**12.8**	**14.1**	**14.0**
East Central Asia	**5.9**	**15.2**	**17.3**	**17.6**	**14.6**	**15.0**
North America	**6.7**	**16.6**	**18.7**	**19.8**	**21.5**	**20.1**
United States	6.6	17.7	17.6	20.5	22.0	**20.3**
Canada	12.2	15.4	11.6	15.2	16.7	**15.4**
Mexico	7.0	14.5	23.9	11.1	21.1	**21.7**
Rest of High Income countries	**14.8**	**15.2**	**23.5**	**25.1**	**23.8**	**19.4**
South East Asia	**15.8**	**14.1**	**23.8**	**26.3**	**24.1**	**21.4**
China	10.3	13.8	17.8	19.5	21.8	**18.6**
Rest of South East Asia	21.2	21.3	36.0	32.5	31.9	**27.1**
South Asia	**10.2**	**31.4**	**43.1**	**44.9**	**40.7**	**31.6**
India	10.5	32.7	43.6	45.5	44.9	**35.5**
Rest of South Asia	9.7	19.8	24.2	21.0	25.9	**18.0**
Middle East & N. Africa	**7.9**	**10.9**	**10.8**	**12.4**	**11.0**	**10.9**
West Africa	**10.8**	**15.0**	**18.7**	**18.9**	**18.0**	**17.7**
Nigeria	10.8	16.1	14.9	15.2	14.3	**14.2**
Rest of W Africa	10.8	13.8	20.5	19.9	19.7	**19.2**
East Africa	**10.2**	**14.5**	**14.6**	**17.2**	**16.5**	**15.6**
Ethiopia	9.1	13.6	14.7	16.1	17.4	**16.2**
Mozambique	13.4	18.1	18.8	11.8	17.9	**17.8**
Tanzania	13.4	15.2	19.3	21.2	17.4	**17.7**
Uganda	10.2	15.9	16.2	16.1	15.7	**15.7**
Zambia	5.0	15.8	13.2	18.8	17.6	**16.2**
Zimbabwe	3.8	16.2	20.9	30.5	19.4	**19.4**
Rest of E Africa	9.3	14.5	12.1	15.8	15.7	**14.2**
South/Central Africa	**5.9**	**11.4**	**11.8**	**13.8**	**13.3**	**12.8**
South Africa	12.8	8.9	10.3	11.7	12.5	**12.0**
Rest of S/C Africa	4.5	14.0	12.5	15.1	14.2	**13.4**
South/Central America	**9.3**	**18.3**	**18.6**	**15.8**	**20.2**	**17.9**
Argentina	8.2	18.3	18.1	18.3	21.6	**18.9**
Brazil	8.3	13.2	13.8	13.3	15.2	**13.6**
Rest of S/C America	10.0	19.5	21.9	20.3	22.1	**20.4**
World	**13.1**	**18.3**	**19.0**	**24.0**	**21.2**	**19.7**

Source: Authors' simulations

Table 6: Effects of crop yield changes on cereal prices due to a nuclear event at Year 0 (annual percent changes)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Cumulative effect [a]
Australia-New Zealand	0.17	1.88	3.41	5.03	27.33	16.27	24.88	1.63	24.87	-11.60	129.90
Europe	0.19	1.73	3.20	4.91	29.39	19.06	31.06	2.01	32.32	-14.52	157.07
East Central Asia	0.19	2.06	3.68	5.25	27.98	16.76	26.49	1.73	27.55	-12.79	138.67
Russia	0.30	2.87	5.04	7.02	33.68	17.85	26.45	1.73	26.31	-12.34	160.26
Rest of ECA	0.19	1.50	2.82	4.30	24.65	16.16	26.49	1.80	28.30	-13.10	126.70
North America	0.19	2.20	3.95	5.88	32.12	18.95	29.37	1.90	29.76	-13.33	162.58
United States	0.19	2.07	3.73	5.56	31.51	19.19	30.51	1.95	31.31	-14.16	163.20
Canada	0.18	1.68	3.28	5.08	30.46	19.24	30.78	2.00	31.70	-14.44	158.50
Mexico	0.29	3.10	5.43	7.68	36.18	17.45	22.16	1.24	16.05	-7.20	150.04
Other High Income	0.20	2.11	3.71	5.03	22.13	11.47	16.43	1.12	16.01	-7.95	90.73
South East Asia	0.21	2.37	4.14	5.49	24.54	12.54	18.30	1.16	18.13	-8.63	104.03
China	0.13	1.66	2.91	4.06	19.71	11.30	17.55	1.19	18.56	-8.79	86.83
Rest of South East Asia	0.32	3.35	5.58	7.23	30.32	14.13	19.20	1.23	17.66	-8.51	126.76
South Asia	0.20	2.47	4.32	6.08	29.80	13.30	16.94	0.95	13.75	-6.30	110.23
India	0.29	2.77	4.93	6.94	34.65	15.21	19.11	1.08	15.19	-6.83	131.79
Rest of South Asia	0.12	1.63	2.73	3.57	14.57	6.99	9.40	0.58	8.73	-4.24	52.04
Middle East/N. Africa	0.10	1.27	2.42	3.62	21.86	15.15	25.58	1.68	27.68	-12.76	114.70
West Africa	0.16	2.08	3.74	5.39	29.35	17.57	28.53	1.84	30.80	-13.62	151.44
Nigeria	0.20	1.89	3.28	4.68	23.32	13.39	20.67	1.39	21.40	-10.06	106.17
Rest of West Africa	0.16	2.18	3.90	5.69	31.77	19.10	31.08	2.00	33.44	-14.66	168.53
East Africa	0.18	1.70	3.19	4.72	25.89	16.04	25.86	1.72	27.73	-12.74	129.47
Ethiopia	0.20	1.78	3.34	5.02	28.78	18.64	31.09	2.08	34.13	-15.51	156.46
Mozambique	0.20	2.33	4.22	6.07	31.50	17.66	26.46	1.67	26.41	-12.22	150.19
Tanzania	0.20	2.26	4.10	6.05	32.89	18.87	28.83	1.82	29.05	-13.23	162.48
Uganda	0.18	1.98	3.58	5.17	28.48	17.52	28.48	1.91	30.51	-14.02	146.92
Zambia	0.19	1.56	2.99	4.44	25.80	16.87	27.82	1.83	30.20	-13.93	134.72
Zimbabwe	0.19	2.23	4.10	6.05	33.82	19.97	31.92	2.00	33.50	-14.82	177.71
Rest of East Africa	0.11	1.46	2.69	3.95	21.69	13.80	22.70	1.58	24.89	-11.67	106.42
South Central Africa	0.10	1.35	2.60	3.95	24.19	16.20	26.63	1.75	28.41	-13.11	124.45
South Africa	0.10	1.09	2.18	3.62	25.15	18.07	30.22	2.02	32.38	-14.72	137.44
Other South/central Africa	0.11	1.53	2.78	4.20	23.62	15.18	24.42	1.63	25.87	-12.18	116.65
South/Central America	0.16	1.97	3.52	5.09	27.63	16.58	26.40	1.73	27.58	-12.58	137.07
Argentina	0.20	2.29	4.13	5.98	32.22	19.12	30.12	1.92	31.02	-14.14	165.80
Brazil	0.14	1.40	2.57	3.89	22.52	14.62	24.15	1.61	26.09	-11.95	112.81
Rest of SC America	0.19	2.12	3.85	5.46	28.96	16.80	26.39	1.71	27.20	-12.37	141.88
World	0.20	2.12	3.80	5.37	26.47	14.36	21.12	1.35	20.73	-9.68	116.68

[a] with respect to base year zero

Source: Authors' simulations

Table 7. Simulated Nutritional Outcomes

Region	Population, mill. (2007)	Number Undernourished (mill.)	Undernourished Share	Percentage Point Change from Baseline	Additional Undernourished (mill.)	Percentage Point Change from Baseline	Additional Undernourished (mill.)	Percentage Point Change from Baseline	Additional Undernourished (mill.)
		Baseline in 2007		Average Single-Yr Shock		Largest Single-Yr Shock		Cumulative 10-Yr Shock	
Sub-Saharan Africa	729.6	201.2	27.6 percent	0.47	3.39	1.28	9.37	6.64	48.47
Middle East & N. Africa	439.3	32.4	7.4 percent	0.22	1.0	0.59	2.58	3.11	13.65
Latin America	556.1	47.1	8.5 percent	0.15	0.8	0.46	2.54	2.21	12.29
East & South-East Asia	1957.6	215.6	11.0 percent	0.23	4.5	0.70	13.79	3.24	63.51
Central Asia	58.7	6	10.2 percent	0.26	0.2	0.68	0.40	3.77	2.21
South Asia	1520.1	331.1	21.8 percent	1.96	29.8	2.50	38.04	4.96	75.35
TOTALS	**5261.4**	**833.4**	**15.8 percent**	**0.8**	**39.7**	**1.3**	**66.71**	**4.1**	**215.48**

Source: Authors' simulations