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The distributional impact of climate change: Why food prices matter

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Abstract

We develop a simple two-sector (food and non-food) general equilibrium model for studying the long-run impact of climate change on food prices and the distribution of welfare in India. We find that food prices were 4 to 8 percent higher and the real income of the landless was 2.4 to 4.8 percent lower in 2009 relative to a counterfactual without climate change and pollution (over the past three decades). Contrary to popular belief, nearly all farmers lose from climate change that causes higher food prices. In 2030, if agricultural productivity is 7% lower compared to a scenario without further climate impacts, then food prices will be 3.6 to 10.8 percent higher and the real income of the landless 1.6 to 5.6% lower. The lower numbers are obtained in open economy scenarios and the higher in closed economy scenarios, showing that trade is very important in protecting the poor. If the economy is closed, then improving the productivity of the agricultural sector has the greatest impact on the welfare of the poor. In contrast, if the economy is open and there are no barriers to labor movement out of agriculture, then the non-agricultural sector plays a bigger role in driving the welfare of the poor than mitigation of climate change.

Keywords: Climate change, distribution, food prices, general equilibrium, India.

JEL codes: O13, O53, Q54

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1 Introduction

It is widely expected that climate change will be felt more severely in developing countries partly because of their tropical climate and partly because of the greater importance of weather driven economic activities, most notably, agriculture [Hertel & Rosch, 2010]. It does not seem though that the GDP impacts will necessarily be large. While agriculture's share in GDP is nearly 30% in the poorest economies (principally in Africa), the share is as low as 13% in the upper low income countries (principally in Asia) ([Bank, 2008]). The GDP impact may, however, not be the right metric to measure the welfare impacts of climate change. All low-income countries are characterized by shares of agriculture in employment that are higher than in GDP. In the poorest economies, agriculture accounts for about 65% of labor force. In the upper low income countries, this figure drops marginally to 57% ([Bank, 2008]).

Another fact that is relevant to whether the GDP impact is a valid matric is that the food budget shares are also large in poor economies. Comparing across different countries, [Pritchett & Spivack, 2013], conclude that "the food share of the typical (median) household in the typical "low income" country is over 50 percent, is between 40 and 50 percent in "lower middle income" countries and 30 to 40 percent even in "upper middle income" countries." These figures are similar to the average budget shares reported for low and middle income countries in [Muhammad et al., 2011]. These numbers suggest that if climate change significantly impacts food prices, then that may have major welfare impacts in poor countries.

A case in point is India where the income share of agriculture is 15% (as against an employment share of nearly 50%). We find from our review of the literature that climate change and ozone pollution decreased yields by 5.7% during the period 1980 to 2009.[1] This means that the first-order income impact of climate change (in agriculture) was less than 1% of GDP.[2] This is, however, misleading as a guide to the impact on economic welfare. Firstly, the share of food in consumption expenditures is, typically, well in excess of agriculture's share in GDP. In the case of India, food accounts for about 50% of consumption expenditures [GOI, 2009]. Therefore, the first order impact of the yield loss (in the period 1980-2009)

[1] We consider ozone pollution together with climate change because the mitigation of each will have a great deal of overlap with the other – in both cases, greater energy efficiency and replacement of combustion with electrical energy from sources that do not involve combustion

[2] Such small impacts have also been found from more elaborate calculations. In a recent paper, [Roson & Mensbrugghe, 2012]use a dynamic global general equilibrium model (ENVISAGE), to assess the economic consequences of climate change impacts. They find that the potential real GDP is expected to be lower in India by about 1% in 2030 and about 2% in 2050 as compared to the counterfactual case with no climate change. [Bosello et al., 2012] find that the real GDP in India will be lower by 3.5% in 2050 as compared to a hypothetical scenario with no climate change.

on consumption and welfare would have been 2.8%. However, even this will understate the welfare loss because the price of food will rise when its supply falls. Furthermore, as food budget shares are higher for the poor, the aggregate loss (even when adjusted for changing prices) may not be a good guide to the distribution of losses across income groups. The welfare effects would also differ between land owners (growing food) and those without land. The distinction is important because a substantial proportion of the workforce in India (as in many developing countries) still works in agriculture. All of this demands that welfare impacts be analyzed within a general equilibrium framework. Therefore, past studies that quantify the impact of GDP loss (either using cross-sectional or panel data) are of limited value when assessing the impacts on economic welfare.

In this paper, we develop a stylized two-sector (food and non-food) general equilibrium framework inspired by [Eswaran & Kotwal, 1993] for studying the impact of climate change on food prices and household welfare in India. The demand side is modelled by a preference structure rooted in Engel's law, according to which there is an inverse relationship between a household's income and its share devoted to food. The analysis is conducted separately under closed and open economy assumptions in order to judge the impact of trade. While price impacts need not be considered for small open economies, India is a large producer for many food commodities.[3] Therefore, the model does not constrain India to be a small open economy. The simplicity of the model allows us to transparently assess the factors driving the results. The framework indicates how the initial conditions in terms of the level and distribution of wealth and land results in heterogeneity in a household's vulnerability to climate change in an economy.

The paper's contribution is its emphasis on the welfare impacts of climate change and its distribution. Existing analyses (as reviewed in the next section) have either not fully incorporated price impacts or done so in complex computable general equilibrium models. This paper offers a tractable and transparent theoretical framework that can be applied to other 'large' developing countries where climate change can be expected to have price effects. A second contribution is to examine the role of trade in buffering the adverse impact of climate change. The third contribution of the paper is to compare the magnitude of climate impacts with those of food and non-food productivity growth and population growth in the medium term (till 2030).

The model is first calibrated to data from 2009. Drawing on the literature on climate change effects on yields, we find that if climate change and ozone pollution had not occurred, crop yields would have been higher by 5.7%. The no-climate change scenario is our counterfactual. We seek to understand what aggregate economic welfare and its distribution would

[3]India accounts for about 20 percent of world rice production and 13 percent of world wheat production.

have been in the counter-factual relative to the baseline calibrated model. Compared to the first order impact of a 2.8% loss in consumption, we find that in a closed economy, allowing for the effect of food-price change increases the welfare loss by more than 50% to about 3.8% of consumption. In our model, the poorest agents are those without any cultivable land. They suffer the maximum loss in economic welfare amounting to 4.8% of their consumption in the counter-factual. Moreover, since most Indian farmers own very little land, nearly all of them are worse off as a result of climate change that lowers their productivity and raises the price of food. Only a small fraction of them gain from the resulting higher land rent.

These results are dramatically different in an open economy. The welfare losses are lower and the welfare of the poor declines by about the same proportion as the average impact which in turn is of the same order as the first order impact on consumption. These results are, of course, sensitive to the impact of climate change on crop yields in the rest of the world. We draw these estimates from the literature as well.

In surveying the literature on the poverty impacts of climate change, [Skoufias et al., 2011] point out that "Most estimates of the poverty impacts of climate change tend to ignore the effect of aggregate economic growth on poverty and household welfare." To address this gap, this paper calibrates the model to projected data for 2030. The main question of interest here is to assess the importance of climate change relative to other factors (productivity growth in the farm and non-farm sectors and population growth) in determining the welfare of the poor. We find that a combination of trade and economic growth can help buffer the poor against climate change. If the economy is closed, then improving the productivity of the agricultural sector has the greatest impact on the welfare of the poor. In contrast, if the economy is open, then the non-agricultural sector plays a bigger role in driving the welfare of the poor. The key implication of the analysis in this paper is that changes in productivity growth will have a much larger impact on the welfare of the poor than mitigation of climate change (unless climate impacts are larger than those considered in this study).

It should be stressed that our loss estimates are biased downwards. We assume that all foods are perfect substitutes, that there are no barriers to trade and that migration of labor between the farm and the non-farm sectors happens smoothly. Frictions in consumption, trade and labor market would result in food prices higher than that predicted by our model. Our assumption of Cobb-Douglas production function in agriculture and the assumption that climate change leads to a shock in agricultural productivity *a la* Hicks-Neutral technical change also result in conservative estimates.

2 Relevant Literature

The major impact of climate change in India on income is expected to come via losses in crop production.[4] Looking at the impacts in the recent past, [Auffhammer et al., 2012] found that during 1966-2002 the rice yield was about 5.7% lower due to climate change since the 1960s. [Gupta et al., 2016] found that wheat yields in India would have been higher in 2009 by 4.8% if climate had not changed during 1981-2009. In another study, wheat and rice yields are lower by 5.2% and 2% in India and by 5.5% and 0.1% in the world respectively, compared to yield projections without climate trends during the period 1980-2008 [Lobell et al., 2011].

Studies have also projected the impacts in India that will be realized in the future. [Mendelsohn et al., 2001] using a Ricardian approach, finds that climate change reduces yields by about 30-60% in the long run (2080) relative to the1990s. [Rosenzweig & Iglesias, 2006] using an agronomic crop model find that yields are expected to fall by about 14.3% in the long run (2080) relative to the 1990s due to climate change. [Guiteras, 2009] using annual panel data on yields and weather, projects that climate change over the period 2010-2039 will reduce major crop yields by 4.5 to 9 %, while in the long-run (2070-2099) and in the absence of adaptation yields are likely to fall by 25 % or more relative to 1990s. In addition to climate change, higher ozone concentrations are expected to reduce yields in 2030 over 2009 by 5-7% for India and by 2-3% for the world ([Van Dingenen et al., 2009] , [Avnery et al., 2011]). Further, it is expected that CO_2 fertilization is likely to increase global yields in the next 20 years at 1.8% per decade [Lobell & Gourdji, 2012].

The estimates of the climate change impact on crop yields vary across studies due to different models and assumptions. [Gosling et al., 2011] provides an extensive review of studies done for India. While these studies are important to quantify the output loss due to climate change, we also need to estimate the impact of climate change on food prices if we want to obtain the effect of climate change on economic welfare. [Nelson et al., 2010] find that climate change will increase the number of malnourished children in 2050 relative to perfect mitigation by about 9-10 percent using the Impact model. Because Impact is a partial equilibrium model it cannot estimate directly the poverty effects of climate induced decline in agricultural productivity .[Jacoby et al., 2015] quantifies the distributional impacts of climate change in rural India. Using a comparative static framework, the impact of climate change on household consumption is expressed as the impact of changes in temperature on returns to land and labor. The key idea is that food prices remaining constant, a fall in agricultural productivity leads to changes in returns to land and labor. In general equilibrium,

[4] There is recent research suggesting adverse impacts of climate change on non-agricultural sectors ([Dell et al., 2013], [Hsiang et al., 2011], [Somanathan et al., 2015]) that we do not examine here.

however, a change in food prices also matters to wages and rentals and their model considers this impact as well. However, the Jacoby et.al model does not solve for equilibrium food prices. The study takes price changes from the projections of [Hertel et al., 2010]. Because the price changes are taken as exogenous, their model is not appropriate to study the role of trade as an adaptation mechanism. For instance, how do welfare impacts vary between a closed and an open economy? Such a question cannot be answered within the Jacoby et.al analysis. In addition, it is not clear whether the framework allows climate change in India to affect world food prices.

Trade effects are likely to be important because climate change is likely to have a more serious impact on tropical countries like India than on temperate countries. This shift in the geographic distribution of production is expected to result in a corresponding shift in trade flows[5]. [Fischer et al., 2002] estimate that by 2080 cereal imports by developing countries would rise by 10-40%. Thus, the net economic effect of climate change on the agriculture of any country will depend as much on its role in agricultural trade as on the impacts of the changed climate on crop yields. [Reilly & Hohmann, 1993] using static world policy simulation (SWOPSIM) model found that international trade will reduce the severity of climate change impacts on world agriculture and result in relatively small impacts on individual economies. A global general equilibrium trade model is employed by [Hertel et al., 2010] to examine the poverty implications of climate-induced crop yield changes. This paper emphasizes the change in food prices and the varying impact it has on economic agents depending on their source of income. While our paper lacks the global span of [Hertel et al., 2010], it offers a simpler and more tractable model that is able to transparently link outcomes to structural parameters and to the trade regime.

In this study, we examine the total welfare loss and the distribution of losses in India under two different climate change scenarios, explicitly taking into account changes in the price of food and its impact on the distribution of income. Food accounted for more than one-half of the average household's expenditure in 2009 and this share was about two-thirds for the poorest household. So a rise in food prices can be very serious and climate change can impose significant welfare losses, with the poor being affected the most.

3 The Model

In our analysis, the economic effects of climate change flow from the impact on total factor productivity (TFP) in agriculture. The analysis takes this impact to be exogenous and as

[5][Huang et al., 2011] provides an extensive review of studies on climate change and trade in agriculture.

being determined by physical processes. The elasticity of agricultural TFP to climate change is denoted as $\sigma^I$and σ^R for India and the rest of the world, respectively. The model solves for the impact of agricultural TFP on food prices as a function of the elasticities $\sigma^I$and σ^R.

3.1 Closed economy case

Consider an economy of N individuals of which N_l are in the labor force. The total land in the economy is denoted by A. Production functions in both food and non-food sectors exhibit constant returns to scale. The agricultural sector produces food (F) using two inputs, land (A_F) and labor (L_F). The food production function is Cobb-Douglas:

$$Y_{_F} = \theta_{_F} A_F^{1-\alpha} L_F^{\alpha}, \tag{1}$$

where $\theta_{_F}$ is the total factor productivity in agriculture. The non-food sector using only labor (L_T) produces a good that, for the sake of concreteness, we will refer to as textiles (T) . We use textiles as the numeraire good and we use P to denote the price of food. The non-food production function is

$$Y_{_T} = \theta_{_T} L_T, \tag{2}$$

where $\theta_{_T}$ is the total factor productivity in non-agriculture. The linear technology means that the wage in terms of textiles is fixed:

$$W = \theta_{_T} \tag{3}$$

Thus, market clearing conditions for land and labor are $A = A_F$ and $N_l = L_F + L_T$. We denote the wage rate by W, labor income per capita by $w = WN_l/N$ and per unit land rent by r. Using (1) and (3), we obtain labor demand in agriculture as

$$L_F = A\left(\frac{\alpha P \theta_{_F}}{\theta_{_T}}\right)^{\frac{1}{1-\alpha}}. \tag{4}$$

Labor market clearing implies

$$L_T = N_l - A\left(\frac{\alpha P \theta_{_F}}{\theta_{_T}}\right)^{\frac{1}{1-\alpha}} \tag{5}$$

We can write the equilibrium rent equation as

$$r = \theta_{_T}^{\frac{\alpha}{\alpha-1}}\left(\frac{1-\alpha}{\alpha}\right)(P\theta_{_F})^{\frac{1}{1-\alpha}}\alpha^{\frac{1}{1-\alpha}}. \tag{6}$$

On the consumption side, individuals are assumed to have identical Stone-Geary preferences, that are used to capture Engel's Law in a simple way. The utility function of an individual is

$$U = (f - \underline{f})^{\rho}(t - \underline{t})^{1-\rho} \tag{7}$$

with $0 < \rho < 1$, $(f - \underline{f}) > 0, (t - \underline{t}) > 0$.

Here, f and t represents total food consumption and non-food consumption of the individual, and $\underline{f}$ and $\underline{t}$ represent the subsistence food and non-food consumption. An individual maximizes utility subject to the budget constraint given by $M = w + ra$ where a is the amount of land possessed by the individual. We obtain the demand for F and T by an individual as

$$f = \underline{f} + \frac{\rho}{P}\left(w + ra - P\underline{f} - \underline{t}\right) \tag{8}$$

$$t = \underline{t} + (1 - \rho)(w + ra - P\underline{f} - \underline{t}) \tag{9}$$

Multiplying (8) by P, we see that ρ is the proportion of the excess of income over subsistence consumption that is spent on food. The expenditure on each commodity is linear in the excess of total expenditure over subsistence expenditure. We obtain total demand for F and T in this economy by adding demand functions of all the individuals. F_d represents total food demand and T_d represents total food demand.

$$F_d = \underline{f}N + \frac{\rho}{P}(wN + rA - P_F\underline{f}N - \underline{t}N)\ , \tag{10}$$

$$T_d = \underline{t}N + (1 - \rho)(wN + rA - P_F\underline{f}N - \underline{t}N)\ , \tag{11}$$

In general equilibrium, all four markets clear: $A = A_F$; $N_l = L_F + L_T$; $F_d = Y_F$; $T_d = Y_T$. The market clearing condition for food can be dropped by Walras' law. We have already used the first two conditions. The general equilibrium of this closed economy is entirely determined by the solution to the remaining textile market clearing condition. Using (2), (3), (5), (6) and (11), we can write this equation only in P and the exogenous parameters:

$$\underline{t}N + (1-\rho)\left(\theta_{_T} N_l + A\left(\theta_{_T}^{\frac{\alpha}{\alpha-1}}\left(\frac{1-\alpha}{\alpha}\right)(P\theta_F)^{\frac{1}{1-\alpha}}\alpha^{\frac{1}{1-\alpha}}\right) - P\underline{f}\ N - \underline{t}N\right) \tag{12}$$

$$= \theta_{_T}\left(N_l - A\left(\frac{\theta_{_T}}{\alpha P\theta_{_F}}\right)^{\frac{1}{\alpha-1}}\right). \tag{13}$$

Totally differentiating (13) with respect to to $\theta_{_F}$ and simplifying, we obtain the elasticity of the price of food with respect to the total factor productivity $\theta_{_F}$. This is given by

$$-\left(\frac{dP}{d\theta_{_F}}\frac{\theta_F}{P}\right) = \varepsilon_{_{P\theta_F}} = \frac{1}{1 - \frac{\underline{f}\ N}{Y_F\left(1+\frac{\eta}{(1-\rho)}\right)}}, \tag{14}$$

where $\eta = \frac{\alpha}{1-\alpha}$. Note that, by assumption $\frac{\underline{f}\ N}{Y_F} < 1$ and $1-\rho > 0$, so $\varepsilon_{_{P\theta_F}} > 1$. In a closed economy, the price of food rises more than proportionally with a decline in $\theta_{_F}$. The elasticity of the price of food with respect to temperature is then just the product of the elasticity of the elasticity of the price of food with respect to the total factor productivity $\theta_{_F}$ ($\varepsilon_{_{P\theta_F}}$) and the elasticity of the total factor productivity $\theta_{_F}$ with respect to temperature (σ^I) and is given by

$$-\left(\frac{dP}{d\tau}\frac{\tau}{P}\right) = \varepsilon_{_{P\tau}} = \sigma^I * \varepsilon_{_{P\theta_F}} = \frac{\sigma^I}{1 - \frac{\underline{f}\ N}{Y_F\left(1+\frac{\eta}{(1-\rho)}\right)}}, \tag{15}$$

where τ is temperature.

Equation (15) relates the food price elasticity to the underlying demand and supply parameters. First, the higher is the share of minimum food consumption in total food supply $\left(\frac{\underline{f}\ N}{Y_F}\right)$, the greater will be the response of food prices to global warming ($\varepsilon_{_{P_F\tau}}$). It is perhaps easiest to see the intuition for this when considering the opposite case when the share of minimum food consumption in total food supply is small. This happens when food is abundant which in turn implies, by Engel's Law incorporated in Stone-Geary preferences, that the share of food in total expenditure is low. Hence, a given percentage decrease in food productivity has only a small impact on total output. Of course, food demand decreases by only a fraction ρ of the decrease in food supply. Thus, to restore equilibrium, labor has to move from the non-food sector to the food sector. However, since the impact on the food supply is small relative to total output, only a small share of the labor force has to move, and so the rise in the food price needed to induce this movement is small. Conversely, when the share of subsistence food consumption in total food consumption is high, then the impact of a productivity decline in the food sector is large relative to the size of the economy and so the food price rise needed to induce a substantial share of the labor force to move to the food sector is correspondingly large.

Second, if α is high, then so is η and therefore the elasticity of food prices with respect to temperature will be low. This follows from the fact that α is the output elasticity of labor. So when this is high, any fall in agricultural productivity is easily met with a small shift of labor from the non-food sector to the food sector and therefore, the required rise in the price of food is small.

Finally, the higher is ρ i.e., the proportion of excess income spent on food, the lower will be $\varepsilon_{P_F \tau}$. As noted earlier, the loss in agricultural productivity reduces incomes and demand for both goods. When ρ is high, the percentage decline in food demand is much greater than when ρ is low. Hence, the required sectoral shifts in labor and output are also smaller in the case when ρ is high. Therefore, the food price increase is also smaller.

3.2 Open economy case

We now allow India to be an open economy. There are 2 economies- India (I) and Rest of the World (R). Both the economies have the same form of the production functions and utility functions as in the closed economy case but they differ with respect to labor endowments and production function parameters. In Appendix A, we derive the general equilibrium equation for P in the open economy case. A readily interpretable special case is when the labor and land shares are the same across India and the rest of the world. Then we have

$$-\left(\frac{dP}{d\tau}\frac{\tau}{P}\right) = -\varepsilon_{P\tau} = \frac{s^I\sigma^I + s^R\sigma^R}{1 - \frac{\underline{f}\,N^G}{(Y_F^G)\left(1+\frac{\eta}{(1-\rho)}\right)}} \tag{16}$$

where s^I is India's share in world food supply and s^R is the share of the rest of the world in world food supply. Comparing (16) and (15), we see that they have a similar form. The numerator of (16) is the weighted average of TFP impact in India and the rest of the world while in the closed economy, the climate change in the rest of the world does not matter. The denominator of (16) is similar to that of (15), except that what matters now is the share of global subsistence needs in global food supply.

India being a tropical country, we expect $\sigma^I > \sigma^R$. Since climate change is expected to have a smaller effect on agricultural productivity in the rest of the world than it is in India, the net increase in the food price in India will be smaller than when the economy is closed. The global ratio of subsistence food consumption to food consumption is lower than the ratio in India. This is another reason why the elasticity of the food price with respect to climate change will be lower in the open economy. Quantifying the role of international trade as an adjustment mechanism is one of the key contributions of this study. The empirical simulations employ the general solution (in the appendix) rather than the special case (16).

3.3 Welfare analysis

We use equivalent variation as a measure of welfare change[6]. Equivalent variation (EV) is defined as the minimum amount of money that an individual is willing to receive to avoid a change in prices and income. In other words, EV satisfies $V(P, M + EV) = V(P', M')$ where V is the indirect utility function. If EV is positive, the individual is better off with price and income change. If EV is negative, the individual is worse off with the price and income change. Using the expenditure function, the equivalent variation can be written as

$$EV = e(P, V(P', M')) - M.$$

where e is the expenditure function. We are interested in the EV of a change in $\theta_{_F}$ to $\theta'_{_F}$ because of climate change. A change in agricultural TFP results in a change in prices from P to P' and a change in income from $w + ra$ to $w + r'a$, both measured in terms of the numeraire textile good.[7] From (7), (8) , (9) and expenditure minimization we can derive the expression for the equivalent variation for an individual owning land a as

$$\begin{aligned} EV = {} & \theta_T \left(\frac{N_l}{N}\right) \left[\left(\frac{P}{P'}\right)^{\rho} - 1\right] + \left(P\underline{f} + \underline{t}\right) \left[1 - \left(\frac{P}{P'}\right)^{\rho}\right] \\ & - \frac{a}{(\theta_T)^{\frac{\alpha}{1-\alpha}}} \frac{1-\alpha}{\alpha} \alpha^{\frac{1}{1-\alpha}} \left[(\theta_{_F} P)^{\frac{1}{1-\alpha}} - \left(\theta'_{_F} P'\right)^{\frac{1}{1-\alpha}} \left(\frac{P}{P'}\right)^{\rho}\right] \end{aligned}$$

Note that if $(\theta_{_F} P)^{\frac{1}{1-\alpha}} < \left(\theta'_{_F} P'\right)^{\frac{1}{1-\alpha}} \left(\frac{P}{P'}\right)^{\rho}$ for $\theta'_{_F} < \theta_{_F}$, then the second term is positive and the EV is increasing in land ownership. By putting $EV = 0$, we obtain the cut-off level of land $\widehat{a}$ such that the individual is indifferent to the change:

$$\widehat{a} = \frac{\theta_T \times \left(\frac{N_l}{N}\right) \left[\left(\frac{P}{P'}\right)^{\rho} - 1\right] + \underline{f}P - \underline{f}P' \left(\frac{P}{P'}\right)^{\rho} + \left[\underline{t} - \underline{t}\left(\frac{P}{P'}\right)^{\rho}\right]}{(\theta_T)^{\frac{\alpha}{\alpha-1}} \left(\frac{1-\alpha}{\alpha}\right) \alpha^{\frac{1}{1-\alpha}} \left[(\theta_{_F} P)^{\frac{1}{1-\alpha}} - \left(\theta'_{_F} P'\right)^{\frac{1}{1-\alpha}} \left(\frac{P}{P'}\right)^{\rho}\right]}$$

Individuals with land ownership greater than $\widehat{a}$ gain from climate change and those with land ownership less than $\widehat{a}$ lose from climate change. The threshold level of land and the

[6]We use Equivalent Variation (EV) and not Compensating Variation (CV) because EV is measured in base year prices and income. This makes it convenient to compare welfare across different scenarios each of which leads to different prices and incomes.

[7]As noted earlier, the wage in terms of textiles is invariant to changes in agricultural TFP.

distribution of losses are calculated in the empirical simulation.

4 Data sources and method used for calibration

4.1 Endowments and Production Function Parameters

The model is calibrated using data from 2009. Table 4.1 displays the list of production parameters, endowment variables, their calibrated values and the data sources used in the process. For both India and the world, the output of food in the production function is obtained from food balance sheets of the Food and Agriculture Organization (FAO)[8]. Total food output in calories is obtained by multiplying each food item by its calorific value and summing over all food items. We find that India's share in world calories is about 14%. θ_F is obtained from the production function (1) given the values of food output Y_F, land A, labor employed in agriculture L_F, and α from Table 4.1. By Equation (3), productivity in the non-food sector is equal to the wage rate. Therefore, non-food productivity in India θ_T^I is taken to be the average wage of agricultural and non-agricultural workers. As we will see later, the non-food productivity in the rest of the world θ_T^R is solved from the general equilibrium of the open economy.

4.2 Consumption parameters

Table 4.2 displays the list of consumption parameters. First, we calculate the calorie price P, measured as an average household price from the consumption schedue of the National Sample Survey (2009). For each food item the National Sample Survey gives expenditure and quantity consumed. We calculate total calories consumed by each household using calorific values for each food item obtained from the National Sample Survey (2009). We calculate the food price for each household by dividing food expenditure of a household by food calories consumed. The average price for all the households is Rs .0104 per kcal.[9]

Second, we estimate the Stone-Geary linear food expenditure function using household-level data on consumption from the National Sample Survey (2009) by non-linear least

[8]The food items in the food balance sheets included cereals, pulses, sugarcrops, sugar and sweeteners, oilcrops, vegetable oils, vegetables, fruits, spices, stimulants (tea, coffee etc), alcoholic beverages, meat, animal fat, milk, and aquatic products.

[9]Outliers were dropped. The households with adult equivalent calorie consumption per day greater than 500 and less than 10000 were excluded.

Table 4.1: Production Parameters (2009)

	Parameter	Value	Source
1	Annual Food output India (Y_F^I) trillion calories/year	1040	Computed from FAO
2	Annual Food output ROW (Y_F^R) trillion calories/year	6410	Computed from FAO
3	India's share in world calories $\left(\frac{Y_F^I}{(Y_F^I+Y_F^R)}\right)$	14%	Computed from FAO
4	Gross cropped area India (A_F^I) in million hectares	195	Land use statistics
5	Arable and permanent crops land for ROW (A_F^R)	1338.35	FAO
6	India population (N^I) in million	1207.74	FAO
7	Work force Participation rate, India	.3966	Intrapolation,Censuses 2001, 2011
8	% of total workers in agriculture, India	.49	[GOI, 2009]
9	Agriculture workers India (L_F^I) million	234.7	Computed as product of items 6,7,8
10	ROW population (N^R) million	5449.14	FAO
11	Work force Participation rate, ROW	.469	[Bank, 2011]
12	% of total workers in agriculture, ROW	.3456	[Bank, 2011]
13	Agriculture workers ROW (L_F^R) million	883	Computed as product of items 10,11,12
14	α, share of labor in output for India	.46	[Eswaran et al., 2007]
15	α, share of labor in output for ROW	.35	[Alston et al., 2010]
16	θ_F^I, Productivity in the food sector in India	4897500	Using 1,4,12,14 as explained in text
17	θ_F^R, Productivity in the food sector in ROW	5539400	Using 2,5,13,15 as explained in text
18	θ_T^I, Productivity in the non-food sector in India (Rs)	30039	[GOI, 2009]

squares to obtain the value of three unknown parameters $\underline{f}$, $\underline{t}$ and ρ. The equation estimated is

$$\frac{P_h\ f_h}{n_h} = P_h\ \underline{f} + \rho\left(\frac{M_h}{n_h} - P_h\underline{f}\ - \underline{t}\right) + \varepsilon_h$$

where P_h is the calorie price of the household h , f_h denotes calories consumed by household h, n_h is number of equivalent adults in household[10] h, M_h represents total income of household h as measured by the sum of food and non-food expenditure and ε_h is the disturbance term. $\underline{f}$ and $\underline{t}$ are constrained to be non-negative. We obtain $\underline{f}$ as 61,5216 calories adult equivalent per year or 1685 calories adult equivalent per day, $\underline{t}$ as 0 and ρ as 0.25. These parameters are recorded in Table 4.2.

4.3 General Equilibrium

We assume that the observed food price of 0.0104 rupees/calorie is the price in the baseline open economy of 2009, that is, the economy in which climate change has occurred. Given

[10] To determine adult equivalent reference scale we used the consumer unit (that is used as an indicator of the energy requirement of a group of persons of different sexes and ages in NSS 2009 nutrition intake report) weight 1 for male in the age group 20-39 as the norm. The average calorie requirements of males and females of other age groups are expressed as a ratio to this norm. The adult-equivalent fraction assigned to each individual varied from .43 for the new borns to 1.03 for males in the age group of 10 to12 years of age.

Table 4.2: Consumption Parameters (2009)

Parameter	Value	Source
P (Rs per Kcal) in the open economy	.0104	Computed from NSSO (2009)
ρ	.25	Estimated from Non-linear Least squares
$\underline{f}$ (calories per day) adult equivalent	1685	Estimated from Non-linear Least squares
$\underline{t}$	0	Estimated from Non-linear Least squares

Table 4.3: Calibrated Values from General Equilibrium

Parameter	Value	Source
θ_T^R, Productivity in the non-food sector (Rs) in rest of the world	37,455	Solved from General Equilibrium of Open Economy
P (Rs per Kcal) in the closed economy	.0119	Solved from General Equilibrium of Closed Economy

the production and consumption parameters in Tables 4.1 and 4.2, the general equilibrium equation in the open economy (given in the Appendix) is used to solve for the only remaining unknown, i.e., productivity in the non-food sector of the rest of the world. This is displayed in Table(4.3). If the economy were closed, the equilibrium price would be different and we can no longer use the open economy price. For the closed economy, the general equilibrium condition in eq(13) is used to compute the equilibrium food price. This is shown in Table (4.3). We find that the price of food would be about 14 percent higher if the economy was closed to trade. The next section numerically simulates the responses of the open and closed economies to past climate and pollution trends.

5 Impact of changes in climate and pollution during 1980-2009

In this section, we seek to understand the impact of historic climate change and pollution trends over a 30-year period (1980-2009) on food prices and welfare of the poor by comparing the economy calibrated to observed parameters to a counterfactual economy with no climate change. Table (5.1) provides information on estimated impacts on crop yields of past changes in climate and pollution. Based on the literature on climate change impacts, we derive the past loss in crop yields for India and the rest of the world by adding the estimated impacts of warming, CO_2 fertilization, and ozone pollution, on crop yields.

For India, a 5.3% fall in θ_F during 1980-2009 is obtained by adding a 3.5 percent fall in yields (as estimated by [Lobell et al., 2011]) and a 4.7 percent fall in yields due to the ozone effect (obtained by backward projection of the estimated impact of ozone during

Table 5.1: Climate Impacts on Agricultural Productivity during 1980-2009

Parameter	India		Rest of the World	
	% change	Source	% change	Source
Global Warming	-3.5	[Lobell et al., 2011]	-3.1	[Lobell et al., 2011]
CO_2 fertilization	+3	[Lobell & Gourdji, 2012]	+3	[Lobell & Gourdji, 2012]
Ozone	-4.7	[Van Dingenen et al., 2009];	-2.4	[Van Dingenen et al., 2009]
		[Avnery et al., 2011]		[Avnery et al., 2011]
Total	-5.3		-2.5	

2000-2030 by [Van Dingenen et al., 2009]) to a 3 percent positive effect of CO_2 fertilization (1.5 percent per decade as given in [Lobell & Gourdji, 2012]). Similarly, we obtain a 2.5% decline in agricultural productivity for the rest of the world during 1980-2009. In case of ozone impacts, we find that there are limited past studies available and thus we have obtained a rough estimate for crop yield loss during 1980-2000 due to ozone pollution by projecting expected future changes (during 2000-2030) backward till 1980. For instance, for India the studies by [Van Dingenen et al., 2009] and [Avnery et al., 2011] find that on average (over rice with 57% share and wheat with 43% share) crop yield losses due to ozone during 2000-2030 in India are likely to be about 2.34 percent per decade. As in the past, ozone concentrations would have been lower than in the present and future, we have assumed 4.7 % loss in yields in India due to ozone over during 1980-2009[11].

5.1 Closed Economy

The closed economy equilibrium in calibrated (i.e., baseline) and counterfactual 2009 economies is described in the first three columns of Table 5.2. The yield loss due to climate change leads to a higher food price and higher rent per hectare than in the counterfactual with no climate change. The wage rate in terms of textiles is fixed but since workers spend part of their incomes on food, the real wage rate is lower when there is climate change.

The price and welfare impacts are presented in Figure 1. As productivity in the agricultural sector falls, so does the food supply. In the closed economy case, the 5.3% decline in agricultural productivity θ_F relative to the counterfactual, results in a food price increase of about 8.3%. With higher P, the marginal revenue product of labor increases in the agricultural sector and labor shifts from the non-food sector to the food sector. The labor force in the food sector (L_F) increases by about 4.8%. The welfare of the average individual as measured by the equivalent variation declines by 3.8%. By contrast, a naive partial equilibrium

[11]We multiply 2.3 by 2 (resulting in 4.7%) and not 3 for estimating the the likely impact of ozone on crop yields in India during past 3 decades 1980-2009. This is done as in the past ozone concerteration would have been lower than in present. This is only a very rough estimate.

Table 5.2: General Equilibrium in the Closed and Open Economies (2009)

Variable	Closed Economy		Open Economy	
	Counterfactual	Baseline	Counterfactual	Baseline
	No climate change		No climate change	
Food Price (Rs/kcal)	.0110	.0119	.0099	0.0104
Annual Wage Rate (Rs)	30039	30039	30039	30039
Rent per hectare (Rs)	27444	28770	22668	22180.5
Food sector share (%)	50	52	43.5	43.1
Share of food in expenditure of landless(%)	59.6	62.5	56	57.5
Food imports as % of food demand	-	-	11	14.4
Non-Food exports as % of Non-food output	-	-	9.5	12.6

analysis would predict a real-income decline of only 2.8% when agricultural productivity declines by 5.7% and the food sector accounts for half the economy. Taking the food price rise into account increases the average welfare loss by more than one-third.

Individuals who do not own any land experience a still greater decrease in real income of about 4.8%. This is because of the fall in the real wage coupled with the rise in land rent. Since wage and rental incomes move in opposite directions, there exists a threshold level of landholding above which an individual gains from the higher food price caused by from climate change. Figure 2 plots equivalent variation as percentage of income against land owned per adult equivalent. The threshold level of land is 0.94 hectares. More than 50% of Indians (adult equivalents) own no land or only a tiny amount of land (less than .009 hectares) and 90% own less than 0.4 hectares (National Sample Survey 2009).

When the price of food increases, the real wage declines and, therefore, substitution and income effects work in the same direction for food for all but large landowners, and food consumption falls. For non-food demand, substitution and income effects work in opposite directions (except for large landowners) and the relative strength of the two effects determines the final consumption of non-food. The model quantifies these effects. For landless workers, the fall in θ_F of 5.3% leads to a decline in non-food consumption by about 7% and a decline in food consumption by about 3%. The share of food in total expenditure increases from 59.6% to 62.5%. The equivalent variation for landless workers is -711 rupees or 4.8% of the income. These numbers illustrate clearly that ignoring general equilibrium effects and distribution can greatly understate the welfare losses from global warming. The real income of the landless falls near one-for-one with declining food productivity even though the food

Figure 1: The Impact of Past Climate Change and Pollution in Closed and Open Economies on Welfare in 2009 Relative to a Counterfactual with no Climate and Pollution Change Over 1980-2009

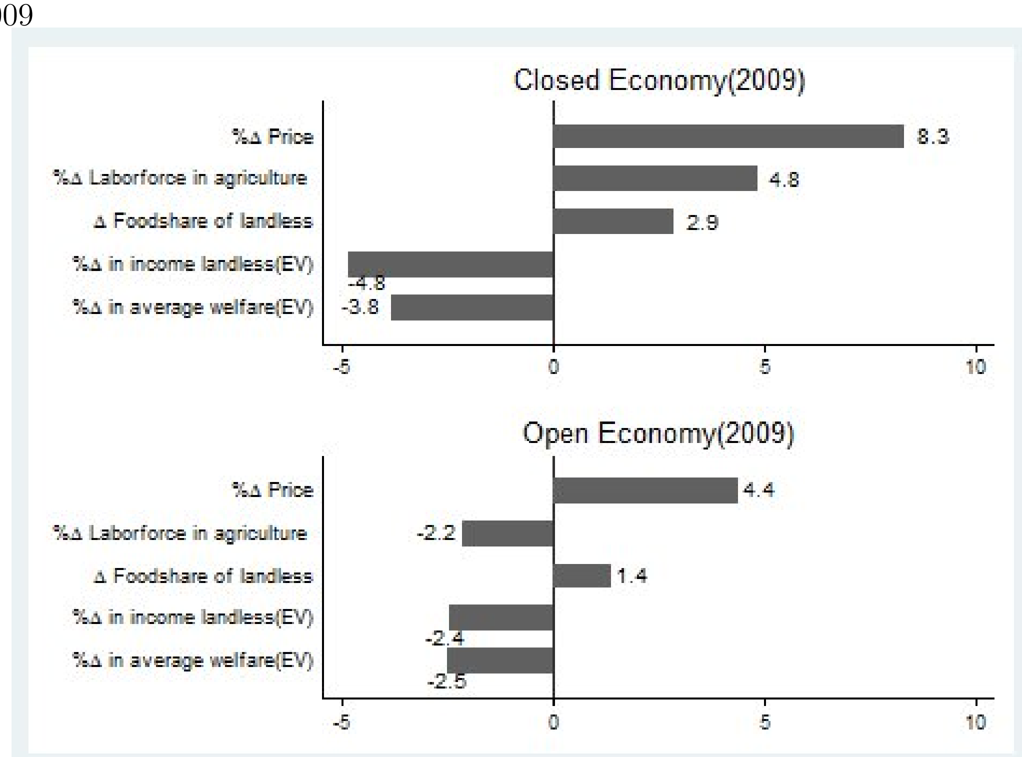
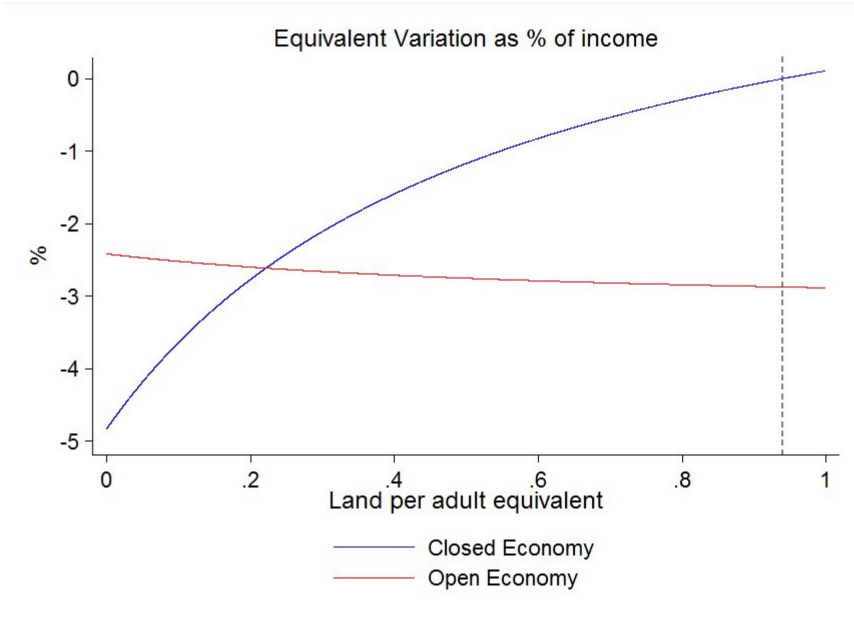


Figure 2: The Impact of Past Climate Change and Pollution in Closed and Open Economies by Land Ownership



sector constitutes only half the economy in the counterfactual scenario.

5.2 Open economy

The open economy equilibrium with and without climate change is described in the last two columns of Table 5.2. India imports about 14.4% of total food demand from the rest of the world in the baseline open economy and as a result, the equilibrium food price of Rs .0104 per calorie is about 15% lower than in the baseline closed economy. The sourcing of food from international markets decreases the share of the food sector in total output to 43% (as against 52% in the baseline closed economy). It decreases the share of workforce employed in the food sector to 26% from 33% in the baseline closed economy. As the non-food total factor productivity θ_T^I is the same in the closed and open economies, the annual wage rate (in terms of the numeraire) in the open economy remains the same as in the closed economy. However, rent per hectare falls because of lower food sector employment.

Figures 1 displays open economy results for the climate change scenarios. Food prices are 4.4% higher with climate change than in the counterfactual economy. The price impact is considerably smaller in the open economy as compared to the closed economy. For a landless person, the EV is -355 rupees or 2.4% of the income. Thus a landless individual is buffered from climate change in the open economy as compared to the closed economy. Moreover, unlike in the closed economy, their loss is of the same magnitude as that of the average individual.

As the gap between the percentage decline in agricultural productivity and the consequent percentage rise in food prices is lower in the open economy, land rents in India are lower relative to the counterfactual with no climate and ozone change. Figure 2 plots EV as percent of income against land held per adult equivalent. The equivalent variation is a decreasing function of landholding and is negative for all farmers. Thus, all farmers lose and in fact the large farmers lose more than the small farmers. The closed economy result is overturned because the increase in the food price is less than the fall in agricultural productivity and, therefore, rents fall. In this scenario (negative) EV for the small landholder of 0.1 hectares is Rs 428 and EV for a large landholder of 1.5 hectares is even more negative at Rs 1440.

This result is similar to [Jacoby et al., 2011] which finds that in the most likely scenario of stable and falling food prices the welfare declines for the wealthiest households are marginally more severe than for the poorest. However, in their more pessimistic scenario for global food prices, wealthy households do a lot better and even gain from climate change.

It is important to note that the real economy impacts would be some where between the closed and open economy results since we observe trade in some agricultural commodities such as oilseeds but not much in staples such as cereals. We conclude that food prices were 4 - 8 percent higher and the real income of the landless poor was 2.4 - 4.8 percent lower relative to counterfactual without climate change and pollution (over past three decades) in 2009.

6 Climate and Growth Impacts in 2030 Compared

In this section, we examine how changes in climate and pollution will impact welfare in an economy calibrated to projected parameters in 2030. The main aim is to compare the impact of climate change to the impact of plausible variations in economic and population growth.

6.1 Growth Scenarios for the economy in 2009-2030.

The parameter values used in the model for 2030 are the same as for 2009 except for population and total factor productivity in the food and the non-food sectors that are assumed to grow at rates taken from the literature. Table 6.1 presents the growth rate projections for these parameters and the sources from which they are drawn. The projections from the literature, including the UN's moderate population growth scenario, are our 'medium growth' scenario. We vary these growth rates one at a time to obtain 'low' and 'high' growth scenarios as follows. For population, we use the UN's high and low population growth scenarios.

Table 6.1: Annual Growth Rates of parameters for the Medium Growth Baseline Scenario assuming no further climate change between 2009 and 2030

Variable	Region	Medium	Source
N	India	1.1% (0.8,1.38)	UNDP Forecasts
θ_F	India	1.5% (0.75, 2.25)	Bosworth and Collins (2007)
θ_T	India	3.04% (.66, 1.21)	Bosworth and Collins (2007)
N	Rest of the world	.94% (.66, 1.21)	UNDP Forecasts
θ_F	Rest of the world	1.84% (.92, 2.76)	Alston etal (2010)
θ_T	Rest of the world	2.2% (1.1, 3.3)	Bosworth and Collins (2003)

Note: Low and high scenarios are discussed in the brackets.
For all variables but population the low scenario has a growth rate that is 50% lower than in the medium scenario and the high scenario has a growth rate that is 50% higher than in the medium scenario.

For the growth rates of food and non-food productivity we simply increase or decrease them by 50% (and round off). Appendix table B.1 shows values of important variables obtained in the calibrated general equilibrium in 2030 under the baseline medium growth scenario expressed as percentage changes from the 2009 values.[12]

6.2 Climate and growth impacts in 2030

We use the published literature to obtain the projected impacts of climate change on agricultural productivity in 2030 under two scenarios, one of moderate and one of severe climate change (and ozone pollution) between 2009 and 2030 (Table 6.2). The 5th Assessment Report of the IPCC projects a "likely" increase in mean surface temperature in South Asia between 1986-2005 and 2016-2035 of $1-1.5°$ C or $0.7-1°$ C every two decades ([IPCC, 2013], pp 1374-1375).[13] Since the 2009-2030 period that we study is in the later half of the IPCC period, it is reasonable to assume that the temperature increase will be at the upper end of the "likely" range. Thus, our moderate scenario assumes a 1° C increase in temperature between 2009 and 2030, while the severe scenario assumes a 2° C increase. The latter is meant to capture a worst-case assumption. Appendix B explains the construction of Table 6.2 in greater detail. The estimates from the literature cited in Table 6.2 imply a reduction in food productivity from the baseline of 7% in India and 2% in the rest of the world in the moderate scenario. In the severe scenario, these declines are 13% and 6% respectively.

[12] Although the closed and open economy do not differ in the rate of growth of food productivity, the relative price of food rises much more in the closed economy. For this reason, the real wage increase is greater in the open economy and the rise in land rent smaller.

[13] "Likely" in IPCC terminology means the probability that the temperature increase will fall in this range is estimated to be about 2/3. There is, therefore, a one-third chance that it is outside this range.

Table 6.2: Climate Impacts on Food Productivity in Moderate and Severe Scenarios, 2009-2030

Parameter	India (% change)			Rest of the World (% change)		
	M	S	Source	M	S	Source
Global** Warming	-5.5	-11	[Lobell et al., 2011]	-3	-6	[Lobell et al., 2011]
CO_2 fertilization	+3.6	+3.6	[Lobell & Gourdji, 2012]	+3.6	+3.6	[Lobell & Gourdji, 2012]
Ozone**	-5	-6	[Van Dingenen et al., 2009]	-2.2	-3.37	[Van Dingenen et al., 2009]
			[Avnery et al., 2011]			[Avnery et al., 2011]
Total*	-7	-13		-2	6	

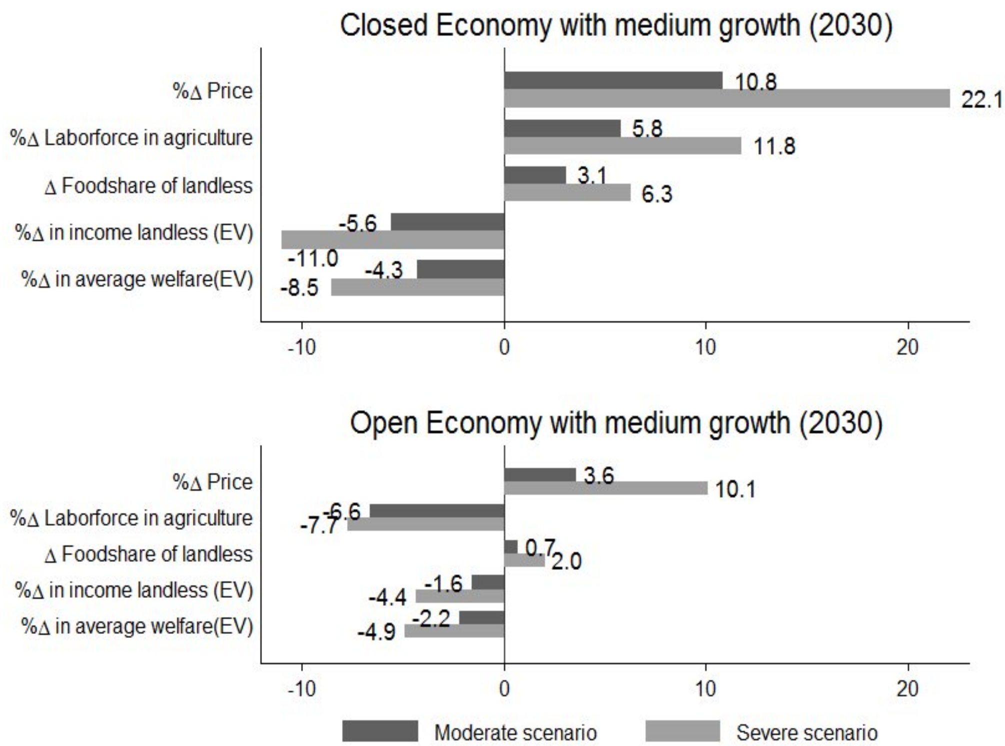
Note: M-Moderate scenario S-Severe scenario.
*The total impacts are rounded to the nearest integer value. ** For India we have taken weighted average of loss estimates for 2 major crops-wheat (with share 43%) and rice (with share 57%). For ROW we have taken weighted average of loss estimates for 3 major crops– wheat (with share 47%), maize (with share12.6%) and rice (with share 40%).

The effects of these food productivity losses on the baseline 2030 economy in the medium growth scenario are shown in Figure 3. In the closed economy, the decline in food supply necessitates an expansion of employment in the food sector by 6% or 12% depending on the severity of climate change. Food prices have to rise to induce labor to move to agriculture. The 7% decline in θ_F in the moderate scenario increases food prices by almost 11%. When θ_F declines by 13% in the severe scenario, food prices rise by 22%. The average welfare loss is 4% in the moderate scenario and 8.5% in the severe scenario. The landless experience a larger welfare loss of 5.6% in the moderate scenario and 11% in the severe scenario. We remark that although the food productivity decline of 7% is 23% larger than the one of 5.7% imposed on the 2009 economy, the negative impact on the real income of the landless is only 17% greater. This is because, as noted in Section 3.1, the share of the food sector is smaller in the richer economy of 2030, so a smaller share of the labor force has to move to the food sector to overcome any given shortfall, and so the necessary rise in the food price is smaller.

In the open economy, agricultural employment contracts with the food supply shortfall being met by imports and therefore price impacts are less severe. The welfare loss from climate change is also much smaller. The welfare loss of the landless is less than the average welfare loss. This result is driven by the decline in land rents owing to the decline in agriculture.

The effects of climate change in Table 6.2 can also be described in terms of reduced growth

Figure 3: Impact of Climate Change and Pollution from 2009-2030 on Welfare in Closed and Open Economies



Note: Moderate scenario of 7% fall in θ_F^I and 2% fall in θ_F^R : Growth rate of agricultural productivity (θ_F^I) in India declines by .36% p.a and in ROW (θ_F^R) declines by .1 p.a relative to no climate change medium growth scenario in 2030.

Severe scenario of 13% fall in (θ_F^I) and 6% fall in (θ_F^R): Growth rate of agricultural productivity (θ_F^I) in India declines by .67% p.a and in ROW (θ_F^R) by .3% p.a relative to no climate change medium growth scenario in 2030.

rates of food productivity in India and the rest of the world over the period 2009-2030. The annual growth rates of θ_F^I and θ_F^R growth are reduced by 0.36 % and 0.1% respectively in the moderate scenario and by 0.67% and 0.3% in the severe scenario. We note that the variations in the growth rate of food productivity that we described above as 'plausible' exceed the declines brought about by climate change and pollution even in the severe scenario.

Besides the medium growth or baseline scenario, we consider 6 other scenarios. In these 6 scenarios, population and productivity in the rest of the world are assumed to grow at the medium rate. The variation then comes from what is assumed for population and TFP growth rates in India. In each of these scenarios, two of the variables are held to medium growth projections while the third variable is switched between high and low growth projections. For instance, the scenario titled high productivity in agriculture is one where agricultural TFP in India has the high growth rate while all other variables (non-agricultural TFP and population in India and all three variables in the rest of the world) follow medium growth projections. Appendix table B.2 summarizes these scenarios.

Figure 4 shows, for the closed and open economy, the real income of the landless poor in these seven scenarios of economic development for the 2030 economy. That is, 2030 income in 2009 prices is obtained by adding 2009 income and the equivalent variation of the change from 2009 to 2030. In each scenario, the length of the bar denotes the income of the landless in the absence of climate change between 2009 and 2030. The first break from the right in the bar shows what their income would be if there is moderate climate change (7% fall in θ_F) and the second break from the right shows what landless income would be if there is severe climate change (13% fall in θ_F).

The first outstanding fact of note is that in 2030, the landless poor are better off than in 2009 in all scenarios even with severe climate change. This is simply because we have assumed, in keeping with most of the literature, that climate effects are level effects and not growth effects. The second fact of note is that the effects of climate change are much smaller in the open than in the closed economy counterpart in each scenario because the opportunity to import food greatly moderates the rise in its price and thus protects the real income of the landless. The general equilibria of the closed and open economies are very different in their welfare impacts. The third result of note is that variation in non-food productivity (θ_T) growth has the largest effect on the income of the landless in both closed and open economies. This is because the projected growth rate in non-food productivity is higher than that of food productivity over these two decades, and so a 50% variation in it dominates variation in population or food productivity. We see that in the open economy, variation in non-food productivity has a much larger effect on the income of the landless than in the closed economy. Again, this is because imports moderate the rise in the food price

Figure 4: Real Income of the Landless under Different Growth Paths in Closed and Open Economies

Note: Moderate scenario of 7% fall in θ_F^I and 2% fall in θ_F^R : Growth rate of agricultural productivity (θ_F^I) in India declines by .36% p.a and in ROW (θ_F^R) declines by .1 p.a relative to no climate change medium growth scenario in 2030.

Severe scenario of 13% fall in (θ_F^I) and 6% fall in (θ_F^R): Growth rate of agricultural productivity (θ_F^I) in India declines by .67% p.a and in ROW (θ_F^R) by .3% p.a relative to no climate change medium growth scenario in 2030.

that results from the higher food demand in an economy with a more productive non-food sector.

We note that climate impacts even in the moderate scenarios dominate population growth impacts in both open and closed economies. However, if the economy is closed, then plausible variations in agricultural productivity growth are larger than climate impacts in the moderate climate change scenario and similar to them in the severe scenario. If the economy is open, then climate impacts dominate the impacts of variation in θ_F^I.

Another way to understand the relative importance of factors that determine the welfare of the poor is to derive the percentage change in the income of the poor in 2030 as a result of a 1% increase in food or non-food productivity or a 1% reduction in the population from the baseline medium growth scenario. When the economy is closed, we find that a 1% increase in food productivity is likely to increase the real income of the landless by 0.82% while a 1% increase in non-food productivity will increase the income of the landless by 0.51%. A 1% decrease in population will increase the real income of the poor by about 0.45%. Agricultural productivity, and, therefore, climate change has larger effects on the welfare of the poor than non-food sector growth, while demographic change also has significant effects.

In the open economy, a 1% increase in agricultural productivity over the baseline medium growth scenario increases the real income of the landless by only 0.08% over the baseline medium growth scenario. But, a 1% increase in non-food productivity increases landless incomes 0.96%, almost one-for-one. In the 2030 economy, India accounts for 18% of the global food supply and imports 35% of its food. Higher agricultural productivity helps the poor by reducing food prices. However, since food prices fall by only a small amount this improves the welfare of the landless only marginally. On the other hand, higher non-agricultural productivity increases the real income of the poor by increasing wages directly and thus has a much bigger impact. Similarly, a 1% lower population increases the income of the poor by only 0.06%. Lower population impacts the poor indirectly by lowering food prices and thus has a much lower impact as in the case of agricultural productivity. If India can import its food without frictions from the rest of the world, improving non-agricultural productivity is likely to increase the welfare of the poor much more than improving agricultural productivity to reduce climate change impacts or spending resources in controlling population. Of course, these results would not be as stark in a model that accounts for diminishing returns to labor in the non-food sector.

7 Conclusion

Some of the key results of the study are as follows. First, most if not at all agents lose from climate change. Since most Indian farmers own very little land, they lose more from higher food prices than they gain. Those without land lose the most only the very few large landowners gain from higher food prices. In percentage terms, the welfare loss to the landless poor is *five* times greater than the first order impact on GDP if the economy is closed. Second, the buffering effect of international trade on the welfare of the poor is very important. The rise in food prices is moderated. Not only are the losses to the poor lower compared to the closed economy, the burden is also more uniformly distributed. All agents, including large landowners, lose and by about the same order of magnitude. It really matters to the poor what happens in the rest of the world. If climate change results in a large decline in agricultural productivity in the the rest of the world as well, then food prices will rise significantly in the open economy and hurt the poor. Third, in the richer economy of 2030, the welfare impacts of climate change are less severe. Thus, climate is only one of the many factors that will shape food security and welfare of the poor in future.

The combination of trade and economic growth can buffer the poor against climate change. In the richer closed economy, improving the productivity of the agricultural sector has the greatest impact on the welfare of the poor. In contrast, in the richer open economy, the non-agricultural sector plays a bigger role in driving the welfare of the poor. The implication is that changes in productivity growth in the non-agricultural sector will have a much larger impact on the welfare of the poor than mitigation of climate change (excluding impacts unforeseen in this study). By importing food and exporting other goods, in which India has a comparative advantage, the poor can be made much better off.

It should be stressed that these results are the outcomes that would obtain without frictions. Frictions would exacerbate the climate change impacts. For instance, by converting all foods to their calorie content, we effectively assume that all foods are perfect substitutes. Incorporating imperfect adaptation in consumer responses would increase the losses from climate change. The paper also assumes that labor is perfectly mobile between sectors. If labor is unwilling or unable to move to food production from the non-food sectors, the extent of price rise and the welfare loss would be higher. Similarly, non-agricultural growth and trade will be of much less help to the poor if the mobility of labor from agriculture to non-agriculture is constrained by a lack of education or other barriers. [Eswaran et al., 2009] find that despite the rapid growth of the non-farm sector in India, its success in drawing labor from agriculture has been limited. They provide some evidence to suggest that lack of human capital has hindered the movement of labor to non-agriculture.

We have also assumed that the productivity loss due to climate change is Hicks neutral and affects the marginal product of both labor and land in the same way. In poor labor-abundant countries, productivity has been driven more by biological innovations than mechanical innovations [Hayami et al., 1971]. If we assumed instead that climate change will affect the marginal product of land more than labor, then this would require a larger sectoral shift of labor from the non-agricultural sector to the agricultural sector, and a greater increase in the food prices, and thus worsen the condition of the poor. In a similar vein, if land and labor were less substitutable than the unitary elasticity of substitution implied by the Cobb-Douglas production function, then climate change would lead to costlier adjustments and greater increases in food prices.

Finally, the model has assumed there are no trade barriers. It is well known that world markets for grains are imperfect and government intervention keeps volumes lower than they would otherwise be [Anderson et al., 2013]. As India is a large country that affects world prices, the rest of the world may errect trade barriers if they wish to keep prices low for their population. This means that the real world outcome can be expected to be intermediate between the open and closed economy model outcomes.

More research is needed in future to study the welfare implications for the poor when the assumptions in the our analysis fail to hold. This is beyond the scope of this paper but is an important issue of future research. While the quantitative investigation is geared to throw light on this issue for India, we expect the methodology of this research can be applied to other developing countries as well.

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APPENDICES

A Model derivation

A.1 Closed economy case

Totally differentiating eq(13) with respect to to θ_F and simplifying, we obtain the elasticity of the price of food with respect to the total factor productivity θ_F.

$$-\left(\frac{dP}{d\theta_F}\frac{\theta_F}{P}\right) = \varepsilon_{P\theta_F} = \left[\frac{\left(\frac{1-\alpha}{\alpha}+\frac{1}{1-\rho}\right)Y_F\left(\frac{\alpha}{1-\alpha}\right)}{\left(\frac{1-\alpha}{\alpha}+\frac{1}{1-\rho}\right)Y_F\left(\frac{\alpha}{1-\alpha}\right)-\underline{f}\ N}\right] = \frac{1}{1-\frac{\underline{f}\ N}{Y_F\left(1+\frac{\eta}{(1-\rho)}\right)}}$$

A.2 Open economy case

We assume that the factor markets clear locally and the goods market clear internationally. The total food production is given as $Y_F = Y_F^I + Y_F^R$.

Here,

$$Y_F^I = \theta_F^I A_F^I \left(\frac{L_F^I}{A_F^I}\right)^\alpha$$

for I and

$$Y_F^R = \theta_F^R A_F^R \left(\frac{L_F^R}{A_F^R}\right)^\beta$$

for R.

Similarly, the total non-food production is given as $Y_T = Y_T^I + Y_T^R$. Here $Y_T^I = \theta_T^I\ L_T^I$ for I and $Y_T^R = \theta_T^R\ L_T^R$ for R. Factor market clearing conditions for land and labor for I are $N_l^I = L_F^I + L_T^I$ and $A^I = A_F^I$. Similarly for R we have $N_l^R = L_F^R + L_T^R$ and $A^R = A_F^R$. We denote the wage rate by W^I in I , w^I per capita wage in I , w^R per capita wage in R and by W^R in R. We denote per unit land rent by r^I in I and by r^R in R.

On consumption side, as previously we have

$$U_i^I = (f_i^I - \underline{f})^\rho (t_i^I - \underline{t})^{1-\rho}$$

for I and

$$U_i^R = (f_i^R - \underline{f})^\rho (t_i^R - \underline{t})^{1-\rho}$$

for R. Individuals in both regions maximize utility subject to their respective income constraints $M_i^I = w^I + r^I a_i$ for I and $M_i^R = w^R + r^R a_i$ for R. As in the previous section we can derive total demands of F and T in both the economies in the following way:

$$F_d^I = \underline{f}N^I + \frac{\rho}{P}(w^I N_l^I + rA^I - P\underline{f}N^I - \underline{t}N^I)$$

$$F_d^R = \underline{f}N^R + \frac{\rho}{P}(w^R N_l^R + rA^R - P\underline{f}N^R - \underline{t}N^R)$$

Global food demand is obtained as $F_d = F_d^I + F_d^R$

Similarly, for non-food we have

$$T_d^I = \underline{t}N^I + (1-\rho)(w^I N_l^I + r^I A^I - P\underline{f}N^I - \underline{t}N^I)$$

$$T_d^R = \underline{t}N^R + (1-\rho)(w^R N_l^R + r^R A^R - P\underline{f}N^R - \underline{t}N^R)$$

Global non-food demand is obtained as $T_d = T_d^I + T_d^R$

As in the closed economy case, we obtain optimal labor, rent and output supply from marginal conditions in both sectors of the respective economies.

In general equilibrium, all four markets clear.Land: $A^I = A_F^I; A^R = A_F^R$;labor: $N_l^I = L_F^I + L_T^I; N_l^R = L_F^R + L_T^R$;Food: $F_d = F_d^I + F_d^R = Y_{_F} = Y_{_F}^R + Y_{_F}^I$

Textile: $T_d = T_d^I + T_d^R = Y_{_T} = Y_{_T}^R + Y_{_T}^I$

As shown previously general equilibrium can be obtained with textile market equilibrium condition as follows: $T_d = T_d^I + T_d^R = Y_{_T} = Y_{_T}^R + Y_{_T}^I$

$$\left(\theta_{_T}^{I\frac{\alpha}{\alpha-1}} \left(\frac{1-\alpha}{\alpha}\right) P\theta_{_F}^{I\frac{1}{1-\alpha}} \alpha^{\frac{1}{1-\alpha}}\right) A^I - P\underline{f}N^I + \left(\theta_{_T}^{R\frac{\beta}{\beta-1}} \left(\frac{1-\beta}{\beta}\right) P\theta_{_F}^{R\frac{1}{1-\beta}} \beta^{\frac{1}{1-\beta}}\right) A^R - P\underline{f}N^R$$
$$+ \frac{1}{(1-\rho)} A^I \left(\frac{\theta_{_T}^I}{\alpha P \theta_{_F}^I}\right)^{\frac{1}{\alpha-1}} + \frac{1}{(1-\rho)} A^R \left(\frac{\theta_{_T}^R}{\beta P \theta_{_F}^R}\right)^{\frac{1}{\beta-1}}$$
$$= \frac{\rho\theta_{_T}^I N^I + \rho\theta_{_T}^R N^R - \rho\underline{t}\ N^I - \rho\underline{t}\ N^R}{(1-\rho)}$$

From the above equation we determine equilibrium international price of food P.Also, we can get food price elasticity in the open economy as

$$-\left(\frac{dP}{d\tau}\frac{\tau}{P}\right) = -\varepsilon_{_{P\tau}} = \frac{s^I \varepsilon(\theta_{_F}^I \tau)(\frac{\eta^I}{1-\rho}+1) + s^R \varepsilon(\theta_{_F}^R \tau)(\frac{\eta^R}{1-\rho}+1)}{1 + s^I(\frac{\eta^I}{1-\rho}) + s^R(\frac{\eta^R}{1-\rho}) - \frac{\underline{f}\ (N^G)}{(Y_{_F}^G)}}.$$
$$= \frac{s^I \varepsilon(\theta_{_F}^I \tau) + s^R \varepsilon(\theta_{_F}^R \tau)}{1 - \frac{\underline{f}\ (N^G)}{(Y_{_F}^G)\left(1+\frac{\eta}{(1-\rho)}\right)}} \text{ if } \eta^I = \eta^R.$$

B Detailed description of scenarios

In the analysis changes in climate and pollution are introduced by changing total factor productivity (θ_F) in the agricultural sector. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the projected change in global mean surface air temperature for the period 2016–2035 (relative to 1986–2005) is likely to be in the range 0.3–0.7°C (medium confidence) (See [IPCC, 2013]). The mean surface temperature increase in South Asia is *likely* to be in the range of 1°C to 1.5°C (medium confidence). In IPCC terminology "likely" means a two-third probability, so there is estimated to be a one-third chance that the actual temperature increase will be outside this range. Based on the existing literature on climate change impacts discussed in the introduction, we derive scenarios for India and the rest of the world by adding the estimated impacts of warming, CO_2 fertilization, and ozone, on crop yields. Table (6.2) shows climate impacts in moderate and severe scenarios drawn from the literature. A moderate scenario corresponds to a one-degree increase in temperature and a severe scenario corresponds to a 2-degree increase in temperature.

A moderate scenario of a 7% fall in θ_F is obtained by adding a 5.5 percent fall in yields due to 1 ^0C temperature rise (as estimated by [Lobell et al., 2011] in Fig s7) and a 5 percent fall in yields due to an increase in ozone pollution in the next two decades (which is esimated by taking average of mid range loss estimates given in two studies -[Van Dingenen et al., 2009] and [Avnery et al., 2011]) to a 3.6 percent positive effect of CO_2 fertilization expected in the next two decades (1.8 percent per decade as given in [Lobell & Gourdji, 2012]). Similarly, we obtain a severe scenario of a 13% decline in agricultural productivity in India by adding 11% fall in yields due to 2 ^0C temperature rise (obtained by doubling the 5.5% impact in moderate scenario of 1 ^0C increase in temperature) and a 6 percent fall in yields due to an increase in ozone pollution in the next two decades (which is esimated by taking average of higher end loss estimates given in two studies -[Van Dingenen et al., 2009], [Avnery et al., 2011]) to a 3.6 percent positive effect of CO_2 fertilization. A moderate scenario of a 2% fall in agricultural productivity for the rest of the world is obtained by adding 3% fall in yields (estimated based on past 3 decades crop losses estimated during 1980-2008) and a 2.2 percent fall in yields due to an increase in ozone pollution in the next two decades (which is esimated by taking the average of mid range loss estimates given in two studies -[Van Dingenen et al., 2009] and [Avnery et al., 2011]) to a 3.6 percent positive effect of CO_2 fertilization. A severe scenario of 6% fall in agricultural productivity in the rest of the world is obtained by adding 6% fall in yields (doubling the impact estimated in moderate scenario) and a 3.37 percent fall in yields due to an increase in ozone pollution in the next two decades (which is esimated by

Table B.1: General Equilibrium in Baseline Cosed and Open Economies (2030)

Variable	Closed Economy % Change over 2009 baseline	Open Economy % Change over 2009 baseline
Food Price (Rs/kcal)	42.9	15.4
Annual Wage Rate (Rs)	87.5	87.5
Real wage Rate (Rs)	70	81.74
Rent per hectare (Rs)	102	36.4
Real Rent per hectare (Rs)	84.14	29.8
Food sector share (%)	-15.6	-36.4
Food share of landless(%)	-14.4	-21.7
Food imports as % of food demand	-	143
Non-Food exports as % of Non-food output	-	60.3

Table B.2: Summarizing 7 Scenarios for 2030

Scenarios (2030)	Region	N^I	θ_F^I	θ_T^I
Medium or Baseline	India	Medium	Medium	Medium
High population	India	High	Medium	Medium
Low population	India	Low	Medium	Medium
High productivity in agriculture	India	Medium	High	Medium
Low productivity in agriculture	India	Medium	Low	Medium
High productivity in non-agriculture	India	Medium	Medium	High
Low productivity in non-agriculture	India	Medium	Medium	Low

Note: In the all above scenarios it is assumed that N^R, θ_F^R and θ_T^R in the rest of the world grow at the medium rate.

taking average of high end loss estimates given in two studies -[Van Dingenen et al., 2009] and [Avnery et al., 2011]) to a 3.6 percent positive effect of CO_2 fertilization. We impose these scenarios on the economy when it is closed to trade and when it is open to trade.