Agricultural Productivity, Hired Labor, Wages and Poverty: Evidence from Bangladesh

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ABSTRACT

This paper provides evidence on the effects of agricultural productivity on wage, labor supply to market oriented activities and labor allocation between own farming and wage labor in agriculture. To guide the empirical work, it develops a general equilibrium model that underscores the role of reallocation of family labor engaged in the production of non-marketed services at home ('home production'). The model predicts positive effects of a favorable agricultural productivity shock on wage and income, but the effect on hired labor is ambiguous; it depends on the strength of reallocation of labor from home to market production by labor surplus and deficit households. Taking rainfall variations as a measure of shock to agricultural productivity and using sub-district level panel data from Bangladesh, we find significant positive effects of a favorable rainfall shock on agricultural wage, labor supply to market work and per capita household expenditure. The share of hired labor in contrast declines substantially in response to a favorable productivity shock which is consistent with a case where labor-deficit households respond more than the labor-surplus ones in reallocating labor from home production.

Key Words: Agricultural Productivity, Home Production, Market Work, Wage, Hired Labor, Labor Supply Response, Poverty

JEL Classification: O13, J22, J43, Q10

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(1) Introduction

A common approach to analyzing the effects of agricultural growth on rural poverty has been to estimate its impacts on rural wages (see, among others, Foster and Rosenzweig (2004), Lanjouw and Murgai(2009)). This is motivated by the observation that a significant proportion of poor people – endowed mostly with labor but few other productive assets (e.g. landless) – participate in rural wage labor market and wage income is the main source of income for them. The available evidence on rural labor markets in developing countries, however, shows that the extent of wage employment is limited (Rosenzweig (1988)), and there is substantial amount of 'surplus labor' in the form of under- and unemployed family labor.[1] In many developing countries, poor households are poor because most of their labor endowment is employed in home-based non-marketed services activities with very low returns, not because they are (openly) unemployed. In the presence of low productivity home production, the poverty impact of agricultural productivity may depend on how allocation of labor from home production to own farming and wage labor changes in response to agricultural productivity growth.[2] The reallocation of labor from low productivity home production to other market oriented activities has been emphasized as a hallmark of long-run structural change of an economy in the literature (Laitner (2000), Buera and Kaboski (2012)).

We provide evidence on the impacts of agricultural productivity changes on wage, labor supply (hours devoted to market oriented activities), and labor allocation between own farming, and wage labor in agriculture. To derive testable hypotheses about the impact of

[1] For instance, Rosenzweig and Foster (2010) finds that 20 percent of rural labor force in India is 'surplus'.

[2] This is more so in African countries where wage employment in agriculture and non-agriculture in rural areas is very limited (see Davis, Guiseppe and Zezza (2014)). The reallocation of labor in response to agricultural productivity growth in African case is between home production and own farming.

agricultural productivity growth on labor allocation and wages, we develop a simple model where household members can be employed in three types of activities: own farming, wage labor in agriculture and household production (non-traded and non-marketed services).[3] There are two types of households in the farm economy who differ in two dimensions: some households are endowed with more labor, and the technology for home production (degree of diminishing returns to labor) is also different between the two groups. The model yields the standard predictions of a positive effect on agricultural wages, and a reallocation of labor from home production to market work in response to a positive agricultural productivity shock. There are two interesting implications of the model particularly relevant for our empirical analysis: (i) while wages respond positively to an agricultural productivity shock, the extent of the wage increase is lower the higher is the reallocation of labor from home production to market work (own farming and wage labor), (ii) the response of the quantity of hired labor depends critically on the differences in the strength of diminishing returns to labor in home production across labor-surplus and labor-deficit households. In particular, it is possible that the amount of labor hired through the labor market may go down in response to an increase in agricultural productivity. Thus a focus on the response of wage and hired labor alone may lead to misleading conclusions regarding the impacts of agricultural growth.

We test the predictions of the model using a upazila (subdistrict) level panel data set from Bangladesh. To understand the implications of agricultural productivity, we exploit variations in rainfall across upazilas and over time, and implement a procedure that focuses

[3]Given the focus on the interactions between home production and agriculture, we abstract away from non-farm production in a village. We, however, emphasize that the predictions regarding agricultural wage and labor allocation are robust; they remain intact in a more general model including non-farm production.

on the effects of rainfall shocks in reduced form regressions on the outcome variables (wage, employment in own farming and hired labor, hours worked for market oriented activities, and per capita consumption) and also on the measure of agricultural productivity (crop yield). The evidence from the reduced form regressions is sufficient to test the predictions of the theoretical analysis which relies on the fact that rainfall variations can be interpreted as shifts in the production function, because rainfall is a major determinant of crop yield in Bangladesh (Sarkar et. al. (2012), Bhowmik and Costa (2012)). We also provide an instrumental variables interpretation of our estimates, using rainfall variations across upazila and over time (relative to mean) as an instrument for crop yield (rice yield). The regressions include upazila fixed effects to remove the influences of time invariant unobserved area characteristics, and year fixed effects to wipe out the common price (international) and other macroeconomic shocks. To be as clinical as possible, we allow for time varying direct impacts of these factors by including interaction of a flood-prone area dummy and travel time to the two metropolitan cities (Dhaka and Chittagong) with the time trend. We included an extensive set of control variables to account for time varying direct effects of infrastructure and other area characteristics. Empirical estimation issues and strategy to deal with them are discussed in detail in Section 3. It is worth emphasizing that while rainfall shocks have been used for identification in a variety of contexts, agricultural productivity is probably among the most natural contexts where rainfall can provide reasonable identifying variations ((Foster and Rosenzweig (2004), Adhvaryu, Chari and Sharma (2013), Bruckner and Ciccone (2011)).

The regression estimates reported later show that a positive rainfall shock has a significant positive effect on wages; a one percent increase in rainfall (relative to the mean) increases wages by about 0.46 percent. The effect on hired labor is, in contrast, negative and statistically significant; a one percent increase in rainfall reduces hired labor by 0.73 percent. The negative response of hired labor is consistent with the case where the labor reallocation from home production by labor deficit households is stronger than that of labor-surplus households. Our results also indicate that households increase hours supplied to the market-related activities in response to a positive rainfall shock, thus providing additional evidence of reallocation of labor from home production. When interpreted as instrumental variables estimates of the effects of productivity increase, the estimates show substantial impact of an increase in rice yield on wage, hired labor, and labor supply to the market activities.

The rest of the paper is organized as follows. Section (2) develops a model of the farm economy with a focus on the role of home production and derives three propositions on the effects of agricultural productivity on labor market. The following two sections present the empirical strategy and data respectively. Empirical results are discussed in section 5. The paper is concluded in the final section.

(2) Agricultural Productivity in a Farm Economy

We construct a simple model of a farm economy consisting of two (types of) households (h and k). Each household owns A units of agricultural land, but they differ in terms of the endowment of labor, household h (L_h^0) with more labor than household k ($L_k^0 < L_h^0$).[4] The households produce two goods: food (agriculture) and a home good. The households also differ in a second dimension, they have access to different technologies for home good production.

[4]A richer model where households differ in land endowment and skilled labor also generate the same st of qualitative conclusions.

Households consume three goods/services: a home good (d), and two market goods (food (f), a non-farm good (m)). Both food and non-farm goods are assumed to be internationally traded, and we take the food commodity as the numeraire. The assumption that both food and non-farm goods are tradable implies that their prices are pinned down at the international market, which is useful for abstracting away from the demand side factors, and focusing only on the supply side responses. Assuming identical preferences, the utility functions for households in the village is as the following:

$$U = u(c_f, c_m, c_d)$$

where c_f is consumption of food, c_m is the consumption of non-farm good. We assume that utility function $u(c_f, c_m, c_d)$ takes the Cobb-Douglas form with φ_i is the share of good/service i.The budget constraint for the market goods can be stated as:

$$Y \geqq c_f + P_m c_m$$

where P_m is the price of the non-farm good, the agricultural good is the numeraire, i.e., $P_f = 1$ and Y is total market income in the village.

The equilibrium in the farm economy is characterized by labor market clearing and an external balance condition (export food and import non-farm good at world prices). By Walras law we can ignore the external balance condition. Wages are thus determined by the labor market clearing condition.

(2.1) Labor Demand for Market work in Agriculture

For workers in the farm economy, there are three employment options: (i) home production, (i) family owned farm, (iii) other farms.[5] Note that we include both own farming and working as hired labor for others as market work, because the focus is on reallocation from home production that includes all non-market economic activities. Households produce food using land and labor with the same CRS technology. The food output by each household can be described as:

$$Q_{fi} = \theta F(A, l_{fi}) = \theta \left(A^{\alpha} l_{fi}^{1-\alpha} \right) \quad \text{for } i = h, k$$

where θ represents total factor productivity in food production, A is the endowment of land which is assumed to be fixed, and l_{fi} is the labor used in food production by household i. The demand for labor in agriculture does not vary across households given that they face the same technology and prices, and labor demand for each household can be derived as:

$$l_{fh} = l_{fk} = \theta^{\frac{1}{\alpha}} A[\frac{(1-\alpha)}{w}]^{\frac{1}{\alpha}} \tag{1}$$

Total labor demand in farming is then:

$$l_f = l_{fh} + l_{fk} = 2(1-\alpha)\triangle_1 \theta^{\frac{1}{\alpha}} (\frac{1}{w})^{\frac{1}{\alpha}} \tag{2}$$

[5]Note that we do not include production of the non-farm good in the model, as the focus of this paper is on the effects of agricultural productivity increase on wage and hired labor in agriculture when there is potentially significant labor supply response through reallocation of labor from home production . A richer model that includes non-farm produced in the village (possibly with skilled labor) yield similar qualitative conclusions. We, however, will discuss the implications of the nonfarm production when discussing the empirical strategy, as general equilibrium responses in the non-farm sector have bearings on the identification and interpretation of the results. For an extended model that focuses on production of non-farm goods and allows for heterogeneity in the skill of labor and nontradability of the non-farm good, please see Foster and Rosenzweig (2004), and Emran and Shilpi (2014).

Where $\triangle_1 = A[1-\alpha]^{\frac{1-\alpha}{\alpha}}$.

(2.2) Labor Supply for Market Work in Agriculture

In addition to using labor in agriculture, each household also engages in the production and consumption of a home good (d). The production functions for the home good is of the following form:

$$Q_{di} = l_{di}^{\delta i} \text{ for } i = h, k \text{ and } 0 < \delta_i < 1$$

Thus the curvature of the home good production function differs across households. The relevant opportunity cost of home production for both households is the market wage rate w. The marginal condition determining the optimal use of labor in home production can be expressed as (assuming $\lambda = 1$, for simplicity):

$$\delta_i l_{di}^{\delta i - 1} = w \text{ for } i = h, k \tag{3}$$

Since labor allocated to home production varies inversely with the wage (equation 3), the supply of labor for market work can be written as:

$$L_i(w) = L_i^0 - l_{di}^* = L_i^0 - \left(\frac{\delta_i}{w}\right)^{(1-\delta_i)^{-1}}, \text{ with } L_i^w = \frac{\partial L_i}{\partial w} > 0 \text{ for } i = h, k \tag{4}$$

The model set up above generates an upward sloping labor supply function for market work. The model is general enough that the home good can also be interpreted as leisure, but it avoids the awkward possibility of a backward bending supply curve of labor in a low income village economy.[6] An alternative model is where there is (open) unemployment, and

[6]It is not realistic to expect that people would like to consume more 'leisure' when managing three

labor supply responses occur primarily at the extensive margin. The formulation adopted here is attractive, because explicit unemployment is not high in rural areas of developing countries, and poor people are poor not because they are unemployed (consuming leisure), but because they work long hours in extremely low productivity activities such as foraging. Those low productivity non-market economic activities are modeled as home production in our model. Note also that our definition of labor supply to market work corresponds to traditional definition of *total* labor supply that includes self employment on own farm as well. The distinction between market work and home production in our case is that market work consists of all work whose output can be and are usually transacted in the market. For instance, labor spent on producing rice that is consumed at home is considered as market work since rice is widely traded in the market. Home production on the other hand consists of services (e.g. meal preparation, child care or simply leisure) which is consumed at home and is not usually sold in the market. The span of home production is much wider in villages in developing countries, because of limited development of markets, for example, the markets for child care and prepared meals are missing in most of villages in developing countries.

The supply of labor to market oriented activities (as opposed to home production) by each household depends on agricultural productivity indirectly through its effects on wage. The larger is the value of δ_i, the larger is the magnitude of supply response of labor for market work. A rise in wage draws labor out of home production and into market work.

Given the assumption of Cobb-Douglas form for the utility function and labor used in home production being determined by the marginal condition in equation (3), demand for

meals a day is a challenge.

market goods can be expressed as:

$$c_i = \frac{\varphi_i Y}{(1-\varphi_d)P_i},\ i = f, m$$

Note that although home good enters into the utility function in a non-separable way, production and consumption of home good is determined by the marginal condition in equation (3). This is due to the fact that production function for home good displays diminishing returns. This in turn ensures an unambiguous upward sloping labor supply function for market work. In the standard labor-leisure models, production function for leisure (home production) is assumed to have constant returns; one unit of labor 'produces' one unit of leisure. In that case, the supply side does not pin down the production (and consumption) of home goods, the demand side plays a critical role. An increase in wage increases demand for home good assuming it is a normal good, and thus the curvature of the labor supply function for market work depends on the relative size of income (negative) and substitution (positive) effects. The assumption of decreasing returns to scale in the home (leisure) production is however more plausible in the context of developing countries. Our empirical analysis later confirms that labor allocated to market activities does increase with an increase in wages and/or agricultural productivity.

(2.3) Market Clearing for Labor

Setting labor demand equal to labor supply, the equilibrium condition in the labor market can be expressed as:

$$l_f = l_{fh} + l_{fk} = 2\triangle_2 \theta^{\frac{1}{\alpha}} (\frac{1}{w})^{\frac{1}{\alpha}} = L_h(w) + L_k(w) \tag{5}$$

where $\Delta_2 = \triangle_1(1-\alpha)$.

Proposition 1: *Given the assumptions that food is produced under CRS technology using land and labor, and the home good is produced under decreasing returns to scale (DRS) technology using labor alone, a positive productivity shock in agriculture (i.e., a higher θ) results in an increase in the wage rate; the higher the response of labor supply to the wage, the lower is the change in the equilibrium wage rate.*

Proof: The market clearing condition in equation (5) can be used to derive the following result:

$$\frac{\partial w^*}{\partial \theta} = \frac{2\Delta_2 \theta^{\frac{1-\alpha}{\alpha}} (\frac{1}{w^*})^{\frac{1}{\alpha}}}{\alpha(L_h^w + L_k^w) + 2\Delta_2 \theta^{\frac{1}{\alpha}} (\frac{1}{w^*})^{\frac{1+\alpha}{\alpha}}} > 0 \tag{6}$$

The first part of the result above follows from the fact that the denominator in equation (6) is positive as long as $\delta_i < 1$. The second part derives from the fact that the denominator is a positive function of the supply response of households for market work to wage change (captured by $L_h^w + L_k^w$).

(2.4) Response of Hired Labor

The increase in the wage rate following an increase in agricultural productivity discussed in proposition (1) above has been a focus of empirical work on the effects of agricultural growth on poverty. A central point of this paper is that the effects on wages are only half of the story, as the income of the poor rural households also depend on whether they are largely dependent on low productivity home-based activities. If the supply of labor to market work (including own farming) is sensitive to productivity and wages, then the primary margin of adjustment may be reallocation of labor from home production to market production. A related important implication of high labor supply elasticity is that the wage response observed in the data will be smaller the higher is the labor supply response, but total income may in fact go up much more because of labor supply response. Thus if one focuses on the wage response alone, it might give us a partial estimate of the impact of an agricultural productivity increase on household welfare which may be significantly biased downward. An immediate solution to this seems to be to supplement the wage analysis with evidence on the response of labor supplied to the market, i.e., hired labor. If agricultural productivity increase shifts the demand curve for labor, then we would expect the use of hired labor to go up. However, this simple intuition turns out to be misleading in a model with home production, because the response of hired labor depends on the differences in the technology of home goods production across labor-rich and labor-deficit households.

How does hired labor in farming respond to a productivity shock? Since labor endowment of household k is smaller than that of household h, household h is a net seller of labor and household k is a net buyer of labor. Let l^w be the labor hired for farming work (by household k) which can be written as:

$$\begin{aligned} l^w &= \Delta_2 \theta^{\frac{1}{\alpha}} [\frac{1}{w}]^{\frac{1}{\alpha}} - L_k(w) \\ &= \Delta_2 \theta^{\frac{1}{\alpha}} [\frac{1}{w}]^{\frac{1}{\alpha}} - \left[L_k^0 - \left(\frac{\delta_k}{w} \right)^{(1-\delta_k)^{-1}} \right] \end{aligned} \tag{7}$$

The response of hired labor by household k with respect to an increase in productivity θ is derived as follows:

$$\frac{\partial l^w}{\partial\theta} = \frac{1}{\alpha}\left(\Delta_2\theta^{\frac{1}{\alpha}-1}[\frac{1}{w}]^{\frac{1}{\alpha}}\right) - \left(\frac{1}{w}\frac{\partial w}{\partial\theta}\right)\left\{\frac{1}{\alpha}\left[\Delta_2\theta^{\frac{1}{\alpha}}[\frac{1}{w}]^{\frac{1}{\alpha}}\right] + \left(\frac{1}{1-\delta_k}\right)\left(\frac{\delta_k}{w}\right)^{(1-\delta_k)^{-1}}\right\} \quad (8)$$

The first term in the right hand side of equation (8) above is the direct productivity effect that increases demand for labor in agriculture, and the last term combines the general equilibrium effects through higher wages on the demand for labor in both home production and agricultural production.

Proposition 2: *In a rural economy where there is heterogeneity in households' endowments of labor, the effects of agricultural productivity on hired labor depend on the labor supply responses of the labor-surplus and labor-deficit households. Assuming constant returns to scale in agriculture and decreasing returns to labor in home production, we have the following results:*

(i) When labor supply response of labor-deficit households with respect to a change in the wage is larger than that of labor surplus households ($\delta_k > \delta_h$) *then an increase in agricultural productivity leads to a decrease in hired labor.*

(ii) When the labor supply response of labor-deficit households with respect to the wage is smaller than that of labor surplus households($\delta_k < \delta_h$) , then an increase in agricultural productivity leads to an increase in hired labor.

Proof: Substituting for $\left(\frac{\partial w^*}{\partial\theta}\right)$from equation (6) above into the equation for $\frac{dl^w}{d\theta}$ (i.e., equation (8)) and rearranging terms we get the following:

$$\frac{dl^w}{d\theta} = \frac{\Delta_2 \theta^{\frac{1}{\alpha}-1} (\frac{1}{w})^{\frac{1}{\alpha}-1} (L_h^w - L_k^w)}{[\alpha w (L_h^w + L_k^w) + 2\Delta_2 \theta^{\frac{1}{\alpha}} (\frac{1}{w})^{\frac{1}{\alpha}}]} \tag{9}$$

Now note that

$$L_h^w - L_k^w = \frac{1}{w}\left[\left(\frac{1}{1-\delta_h}\right)\left(\frac{\delta_h}{w}\right)^{(1-\delta_h)^{-1}} - \left(\frac{1}{1-\delta_k}\right)\left(\frac{\delta_k}{w}\right)^{(1-\delta_k)^{-1}}\right]$$

The proof then follows from the fact that $L_h^w - L_k^w > 0$ if $\delta_h > \delta_k$ and $L_h^w - L_k^w < 0$ if $\delta_h < \delta_k$.

The intuition behind the results in proposition (2) reflects the fact that an increase in agricultural productivity increases returns to own-farming, and induces both types of households to substitute away from home production which is subject to decreasing returns to labor. Part (i) of proposition (2) shows that when L_k^w is quite large, the induced supply response of deficit household could displace hired labor. It is interesting to note that even though the amount of hired labor can go down in response to a productivity increase in agriculture, the wage response is always positive. For low value of supply response of the deficit household, substitution between home production and own farming is smaller, leading to a higher wage and more hired labor. Note that in the above framework, if there is no adjustments at the margin of home production (which includes leisure), and thus $L_h^w = L_k^w = 0$, the impact of agricultural productivity increase on hired labor is zero. While a zero response of hired labor can also result from a coincidence where $\delta_h = \delta_k$, admittedly this is not a very realistic case. The response of hired labor to agricultural productivity can thus be a fruitful metric for gauging the importance of home production and labor supply response. This is especially important for empirical analysis because the household surveys in developing countries usually lack reliable information on home production activities.

Although the response of hired labor to agricultural productivity shock is ambiguous a priori and thus can lead to misleading conclusions about the poverty impact of agricultural productivity changes, note that the response of total labor devoted to market work is positive under the plausible assumption that $\delta_h > 0, \delta_k > 0$. In the empirical analysis, we thus look at both hired labor and total labor devoted to market production as opposed to home production.

Proposition 3: *Regardless of its impact on hired labor, an increase in agricultural productivity increases total income in a village. The increase in village income is higher, the higher is the labor supply response with respect to wage (i.e, larger values of δ_k and δ_h).*

Proof: The net income of each household is the sum of land and labor income from market activities. The net income of the two households are thus:

$$Y = 2\theta^{\frac{1}{\alpha}} \triangle_1 \{\frac{1}{w}\}^{\frac{1-\alpha}{\alpha}}$$

Where $\triangle_1 = A[1-\alpha]^{\frac{1-\alpha}{\alpha}}$ and Y is the total village income. The change in village income in response to an agricultural productivity shock can be derived as:

$$\frac{dY}{d\theta} = \frac{\partial Y}{\partial \theta} + \frac{\partial Y}{\partial w}\frac{\partial w^*}{\partial \theta}$$

Substituting from equation (6) for $\frac{\partial w^*}{\partial \theta}$ and rearranging terms, we have the following:

$$\frac{dY}{d\theta} = \frac{Y\left[\left(2\triangle_2 \theta^{\frac{1}{\alpha}} (\frac{1}{w})^{\frac{1}{\alpha}}\right) + L_h^w + L_k^w\right]}{\theta\left(2\triangle_2 \theta^{\frac{1}{\alpha}} (\frac{1}{w})^{\frac{1}{\alpha}}\right) + \alpha\theta\left[L_h^w + L_k^w\right]} > 0 \tag{10}$$

It is easy to check from equation (10) above, the increase in income is higher when the labor supply responses of the households are higher. In this model there are thus two sources of income gains following an increase in agricultural productivity: a reallocation of labor from home production to agriculture, and a higher productivity of agricultural activity. In other words, income and poverty impact of agricultural productivity will be larger when households can increase their labor supply to market work, which does not necessarily imply an increase in hired labor through the market as shown in proposition (2) earlier. This result is important because it underscores the importance of looking at the effects on both price (wage) and total labor supplied to the market (not only hired labor) to understand the effects of an agricultural productivity increase on the poor.

(3) Empirical Framework

To estimate the effects of agricultural productivity growth on wages, labor allocation across own farming and hired labor, and household consumption, we construct a subdistrict (upazila) level panel data set using three rounds of household Income and expenditure Surveys (HIESs). To test the theoretical predictions in propositions 1-3, a natural regression specification is:

$$O_{ijt} = \rho_j + \rho_t + \pi\theta_{jt} + \Pi_1 Z_{jt} + \varepsilon_{ijt} \tag{11}$$

where i indexes the outcome variables (e.g. share of employment in an activity, wage, per capita household consumption expenditure etc), j denotes upazila, O_{ijt} is the outcome variable i, ρ_j and ρ_t denote the effects of upazila and year specific factors respectively. Our focus variable is θ_{jt} which measures agricultural productivity, Z_{jt} is a vector of upazila characteristics and ε_{ijt} is the error term. Estimation of the impact of agricultural productivity on employment and wages however presents some difficulties. Unobserved upazila characteristics when correlated with both wage/employment and agricultural productivity may create spurious correlations, and provide biased estimates of the effects of agricultural productivity change. For example, consider the heterogeneity in access to markets due to geographic location; an upazila which is closer to the metropolitan cities (Dhaka and Chittagong) will have higher agricultural productivity (higher demand, and cheaper and more reliable supply of inputs such as fertilizer and pesticide) and higher wages (because of employment opportunities in the cities). Thus when we regress wages on crop yield, we might find a positive "effect", both driven primarily by differences in access to markets across different upazila. It is, in general, not possible to control for all such potential confounding factors in a regression specification, and thus OLS results may be misleading. An important advantage in our application is that we construct a panel data set, which allows us to use upazila fixed effects ($\rho_j$in the regression equation (11) above) to remove the effects of all time invariant but unobserved upazila characteristics. The year fixed effects (ρ_t) control for any macro economic and international shocks (including commodity price shocks) that may have affected both agricultural productivity and outcomes of our interest.[7]

In the empirical analysis, we follow a two step procedure: first, a reduced form regression of an outcome variable (for example, wage) on the instrument, and second, a reduced

[7]The year fixed effects will control for any general equilibrium effect common to all households (e.g. prices).

form regression of the productivity measure (yield per acre) on rainfall. This two-step procedure has some important advantages in our application. First, the reduced form estimates of the effects of rainfall on the outcome variables such as wages and employment in agriculture are of interest on their own; for example, they provide us evidence on the potential benefits of increased irrigation investment on the rural economy. Second, when the focus is on the effects of productivity increase in agriculture, one can interpret the variations in rainfall as variations in the parameter θ in the model. Finally, with a focus on the standard measures of agricultural productivity such as crop yield, and rainfall as an instrument, the reduced form estimates of rainfall on wages, employment and consumption are still useful. Because they provide evidence on the *existence* of a causal effect of higher crop yield which is not subject to weak instrument bias (Chernozhukov and Hansen(2008)).[8] We estimate the following reduced form regressions:

$$O_{ijt} = \rho_j + \rho_t + \pi_1 R_{jt} + \Pi_1 Z_{jt} + \varepsilon_{ijt} \quad (12)$$

$$V_{jt} = \eta_j + \eta_t + \pi_2 R_{jt} + \Pi_2 Z_{jt} + \upsilon_{jt} \quad (13)$$

where R_{jt} is the annual rainfall in upazila j and V_{jt} is the measure of productivity. In empirical estimation, rainfall variable is expressed in logarithm. Thus our empirical model with upazila and year fixed effects provides estimates of the impact of rainfall shock on the growth of outcome variables. Rainfall shock for a upazila is defined as the deviation of rainfall in any year from its mean over all the years. A positive coefficient of rainfall ($\pi_2 > 0$) for instance in the yield regression means that an increase in rainfall over its mean

[8]We, however, emphasize that the main results of this paper do not depend on the exclusion restriction on rainfall; what we need is that rainfall affects productivity significantly.

level (a positive rain shock) increases rice yield.

We implement a fixed effects estimation procedure that removes the upazila level unobserved fixed factors by de-meaning all variables in the regression. Such demeaning may, however, exacerbate the attenuation bias as it is likely to magnify any measurement error in the measure of agricultural productivity (Griliches (1963)). We use an instrumental variable approach to remedy the attenuation bias and also the possible biases due to any other omitted variables not taken care of by the upazila and year fixed effects. Following a large and mature literature, agricultural productivity is measured by crop yield (Foster and Rosenzweig (2004), Adhvaryu, Chari and Sharma (2013)). More specifically, we use rice yield per acre, as rice is the predominant subsistence and cash crop in Bangladesh. We exploit rainfall variations as an instrument for rice yield. Rainfall is found to affect agricultural yields in both developed and developing countries, and hence is considered widely a credible instrument for agricultural yields (Foster and Rosenzweig (2004), Adhvaryu, Chari and Sharma (2013), Rajan and Ramcharan (2010), Bruckner (2012)).[9]

To ensure that rainfall primarily captures variation in agricultural productivity, we include an appropriate set of controls in Z_{jt}. One may argue that the agricultural labor market will be influenced by the effects of rainfall on non-farm activities. For example, construction employment may rise with higher rainfall if rainfall leads to flooding and destruction of the infrastructure which results in higher repair and reconstruction work. In so far as agricultural labor is also employable in construction work, this will have an impact on the agricultural wages. Flooding and destruction may, on the other hand, lead to a

[9]Rainfall has been used as an instrument in a variety of contexts ranging from civil war to foreign aid flow in the recent economic literature. While there are limitations to relying on rainfall variations for identifying information in many applications, rainfall variations are probably the most natural candidate for exogeneous variations in agricultural productivity, especially in developing countries.

negative correlation between rainfall and non-farm labor demand if it disrupts production activities. The positive and negative effects of nonfarm sector on the agricultural labor market may, in some cases, largely offset each other. One can include a flood-plain dummy to control for such effects. Note that the negative effects of flood caused by heavy rainfall, especially, on prices and wages will depend on the location of an upazila, because access to urban markets provides a cushion against such shocks. Travel time to the urban markets can be used to account for such heterogeneity. Travel time would also capture the spatial variations in the prices of tradables, because it is a reliable proxy for the transport and other marketing costs. Since both travel time and floodplain dummy are time-invariant (or can change only very slowly over years), they are subsumed by upazila fixed effects. As a conservative strategy, we allow for time varying effects of these two variables, and include their interactions with time trend in the regressions. We also include the proportion of households in a upazila with electricity as a control. [10] Availability of electricity may foster non-farm activities that are less susceptible to the weather, and may have differential effect on part of the agricultural labor market through substitutability of labor. To capture changes in labor endowment, we control for upazila population, and proportion of active labor force with secondary or above education (human capital). We also control for upazila population in 1991 (initial condition) interacted with the time trend. Note, however, that it is a conservative specification, because by controlling for variations in labor endowment across upazilas and over time, we also deny the possibility that agricultural productivity changes affect the population in a village.

A final issue for the empirical specification is that rainfall is expected to have significant

[10] Our empirical results are robust to controls for agglomeration economies such as area share in total industry employment in 1991.

effect on rice yield only if the upazila is predominantly rural in its economic activity. We thus exclude upazilas located in two main metropolitan areas from our sample. In addition, we control for the share of "urban" households in total households in the upazila.

(4) Data

For the empirical analysis, we combine different data sources to define a upazila (sub-district) level panel data set covering the period 2000 to 2009/2010. Our main data source for the outcome variables (wage, employment in different activities and household consumption expenditure) is three rounds of the Household Income and Expenditure Surveys (HIESs), available for 2000, 2005, and 2010. The HIESs are based on a nationally representative sample of households.[11] These surveys are conducted primarily for the estimation of poverty incidence and thus provide reliable information on household economic activities, per capita household expenditure and regional price deflators. Upazila level data on outcome and explanatory variables are generated from the HIESs using appropriate population weights.

As noted earlier, productivity growth in agriculture is measured by growth in crop yield. The predominant crop in Bangladesh is rice/paddy, of which three different types (Boro, Aman and Aus) are grown.[12] The official source of agricultural statistics provides yield data at district level, and unfortunately there are no estimates at the upazila level.[13] The source of the yield data used in this paper is the community part of the HIES. We

[11] The sample sizes for HIES are 7,440 in 2000 10,080 in 2005 and 12,240 in 2010.

[12] High yielding variety of Boro rice now accounts for more than half of rice production (56%). Aman is the next important crop accounting for 44% of rice production. Yields of both of these varieties are much higher than Aus.

[13] These data are actually reported at old (and much larger) district level – there are about 20 old districts. With newly created districts, there are now 64 districts in Bangladesh. The source of these data are Statistical Yearbooks published by the Bangladesh Bureau of Statistics.

define rice yield per acre as the average of yields of Boro, Aman and Aus rice. The upazila (subdistrict) level yields are the average over villages surveyed within a upazila. Since the number of villages within a upazila are limited, the estimated yield may involve significant measurement error. We compared yield growth estimates from HIES aggregated to the district level to the corresponding estimates from the official agricultural statistics, and they show comparable growth during the decade of 2000. The yield estimates at the upazila (subdistrict) level used in this paper thus are useful as a measure of productivity.

Rainfall data are drawn from Bandyopadhyay and Skoufias (2012). The original data on rainfall come from the Climate Research Unit (CRU) of the University of East Anglia. The CRU reported estimates of monthly rainfall for most of the world at the half degree resolution from 1902 to 2009. The CRU estimation combines weather station data with other information to arrive at the estimates.[14] To estimate the sub-district (upazila/thana) level rainfall from the CRU data, Bandyopadhyay and Skoufias (2012) use area weighted averages.[15] Travel times to the metropolitan cities are computed using GIS software and the road network from mid-1990s. Data on flood prone areas are drawn from the Bangladesh water board database. All population variables are drawn from the population censuses.

Over the years, a number of larger upazilas were split to form new upazilas, thus increasing the total number of upazilas from 486 in 1990 to 507 in 2000 to 543 in 2010. We use upazila maps to identify the borders of upazilas over time and matched all upazilas

[14]Previous versions of the CRU data were homogenized to reduce variability and provide more accurate estimation of mean rain at the cost of variability estimation. The version 3.1 data is not homogenized and thus allows for better variability estimates. The estimates of rainfall near international boundaries are not less reliable as compared with those in the interior of the country, as the CRU estimation utilizes data from all the weather stations in the region.

[15]For example if an Upazila/thana covers two half degree grid cells for which CRU has rainfall estimates, then upzila/thana rainfall is estimated as the average rainfall of the two grid-cells, where the weights are the proportion of the area of the upazila/thana in each grid-cell. For details, please see Bandyopadhyay and Skoufias(2012).

in 2000 and 2010 to 1990 upazilas. The upazila level panel is defined using 1990 upazila boundaries. The number of upazilas in the sample used for econometric analysis is, however, smaller (355 upazilas with data for more than one year), as we drop upazilas located in the two largest metropolitan areas (Dhaka and Chittagong).

Table 1 provides the summary statistics for upazilas over the years. Consistent with the secular decline in agricultural employment in developing countries discussed in the literature on structural change, agricultural employment declined from 46 percent in 2000 to 41 percent in 2010. Within the farming sector, employment in agricultural daily labor registered a sharper decline than self-employment. A large proportion of the decline in agricultural employment has been absorbed in daily (unskilled) labor in the non-agricultural sector, and a smaller proportion in self-employment. Wages for agricultural labor increased substantially over time, with the growth of nominal wage equal to 8.9 percent per annum between 2000 and 2010. The annual average growth in real wage (deflated by CPI) is about 2.1 percent between 2000 and 2010.

The summary statistics in Table 1 also indicate substantial growth in rice yield between 2000 and 2010. Average rice yield per acre grew by an annual rate of 3.8 percent. This rate is consistent with about 3.7 percent growth in agricultural GDP during the same time.[16] There has been considerable expansion of irrigation during the decade as well - from 60 percent in 2000 to 68 percent in 2010. The estimated standard deviation (Table 1) shows that there are considerable variations in rice yields across upazilas. Per capita household expenditure also exhibited considerable growth about 3.5 percent per annum. Strong growth in per capita household expenditure is reflected in the substantial decline

[16]Crop agriculture accounts for 56 percent of agricultural GDP and rice is the single most important crop in Bangladesh not only as a subsistence but also as a cash crop.

in poverty during this time: the incidence of poverty declined from 48.9 percent in 2000 to 31.5 percent in 2010 (World Bank, 2013). Among the other variables, access to electricity by households improved considerably during the decade (6.3 percent annual growth rate). There is a decline in the proportion of urban households in our sample over the years which reflects higher growth of population in metropolitan cities compared with the other urban areas (rural towns).

(5) Empirical Results

In this section, we present the main empirical results along with some robustness checks. The main variables: wages, per capita expenditure, yield, and rainfall are expressed in logarithms, while the hired agricultural labor is measured as share of total employment. All regressions include upazila and year fixed effects. All standard errors are corrected for correlation in the error term within upazila.

(5.1) Rainfall and Agricultural Productivity

We begin with the evidence on the effects of rainfall variations on agricultural productivity. Table 2 reports the results from regressions where log of crop yield is regressed on log of rainfall after controlling for upazila and year fixed effects. Column (1) shows the results when no other explanatory variable is included in the regression. The specification in column (2) includes the full set of upazila level time-varying controls as discussed in empirical strategy section (section 3). All of the regressions show statistically and numerically significant impact of rainfall on rice yield which is consistent with a priori expectations. The estimated coefficients imply an increase in yield growth when there is a positive shock in rainfall over its mean level. This result is consistent with findings from a rich body of evidence accumulated by the agronomists and crop scientists that shows that rainfall is a major determinant of yield growth in rice in Bangladesh in the recent decades (see, for example, Sarkar et. al. (2012)).

While positive rainfall above the mean increases rice yield, for appropriate interpretation of the results, it is useful to understand whether this reflects only the impact of transitory weather shock on farming. While the rainfall variations across upazilas and over time are expected to affect the yield directly, they are also likely to affect long-term productivity differences by influencing investment in irrigation. The third column reports estimated effect of rainfall variations on the area irrigated in a specification with upazila fixed effects and other controls used in our main regressions. Thus the estimated coefficient shows the determinant of irrigation *expansion* over time. A positive and statistically significant coefficient on the rainfall variable in this regression indicates that irrigation expansion over our sample period has happened increasingly in areas with relatively higher rainfall.[17] Thus rainfall variable in our panel regressions captures not only transitory shock in agriculture but also the diffusion of modern technology in farming over time.[18] Note also that irrigation may also reduce risk by decreasing variability of yield, but may not affect the average yield if it does not lead to the adoption of modern rice varieties. The expansion of irrigation in Bangladesh allowed adoption of Boro rice whose yields are significantly higher than other rice types (Aman and Aus). This is confirmed in the results in Table 2 which shows that higher rainfall does increase yield significantly.

[17]Historically, irrigation is adopted first in the drier regions in Bangladesh resulting in a negative correlation between area irrigated and rainfall in the cross-section data. However, expansion of irrigated areas happened increasingly in high rainfall areas – as confirmed by our panel regression result.

[18]Note also that modern farming technology such as irrigation may also reduce risk by decreasing variability of yield even without increasing yields. That is not the case in Bangladesh. The expansion of irrigation in Bangladesh allowed adoption of Boro rice whose yields are significantly higher than other rice types (Aman and Aus). This is confirmed in the results in Table 2 which shows that higher rainfall does increase yield significantly.

Another issue in the IV interpretation of rainfall is that it may be capturing not only agricultural productivity shocks but also resulting price changes. In a completely segmented rice market at the upazila level, a rainfall shock would affect the equilibrium rice price through income effect. However rice market is the most developed and spatially integrated market in Bangladesh (see, for example, Golleti, Ahmed and Farid (1995), Hossain and Verbeke (2010)). In addition, we control for the distances to the main city markets, which would capture spatial price dispersion due to transport costs. The theoretical model assumes that rice price is pinned down by the international market, and available evidence on rice markets in Bangladesh clearly supports this assumption.

(5.2) Rainfall, Agricultural Productivity and Labor Market Outcomes

We start by presenting the regression results for wages for hired daily laborers employed in farming.[19] Consistent with proposition (1) of the theoretical model, the results in column (1) of Table 3 show a statistically significant and positive impact of rainfall on agricultural wages. This result suggests that the income of unskilled workers employed in agriculture, who are mostly landless poor people, gets a boost from higher agricultural productivity. The estimated coefficient implies that a one percent increase in rainfall increases agricultural wages by 0.46 percent. Our theoretical results imply that even when agricultural productivity increase has a significant positive effect on the wages of unskilled farm labor, hired labor in farming may increase or decrease depending on the relative shifts in the labor demand (due to productivity growth) and supply (due to reallocation of labor from home to market work).

[19]The number of observations for wage regression is slightly less (341 upazilas). This is because the wage data is trimmed by dropping 2.5% of observations in both upper and lower tails of the distribution. While such trimming is done to correct for coding mistakes. However, such trimming does not affect our result: if anything the estimated coefficient of rainfall is larger in the untrimmed data.

Column 2 of Table 3 reports the regression results for hired labor expressed as a proportion of total employment.[20] Before presenting the estimates, we note that according to the theoretical analysis presented above, if there is no home production and thus the total supply of labor is fixed, then agricultural productivity increase has a strong positive impact on wages, but does not have any impact on hired labor (see proof of proposition 2). In a more complete model with production of non-farm goods, there can be a *positive* response of hired agricultural labor even if there is no home production, because labor is reallocated from the non-farm sector through the labor market in response to a productivity shock in agriculture. The evidence in column 2 of Table 3, however, contradicts both of these predictions, because we find a significant decline in hired labor in agriculture in response to a positive rainfall shock. The evidence also indicates that rainfall has a statistically and numerically significant positive effect on the share of own-farming in total employment (column 3 in Table 3). This confirms that in response to a positive shock in agricultural productivity, households reallocate more labor to own farming.

As noted above, a negative effect on the hired agricultural labor is not consistent with a model if there is no home production and/or labor supply response. However, it is consistent with the case where labor deficit households respond more than labor surplus households to a wage change through adjustments in home production (in terms of parameters of the theoretical model, $\delta_k > \delta_h$).

However, one can argue that an alternative explanation for the observed effects on hired labor and wages can also be offered in terms of heterogeneity in technology of market goods instead of heterogeneity in home production. Consider the case where there is no labor

[20]The regression results are unaffected if shares are defined in terms of hours worked.

supply response (e.g. labor supply to market work is fixed) but there is heterogeneity in the technology of the locally produced market good (food) between the households. Suppose that the labor deficit households use mechanized technology for rice cultivation so that productivity shock has no impact on its labor demand. On the other hand, labor surplus household uses more labor intensive technology and a rise in agricultural productivity increases its labor demand. Such heterogeneity can lead to higher wages and lower hired labor as surplus households reallocate labor to own farming in response to agricultural productivity increase, and thus the supply of labor to the market goes down. It is however important to appreciate that if the labor market response is driven by reallocation within the market goods sector, then we should not observe any change in the total labor supply to market work. We present a formal test of this prediction later in the paper. We emphasize here that there are good reasons to suspect that such technological heterogeneity in food production cannot drive the behavior of wages and hired labor in the context of Bangladesh. Because the level of mechanization is low in Bangladesh and there is very little heterogeneity in the technology used in production of any particular variety of rice across the country.

We provide direct evidence below that a positive rainfall shock induces the households to increase total labor supply to market activities as measured by hours worked in column 4 of Table 3.[21] The dependent variable here is log of per capita hours spent on market work. The results indicate a statistically significant and positive impact of rainfall on hours spent on market work. This provides strong support to the conclusion that households allocate

[21]As in most households surveys in developing countries, HIESs have no data on time spent on home production over the time period considered here (2000-2010). We, however, have data on hours worked on market activities (including own farming). If households indeed reallocated labor from home activities to market work, then one would expect a rise in hours devoted to market work in response to agricultural productivity shock. From the information on employment and hours spent on each activity provided by the HIESs, we compute the per capita hours spent on market work.

more labor to market activities (as opposed to home production and/or leisure) in response to agricultural productivity shock and that observed effects of agricultural productivity increase on hired labor and wages are not simply due to reallocation of labor within market oriented activities due to heterogeneity in production technology utilized by households in food (rice) production.

The results presented so far confirms that agricultural daily wage increases with a positive rainfall shock. But there is a decline in hired labor in response to positive productivity shock. From the theoretical analysis a higher wage and a positive response in labor supply to market activities imply that we would expect a significant positive effect on household income. While data on wages are available in the HIES, these surveys unfortunately do not provide any reliable information on income from self-employment in agriculture and non-farm activities. Thus we cannot directly estimate the impact of positive agricultural productivity shock on village income. The surveys, however, provide good information on household consumption expenditure. In the absence of information on income from self-employment, we take per capita household expenditure as an indicator of household income and welfare. The regression result with log of per capita expenditure as the dependent variable is reported in column 5 of Table 3. The results show statistically significant and numerically large positive impact of rainfall shock on per capita expenditure. The coefficient estimate implies that a one percent increase in rainfall increases per capita expenditure by 0.25 percent.

The regression results suggest a decline in hired labor in response to rainfall shock. Since the poor are more likely to be dependent on hired labor, we check how rainfall shock affects their consumption poverty. The average per capita expenditure level of households belonging to the bottom 40 percent of expenditure distribution in a upazila is taken as a proxy for the welfare of the poorer section of population. The regression result with dependent variable as the log of per capita expenditure of households at the 40 percent of expenditure distribution is presented in column 6 of Table 5. The result indicates statistically significant positive effect of rainfall shock on per capita expenditure of these poorer households as well. The magnitude of the estimated coefficient (0.265) is slightly larger than that for the full sample (0.252) but they are statistically indistinguishable from each other. Though the amount of hired labor declines in response to rainfall shock, the resulting decline in income and expenditure of the poorer households are more than offset by an increase in wage, and hours worked in market activities and self employment.[22] As a result, agricultural productivity increase has a significant and positive impact on per capita expenditure by poorer households. The evidence in Table 5 suggests that the poor benefit equally from the positive rainfall shock as the non-poor.

(5.3) Robustness Check

The sample of upazilas used for estimation in Table 3 includes all upazilas outside the two metropolitan cities, and thus some upazilas which are fairly urbanized (significant proportion of urban households) are also included. A reader may wonder whether our results are affected if we restrict the sample to predominantly rural upazilas (less than half population in urban municipalities). The results shown in Table 4 indicate that the overall results regarding rainfall shocks impact on wage, hired labor, market work and per capita expenditure hold true in this restricted sample as well. It is especially reassuring that the

[22]A reduction in home production however leads to a decrease in utility from this particular source. Yet our results show that agricultural productivity increase leads to overall welfare gain due to shift of the agricultural production possibility curve outward.

results from this robustness check are remarkably close to the results reported in Table 3.

(5.4) Economic Significance

The estimated effects of rainfall variations on wage, and labor allocation between employment in own farming and hired labor in agriculture as reported in Table 3 provide strong evidence in favor of a model with significant labor supply response in market activities as households reallocate labor from home production. The evidence presented in Table 2 also establishes clear and strong links between agricultural productivity as measured by rice yield per acre and irrigation on the one hand and rainfall variations on the other. The rainfall shocks thus can be interpreted as shocks to the productivity parameter θ in our model. It is thus reasonable to interpret the results on the effects of rainfall variations as capturing largely the effects of agricultural productivity. As we noted in the empirical strategy section, our result can also be given an instrumental variables interpretation, which allows us to provide point estimates of the causal effects of agricultural productivity increase on the agricultural labor market.

Using the coefficient estimates in Tables 2 and 3, we compute the IV estimates of the impact of agricultural productivity on outcomes of our interest. The IV estimate for the effects of agricultural productivity on the wages of daily labor implies that a one percent increase in agricultural productivity (crop yield per acre) increases the wage for unskilled agricultural labor by about 0.93 percent, which is a substantial impact. A one percent increase in the productivity increases share of people engaged in own farming by about 1.4 percent, while it reduces the hired daily labor in agriculture by 1.5 percent.[23] The estimate

[23] While household may also draw labor out of non-farm activities and into own farming in response to agricultural productivity shock, our results show that bulk of the reallocation happens within agricultural activities– between own farming and hired labor (see columns 2 and 3 in Table 3).

for per capita expenditure implies that a one percent increase in agricultural yield increases per capita expenditure of all households by 0.5 percent and of poorer households by 0.52 percent. The implied causal effects of agricultural productivity growth on agricultural wages, labor reallocation to own farming and poverty are thus numerically substantial.

(6) Conclusions

This paper provides a theoretical and empirical analysis of the effects of agricultural productivity on the rural labor market and poverty using a upazila (subdistrict) level panel data set from Bangladesh. The focus is on the response of agricultural wage, and labor allocation between home production and agriculture (own farming and hired labor), and their implications for poverty measured in terms of per capita household consumption. The theoretical model emphasizes the role of sensitivity of labor allocation between home production and market activities and the importance of self employment in agriculture. The predictions from the theoretical analysis highlights the limitations of focusing on the effects of agricultural productivity change on the standard labor market indicators: wage and hired labor. The positive effects of a productivity increase on the wage rate may be muted if the labor supply response from home production is high enough. The effect on hired labor is not unambiguous, a higher agricultural productivity may even reduce the amount of hired labor in agriculture. Even when the impacts on both wage and hired labor are positive, the main margin of adjustment for many households may be between home production and own farming. The important point here is that one can have significant positive effect of agricultural productivity on household consumption through a positive response of labor hours devoted to market activities as opposed to home production, even if we see little or "perverse" effects on wage and employment through labor market (hired labor).

Following a large literature on the importance of rainfall shocks in agricultural productivity variations in Bangladesh, we exploit rainfall shocks (relative to the mean level) across upazila and over time to understand the effects of productivity increase on the wage, hired labor, total hours devoted to market activities, and household consumption (per capita). We use a two step empirical approach that focuses on the reduced form regressions of rainfall on the measure of productivity (rice yield per acre) and on the set of outcome variables noted above. The advantage of this approach is that we can test the theoretical predictions without imposing the exclusion restriction on rainfall required in an instrumental variables approach. The reduced form approach is credible given the evidence from a large literature that finds rainfall variations to have substantial effects on productivity (rice yield) in Bangladesh (see, for example, Sarkar et. al. (2012), Bhowmik and Costa (2012) and the references cited there in), which is also confirmed in our data. The evidence from the reduced form regressions show that a higher rainfall shock increases agricultural wages significantly, but reduces the amount of agricultural hired labor. The negative effect on hired labor is not consistent with our model if there is no home production from which households can reallocate labor in response to agricultural productivity increase. But existence of home production is only necessary, the negative response in hired labor also requires heterogeneity in marginal returns to labor in home production. The results on total labor supply to market activities show a statistically significant and numerically substantial positive impact of rainfall shocks. The evidence also indicates that a positive rainfall shock increases per capita consumption significantly, thus implying that agricultural productivity increase played an important role in poverty reduction achieved in the last two decades in rural Bangladesh (World Bank, 2013). We also provide point estimates of the causal effect of an increase in crop yield (rice) on the outcome variables by imposing exclusion restriction on rainfall in the outcomes regressions. We use upazila and year fixed effects, and include a set of carefully chosen variables to control for time varying heterogeneity to enhance the plausibility of the exclusion restriction. The IV estimates suggest that a one percent increase in crop yield increases agricultural wage by about one percent, and reduces the share of hired labor by more than one percent.

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Table 1: Summary Statistics

	2000		2005		2010	
	Mean	SD	Mean	SD	Mean	SD
Share of Employment in						
Self-farming	26.9%	18.2%	23.9%	17.0%	25.7%	17.5%
Agricultural Daily Labor	19.4%	16.5%	15.9%	14.0%	15.5%	13.2%
Self-Non-agriculture	19.9%	13.8%	22.9%	14.2%	20.9%	12.3%
Per Capita Real consumption (Taka)	812.51	349.96	889.83	317.14	1142.57	360.35
Agricultural Wage (taka)	66.90	49.16	56.70	24.01	158.05	68.25
Rice Yield (ton/acre)	0.95	0.11	1.01	0.13	1.35	0.46
Population in 1991	314630	148304	297031	147249	295322	144862
Proportion Urban	0.24	0.30	0.23	0.00	0.20	0.22
Proportion of household with electricity	0.32	0.32	0.40	0.31	0.51	0.31
Percent with irrigation	61.47	29.97	59.79	31.39	67.20	23.79
Proportion of workers with secondary or above education	0.14	0.08	0.14	0.07	0.15	0.07
Rainfall (mm)	1390.9	423.4	1635.8	382.2	1457.2	361.6

Table 2: Rice Yields, Irrigation and Rainfall

	Log(Rice Yield)		% of Area Irrigated
	(1)	(2)	(3)
Log(Rainfall)	0.376***	0.493***	24.17**
	(6.382)	(9.098)	(2.118)
Travel time to nearest large city		0.0005***	0.0199***
		(10.80)	(3.672)
Proportion of households with electricity		0.00718	8.296
		(0.269)	(1.616)
Share of urban population		-0.130*	4.502
		(-1.854)	(0.420)
Log(Population)		0.00754	0.237
		(0.368)	(0.0796)
Proportion with secondary or above education		1.291**	-212.4**
		(1.970)	(-2.492)
Log(population91)*trend		-0.0108	1.551
		(-0.728)	(0.710)
Floodplain*trend		0.00360	-3.066
		(0.256)	(-1.296)
Year and Upazila Fixed Effects	Yes	Yes	Yes
R-squared	0.509	0.623	0.084
Number of Upazilas	355	355	355

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3: Agricultural Productivity, Rainfall, Wages, Employment and Poverty

	Log(agricultural wage)	Employment in Agriculture		Log (per capita hours worked)	Log (per capita consumption)	Log (per capita consumption of the poor)
		Hired Labor	Own-farming			
Log(Rainfall)	0.458***	-0.124**	0.175***	0.209**	0.252**	0.265***
	(3.108)	(-2.373)	(3.510)	(2.442)	(2.503)	(2.973)
Travel time to nearest large city	-8.66e-05	-2.67e-05	2.23e-05	-0.000104**	0.000139**	8.76e-05
	(-1.150)	(-0.751)	(0.747)	(-2.278)	(2.199)	(1.535)
Proportion of households with electricity	0.0903	-0.180***	-0.0881**	0.196***	0.390***	0.300***
	(1.258)	(-6.647)	(-2.623)	(4.952)	(9.137)	(7.918)
Share of urban population	0.118	-0.00654	-0.0285	-0.0264	-0.0737	-0.0871
	(0.659)	(-0.158)	(-0.596)	(-0.381)	(-0.828)	(-1.002)
Log(Population)	0.156***	0.00429	0.0260*	0.0544**	0.0479*	0.0393
	(3.102)	(0.328)	(1.902)	(2.183)	(1.771)	(1.644)
Proportion with secondary or above education	-1.643	0.263	-0.440	-0.343	0.749	0.368
	(-1.019)	(0.640)	(-0.811)	(-0.454)	(0.788)	(0.462)
Log(population91)*trend	-0.0182	0.0259**	-0.0399***	0.00737	0.00298	0.0113
	(-0.658)	(2.210)	(-3.570)	(0.434)	(0.152)	(0.633)
Floodplain*trend	0.0362	0.00669	-0.0104	-0.0245	-0.0652***	-0.0611***
	(1.294)	(0.516)	(-0.860)	(-1.110)	(-2.992)	(-3.127)
Year and Upazila Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.814	0.150	0.094	0.175	0.507	0.570
Number of Upazilas	341	355	355	355	355	355

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Robustness Checks: Estimates from Predominantly Rural Sample (less than 50 percent population in urban municipalities)

	Log(agricultural wage)	Employment in Agriculture		Log (per capita hours worked)	Log (per capita consumption)	Log (per capita consumption of the poor)
		Hired Labor	Own-farming			
Log(Rainfall)	0.397***	-0.115**	0.209***	0.239**	0.296***	0.329***
	(2.684)	(-1.974)	(3.502)	(2.472)	(2.923)	(3.828)
Year and Upazila Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Full set of controls	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.819	0.156	0.091	0.189	0.522	0.589
Number of Upazilas	316	320	320	320	320	320

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1