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Factor Endowments, Wage Growth, and Changing Food Self-Sufficiency

Evidence from Country-Level Panel Data

Keijiro Otsuka

Yanyan Liu

Futoshi Yamauchi

Markets, Trade and Institutions Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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AUTHORS

Keijiro Otsuka, National Graduate Institute for Policy Studies

Professor, Development Economics

otsuka@grips.ac.jp

Yanyan Liu, International Food Policy Research Institute

Research Fellow, Markets, Trade and Institutions Division

Futoshi Yamauchi, World Bank

Senior Economist

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ABSTRACT

Asian countries have witnessed a sharp increase in real wage as a result of rapid economic growth and structural transformation in recent years. Using a country level panel data from 1980 to 2010, this paper examines the effects of real wage increase on Asian agriculture that traditionally used family labor intensively on small farms. The empirical evidence supports our hypothesis that an increase in real wages, along with absorptions of labor into nonagricultural sectors, has been inducing the substitution of labor by machines in agriculture. However, this process is less successful in the countries that are constrained by their small operational land sizes, resulting in lowered land productivity. We also demonstrated that dynamic changes in yield are an important determinant of food self-sufficiency ratio. The above findings imply that in the near future, Asian agriculture can face a challenge in maintaining domestic food production. Given the large size of consumer demands in the region and its increasing trend, the future path of Asian agriculture could be a significant constraint on the global food supply–demand balance.

Keywords: Asian economic transformation, cereal self-sufficient ration, machine use, farm size

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1. INTRODUCTION

It has been increasingly recognized that rapidly growing Asia is becoming both a driving force of economic growth in the world and also a source of uncertainty in the global food economy due to its increasing importation of grains. Economic growth, urbanization, and transformation of the economic structure in Asia have been the fastest in the world. This trend has not only released poverty burdens from rural areas by absorbing labor into nonagricultural sectors but also altered food and labor demand–supply balances in the region.

Historically, family labor tends to be more intensively used on smaller farms in the absence of efficient labor markets, which in turn results in an inverse relationship between farm size and crop yield (Feder 1985). In fact, Asian agriculture has been dominated by labor-intensive small farms mainly relying on family labor. However, such an inverse relationship could be altered with a rising wage growth, creating potentially significant effects on the efficiency of small-scale farming in Asia and eventually on the global food economy. Although this issue has long been observed and often studied in developing-country agriculture (Berry and Cline 1979; Benjamin and Brandt 2002; Foster and Rosenzweig 2011a, 2011b), no macro cross-country evidence has been provided, and implications for global food supply–demand have not been discussed. In this paper, we use country-level panel data to analyze dynamics of changes in productivity, labor, and machine use (and their substitutability) by explicitly focusing on the role of farm size.

Our hypothesis may be sketched as follows. An increase in real wages increases the production cost of a labor-intensive farming system and thereby decreases comparative advantage in agriculture based on the labor-intensive production methods widely observed in many parts of Asia. To restore comparative advantage, at least partially, farm size expansion and large-scale mechanization must take place so as to save high-cost labor, as observed in the United States over the 1930–70 period (Kislev and Peterson 1982). However, an introduction of large-scale mechanization is difficult in the presence of rigidities in land reallocation. This pressure to save labor is not serious in areas that have abundant land, for example, in Latin American countries, because of the ease of expanding farm size and introducing large machinery to save labor. An increase in purchasing power (real wages) also increases the demand for livestock products as well as feedgrains, which, coupled with increasing inefficiency of small-scale farming, likely leads to a decrease in the self-sufficiency ratio of foodgrains in Asia.

Otsuka (2013) pointed out that since land markets are imperfect, major inefficiency in the allocation of farmland will be bound to arise in Asia, in which inefficient small farms and efficient large farms coexist. Foster and Rosenzweig (2011a, 2011b) also showed some evidence to support the Otsuka’s argument in India. Using household panel data from Indonesia, Yamauchi (2012a) recently showed that when real wages increase in Indonesia, farmers with large holdings tend to acquire more lands by renting in land and also tend to install machines.

The paper is organized as follows. The next section lays out a model that clarifies our theoretical insights. Section 3 describes the empirical framework and data. Empirical results are summarized in Section 4. Section 5 concludes.

2. MODEL

In this section we lay out a simple model that characterizes some key features of agricultural producer behavior when facing changes in real wage and human capital accumulation in the economy. Our model, nested in the standard agricultural household model (Singh, Squire, and Strauss 1986), incorporates (1) labor supply to nonagricultural sectors, (2) wage as a function of human capital, (3) imperfect substitution between family and hired labor, and (4) complementarities between land and capital (machines).

We begin with a static setting. The producer maximizes utility from consumption c and leisure l , $u(c, l)$ under the standard assumptions, subject to the producer's budget and time allocation constraints:

$$\begin{aligned} c &\leq \theta F(\bar{A}, K, \phi L^f, L^h) - w(\bar{h})L^h - p_k K + w(\bar{h})(1 - \phi)L^f \\ l + L^f + s(L^h) &\leq T, \end{aligned}$$

where $\theta F(\bar{A}, K, \phi L^f, L^h)$ is a production function using land $\bar{A}$, capital (machines) K , family labor ϕL^f , and hired labor L^h . Parameter θ is technical change. The household decides total family labor supply L^f and then allocates it to own-farm and nonfarm work (determined by the share ϕ). We assume that the producer needs to spend some time to supervise hired labor, captured by $s(L^h)$, which is increasing in L^h .

Therefore, family and hired labor are not perfectly substitutable. Owned land is assumed to be equally distributed among farmers:

$$\bar{A} = A/N,$$

where A is the total land endowment in the economy and N is the number of farmers. Factors incur cost with respective factor prices: labor wage $w(\bar{h})$ and machine price p_k . Wage is an increasing function of the average human capital, $\bar{h}$. We assume that land has greater complementarities with machines than does labor, that is, $\frac{\partial^2 F}{\partial K \partial A} \gg \frac{\partial^2 F}{\partial L \partial A} \simeq 0$ or ≤ 0 under certain regions of $\bar{A}$. Thus the marginal product of machines increases with land, but that of labor could decrease or be unaffected.

The first-order conditions are derived as follows (the second-order conditions are satisfied under the standard assumptions):

$$\begin{aligned} c: u_c - \lambda &= 0, \\ l: u_l - \mu &= 0, \\ K: \theta F_K - p_k &= 0, \\ L^h: \lambda [\theta F_{L^h} - w(\bar{h})] - \mu s'(L^h) &= 0, \\ L^f: \lambda [\theta \phi F_{L^f} + w(\bar{h})(1 - \phi)] - \mu &= 0, \text{ and} \\ \phi: \theta F_{L^f} - w(\bar{h}) &= 0. \end{aligned}$$

From the conditions for family labor supply L^f and labor allocation ϕ , we have

$$w(\bar{h}) = \frac{\mu}{\lambda} = \frac{u_l}{u_c}.$$

The condition for hired labor L^h is rearranged as

$$\theta F_{L^h} = w(\bar{h})[1 + s'(L^h)].$$

Due to the supervision time, the marginal cost for hired labor is higher than the market wage $w(\bar{h})$. Thus, unless it is necessary to hire labor, the household will use its family labor. Note that we assume the same wage for hired labor and nonfarm family labor (this assumption can be relaxed to introduce a premium in nonagricultural sectors and a gap in human capital between agricultural laborers and farm households,

which induces a division of labor: a greater supply of family labor to nonfarm pursuits while using hired labor on-farm).

The marginal rates of substitution and transformation are

$$\frac{F_K}{F_{L^f}} = \frac{p_k}{w(\bar{h})}, \frac{F_K}{F_{L^h}} = \frac{p_k}{w(\bar{h})[1+s'(L^h)]}, \text{ and } \frac{F_{L^f}}{F_{L^h}} = \frac{1}{1+s'(L^h)} < 1.$$

Machines are substituted for hired labor first since the latter has a higher marginal cost due to the supervision time required in production. Moreover, hired labor is engaged in simple tasks in practice, which can be done by machines. When $w(\bar{h})$ increases, the household aims to save labor (or supply its labor to nonagricultural sectors, or both), but the complementarity between machines and land dictates the substitutability between labor and machines. The use of machines tends to increase, but the marginal productivity of machines depends on landholding size. Similarly, when p_k decreases, the same mechanics hold. In sum,

$$w(\bar{h}) \uparrow \Rightarrow K \uparrow \text{ more if } \bar{A} \text{ large } (F_K \text{ large as } \frac{\partial^2 F}{\partial K \partial A} > 0) \text{ and}$$

$$p_k \downarrow \Rightarrow K \uparrow \text{ the same condition holds.}$$

The decision functions (K, L^h, L^f, ϕ) are functions of $(\bar{A}, p_k, w(\cdot), \bar{h}, \theta)$. Parameter θ is technical change, but in the above model, it is indistinguishable from the price of the agricultural commodity produced in $F(\cdot)$, normalized as unity. The price is a function of the demand-and-supply balance, so we include per capita gross domestic product (GDP) y as part of the exogenous factors, that is, $(\bar{A}, p_k, w(\cdot), \bar{h}, \theta; y)$. The observable endogenous variables from the macroeconomic series are

$$\frac{Y}{A} = g^1(\bar{A}, p_k, w(\cdot), \bar{h}, \theta; y),$$

$$\frac{L}{A} = \frac{\phi^{L^f+L^h}}{A} = g^2(\bar{A}, p_k, w(\cdot), \bar{h}, \theta; y), \text{ and}$$

$$\frac{K}{A} = g^3(\bar{A}, p_k, w(\cdot), \bar{h}, \theta; y).$$

In the empirical analysis, we linearly approximate and estimate the above functions. For its dynamic version, see Yamauchi (2012b).

In the next section we describe our empirical framework and the empirical implementation of our hypothesis tests on the basis of the above agricultural household model.

3. DATA AND EMPIRICAL METHOD

Our empirical analysis relies on country-level panel data from 1980 to 2010. We first estimate three equations on agricultural production (machine use, labor use, and yield) to test the hypotheses formulated by the theoretical model. Then we estimate the self-sufficiency ratio (SSR) of cereals as a function of factors on the demand and supply sides. The key factor in the SSR equation is yield, which is affected by real wages and landholdings.

For the three equations on agricultural production, the dependent variables are machine use per hectare, labor input per hectare, and yield per hectare, respectively. The key explanatory variables include average landholdings per household, gross domestic product (GDP) per capita, real wage rate of agricultural labor, and average years of schooling in the population aged 15-64. We use agricultural wage rate to proxy for unskilled labor cost, and we use average years of schooling in ages 15-64 to proxy for the country's human capital.¹

These data are from a number of sources. Agricultural production data are retrieved from FAOSTAT (FAO 2012). We calculate average yield per hectare for cereals by dividing the total cereal output by total harvest area. Machine use per hectare and labor per hectare are computed by dividing the total number of agricultural tractors in use and the total economically active population in agriculture, respectively, by total area of agricultural land. The average landholdings are from the World Census of Agriculture. This dataset covers 125 countries in total. However, most of the countries have available data for only one or two years. Real GDP per capita is collected from the World Bank Indicators data bank.

The wage data of the agriculture sector are mainly from the LABORSTA database (ILO 2012) of the International Labour Organization (ILO). LABORSTA provides wage rate and total employment by economic activity. We compute agricultural wage as the weighted average over the sectors of agriculture, hunting, forestry, and fishing, using total employment by these sectors as weights. For a few Asian countries where the ILO data are missing, we resort to the individual countries' national statistical bureaus to supplement the missing data as far as possible.² The human capital data are from the Barro-Lee dataset (Barro and Lee 2010), which provides average years of schooling for different age ranges and the corresponding population for each country. We compute the average years of schooling for the population aged from 15 to 64. Barro-Lee data (Barro and Lee 2010) are available every five years. We interpolate the variable for every year by linear projection.

The empirical model is specified as below:

$$y_{it} = \alpha_i + z_{it}\beta_1 + l_i * z_{it} \beta_2 + D\{l < \bar{l}\}_i * z_{it} \beta_3 + D\{l < \bar{l}\}_i * l_i * z_{it} \beta_4 + m_{it}\gamma + Yr_t\delta + \varepsilon_{it}, \quad (1)$$

where i indexes country and t indexes year. y_{it} is logarithm of the dependent variables, machine use per hectare, labor input per hectare, and yield per hectare. z_{it} is the vector of real wage of agricultural labor and average years of schooling for the age 15-64 population. l_i is average landholdings for country i . For the countries with more than one year's data available on landholdings, we use the year closest to 1980 for consistency. $D\{l < \bar{l}\}_i$ indicates landholdings' being lower than a critical value, $\bar{l}$. m_{it} is other control variables including logarithm of per capita GDP and its square term. α_i is country-specific effects, and Yr_t represents year dummies. We use fixed-effects linear regression to estimate equation (1).

We interact landholdings with z_{it} to allow the partial effects of unskilled wages and human capital to vary by landholdings. Furthermore, we expect these partial effects to be nonlinear in landholdings. For example, farms with landholdings lower than some critical value are likely to rely exclusively on family labor while larger farms have to use hired labor. To capture the nonlinearity, we include the interaction terms $D\{l < \bar{l}\}_i * z_{it}$ and $D\{l < \bar{l}\}_i * l_i * z_{it}$. The parameters of interest are the

¹ We do not have a good indicator for real capital price, so it is omitted in the empirical model.

² These supplemental data include Thailand 2001–08; Vietnam 2007, 2009–10; and Pakistan 2007–08.

β s. The partial effect of real wages for countries with larger average landholdings (characterized by $l_i > \bar{l}$) is $(\beta_1 + l_i\beta_2)$. And $(\beta_1 + \beta_3 + l_i(\beta_2 + \beta_4))$ is the partial effect of real wages for countries with smaller average landholdings (characterized by $l_i < \bar{l}$). The parameters of β_2 and $(\beta_2 + \beta_4)$ indicate how the partial effects of real wages change with landholdings for the two types of countries.

The SSR equation is specified as

$$SSR_{it} = \alpha_i + \beta_1 \ln(GDP)_{it} + \beta_2 \ln(GDP)_{it}^2 + \beta_3 \ln(yield)_{it} + \beta_4 \ln(yield)_{it}^2 + \beta_5 \ln(pop_density)_{it} + Yr_t\delta + \varepsilon_{it}, \quad (2)$$

where SSR_{it} is SSR of cereals, which is computed as

$$SSR = \frac{Production\ quantity}{production\ quantity + import\ quantity - export\ quantity};$$

$\ln(GDP)_{it}$ is logarithm of real GDP per capita; $\ln(yield)_{it}$ is logarithm of yield per hectare of cereals; and $\ln(pop_density)_{it}$ is logarithm of population density computed as total population divided by total area of arable land. While GDP per capita is demand factor, population density indicates the number of consumers fed by one hectare of agricultural land. Yield is the supply-side factor, through which the landholdings and real wages play a role in affecting a country's SSR.

4. RESULTS

We estimate the three agricultural production equations using fixed-effects linear regression. The results for the machine use equation are reported in Table 4.1. Besides the variables discussed earlier, we include price of imported machines and average value of machine stock (which equals total net value of machinery over total number of agricultural tractors) in the right-hand side of the equation to control for the capacity and quality of the agricultural tractors in use.

Table 4.1—Estimation results of the machine use equation, dependent variable being the logarithm of number of agricultural tractors used per hectare, 53 countries, 1980–2007

	(1)	(2)	(3)	(4)
Ln GDP	0.868** (2.06)	-0.490 (-1.10)	0.419 (0.92)	0.455 (1.01)
Ln GDP, squared	-0.0744*** (-3.12)	-0.00251 (-0.10)	-0.0500* (-1.96)	-0.0577** (-2.28)
Ln agricultural wage	0.0979*** (4.19)	0.173*** (5.93)	0.224*** (7.09)	0.175*** (3.34)
Low landholdings * Ln ag wage			0.427 (0.77)	0.403*** (4.29)
Ln landholdings * Ln ag wage		-0.0715*** (-4.93)	-0.101*** (-6.45)	-0.0756*** (-3.16)
Low landholdings * Ln landholdings * Ln ag wage			0.446 (1.38)	0.381*** (4.76)
Average years of schooling (age 15–64)	0.0731*** (4.11)	0.0493*** (2.81)	0.116*** (5.63)	0.132*** (5.44)
Low landholdings * average years of schooling			-0.0914 (-1.33)	-0.0964*** (-3.27)
Ln landholdings * average years of schooling		-0.0310*** (-5.51)	-0.0619*** (-8.73)	-0.0669*** (-7.59)
Low landholdings * Ln landholdings * average years of schooling			0.0350 (0.78)	0.0356 (1.64)
Ln price of imported machines	0.00803 (0.92)	0.0101 (1.19)	0.0163* (1.96)	0.0147* (1.79)
Ln average value of machine stock	-0.211*** (-2.93)	-0.162** (-2.30)	-0.197*** (-2.84)	-0.211*** (-3.06)
Year dummies	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes
Number of observations	716	716	716	716

Source: Authors' estimation.

Notes: GDP = Gross domestic product. t-statistics are in parentheses. * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Ln landholdings is demeaned by the sample mean. Low landholdings indicates landholdings ≤ 2 ha/holding in Model (3) and landholdings ≤ 5 ha/holding in Model (4).

We estimate four models with different sets of explanatory variables. Models 3 and 4 are the full model as described in equation (1). Model 3 uses a cutoff point of 2 hectares per holding for the dummy variable $D\{l < \bar{l}\}_i$, while Model 4 uses a cutoff point of 5 hectares. For Model 1, we have significantly negative coefficients of the two wage indicators (agricultural wage and human capital), suggesting a substitution effect between machine and labor inputs. Surprisingly, in Model 2, the interaction of landholdings and the two wage indicators are both negative, suggesting that machine use with larger landholdings is less responsive to wage increase than smaller holdings. In Models 3 and 4, we further interact the indicator of having small landholdings with the interactions of landholdings and the two wage indicators.

To facilitate interpretation of the results from Model 3,³ we compute the mean partial effects (MPEs) of wage and human capital for smaller and larger farms, as reported in the first panel of Table 4.2. The derivatives of the partial effects with respect to average landholding are also reported in the same table to show how the partial effects change with landholdings. The MPE of agricultural wage is positive for countries with both small and large holdings, consistent with the results from Models 1 and 2 of Table 4.1. However, the MPEs in countries with small holdings are smaller than those in countries with larger holdings, pointing to a lower substitution effect between machinery and labor for smallholding countries. The results also suggest larger-holding farmers in the countries with average landholdings lower than 2 hectares are more responsive to an increase in agricultural wages than are smallholders in these countries. These results are consistent with the model prediction. However, among land-sufficient countries (defined as those having average landholdings larger than 2 hectares), the substitution effect is decreasing with average landholdings. This puzzling result perhaps reflects the failure of using the number of tractors in stock to capture actual machine use. When the mechanization level is already high, an increase in labor cost will likely promote the use of machines with higher capacity rather than use of more machines. It appears that average value of machine stock does not adequately control for the effects of quality of machineries.

Table 4.2—Mean partial effects of wage indicators and their corresponding derivatives with respect to landholdings on machine use, labor use, and yield

	Average landholdings < 2 ha		Average landholdings > 2 ha	
	MPE	$\partial \text{PE} / \partial \text{landholdings}$	MPE	$\partial \text{PE} / \partial \text{landholdings}$
Machine use equation				
Agricultural wage	0.048 (0.58)	0.344 (1.07)	0.156*** (-4.00)	-0.101*** (-6.45)
Average years of schooling of labor force	0.072*** (3.03)	-0.027 (-0.61)	0.075*** (-3.03)	-0.062*** (-8.73)
Labor use equation				
Agricultural wage	-0.165*** (-4.35)	0.132 (1.28)	-0.026 (-0.51)	-0.009 (-0.88)
Average years of schooling of labor force	-0.068*** (-5.21)	0.114*** (7.28)	-0.145 (-0.81)	-0.011** (-2.21)
Yield equation				
Agricultural wage	-0.018 (-0.34)	0.512*** (3.62)	-0.087 (1.38)	0.032** (2.18)
Average years of schooling of labor force	-0.025 (-1.41)	0.046** (2.19)	-0.028 (1.10)	0.019*** (2.95)

Source: Authors' estimation.

Notes: MPE = Mean partial effects. T-statistics are in parentheses. * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$.

³ We omitted the results from Model 4 to save space. The results from Model 4 are available upon request.

Table 4.3 summarizes results for the labor use equation. Similar to the machine use equation, we estimate four models, among which Models 3 and 4 are the full models, with a different cutoff point of the dummy variable indicating small landholdings. The results of Models 3 and 4 (combined with the second panel in Table 4.2) show that for land-sufficient countries labor use decreases in response to a wage increase and that countries with larger average holdings are more responsive to a wage increase than are smallholding countries. For land-insufficient countries, increased wage rates also reduce labor use; the reduction of labor use is less in larger-holding countries. Given that machine use is not responsive to an increase in agricultural wages, one would expect that land-insufficient countries may decrease yield, agricultural land, or both when faced with a wage increase.

Table 4.3—Estimation results of the labor input equation, dependent variable being the logarithm of total economically active agricultural population per hectare, 60 countries, 1980–2008

	(1)	(2)	(3)	(4)
Ln GDP	3.302*** (15.57)	2.657*** (10.42)	3.563*** (13.22)	2.764*** (10.34)
Ln GDP, squared	-0.186*** (-14.98)	-0.151*** (-10.42)	-0.204*** (-13.50)	-0.156*** (-10.38)
Ln agricultural wage	-0.0400*** (-2.84)	-0.0601*** (-3.39)	-0.0201 (-0.94)	0.0768** (2.15)
Low landholdings * Ln ag wage			0.0861 (0.47)	-0.232*** (-3.95)
Ln landholdings * Ln ag wage		0.00790 (0.96)	-0.00863 (-0.88)	-0.0524*** (-3.38)
Low landholdings * Ln landholdings * Ln ag wage			0.140 (1.36)	0.0507 (1.23)
Average years of schooling (age 15–64)	-0.0721*** (-6.20)	-0.0842*** (-7.23)	-0.138*** (-10.41)	-0.131*** (-8.45)
Low landholdings * average years of schooling			0.269*** (9.71)	0.123*** (6.79)
Ln landholdings * average years of schooling		-0.0203*** (-5.36)	-0.0106** (-2.21)	-0.000781 (-0.13)
Low landholdings * Ln landholdings * average years of schooling			0.124*** (7.76)	0.0213* (1.84)
Year dummies	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes
Number of observations	955	955	955	955

Source: Authors' estimation.

Notes: GDP = Gross domestic product. T-statistics are in parentheses. * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Low landholdings indicates landholdings ≤ 2 ha/holding in Model (3) and landholdings ≤ 5 ha/holding in Model (4).

The estimation results for the yield equation are reported in Table 4.4 and the third panel of Table 4.2. The partial effects of the two wage indicators are both negative for both land sufficient and insufficient countries. The positive coefficients of the interactions of landholdings and the two wage indicators suggest that countries with larger landholdings may be expected to have less decrease in yield when faced with the same percentage of wage increase than smallholder countries.

Table 4.4—Estimation results of the yield equation, dependent variable being the logarithm of yield of cereals per hectare, 61 countries, 1980–2008

	(1)	(2)	(3)	(4)
Ln GDP	0.452 (1.64)	0.820** (2.47)	1.149*** (3.17)	0.564 (1.57)
Ln GDP, squared	-0.0101 (-0.63)	-0.0295 (-1.57)	-0.0489** (-2.41)	-0.0159 (-0.78)
Ln agricultural wage	-0.0571*** (-2.81)	-0.0850** (-2.20)	-0.167*** (-3.26)	-0.172* (-1.96)
Low landholdings * Ln ag wage			0.115 (1.60)	0.128 (1.28)
Ln landholdings * Ln ag wage		0.0109 (0.92)	0.0323** (2.18)	0.0333 (1.45)
Low landholdings * Ln landholdings * Ln ag wage			0.480*** (3.38)	-0.0723 (-1.25)
Average years of schooling (age 15–64)	-0.000891 (-0.06)	-0.0114 (-0.72)	-0.0760*** (-3.27)	-0.0606** (-1.98)
Low landholdings * average years of schooling			0.0483** (2.14)	0.0577* (1.89)
Ln landholdings * average years of schooling		0.00893* (1.81)	0.0193*** (2.95)	0.0212** (2.56)
Low landholdings * Ln landholdings * average years of schooling			0.0269 (1.24)	-0.0191 (-1.21)
Year dummies	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes
Number of observations	922	922	922	922

Source: Authors' estimation.

Notes: GDP = Gross domestic product. T-statistics are in parentheses. * $p = 0.10$, ** $p = 0.05$, *** $p = 0.01$. Ln landholdings is demeaned by the sample mean. Low landholdings indicates landholdings ≤ 2 ha/holding in Model (3) and landholdings ≤ 5 ha/holding in Model (4).

For self-sufficiency ratio, we estimate equation (2) for the whole sample and for samples in Asian countries, African countries, and Latin American countries, separately (Table 4.5). As expected, the self-sufficiency ratio (SSR) is increasing in yield and decreasing in population density. For Asian countries, SSR is increasing in GDP per capita at a decreasing rate, and it is increasing in yield at an increasing rate. Therefore, with rapid economic growth, we expect the SSR in Asian countries to become lower, especially for those with small landholdings, such as China and India. Different from Asian countries, SSR in African countries is decreasing in GDP per capita at a decreasing rate. It is increasing in yield at an increasing rate, similar to the situation in Asian countries. The GDP effects are jointly insignificant for Latin American countries. Again yield plays an important role in SSR.

5. CONCLUSIONS

This paper showed evidence supporting our hypothesis that an increase in real wages, along with absorptions of labor into nonagricultural sectors, has been inducing the substitution of labor by machines in agriculture. However, this process is less successful in the countries that are constrained by their small operational land sizes, resulting in lowered land productivity. We also demonstrated that dynamics of yield are an important determinant of self-sufficiency ratio. The above findings from macro panel data imply that in the near future, Asian agriculture that traditionally used family labor intensively on small farms can face a challenge in maintaining domestic production. Given the huge size of consumer demands in the region, the future path of Asian agriculture could be a significant constraint on the global food supply–demand balance.

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2033 K Street, NW
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Fax: +1-202-467-4439
Email: ifpri@cgiar.org