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

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ABSTRACT

The rice yield and real agricultural wage in Bangladesh increased by 3.8 percent and 2.1 percent per annum respectively from 2000 to 2010. Over the same period, the share of hired labor in agriculture decreased from 19.4 percent to 15.5 percent. A focus of this paper is to understand if the observed changes in wages and hired labor are in part due to agricultural productivity growth as reflected in increasing rice yield. To estimate the effects of agricultural productivity, we take advantage of an Upazila (subdistrict) level panel data set from Bangladesh and exploit variations in rainfall across Upazilas and over time. We find that a positive rainfall shock has a significant positive effect on crop yields, wages, per capita household expenditure and labor supplied to market activities (including own farming). The effect on hired labor is, in contrast, negative and statistically significant. In a standard neoclassical model, higher agricultural productivity affects wages and hired labor through labor demand; a rightward (leftward) shift increases (reduces) both wages and the amount of hired labor. The finding of a negative hired labor response to agricultural productivity growth with a higher wage thus appears puzzling. We develop a model where heterogeneity in labor supply response due to differences in productivity in home goods production can lead to a decline in hired labor when agricultural productivity increases, even though the equilibrium wage increases. Since the poor in rural areas depend disproportionately on wage labor, a decline in hired labor may be interpreted by some as evidence of adverse effects on poverty and inequality. The theoretical analysis, however, shows that the poor benefit from agricultural productivity growth even when the labor supply responses result in a decline in hired labor.

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

JEL Classification: O13, J22, J43, Q10

(1) Introduction

The effects of agricultural productivity growth on rural poverty have been a topic of lively debate during the past couple of decades among development economists (see, among others, Datt and Ravallion (1998), Foster and Rosenzweig (2004), Datt and Ravallion (2011)).¹ While Datt and Ravallion(1998) find agricultural yield growth to be an important factor behind poverty reduction in India between 1960 and 1990, Foster and Rosenzweig (2004) report that agricultural productivity growth also increased inequality. In a standard model of the rural labor market, changes in agricultural productivity affect employment and wages by shifting the demand for labor. An early concern in the literature on the green revolution (Griffin (1974)) emphasized possible adoption of labor-saving technology such as tractors along with new varieties of rice and wheat, thus suggesting that the labor demand curve would shift to the left. The alternative view, substantiated by accumulated evidence over 1970s and 1980s, is that productivity growth due to high-yielding varieties of rice and wheat in fact increased the demand for labor. These alternative views yield sharp predictions about the effects of agricultural productivity growth: both wages and employment (and hired labor) increase (rightward demand shift) or decrease (leftward demand shift) in tandem. In this perspective, the effects of productivity growth on wages are sufficient to discriminate between the alternative views, which may explain the almost exclusive focus on wages in most of the literature, and the consequent neglect of any potential effects on labor supply and hired labor.

In Bangladesh, the rice yield and real agricultural wage increased by 3.8 and 2.1 percent annually between 2000 and 2010, respectively. The share of hired labor in agriculture decreased from 19.4 percent in 2000 to 15.5 percent in 2010. To the extent the observed changes in wages and hired labor are partly due to agricultural productivity growth (higher rice yield), the existing explanations that focus exclusively on the demand for labor fail to explain the evidence. In this paper, we make two contributions. First, we develop a more complete model where heterogeneity in the labor supply response to the wage plays

¹For recent literature surveys, see World Development Report (2008), and Schneider and Gugerty (2011).

an important role, and show that agricultural productivity growth may cause wages, and hired labor employment to move in the opposite directions. Second, we provide credible estimates of the effects of agricultural productivity growth on wages, hired labor and labor allocation between home goods production and market oriented activities. The evidence shows that higher rice yields in Bangladesh increase wages in agriculture, but reduces the amount of hired labor, thus contradicting the widely held demand shift views where they move in the same direction. The results are, however, consistent with the model developed in this paper which brings into focus the role played by heterogeneity in labor supply response.

Since the poor in rural areas depend disproportionately on wage labor, a decline in hired labor can be interpreted by some as evidence that agricultural productivity growth has had adverse effects on the poorest households in Bangladesh. Our theoretical and empirical analysis, however, shows that such an interpretation would be incorrect, as the decline in hired labor reflects the fact that households have more productive use of their labor in own farming. We also provide evidence that there is a positive effect of agricultural productivity growth on household per capita consumption, which strengthens the conclusion that the households benefit from agricultural productivity growth even though the prevalence of hired labor declines.

The focus on heterogeneous labor supply response is important in the context of developing countries where wage employment in rural labor markets is often limited (Rosenzweig (1988)), and a substantial amount of ‘surplus labor’ in the form of underemployed and unemployed family labor exists.² In many developing countries, poor households are poor because most of their labor endowment is employed in low-productivity home-based non-marketed activities such as foraging, child care, and food preparation, not because they are (openly) unemployed.³ When low-productivity home production is prevalent, the poverty

²For instance, Rosenzweig and Foster (2010) find that 20 percent of the rural labor force in India is ‘surplus’.

³The concept of home production we use is essentially that of Becker (1965) (for a recent discussion, see Heckman (2015)). One might argue that the absence of open unemployment in our model may overstate

impact of agricultural productivity may depend primarily on how the allocation of labor from home production to own farming and wage labor changes in response to agricultural productivity growth.⁴ The analysis in this paper highlights the potential pitfalls in drawing policy recommendations from piecemeal analysis that focuses solely on the labor market outcomes. Little or no response of wages to agricultural productivity growth does not necessarily imply no effects on poverty, since a substantial increase in labor supply to more productive agricultural activity can lead to significant reduction in poverty even at a constant wage rate.

To estimate the effects of agricultural productivity, we take advantage of an Upazila (subdistrict) level panel data set from Bangladesh, and exploit variation in rainfall across Upazilas and over time. We implement an approach that focuses on the effects of rainfall shocks in reduced form regressions on the outcome variables (wage, employment in own farming and in 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 theoretical predictions, which relies on the fact that spatial and temporal variation in rainfall 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 variation across Upazilas and over time (relative to the mean) as an instrument for crop yield (rice yield). The regressions include Upazila fixed effects to remove the time invariant unobserved spatial heterogeneity, and year fixed effects to wipe out the common price (international) and other macroeconomic shocks. To be as clinical as possible, we allow

the benefits of agricultural productivity growth. However, it is easy to check that a higher demand for labor due to the Green Revolution results in more hired labor and lower unemployment, *ceteris paribus*, in an efficiency wage model of unemployment (both nutrition-productivity (Mirrlees (1974), Stiglitz (1976)) and moral hazard (Shapiro and Stiglitz (1984)) variants). Thus a model with unemployment does not alter the conclusions regarding the welfare effects.

⁴This is more so in African countries where wage employment in agriculture and non-agriculture in rural areas is very limited (see Davis, Guisepe and Zezza (2014)). The reallocation of labor in response to agricultural productivity growth in the African case is between home production and own farming.

for time-varying direct impacts of these factors by including interactions of a flood-prone area dummy and travel time to metropolitan cities (Dhaka and Chittagong) with the time trend. We include an extensive set of control variables to account for time-varying direct effects of infrastructure and other area characteristics.⁵ Empirical estimation issues and the strategy to deal with them are discussed in detail in Section 2.⁶

The regression estimates reported later show that a positive rainfall shock has a significant (at the 1 percent level) *positive* effect on wages; a 1 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 at the 5 percent level; a 1 percent increase in rainfall reduces hired labor by 0.73 percent. The negative response of hired labor is not due to an increase in nonfarm employment; total agricultural employment remains nearly unchanged in response to a positive rainfall shock. Our results also indicate that households increase hours supplied to the market-oriented activities in response to a positive rainfall shock, thus providing additional evidence of reallocation of labor from home production. We include own farming and wage labor in ‘market-oriented activities’. When interpreted as instrumental variables estimates of the effects of productivity increase, the estimates show substantial impact of an increase in rice yield on wages, hired labor, and labor supply to the market activities.

We provide an intuitive graphical exposition of the main insight of our theoretical analysis to explain the apparently puzzling finding of a negative response of hired labor to a positive agricultural productivity shock. The negative response of hired labor is consistent with the case where labor reallocation from home production by labor deficit households is stronger than that by labor-surplus households in the initial equilibrium. The recent literature on the effects of agricultural productivity on rural labor markets mainly focuses on

⁵The rationale behind the choice of control variables is discussed in Section 2.

⁶It is worth emphasizing that while the 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)).

labor reallocation between agriculture and non-agricultural sectors while taking labor supply as fixed (Foster and Rosenzweig, 2004). There is also a long tradition of examining the economy-wide impacts of agricultural productivity growth using Computable General Equilibrium (CGE) models (for a review of the literature, see Schneider and Gugerty(2011)). Some of the CGE-based analyses consider the implications of surplus labor (e.g., Dorosh and Thurlow (2014)), but they do not explicitly model the labor market interactions that can give rise to surplus labor endogenously. In spirit, our analysis is perhaps closest to that of Fontana and Wood (2000). Fontana and Wood (2000) simulated the effects of trade policy changes (e.g., rise in import price of food, incentives provided to manufacturing, etc.) on female and male allocation of time among reproduction (child bearing and rearing), leisure and market activities, and on rural wages, using a Social Accounting Matrix (SAM). In response to an increase in imported food price, Fontana and Wood (2000) find that both women and men reallocate their labor from home production (reproduction and leisure) to market work – primarily in agriculture – and rural wages increase in the new equilibrium. In contrast with Fontana and Wood (2000), we make a distinction within employment in market activities between hired labor and self-employment in agriculture, and our focus is on the effects of improvements in agricultural productivity.

The rest of the paper is organized as follows. Section (2) develops a model of the rural economy that focuses on the implications of labor supply heterogeneity. The empirical strategy is discussed in section (3), followed by a description of data in Section (4). The empirical results as well as an intuitive diagrammatic explanation of the findings are discussed in section 5. The paper concludes in the final section.

(2) A Model of the Effects of Agricultural Productivity Growth on Rural Labor Market

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 ($L_k^0 < L_h^0$).⁷ The households produce two goods: food (agriculture) and a home good. The concept of home good we use is essentially that of Becker (1965) and consists of services that are primarily produced and consumed within the household. The archetypal home production includes food (meal preparation), children, and housing (Becker (1965), Heckman (2015), Fontana and Wood(2000)). The households also differ in a second dimension; they have access to different technologies for home good production.

Households consume three goods/services: a home good (d), and two market goods (food (f), a nonfarm good (m)). Both food and nonfarm goods are assumed to be internationally traded, and we take the food commodity as the numeraire. The assumption that both food and nonfarm 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.⁸ Assuming identical preferences, the utility function for households in the village is the following: $U = u(c_f, c_m) + u(c_d) = c_f^\varphi c_m^{1-\varphi} + \sigma c_d$, where c_f is consumption of food, c_m is consumption of the nonfarm good. The budget constraint can be stated as: $Y^F \geq c_f + P_m c_m + P_d^* c_d$, where P_m is the price of the nonfarm good, P_d^* is the shadow price of the home good, and the agricultural good is the numeraire, i.e., $P_f = 1$, and $Y^F = wL^0 + rA$ is the full income, with w denoting the village wage rate and r the rental rate for land.

(2.1) Production of the Home Good and Labor Supply to Market Work

The production function for the home good is assumed to display decreasing returns to scale: $Q_{di} = l_{di}^{\delta_i}$ for $i = h, k$ and $0 < \delta_i < 1$, where l_{di} is the amount of labor used in home good production by household i . The curvature of the home good production function thus differs across households, which turns out to be critical for the theoretical results below.

⁷A richer model, where households differ in land endowment and skilled labor, generates the same set of qualitative conclusions. We discuss this issue in the online appendix.

⁸The simplifying assumption that nonfarm goods are traded would apply to manufacturing. Many nonfarm services activities are non-traded and would respond to a change in the village income. Please see the discussion in the appendix.

The household's optimization problem can be simplified by imposing the condition that home good production and consumption be the same for a household in equilibrium. The optimization problem can be stated as

$$Max_{C_f, C_m, l_{di}} U_i = c_f^\varphi c_m^{1-\varphi} + \sigma c_{di} = c_f^\varphi c_m^{1-\varphi} + \sigma l_{di}^{\delta_i} \quad (1)$$

$$\ni w (L_i^0 - l_{di}) + rA = c_f + P_m c_m \quad (2)$$

To derive the budget constraint in equation (2), subtract wl_{di} from both sides of the full income budget constraint : $wL^0 - wl_{di} + rA = c_f + P_m c_m + P_{di}^* C_{di} - wl_{di}$. Now budget constraint (2) follows from noting that the shadow price of labor is w for all households, which along with the equality of the full budget constraint, implies that $P_{di}^* C_{di} = wl_{di}$.⁹ For notational parsimony, denote the money income as $Y_i = w (L_i^0 - l_{di}) + rA$.

The first order conditions can be derived as:

$$\sigma \delta l_{di}^{\delta_i-1} - \lambda w = 0 \quad (3)$$

$$\varphi c_f^{\varphi-1} c_m^{1-\varphi} - \lambda = 0 \quad (4)$$

$$(1 - \varphi) c_f^\varphi c_m^{-\varphi} - \lambda P_m = 0 \quad (5)$$

where λ is the Lagrange multiplier associated with budget constraint (2) above. Using equations (4) and (5) along with the budget constraint in equation (2), we derive optimal consumption for market goods as: $c_f = \varphi Y_i$, and $c_m = \frac{(1-\varphi)Y_i}{P_m}$.

Without a solution for optimal labor allocation to home goods, we do not know the value of market income Y_i . But we can use equation (4) to solve for λ as:

$$\lambda = \varphi c_f^{\varphi-1} c_m^{1-\varphi} = \varphi (\varphi Y)^{\varphi-1} \left[\frac{(1-\varphi)Y}{P_m} \right]^{1-\varphi} = \varphi^\varphi (1-\varphi)^{1-\varphi} P_m^{\varphi-1} = \hat{\lambda}$$

The marginal condition determining the optimal use of labor in home production can be

⁹The nonsatiation property of the utility function ensures that the full income budget constraint is satisfied as equality.

expressed as:

$$\sigma \delta_i l_{di}^{\delta_i - 1} = \hat{\lambda} w \quad \text{for } i = h, k \quad (6)$$

Equation (6) along with the budget constraint for the home good $P_{di}^* C_{di} = w l_{di}$ can be used to solve for the household-specific shadow price of the home good as $P_{di}^* = \frac{\sigma \delta_i}{\hat{\lambda}}$.

From equation (6), the amount of labor allocated to home production varies inversely with the wage. The supply of labor for market work can be written as:

$$L_i(w) = L_i^0 - l_{di}^* = L_i^0 - \left(\frac{\sigma \delta_i}{\hat{\lambda}} \right)^{(1-\delta_i)^{-1}}, \quad \text{with } L_i^w = \frac{\partial L_i}{\partial w} > 0 \quad \text{for } i = h, k \quad (7)$$

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.¹⁰ An exogenous rise in wage draws labor out of home production and into market work.¹¹

The model setup generates an upward sloping labor supply function for market work. As noted earlier, the model is general enough that the home good can also be interpreted as leisure, but avoids the awkward possibility of a backward bending supply curve of labor in a low-income village economy.¹² An alternative model is where there is (open) unemployment, and 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 pro-

¹⁰Note that if we also add heterogeneity in the demand function so that $\sigma_i \neq \sigma_j$, the main results of the paper go through.

¹¹Heterogeneity in δ not only implies that the curvature is different, but also that the productivity (output for a given level of labor) differs, except for the case when $l_{di} = 1$.

¹²It is not realistic to expect that people would like to consume more 'leisure' when managing three meals a day is a challenge.

duction in our model.¹³ Our definition of labor supply to market work corresponds to the 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 is 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, in contrast, consists of services (e.g. meal preparation, child care or simply leisure) which are consumed at home and not usually sold in the market.

The equilibrium in the farm economy is characterized by land and labor market clearing and an external balance condition (export food and import nonfarm good at world prices). By Walras law, we can ignore the external balance condition. Wages are thus determined by the labor market clearing condition, and the rental rate for land is determined by the total supply of land.

(2.2) Labor Demand for Market Work in Agriculture

For workers in the farm economy, there are three employment options: (i) home production, (ii) family-owned farm, (iii) other farms.¹⁴ Households produce food using land and labor with the same constant returns (CRS) technology. The food output by each household can be described as: $Q_{fi} = \theta F(A, l_{fi}) = \theta (A^\alpha l_{fi}^{1-\alpha})$ 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

¹³The model outlined here does not allow for the possibility of labor market rigidity that may arise from socio-cultural practices (e.g., purdah restriction), which in turn lock household workers (especially female) into low-productive home production activities. Welfare gain from moving workers from home production to market work would be much higher in the presence of such rigidities. However, overall conclusions of the model regarding home versus market work are valid under that alternative scenario as well.

¹⁴Note that we do not include production of the nonfarm good in the model. For an extended model that focuses on production of nonfarm goods and allows for heterogeneity in skill and nontradability of the nonfarm good, please see Foster and Rosenzweig (2004), and Emran and Shilpi (2014).

same technology and prices, and labor demand for each household can be derived as:

$$l_{fh} = l_{fk} = \theta^{\frac{1}{\alpha}} A \left[\frac{(1-\alpha)}{w} \right]^{\frac{1}{\alpha}} \quad (8)$$

Total labor demand in farming is then:

$$l_f = l_{fh} + l_{fk} = 2(1-\alpha)\Delta_1\theta^{\frac{1}{\alpha}}\left(\frac{1}{w}\right)^{\frac{1}{\alpha}} \quad (9)$$

Where $\Delta_1 = A[1-\alpha]^{\frac{1-\alpha}{\alpha}}$.

(2.3) Effects on Wage

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

$$l_f = l_{fh} + l_{fk} = 2\Delta_2\theta^{\frac{1}{\alpha}}\left(\frac{1}{w}\right)^{\frac{1}{\alpha}} = L_h(w) + L_k(w) \quad (10)$$

where $\Delta_2 = \Delta_1(1-\alpha)$.

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 is the response of labor supply to the wage, the lower is the change in the equilibrium wage rate.*

(2.4) Response of Hired Labor

Since the 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:

$$\begin{aligned}
l^w &= \Delta_2 \theta^{\frac{1}{\alpha}} \left[\frac{1}{w} \right]^{\frac{1}{\alpha}} - L_k(w) \\
&= \Delta_2 \theta^{\frac{1}{\alpha}} \left[\frac{1}{w} \right]^{\frac{1}{\alpha}} - \left[L_k^0 - \left(\frac{\sigma \delta_k}{\lambda w} \right)^{(1-\delta_k)^{-1}} \right]
\end{aligned} \tag{11}$$

Proposition 2: *In a rural economy where there is heterogeneity in households' endowment 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 result:*

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

The intuition behind the results in proposition (2) reflects the fact that a higher 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. Proposition (2) shows that when L_k^w is quite large, the induced supply response of deficit households could reduce hired labor.¹⁵ It is important to emphasize that although the amount of hired labor can decrease in response to a productivity increase in agriculture, the wage response is always positive. In the above framework, if there are no adjustments at the margin of home production (which includes leisure), and thus $L_h^w = L_k^w = 0$, the impact of an increase in agricultural productivity on hired labor is zero. 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

¹⁵For a 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.

reliable information on home production activities.

Although the response of hired labor to an agricultural productivity shock is ambiguous a priori, and thus can lead to misleading conclusions about the poverty impact of agricultural productivity changes, 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: See the appendix.

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 in agricultural activity. In other words, the income and poverty impacts 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. This result is important because it underscores the importance of looking at the effects on both price (wage) and quantity (total labor supplied to the market, not only hired labor) adjustments 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 examine the impact of agricultural productivity on employment and

wage, we use the following regression specification:

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

where i indexes the outcome variables (e.g., the share of employment in an activity, wages, per capita household consumption expenditure, etc.), j denotes the Upazila, O_{ijt} is the outcome variable, and ρ_j and ρ_t denote the effects of Upazila- and year-specific factors, respectively. Our focus variable is θ_{jt} 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 presents some difficulties. Unobserved Upazila characteristics that are 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; Upazilas that are 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. In general, it is 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 (ρ_j in regression equation (1) above) to remove the effects of all time invariant but unobserved Upazila characteristics. The year fixed effects (ρ_t) control for any macroeconomic and international shocks (including commodity price shocks) that may have affected both agricultural productivity and the outcomes of interest.¹⁶

In the empirical analysis, we follow a two-step procedure. First, a reduced form regres-

¹⁶The year fixed effects will control for any general equilibrium effect common to all households (e.g., prices).

sion of an outcome variable (for example, wage) on the instrument, and second, a reduced form regression of the productivity measure (yield per acre) on rainfall are estimated. 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 rainfall differences as variation in the parameter θ . Finally, given the evidence that rainfall significantly increases rice yield, the reduced form estimates of rainfall on wages, employment, and consumption are useful, because they provide evidence on the *existence* of causal effects of higher crop yield that are not subject to weak instrument bias (Chernozhukov and Hansen(2008)).¹⁷ We estimate the following reduced form regressions:

$$O_{ijt} = \rho_j + \rho_t + \pi_1 R_{jt} + \Pi_1 Z_{jt} + \varepsilon_{ijt} \quad (13)$$

$$V_{jt} = \eta_j + \eta_t + \pi_2 R_{jt} + \Pi_2 Z_{jt} + v_{jt} \quad (14)$$

where R_{jt} is the annual rainfall in Upazila j and V_{jt} is the measure of productivity. In the empirical estimation, the 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 the outcome variables. Rainfall shock for an 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 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

¹⁷We emphasize again that the main results of this paper do not depend on the exclusion restriction on rainfall imposed in the IV interpretation; what we need is that rainfall affects productivity significantly.

in the measure of agricultural productivity (Griliches (1963)). We use an instrumental variable approach to remedy the attenuation bias and 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 widely considered a credible instrument for agricultural yields (Foster and Rosenzweig (2004), Adhvaryu, Chari and Sharma (2013), Rajan and Ramcharan (2010), Bruckner (2012)).¹⁸

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 nonfarm 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 agricultural wages. Flooding and destruction may also lead to a negative correlation between rainfall and nonfarm labor demand if it disrupts production activities. The positive and negative effects of the nonfarm sector on the agricultural labor market may, in some cases, largely offset each other. One can use a floodplain 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 urban markets can be used to account for such heterogeneity. Travel time also captures the spatial variations in the prices of tradable goods, because it is a reliable proxy for the transport and other marketing costs. Since

¹⁸Rainfall 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 variation for identifying information in many applications, rainfall variations are probably the most natural candidate for exogenous variations in agricultural productivity, especially in developing countries.

travel time and the 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 the time trend in the regressions. We also include the proportion of households in a Upazila with electricity as a control.¹⁹ Availability of electricity may foster nonfarm activities that are less susceptible to the weather, and may have a 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 the 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. It is, however, important to appreciate 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 the agricultural productivity changes affect the population in a village.

A final issue for the empirical specification is that rainfall is expected to have a significant 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 the survey years of 2000, 2005, and 2010. The HIESs are based on a nationally representative sample of households.²⁰ These surveys are conducted primarily for the estimation of poverty incidence and thus provide reliable information on house-

¹⁹Our empirical results are robust to controls for agglomeration economies such as the share of an area in total industry employment in 1991.

²⁰The sample sizes for the HIESs are 7,440 in 2000, 10,080 in 2005, and 12,240 in 2010.

hold economic activities, per capita household expenditure, and regional price deflators. Upazila-level data on the outcome and explanatory variables are generated from the HIESs using appropriate population weights.²¹

Productivity growth in agriculture is measured by the growth in crop yield. The predominant crop in Bangladesh is rice/paddy, of which three different types (Boro, Aman, and Aus) are grown.²² The official source of agricultural statistics provides yield data at the district level; unfortunately, there are no estimates at the Upazila level.²³ The source of the yield data used in this paper is the community part of the HIES. We 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 the villages surveyed within an Upazila. Since the number of villages within an Upazila are limited, the estimated yield may involve significant measurement error. We compare the yield growth estimates from HIES aggregated to the district level to the corresponding estimates from the official agricultural statistics. It is reassuring that they show comparable growth rates during the decade of 2000s. 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

²¹The HIES data are collected over a year to cover all of the agricultural seasons. However, the officially released data do not identify the dates when the data were collected. Thus, we cannot distinguish between the agricultural seasons. The rice yield data are the average of Boro and Aman. Focusing only on Aman crop reduces the sample size substantially. The yields of Boro and Aman crops correlate rather strongly and positively. The HIESs do not have enough information on the winter crops, such as wheat, oilseeds, and pulses. This is, however, not a concern for the paper, as rice is the most widely grown main crop in Bangladesh.

²²The 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 that of Aus.

²³These data are actually reported at the old (and much larger) district level – there are about 20 old districts. With the 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.

other information to arrive at the estimates.²⁴ To estimate the subdistrict (Upazila/thana) level rainfall from the CRU data, Bandyopadhyay and Skoufias (2012) use area weighted averages.²⁵ Travel times to metropolitan cities are computed using GIS software and the road network from the 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, several 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 used Upazila maps to identify the borders of Upazilas over time, and matched all Upazilas in 2000 and 2010 to 1990 Upazilas. The Upazila-level panel is defined using the 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 the Upazilas located in the two largest metropolitan areas (Dhaka and Chittagong).

Table 1 provides the summary statistics for the 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. In 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) was about 2.1 percent between 2000 and 2010.

²⁴Previous 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 are not homogenized and thus allow 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.

²⁵For 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).

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.²⁶ There was a 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 were 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 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. Wages, per capita expenditure, yield, and rainfall are expressed in logarithms, while 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 the log of crop yield is regressed on the 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

²⁶Crop agriculture accounts for 56 percent of agricultural GDP and rice is the single most important crop in Bangladesh, not only as a subsistence crop, but also as a cash crop.

in the empirical strategy section (Section 2). All 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 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)).

Although 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 shocks 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 the 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 happened increasingly in areas with relatively higher rainfall.* Historically, irrigation was 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 over the years happened increasingly in the high rainfall areas, resulting in a *positive* correlation – as confirmed by our panel regression result. Thus the rainfall variable in our panel regressions captures not only transitory shocks in agriculture, but also the diffusion of modern technology in farming over time. Irrigation may also reduce risk by decreasing the variability of yield, without raising the average yield, if it does not lead to the adoption of modern rice varieties. The expansion of irrigation in Bangladesh allowed the 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 the 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 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 the spatial price dispersion due to transport costs. Moreover, available evidence on rice markets suggests that the rice price in Bangladesh is indeed pinned down by the international market.

(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.²⁷ The result in column (1) in Table 3 shows a statistically significant and positive impact of rainfall on agricultural wages. This suggests that the income of unskilled workers employed in agriculture, who are mostly landless poor, gets a boost from higher agricultural productivity. The estimated coefficient implies that a 1 percent increase in rainfall increases agricultural wages by 0.46 percent. Column 2 in Table 3 reports the regression result for hired labor expressed as a proportion of total employment.²⁸ The evidence in column 2 in Table 3 shows a significant decline in hired labor in agriculture in response to a positive rainfall shock: the estimated coefficient of log of rainfall deviation from its average level over the years is -0.124, with t-statistic=2.37. 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) (coefficient=0.175 with t-statistic=3.51). As both shares are expressed in terms of total employment, the net increase in agriculture's share in total employment is small (0.051). Indeed the coefficient

²⁷The number of observations for wage regression is slightly less (341 Upazilas). This is because the wage data are trimmed by dropping 2.5% of observations from both the upper and lower tails of the distribution. This trimming is done to correct for coding mistakes. However, such trimming does not affect our results, if anything, the estimated coefficient of rainfall is larger in the untrimmed data.

²⁸The regression results are unaffected if the shares are defined in terms of hours worked.

is not statistically different from zero (t-statistic=0.69). This confirms that in response to a positive shock in agricultural productivity, households reallocate more labor to own farming, while the overall share of agriculture in total employment remains nearly the same.

(5.3) Understanding the Decline in Hired Labor in Agriculture: Heterogeneity in Labor Supply Responses

In a canonical neoclassical model with positively sloped labor supply, an increase in agricultural productivity shifts the labor demand curve to the right, and thus results in an increase in agricultural wage and labor employed in agriculture. In an extended model with production of nonfarm goods, as in Foster and Rosenzweig (2004), and in the open economy version of the Matsuyama (1999) model, there can be a *positive* response of hired labor as well as of own farm labor, because labor is reallocated from the nonfarm sector through the labor market in response to a positive productivity shock in agriculture. In the closed economy version of the Matsuyama model (1999), employment in agriculture could decline as labor moves into manufacturing due to the demand effects of agricultural productivity growth, yet it cannot explain the differential responses of own and hired labor in agriculture found in the empirical analysis above.

We provide a graphical exposition of the insight behind the theoretical results in section (2) above, which provide a consistent explanation for the empirical results. We start with the simple case where the difference in the endowments of land and labor is the only source of heterogeneity in the model. Given the same production technology for home production, the labor supply function is upward sloping and symmetric. In other words, the labor supply curves for households h and k are parallel to each other, but labor supply of $h(L_h^S)$ lies to the right of that of $k(L_k^S)$, as shown in Figure 1. The demand curve for labor is downward sloping given the constant returns technology in agricultural production. Since there is no heterogeneity in land endowments, both households face the same demand curve for labor (labeled L_k^D and L_h^D respectively).²⁹ The equilibrium wage is determined at w^* ,

²⁹The aggregate demand and supply are the summation of demand and supply across households, respectively. While the labor market equilibrium is determined at the intersection of aggregate demand and

where the aggregate demand and supply curves intersect each other. Household k uses w^*A amount of own labor, and AB amount of hired labor on its farm, whereas household h uses CD on its own farm and sells BC to household k . The amount of hired labor is thus equal to $AB = BC$. Note also that at equilibrium, household level demand curve bisects the horizontal distance between the two labor supply curves and amount of hired labor is equal to half this distance. This allows us to use household level demand and supply curves to examine the impacts of an increase in agricultural productivity on wage, own employment and hired labor in farming.

Now consider a positive shock to agricultural productivity. The increase in agricultural productivity shifts the household level labor demand curve parallel to the right to $L_j^{D'}$. The new equilibrium wage rate is determined at the level where new demand curve bisects the horizontal distance between the two labor supply curves. Since the labor supply curves are parallel to each other, the distance between them are the same at all different wage levels. In other words, in this symmetric case, the amount of labor hired by household k -which is labor-deficit due to its smaller labor endowment – is still equal to $DE = AB$ which is in turn equal to $EF = BC$ – the amount supplied by labor surplus household h . In the new equilibrium, while wage rate and total labor supply increase in response to a positive shock to agricultural productivity, there is no change in the amount of hired labor.

Consider the case where production technology for home good varies across households. Specifically, we assume that elasticity of home production with respect to labor to be higher for labor-deficit households, resulting in a labor supply curve which is flatter, and hence more elastic. Accordingly, the labor supply curve of household k is flatter than that of household h in Figure 2. Because of the difference in the slopes of the supply curves, the horizontal distance between them decreases with an increase in wage rate. As before, the initial equilibrium wage rate w^* is determined at the level where demand curve bisects the horizontal distance between the two supply curves. The hired labor in the equilibrium is half the distance between A and C . We consider an outward and parallel shift in household

supply curves, we omit those curves from the graph to reduce clutter.

level demand curve due to productivity increase. At the new equilibrium, the amount of hired labor is equal to half the distance between D and F . Because labor supply curve L_h^S is steeper than L_k^S , and new equilibrium wage rate is higher, it follows that $DE < AB$. In other words, amount of hired labor decreased in the new equilibrium. In the opposite case, where L_h^S is flatter than L_k^S , hired labor will increase in response to agricultural productivity increase.

As shown in Figures 1 and 2, the effects of a positive agricultural productivity shock depend on the relative shifts in the labor demand (due to productivity growth) and supply responses of labor surplus and labor-deficit households (due to reallocation of labor from home to market work). An increase in wages due to higher agricultural productivity induces both deficit and surplus households to reallocate labor away from the home production to the market work, where market work is defined to include all employment in agriculture (own farming plus hired labor). A decline in hired labor in the face of an increase in wage can result when the labor-deficit households reallocate labor from home production to the market work at a faster rate than the labor surplus households. Heterogeneity in the production technologies of home goods between the labor surplus and labor deficit households is thus the key parameter that determines the differential supply responses of these households. In addition to explaining the empirical evidence of a decline in hired labor and an increase in agricultural wages, it is clear from Figures 1 and 2 that an increase in the agricultural productivity will be associated with an increase in total labor supply to market work. This prediction is important for discriminating among the competing hypotheses explaining the decline in hired labor (please see the discussion in section 5.4 below).

(5.4) Alternative Explanations

One can argue that an alternative explanation for the observed effects of agricultural productivity on hired labor and wages can be offered in terms of heterogeneity in the technology of market goods instead of heterogeneity in home production. Consider the case

where there is no labor 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 the productivity shock has no impact on their labor demand. On the other hand, labor surplus households use more labor intensive technology, and a rise in agricultural productivity increases their labor demand. Such heterogeneity can lead to higher wages and lower hired labor as surplus households reallocate labor to own farming in response to an increase in agricultural productivity, 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 activities, then we should not observe any change in the total labor supply to market work. 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. This is 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 (see column 4 in Table 3).³⁰ The dependent variable here is the 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 more labor to market activities (as opposed to home production and/or leisure) in response to agricultural productivity shocks, and that the observed effects of a higher agricultural productivity on hired labor and wages are not simply due to reallocation of labor within market oriented activities due to heterogeneity in production technology

³⁰As in most household 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 the households indeed reallocated labor away from the home activities to market work, as in the model of section (2), then one would expect a rise in hours devoted to market work in response to the agricultural productivity shock. From the information on employment and hours spent on each activity provided by the HIESs, we compute per capita hours spent on market work.

utilized by households in food (rice) production.

Another possibility is that the income effect of a positive productivity shock increases the demand for non-traded nonfarm services (Engel curve effect), and the sectoral share of employment in agriculture declines as a result. A reallocation of labor from agriculture to nonfarm activities thus may constitute an additional mechanism through which agricultural productivity growth affects wages and employment in agriculture. The evidence, however, contradicts such a mechanism. First, the coefficients of rainfall in the hired labor and self-employment regressions nearly cancel each other out, suggesting no significant change in agriculture's overall share in employment. A formal test also confirms this; the coefficient of rainfall in total agricultural employment share is positive, but numerically small (0.05), and statistically insignificant, with a p-value of 0.69. This result shows that the decline in hired labor in farming is not due to workers leaving agriculture and joining nonfarm activities. If anything, the labor supply to agriculture increases in response to a positive productivity shock.

(5.5) Rainfall, Agricultural Productivity, and Poverty Outcomes

The results presented so far show that the daily wage in agriculture increases with a positive rainfall shock, but there is a decline in hired labor. How does household income respond to the agricultural productivity shock? 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 nonfarm activities. Thus, we cannot directly estimate the impact of a positive agricultural productivity shock on the 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 results, with log of per capita expenditure as the dependent variable, are reported in column 5 in Table 3. The results show a statistically significant and numerically large positive impact of rainfall shock on per capita expenditure. The coefficient estimate implies that a 1 percent increase in

rainfall increases per capita expenditure by 0.25 percent.

Since the poor are more likely to be dependent on labor income from the market, we check how a rainfall shock affects their consumption poverty. The average per capita expenditure level of households belonging to the bottom 40 percent of the expenditure distribution in an Upazila is taken as a proxy for the welfare of the poorer section of the population. The regression results for the log of per capita expenditure of households at the 40 percent of expenditure distribution are presented in column 6 in Table 3. The results indicate a statistically significant positive effect of a rainfall shock on the 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. Although the amount of hired labor declines in response to a rainfall shock, this is not a bad news, as the decline reflects the fact that they allocate labor to more productive own farming, and get higher wages for the labor they still sell to the market. As a result, the poor benefit equally from the higher productivity in agriculture as the non-poor.

(5.6) Robustness Check

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

(5.7) Economic Significance

The estimated effects of rainfall variations on wages and labor allocation between 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 as households reallocate labor away 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. 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 results can also be given an instrumental variables interpretation, which allows us to provide point estimates of the causal effects of higher agricultural productivity 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 the outcomes of interest.³¹ The IV estimate for the effects of agricultural productivity on the wages of daily labor implies that a 1 percent higher agricultural productivity (crop yield per acre) increases the wage for unskilled agricultural labor by about 0.93 percent, which is a substantial impact. A 1 percent higher productivity increases the share of people engaged in own farming by about 1.4 percent, while it reduces the hired daily labor in agriculture by about 1.5 percent.³² The estimate for per capita expenditure implies that a 1 percent increase in the agricultural yield increases the per capita expenditure of an average household by 0.50 percent and of the 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 an Upazila (subdistrict) level

³¹The IV estimates are not reported separately, because one can recover them by dividing the reduced form estimate in the outcome equation by the reduced form estimate in the productivity equation (i.e., the first stage of 2SLS). For a discussion, see for example, Angrist and Pischke (2009).

³²While the households may also draw labor out of nonfarm activities and into own farming in response to an agricultural productivity shock, our results show that the bulk of the reallocation happens within the agricultural activities— between own farming and hired labor (see columns 2 and 3 in Table 3).

panel data set from Bangladesh. The focus is on the response of agricultural wages, 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.

Following Chernozhukov and Hansen (2008), we use a two-step empirical approach that relies on the reduced form regressions of rainfall on the measure of productivity (rice yield per acre) and on the set of outcome variables (wages, hired labor, total hours devoted to market activities, and household per capita consumption). The advantage of this approach is that we can test the theoretical predictions without imposing any exclusion restrictions on rainfall required in an instrumental variables approach.

The evidence from the reduced form regressions shows that a higher rainfall shock increases agricultural wages significantly, but reduces the amount of hired labor in agriculture. The evidence cannot be explained in a traditional model of the rural economy with no heterogeneity in labor supply responses of the households, although the households differ in land and labor endowments. Using a simple model where the households vary in their labor supply response to wage, because of the differences in the technology of home production, we show that the amount of hired labor can decrease after a positive productivity shock in agriculture. This happens when the labor supply curve is flatter (more elastic) for a labor-deficit household (net buyer) compared with that of a labor surplus (net seller) household. The existence of home production is only a necessary, but not sufficient, condition for explaining the negative response of hired labor to a productivity increase; it also requires heterogeneity in the marginal returns to labor in home production, and consequently in the labor supply.

The estimates of the effects on total labor supply to market activities show a statistically significant and numerically substantial positive impact of rainfall shocks. This evidence favors an explanation of the negative response of hired labor based on heterogeneity in home production over alternative explanations based on nonfarm production or heterogeneity in farming technology. The empirical evidence also indicates that a positive rainfall shock increases per capita consumption significantly, thus implying that the agricultural pro-

ductivity 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 the exclusion restriction on rainfall in the outcomes regressions. The IV estimates suggest that a 1 percent increase in crop yield increases agricultural wages by about 1 percent, reduces the share of hired labor by more than 1 percent, and increases per capita expenditure by 0.50 percent.

Appendix

Proof of Proposition 1

The market clearing condition in equation (10) in the text can be used to derive the following result:

$$\frac{\partial w^*}{\partial \theta} = \frac{2\Delta_2\theta^{\frac{1-\alpha}{\alpha}}\left(\frac{1}{w^*}\right)^{\frac{1}{\alpha}}}{\alpha(L_h^w + L_k^w) + 2\Delta_2\theta^{\frac{1}{\alpha}}\left(\frac{1}{w^*}\right)^{\frac{1+\alpha}{\alpha}}} > 0 \quad (15)$$

The first part of proposition (1) follows from the fact that the denominator in equation (15) 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 $L_h^w + L_k^w$).

Proof of Proposition 2

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

$$\frac{\partial l^w}{\partial \theta} = \frac{1}{\alpha} \left(\Delta_2\theta^{\frac{1}{\alpha}-1} \left[\frac{1}{w} \right]^{\frac{1}{\alpha}} \right) - \left(\frac{1}{w} \frac{\partial w}{\partial \theta} \right) \left\{ \frac{1}{\alpha} \left[\Delta_2\theta^{\frac{1}{\alpha}} \left[\frac{1}{w} \right]^{\frac{1}{\alpha}} \right] + \left(\frac{1}{1-\delta_k} \right) \left(\frac{\sigma\delta_k}{\lambda w} \right)^{(1-\delta_k)^{-1}} \right\} \quad (16)$$

The first term in the right hand side of equation (16) 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.

Substituting for $\left(\frac{\partial w^*}{\partial \theta}\right)$ from equation (15) above into the equation for $\frac{dl^w}{d\theta}$ (i.e., equation (16)) and rearranging terms we get the following:

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

Now note that

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

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 $\delta_h < \delta_k$.

Proof of Proposition 3

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

$$Y = 2\theta^{\frac{1}{\alpha}} \Delta_1 \left\{ \frac{1}{w} \right\}^{\frac{1-\alpha}{\alpha}}$$

Where $\Delta_1 = A[1-\alpha]^{\frac{1-\alpha}{\alpha}}$ 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 (15) for $\frac{\partial w^*}{\partial \theta}$ and rearranging terms, we have the following:

$$\frac{dY}{d\theta} = \frac{Y \left[\left(2\Delta_2 \theta^{\frac{1}{\alpha}} \left(\frac{1}{w}\right)^{\frac{1}{\alpha}} \right) + L_h^w + L_k^w \right]}{\theta \left(2\Delta_2 \theta^{\frac{1}{\alpha}} \left(\frac{1}{w}\right)^{\frac{1}{\alpha}} \right) + \alpha \theta [L_h^w + L_k^w]} > 0 \quad (17)$$

It is easy to check from equation (17) above, the increase in income is higher when the labor supply responses of the households are higher.

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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 Self-Non-agriculture	19.4%	16.5%	15.9%	14.0%	15.5%	13.2%
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*** (6.382)	0.493*** (9.098)	24.17** (2.118)
Travel time to nearest large city		0.0005*** (10.80)	0.0199*** (3.672)
Proportion of households with electricity		0.00718 (0.269)	8.296 (1.616)
Share of urban population		-0.130* (-1.854)	4.502 (0.420)
Log(Population)		0.00754 (0.368)	0.237 (0.0796)
Proportion with secondary or above education		1.291** (1.970)	-212.4** (-2.492)
Log(population91)*trend		-0.0108 (-0.728)	1.551 (0.710)
Floodplain*trend		0.00360 (0.256)	-3.066 (-1.296)
Year and Upazila Fixed Effects	Yes	Yes	Yes
R-squared	0.509	0.623	0.084
Number of Upazilas	355	355	355

Standard errors are clustered at upazila level. 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*** (3.108)	-0.124** (-2.373)	0.175*** (3.510)	0.209** (2.442)	0.252** (2.503)	0.265*** (2.973)
Travel time to nearest large city	-8.66e-05 (-1.150)	-2.67e-05 (-0.751)	2.23e-05 (0.747)	-0.000104** (-2.278)	0.000139** (2.199)	8.76e-05 (1.535)
Proportion of households with electricity	0.0903 (1.258)	-0.180*** (-6.647)	-0.0881** (-2.623)	0.196*** (4.952)	0.390*** (9.137)	0.300*** (7.918)
Share of urban population	0.118 (0.659)	-0.00654 (-0.158)	-0.0285 (-0.596)	-0.0264 (-0.381)	-0.0737 (-0.828)	-0.0871 (-1.002)
Log(Population)	0.156*** (3.102)	0.00429 (0.328)	0.0260* (1.902)	0.0544** (2.183)	0.0479* (1.771)	0.0393 (1.644)
Proportion with secondary or above education	-1.643 (-1.019)	0.263 (0.640)	-0.440 (-0.811)	-0.343 (-0.454)	0.749 (0.788)	0.368 (0.462)
Log(population91)*trend	-0.0182 (-0.658)	0.0259** (2.210)	-0.0399*** (-3.570)	0.00737 (0.434)	0.00298 (0.152)	0.0113 (0.633)
Floodplain*trend	0.0362 (1.294)	0.00669 (0.516)	-0.0104 (-0.860)	-0.0245 (-1.110)	-0.0652*** (-2.992)	-0.0611*** (-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

Standard errors are clustered at upazila level. 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*** (2.684)	-0.115** (-1.974)	0.209*** (3.502)	0.239** (2.472)	0.296*** (2.923)	0.329*** (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

Standard errors are clustered at upazila level. Robust t-statistics in parentheses

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

Figure 1: Equilibrium in the Hired Labor Market: Impacts of an outward shift in Labor Demand, Symmetric Labor Supply Response Case

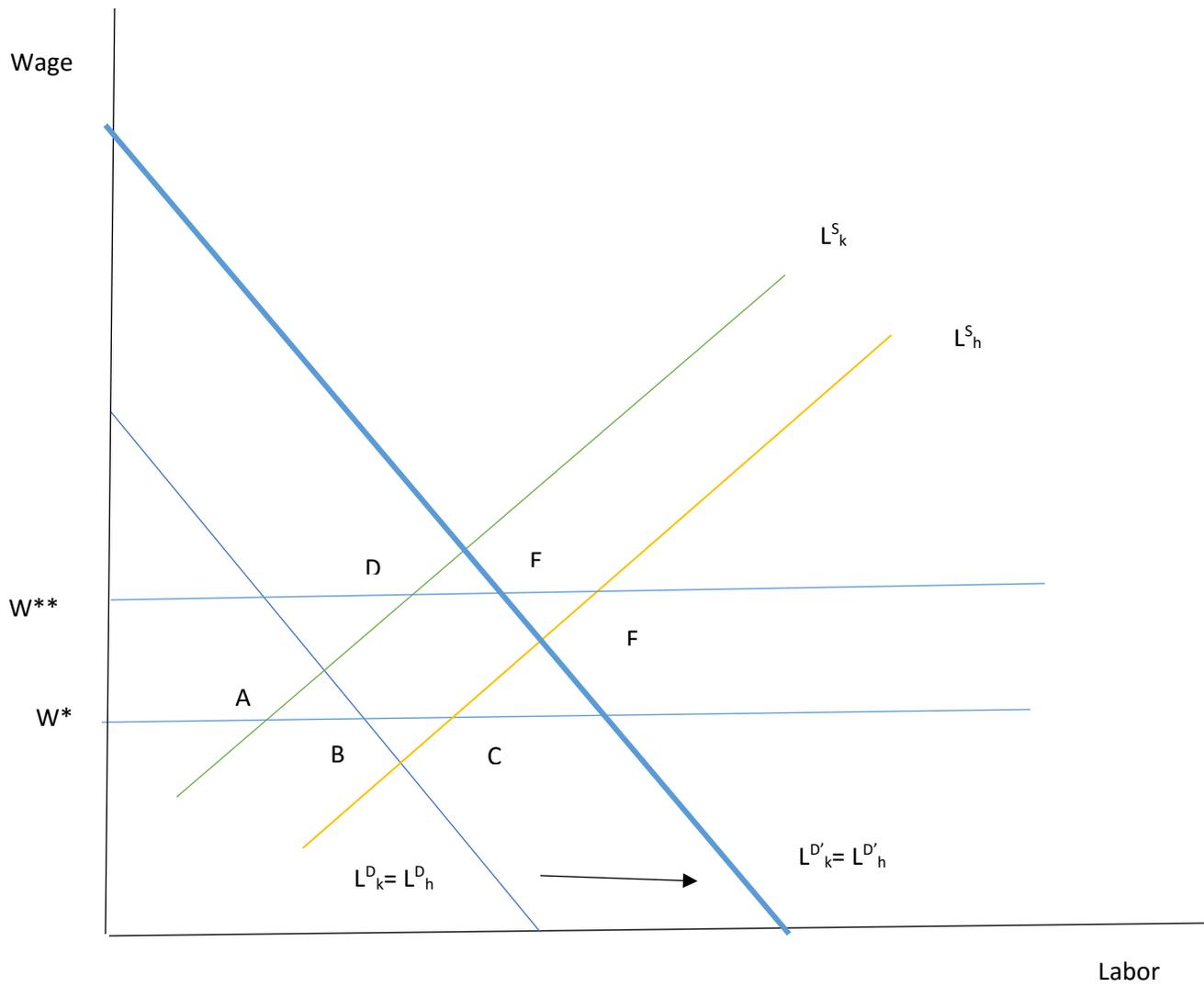
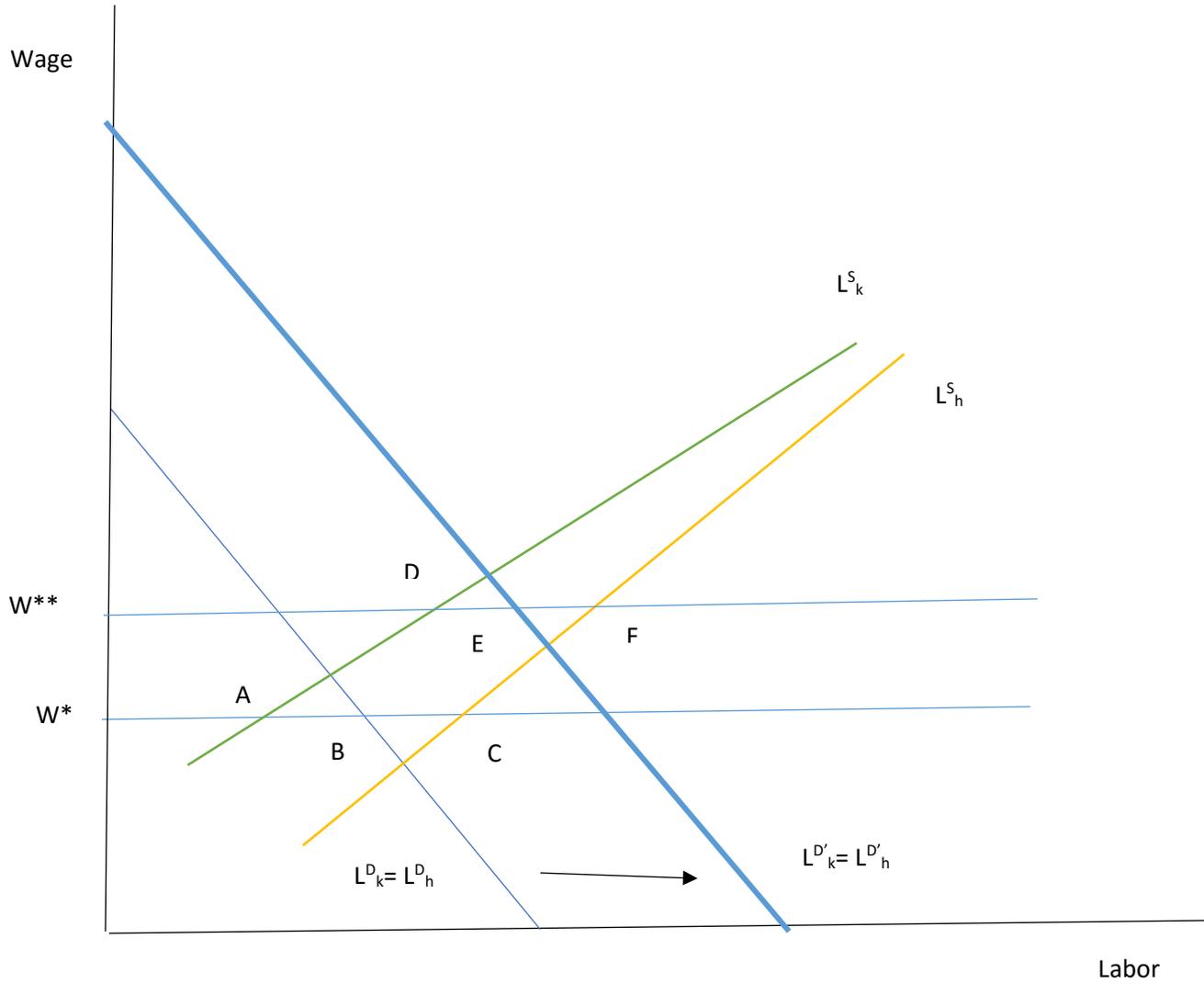


Figure 2: Equilibrium in the Hired Labor Market: Impacts of an outward shift in Labor Demand, Asymmetric Labor Supply Response Case



Not for Publication: Online Appendix to the Theoretical Model

(1) The Concept of Home Production

The concept of home production we use is essentially that of Becker (1965) and consists of services that are primarily produced and consumed within the household. The archetypal home production include food (meal preparation), children, and housing (Becker (1965), Heckman (2015), Fontana and Wood(2000)). The home goods are neither “food” nor “cash crops” in the sense of de Janvry et al (1991). They define cash crops as crops that are not consumed by the household, and produced solely for the market. In Bangladesh context, only tea crops can be called cash crops, even jute is not a cash crop according to their definition, as households consume part of it, even though most of it is sold. Tea is not produced by farmers, and the importance of jute production has gone down steadily in last 35 years. The households usually produce rice or vegetables to sell in the market, which we subsume under food crop. Also note that in our model, there is only one crop (rice) which is a food staple. But it is not appropriate to call it a subsistence crop, because the rice market is very well-developed. The subsistence farming in this case can be thought of as only those households that do not participate in the market as they fall in the transaction cost band (household specific missing market a la de Janvry et al (1991). But such cases are likely to be a very small proportion, because most of the households in rural Bangladesh participate in the market (either as a net seller or buyer). The home production in our model is nontraded.

(2) Implications of Heterogeneity in Land Endowments

For the sake of simplicity and given the focus on labor market, the model developed in the paper focuses on the heterogeneity in labor endowments, and assume that the land endowment to be same across households. Given the constant returns technology in the production of food, what is needed for hired labor market to exist in our model is heterogeneity in labor to land ratio. In other words, the main results remain intact under the alternative assumption

that the labor endowments of households are the same but their endowments of land differ. In particular, we would assume that household k has more land than household h . This is equivalent to the assumption that household k is relatively labor deficit and household h labor surplus. The rest of the analysis will then remain the same as described in the main text.

An interesting case is where some households are functionally landless (landholding too small) as is common in rural Bangladesh. To take an extreme example, suppose household h owns no land. An increase in labor demand and hence wages in response to a positive agricultural productivity shock will increase labor supply of household h . In this case, we cannot have an equilibrium where hired labor decreases and wages increase in response to a positive agricultural productivity shock. This case is, however, equivalent to the assumption that $\delta_h > \delta_k$ in our model. Our model is thus more general in the sense that it is able to identify conditions under which one can observe different responses of hired labor (increase, decrease or no change) in response to agricultural productivity changes.

(A.6) Implications of Nonfarm Production in the Village

Since our empirical analysis focuses on the labor allocation within the farming sector (between self employment and hired labor), the theoretical model abstracts away from nonfarm production in the village. We also assume that the nonfarm good consumed by the households is imported from the outside of the village at a parametric price, which allows us to abstract from the demand side influences. While developing a model with nonfarm activities under different technologies and different trading statuses is beyond the scope of this paper, we can draw useful intuitions from the existing models on this topic.¹ First, consider the case where the non-farm activity is non-traded and produced under decreasing returns to scale (DRS) technology. Then this activity looks just like the home goods sector in our model. An increase in the agricultural productivity will lead to a decrease in employment in non-farm activities in the village, in this case. How the increase in employment in agriculture is distributed between

¹A more detailed model is developed in Emran and Shilpi (2014).

hired labor and self-employment will be determined again by the differences in the technology of home production between households. Second, consider the other extreme example, where the non-farm activity is traded, and the demand linkage is no longer in play. As shown in Foster and Rosenzweig (2004), the increase in the rural wage implies a decline in employment in nonfarm in this case. Again, the labor share of agriculture increases, and its reallocation between self employment and hired labor is determined by technologies in home production. In the intermediate case, where the nonfarm good is non-traded and produced under constant returns, employment in agriculture and nonfarm changes proportionately (Foster and Rosenzweig, 2004). Finally, in addition to being non-traded and produced under constant returns, if the income elasticity of nonfarm good is very high (more than 1) and that of food low, the labor allocation to non-farm may increase in response to agricultural productivity growth (Emran and Shilpi, 2014). To see this in a simple setting, consider the polar case, where the income elasticity of demand is such that all additional income from agricultural productivity gains is spent on nontraded non-agricultural services. This assumption maximizes the impact of agricultural productivity on nonfarm services. Also, assume that there is no impact on the demand for labor in agriculture (which is similar to the assumption that the production function in agriculture is Leontief, an extreme assumption nonetheless). Under these extreme assumptions, one can find labor to reallocate from farming to non-farm. Yet, without introducing some types of heterogeneity in the labor supply responses, one cannot explain the reallocation of hired vs. self-employment within the farming sector. Even when these extreme assumptions are valid, one should observe a decline in share of labor employed in agriculture. It affects only the labor reallocation between farm and non-farm, not necessarily between the hired labor and self employment in agriculture. As we see from the different scenarios discussed above, household level heterogeneity in the production of home goods and endowment of resources (labor relative to land) are essential for generating implications of agricultural productivity change for reallocation of labor within the agricultural sector.