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# Joint Determination of Improved Variety Adoption, Productivity and Efficiency of Pulse Production in Bangladesh: A Sample-Selection Stochastic Frontier Approach

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**Abstract:** Pulses are an important source of protein and have recently gained international prominence. This paper jointly identifies the determinants of improved variety adoption, productivity and efficiency of 2700 pulse producers from 10 pulse-growing districts of Bangladesh using a Sample-selection Stochastic Production Frontier model. Result revealed that the decision to adopt improved pulse technology is significantly influenced by yield, farming experience, education and extension contact while subsistence pressure discourages adoption. Land, fertilizer, mechanical power, pesticides and labour are the significant determinants of improved pulse productivity. Productivity is significantly lower for improved varieties of lentil, blackgram and chickpea as compared to mungbean and for farmers who use own-sourced seed. Location of the growing area does matter. Improved pulse productivity is significantly higher in five of the ten districts. The mean level of technical efficiency of improved pulses is estimated at 0.73, implying that productivity can be substantially improved by eliminating inefficiency. Policy implications include investments in R&D and extension services by involving farmers in R&D endeavours and enhancing farmer-based seed production and distribution schemes to develop and disseminate improved pulse technology, improving farmers' education and tenurial reforms to facilitate smooth operation of the land market and mechanical power services to increase pulse productivity and production in Bangladesh.

**Keywords:** sample-selection framework; stochastic production frontier; technical efficiency; improved pulse technology adoption; pulses; Bangladesh

## 1. Introduction

Pulses are the dried edible seeds of plants that belong to the legumes family. Pulses are grown in pods and are of varied shapes and colours. Pulses are a good source of protein and commonly known as meat for the poor [1]. Pulses provide several amino acids as compared to meat and meat products [2,3]. Increased production and consumption of pulses is essential to sustain global agriculture and food systems [4]. Pulses received prominence in the international arena recently owing to the recognition of a strong association between soils and pulses for sustainable agriculture [4]. Pulses (e.g., lentil, mungbean, blackgram, chickpea and grasspea) and other legumes (e.g., faba beans) can play an important role in supporting multiple objectives of the UN Sustainable Development Goal 2030 by contributing to hunger and malnutrition, productivity and income of the poor farmers, and sustainable agriculture [5,6]. As a result, the Global Pule Confederation (GPC) developed a 10-year research strategy for pulse crops in December 2016, aimed at unlocking the potential of pulses for sustaining agriculture and human well-being [4].

Pulses play an important role in the daily diet of Asians, particularly Indian and Bangladeshi people, as they provide a cheap source of protein. They also play a vital role in providing fodder for farm animals either directly through grazing or as feed after the pods are harvested. Pulses are usually cultivated as mixed crops along with crops such as cotton, mustard, or as catching-up crops between two cereal crops [2].

Pulses have played an important role in sustaining productivity of soils through centuries. The pulse-based cropping systems are environmentally sustainable, as they require less use of fertilizers, pesticides and irrigation in addition to enhancing productivity of cropping systems by increasing yield of subsequent crops [7]. Reddy et al. [2] noted that pulse-based cropping systems are more suitable for resource poor farmers and in water-scarce regions. Pulses fix atmospheric nitrogen (N) through root nodules and add a substantial amount of protein-rich biomass to the soil. By inclusion of pulses in the cropping system, the heavy N requirement of modern intensive cereal-based cropping can be partly met and the physical and chemical properties of soils are generally improved. This is because pulses in rotation with cereals economize on the use of N to the extent of 30–40 kg/ha [8,9]. Adding pulses to a cropping system can also help in disrupting pest, weed, and disease cycles, enhancing nutrient and water use efficiency, reducing the impact of weather-related hazards and improving system diversity [4].

Pulses fit well in the existing cropping systems of Bangladesh due to their short duration, low input, minimum care requirement and drought tolerant nature [10]. India is the largest producer of pulses, producing 67.4% of the global pulse production with an average yield of 920 kg/ha in 2013, followed by Australia, producing only 6.2% of global production with a higher average yield of 1418 kg/ha [11]. However, the total production of pulses in India as well as Bangladesh is insufficient to meet demand in both countries because the pulse area and production has been consistently declining over time [3,11,12]. For example, the area under pulses has declined from 716.6 thousand ha in 1986 to only 253.9 thousand ha in 2012 and total production fell from 510.2 thousand t to 232.1 thousand t during the same period in Bangladesh [13–18]. On the other hand, pulse import has increased from 179.2 thousand t in 1990 to 385.6 thousand t in 2012 with a peak import of 823.3 thousand t in 2009 [19], thereby draining valuable foreign currency every year. The average yield of pulse is also low, estimated at 1005 kg/ha [20].

According to the World Health Organization (WHO), the recommended rate of pulse consumption is 45 gram/capita/day whereas the present rate of consumption in Bangladesh is only 17 gram/capita/day [21]. It is envisaged that just to maintain the present consumption rate, pulse production has to be increased by 21.5% from its present supply by 2020 [20]. On the other hand, net availability of pulses in India has declined from 60.7 gram/capita/day in 1951 to 41.6 gram/capita/day in 2012 [11], but is still substantially higher than Bangladesh. Since the area under pulses is consistently declining in the face of strong competition from cereal production (e.g., Boro or dry winter irrigated rice, wheat and/or maize), the increased supply must come through improvements in productivity, which can be achieved by adopting improved varieties of pulses as well as improving production efficiency by using inputs optimally.

Realizing the importance and demand for pulses, the government of Bangladesh has emphasized research and extension programs and has also invested heavily to attain self-sufficiency in pulse production. The Bangladesh Agricultural Research Institute (BARI), Bangladesh Institute of Nuclear Agriculture (BINA) and Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) were entrusted to conduct research to develop improved pulse varieties. Five major types of pulses, namely, lentil (*Lens esculanta*), mungbean (*Vigna radiata*), blackgram (*Vigna mungo*), chickpea (*Cicer arietinum*) and grasspea (*Lathyrus sativas*), are grown in Bangladesh. Although lentil, chickpea and grasspea are grown during the winter season, mungbean and blackgram can be grown in both winter and summer seasons. By 2011, a total of 28 improved varieties of pulses (7 lentil, 6 mungbean, 9 chickpea, 3 blackgram and 3 grasspea) were released to the farmers [12]. The Department of Agricultural Extension (DAE) is the main organization responsible for technology transfer through its countrywide network. Although these technologies were found to be suitable for the farmers, a large number of farmers throughout the country are still reluctant to adopt improved pulses.

A limited number of studies exist on the adoption of improved varieties, profitability and/or production performance of pulses in Bangladesh with varied conclusions. For example, Miah et al. [22] noted that 44% of the sampled farmers had adopted improved pulses while Sarker [23] and Haque et al. [24] noted that 100% of sampled farmers had adopted improved varieties of lentil and mungbean, respectively. Lack of good quality seed as well as pest and disease infestation were identified as the main constraints in adopting improved varieties of pulses [22,24]. Similarly, Islam et al. [25] reported 35% higher profit for improved varieties of blackgram, Islam and Ali [26] estimated a Benefit Cost Ratio (BCR) of 1.80 for improved varieties of lentil whereas Islam et al. [25] and Haque et al. [24] reported BCRs of 2.35 and 1.69 for improved varieties of mungbean, respectively. Miah et al. [25] estimated a mean technical efficiency of 91%, 85% and 76% for lentil, blackgram and mungbean, respectively. Hasan et al. [27] noted that the average technical efficiency of improved pulse production (i.e., lentil, mungbean and blackgram combined) in Bangladesh is 79.8% (with environmental variables included in the model) and 64.7% (without considering environmental variables in the model). Haque et al. [24] noted that 67% of the sampled farmers achieved a technical efficiency of 90% or above in improved varieties of mungbean production in Bangladesh.

A major limitation of the aforementioned studies is that they investigated either improved variety adoption or technical efficiency of one or more pulses independently, which does not provide a comprehensive answer as to why the level of improved varietal technology adoption is highly varied across pulse types and also why production efficiency levels of individual pulse types vary so much. Also, there are methodological limitations of these studies which concentrated on studying each pulse type independently. This is because farmers are exposed to same/similar level of information on price, yield and market for pulses, yet some of them adopt improved varieties and others do not. Therefore, modelling farmers adopting improved varieties of one type of pulse (e.g., lentil) only leads to sample selection bias because the actual population of pulse producers includes both traditional and improved pulse producers, from which samples should be drawn using a standard statistical procedure. In other words, in this model of rational variety choice, using observations from a single variety (be it traditional or improved pulses) alone is likely to produce biased estimates of the production function which will be carried onto biased estimates of efficiency. This happens because omission of a particular variety from estimation leads to non-zero conditional expectations of the error terms of individual production functions of traditional and improved pulses [28,29]. Finally, most of these studies were conducted on a limited sample size covering a narrow geographical location.

In this study, we overcome all these weaknesses by applying a method that can jointly evaluate the determinants of improved pulse technology adoption, productivity of pulses and production efficiency of the producers, which is our contribution to the existing literature on pulses. Also, we conducted our study covering the major five type of pulses grown in Bangladesh using a relatively large sample size.

Given this backdrop, the specific aims of this study are to simultaneously identify: (a) the determinants of switching from traditional to improved varieties of pulses; (b) the factors influencing productivity of improved pulses conditional on the selection of the technology; and (c) production efficiency scores of individual producers growing improved varieties of pulses. We utilize the Sample-selection Stochastic Frontier model developed by Greene (2006) which corrects the sample-selection bias inherent in the previous studies discussed above. We apply our framework to a large survey sample of 2700 pulse growers producing five major type of pulses (i.e., mungbean, lentil, blackgram, chickpea and grasspea), composed of both traditional and improved varieties, from 10 major pulse-growing districts of Bangladesh. Other than overcoming the methodological weaknesses discussed above, another main justification of conducting a combined analysis of all pulses together is to identify the robust/common factors influencing the decision to adopt improved varieties of any type of pulse and overall production performance of improved variety pulse producers. The results of this study are expected to be useful for agronomists, extension agents, policy makers and relevant stakeholders interested in enhancing adoption of improved varieties of all types of pulses and at the same time increasing production of pulses by enhancing the productivity and efficiency of the pulse producers in Bangladesh.

The paper is organized as follows. The next section describes the theoretical framework of the model. Section 3 describes the data. Section 4 presents the results. The final section concludes and draws policy implications.

## 2. Methodology

### 2.1. Theoretical Framework

As stated earlier, the main aim of this study is first to identify the factors influencing adoption of improved varieties of pulses, and conditional on that choice, identify the drivers of productivity and efficiency of improved variety pulse producers, which was done jointly in order to circumvent the methodological weaknesses in conducting these two analyses separately. The framework required to conduct this joint exercise is known as the 'sample-selection stochastic frontier analysis. The conventional approach to correct for sample selection bias was proposed by Heckman [30] which is a popular method but still has a weakness because the framework is appropriate for linear models, i.e., standard regression models, only [31]. The method is inappropriate for non-linear models, such as probit or Tobit models, which are the standard methods used to analyse technology adoption decisions [31]. This is because the impact on the conditional mean of the non-linear model of interest (e.g., the probit model of improved pulse technology adoption) may not take the form of an inverse Mills ratio, which was used to correct for the sample-selection bias in Heckman's approach by incorporating this ratio along with the other regressors in the pulse production function model conducted at the second stage. Also, the bivariate normality assumption needed to justify the inclusion of the inverse Mills ratio in the second model (e.g., the production function) does not appear anywhere in Heckman's (1976) method. Further, conditioned on the sample-selection (i.e., improved variety adopters), the dependent variable (i.e., pulse production) may not have the distribution described by the model in the absence of selection [31]. Subsequently, Greene [31,32] proposed an internally consistent method of incorporating 'sample-selection' bias in a stochastic frontier framework, which was adopted in our study and is described below.

Farmers are assumed to choose between improved and traditional pulse varieties to maximize returns subject to a set of socio-economic factors. The decision of the $i$th farmer to choose improved pulses is described by an unobservable selection criterion function, $I_i$*, which is postulated to be a function of a vector of factors representing farmers' socio-economic circumstances. The selection criterion function is not observed. Rather, a dummy variable, $I$, is observed. The variable takes a value of 1 for improved pulse producers and 0 otherwise. The model is specified as [28,29]:

$$I_i^* = \boldsymbol{\alpha}'\mathbf{z}_i + w_i, I_i = 1\ (I_i^* > 0) \tag{1}$$

where $z$ is a vector of exogenous variables explaining the decision to grow improved or traditional pulses, $\alpha$ is a vector of parameters and $w$ is the error term distributed as $N(0,\sigma^2)$. This is a standard method for identifying technology adoption decision of any type.

The production behaviour of the improved pulse growing farmers is modelled by using a restricted translog stochastic production frontier function. It should be noted that only the improved variety pulse production frontier model is shown here. The model selects the improve pulse producers from the total sample (composed of both improved and traditional pulse producers) based on the information provided in the probit variety selection Equation (1) [28,29]:

$$y_i = TL(\boldsymbol{\beta}'\mathbf{x}_i + \boldsymbol{\gamma}'\mathbf{x}_i + v_i - u_i) \quad iff\ I = 1 \tag{2}$$

where $x$ represent inputs, $y$ represents improved pulse output, $\beta$ and $\gamma$ are the parameters; and $v$ is the two sided random error, independent of the $u$, representing random shocks (e.g., measurement errors, omitted explanatory variables and statistical noise); and $u$ is a non-negative random variable associated with inefficiency in production, assumed to be independently distributed as a zero-truncated normal distribution, $u = |U|\ with\ U \sim N[0, {\sigma_u}^2]$.

The 'sample-selection bias' arises as a result of the correlation of the unobservables in the stochastic frontier function with those in the pulse variety selection equation [32]. In this sample-selection framework proposed by Greene [31,32], it is assumed that the unobservables in the variety selection equation are correlated with the 'noise' in the stochastic frontier model. In other words, $w$ in Equation (1) is correlated with $v$ in Equation (2), and therefore, ($v$, $w$) are distributed as bivariate normal distribution with $[(0,0), ({\sigma_v}^2, \rho\sigma_v, 1)]$. The vectors ($y$, $x$) are observed when $I$ = 1.

Development of the estimator for this model is detailed in [31,32]. We only report the final log likelihood function to be estimated [31]:

$$\log\ L_s = \textstyle\sum_i \log \frac{1}{R} \sum_{r=1}^{R} \left\{ I_i \left[ \frac{2}{\sigma_u}\, \phi\left( \frac{\boldsymbol{\beta}'x + \sigma_v v_{ir} - y)}{\sigma_u} \right) \Phi\left( \frac{\boldsymbol{\alpha}'z + \rho\ v_{ir}}{\sqrt{1-\rho^2}} \right) \right] + (1 - I_i) \left[ \Phi\left( \frac{-\boldsymbol{\alpha}'z - \rho\ v_{ir}}{\sqrt{1-\rho^2}} \right) \right] \right\} \tag{3}$$

Since the integral of this function does not exist in a closed form, Greene [31,32] proposes computation by simulation. When $\rho$ = 0 (i.e., the parameter which measures the correlation between $w$ in (1) and $v$ in (2)), the model reduces to that of the conventional stochastic frontier model, and thus provides us with a method of testing existence of sample-selection bias or selectivity [32]. In other words, if and only if $\rho$ = 0, then one can estimate production frontier function of traditional variety of pulses and improved variety of pulses independently and there will be no problem of sample selection bias.

### *2.2. Study Area and the Data*

The study uses cross-sectional primary data collected during 2012. A total of five major pulses, namely, lentil, mungbean, blackgram, chickpea and grasspea, was considered for this study. These five pulses covered more than 90% of the total pulse area in Bangladesh in 2011. Based on the area coverage of individual pulses in 2011, three districts consisting of high, medium, and low intensity of area under each type of pulses were purposively selected. This would imply selection of 15 districts but because some district produces more than one type of pulse, only a total 10 different districts were covered. These are: Natore, Rajshahi, Chapainawabganj, Jessore, Jhenaidah, Meherpur, Madaripur, Faridpur, Rajbari, and Patuakhali. Next, based on the intensity of area covered under each pulse, three upazilas (sub-districts) in each district were selected. The information on the area and production of selected pulse was collected from respective upazilas and district-level Department of Agricultural Extension (DAE) offices. Next, from each upazila, one village under one block was selected with the help of knowledgeable persons and DAE personnel i.e. Sub-Assistant Agriculture Officer (SAAO). A complete list of all pulse growers from the selected village was prepared with the help of SAAO. From that list, 180 farmers were selected randomly from each upazila taking 60 farmers from each village. Data were randomly collected from improved and traditional pulse variety growers. Thus, a total of 2700 (3 districts × 3 upazilas × 60 farmers × 5 pulse types) pulse growers were selected for the interview. The interview schedule was pre-tested and one of the authors and a trained enumerator collected the data using face-to-face interviews with the growers after briefing them about the objectives of the study.

Two sets of variables are needed for this study: One for the probit variety selection equation model and the other for the stochastic production frontier model, discussed below. The dependent variable in the probit equation is the farmers' variety selection criterion. This is a binary variable that takes the value of 1 if a plot is planted with improved pulse and 0 otherwise. Farmers were specifically asked about the adoption of an improved variety of each pulse type, the details of which are presented in Appendix A Table A1. Table A1 shows that farmers used 6 types of improved varieties of lentil and mungbean, 8 types of chickpea, 3 types of blackgram and 2 types of grasspea in the study areas. The explanatory variables include pulse yield, farming experience, education, subsistence pressure, information on main occupation, agricultural training, extension contact and land type.

All the input and output variables used in the stochastic production frontier were measured on a per farm basis. The eight input variables used in the model include land, labour, chemical fertilizers, pesticide, irrigation, mechanical power services, seed and organic manure and all are expected to have a positive relationship with pulse output. Also, dummy variables were used to account for pulse type, non-use of some inputs, location or growing district, optimum sowing period and use of own sourced seed. The variables used in the probit model and the production function model are based on the literature and justification thereof [2,22,24,27,33]. Since the variables in the probit variety selection equation and the stochastic production frontier differ, the structural model satisfies the identification criterion [34].

## 3. Results

### 3.1. Distribution of Pulse Grower by Region and Agro-Ecological Zone

Bangladesh consists of 30 agroecological zones (AEZ) constructed by the FAO in 1988 which can be broadly mapped onto a sub-district level created by Bangladesh Agricultural Research Council [35]. Table 1 presents the distribution of pulse growers by district, sub-district and agro-ecological zones. It is clear from Table 1 that the majority of the pulses are grown in a single agro-ecological zone, i.e., High Ganges River Floodplain (HGRF), followed by a few in the Lower Ganges River Floodplain (LGRF), Ganges Tidal Flooplain (GTF) and Active Ganges Floodplain (AGF). In fact, four of the five pulse types investigated in this study are grown in HGRF. Only grasspea production is concentrated in LGRF, GTF and AGF.

The land elevation data created by BARC in Bangladesh are classified according to flooding depth of the landscape. These are: High Land (i.e., no flooding); Medium High Land (flooding depth of 0.10–0.90 m); Medium Low Land (flooding depth of 0.91–1.83 m); and Low Land (flooding depth of > 1.83 m). Both HGRF and LGRF are characterized by higher proportions of high and medium-high land elevations and the soil types are silt loam and silty clay loam with generally low fertility conditions and organic materials [36]. The GTF and AGF contain relatively medium-low and low-lying areas with heavy silty clay soils with medium to high fertility conditions and organic materials [36]. Nevertheless, all pulses are grown within Ganges Floodplains, where the agro-ecological conditions are largely similar with some differences as explained above and perhaps explains why pulse production is concentrated in these AEZs only.

**Table 1.** Distribution of the samples by pulse type, regions and agroecological zones.

| Crops | District | Upazila (Subdistrict) | Agroeccological Zone |
|---|---|---|---|
| Lentil | Natore | *Lalpur* | High Ganges River Floodplain |
| | | *Natore Sadar* | High Ganges River Floodplain |
| | | Baraigram | High Ganges River Floodplain |
| | Jessore | Bagarpara | High Ganges River Floodplain |
| | | *Chougacha* | High Ganges River Floodplain |
| | | *Jhekorgacha* | High Ganges River Floodplain |
| | Meherpur | Meherpur Sadar | High Ganges River Floodplain |
| | | Mujibnagor | High Ganges River Floodplain |
| | | Gangni | High Ganges River Floodplain |

**Table 1.** *Cont.*

| Crops | District | Upazila (Subdistrict) | Agroeccological Zone |
|---|---|---|---|
| Mungbean | Patuakahi | *Golachipa* | Ganges Tidal Floodplain |
| | | Baufal | Ganges Tidal Floodplain |
| | | Dosmina | Ganges Tidal Floodplain |
| | Rajshahi | Charghat | High Ganges River Floodplain |
| | | Putia | High Ganges River Floodplain |
| | | Bagha | High Ganges River Floodplain |
| | Jessore | *Jhekorgacha* | High Ganges River Floodplain |
| | | Jessore Sadar | High Ganges River Floodplain |
| | | *Chougacha* | High Ganges River Floodplain |
| Blackgram | Chapainawabganj | Shibgonj | High Ganges River Floodplain |
| | | Chapainawabganj Sadar | High Ganges River Floodplain |
| | | Gomostapur | High Ganges River Floodplain |
| | Natore | *Lalpur* | High Ganges River Floodplain |
| | | *Natore Sadar* | High Ganges River Floodplain |
| | | Bagatiapara | High Ganges River Floodplain |
| | Jhenaidah | Mohespur | High Ganges River Floodplain |
| | | Horinakund | High Ganges River Floodplain |
| | | Kotchadpur | High Ganges River Floodplain |
| Grasspea | Patuakhali | Patuakhali Sadar | Ganges Tidal Floodplain |
| | | Baufal | Ganges Tidal Floodplain |
| | | *Golachipa* | Ganges Tidal Floodplain |
| | Madaripur | Rajair | Low Ganges River Floodplain |
| | | Shibchar | Low Ganges River Floodplain |
| | | Kalkinee | Low Ganges River Floodplain |
| | Rajbari | Rajbari Sadar | Active Ganges Floodplain |
| | | Pangsha | Active Ganges Floodplain |
| | | Baliakandi | Low Ganges River Floodplain |
| Chickpea | Rajshahi | Godagari | High Ganges River Floodplain |
| | | Tanore | High Ganges River Floodplain |
| | | Poba | High Ganges River Floodplain |
| | Jhenaidah | Sailukupa | High Ganges River Floodplain |
| | | Jhenaidah Sadar | High Ganges River Floodplain |
| | | Kaligonj | High Ganges River Floodplain |
| | Faridpur | Faridpur Sadar | Low Ganges River Floodplain |
| | | Modukhali | Low Ganges River Floodplain |
| | | Sadarpur | Low Ganges River Floodplain |

Note: Figures in italics show same subdistricts selected for different pulses although the actual villages may differ.

### *3.2. Yield Level and Input Use by Pulse Crops*

Out of a total of 540 samples of each pulse type, the level of improved pulse variety adoption for mungbean is 100%, lentil 92.78%, chickpea 65.75%, blackgram 40.17% and grasspea only 2.4%, which demonstrates a high level of variability and is quite puzzling given that the yield of all improved pulses is significantly higher than the traditional varieties (Table 2). Since the mungbean producers used 100% improved varieties, there is no observations on traditional varieties of mungbean. Among the individual pulse type, the yield levels of improved varieties of lentil, mungbean and chickpea are higher than the yield of blackgram and grasspea, which may explain the lower level of adoption for these latter pulse types. The observed 100% adoption rate of improved mungbean matches the rate reported by Haque et al. [24], the adoption rate of 92.78% for improved lentil is also comparable to the 100% reported by Sarker [23]. The national adoption rate of improved varieties of mungbean is 97.82%, lentil is 87.55%, chickpea is 71.95%, blackgram is 47.57% and grasspea is 3.10% for the year 2011–2012 [12], which is very close to our estimates, thereby providing confidence in the representativeness of the data.

**Table 2.** Yield advantages of improved pulses varieties over traditional ones.

| Pulse Crops | Yield (kg/ha) of Pulses | | Mean Differences (kg/ha) | Percent of Yield Advantage of Improved Variety over Local Variety |
|---|---|---|---|---|
| | Improved | Local | | |
| Lentil | 1479 | 880 | 599 | 68.07 |
| Mungbean | 1237 | 0 | Not applicable | Not applicable |
| Blackgram | 932 | 638 | 294 | 46.08 |
| Grasspea | 1068 | 811 | 257 | 31.69 |
| Chickpea | 1338 | 984 | 354 | 35.98 |

Source: Field Survey, 2011–2012.

Table 3 presents key input use rates for improved and traditional varieties of different pulses considered in this study. It is clear from Table 3 that the input use rates vary by pulse type and also by variety. Generally, input use rates are higher for improved varieties of all pulses as compared to traditional pulses. High levels of human labour and fertilizer use rates were observed for improved lentil and mungbean production. This perhaps explains the high level of yield advantage of these two pulse types compared to other pulses presented in Table 2.

**Table 3.** Input use pattern of local and HYV pulses production in the study areas.

| Items | Lentil | | Mungbean | Blackgram | | Chickpea | | Grasspea | |
|---|---|---|---|---|---|---|---|---|---|
| | Improved | Local | Improved | Improved | Local | Improved | Local | Improved | Local |
| Human labour (days/ha) | 89 | 62 | 98 | 58 | 47 | 59 | 46 | 42 | 35 |
| Seed (kg/ha) | 35 | 35 | 22 | 29 | 26 | 37 | 36 | 80 | 75 |
| Cow dung (kg/ha) | 2984 | 3566 | 1575 | 1121 | 262 | 1152 | 726 | 0 | 46 |
| Urea (kg/ha) | 38 | 35 | 29 | 27 | 22 | 14 | 8 | 14 | 21 |
| TSP(kg/ha) | 81 | 80 | 39 | 38 | 9 | 22 | 15 | 0 | 4 |
| MoP (kg/ha) | 47 | 33 | 27 | 31 | 5 | 14 | 10 | 0 | 2.5 |

Source: Field Survey, 2011–2012.

### 3.3. Summary Statistics of the Variables Used in the Econometric Model

Table 4 presents the summary statistics of the key selected indicators classified by pulse varieties used in the econometric models. It is clear from Table 4 that most of the variables representing socio-economic features, technology adoption and inputs are significantly different between the improved and traditional pulse varieties. The yields of improved pulses are significantly higher as expected, also shown in Table 3. The overall yield of improved pulses is estimated at 1289.13 kg/ha as compared to 783.32 kg/ha for traditional pulses. The estimate of improved pulse of 1289.13 kg/ha is much higher than the yield estimate of improved pulse at 1131 kg/ha and improved mungbean yield of 1196 kg/ha reported by Hasan et al. [27] and Haque et al. [24] for Bangladesh, respectively. On the other hand, Reddy et al. [2] reported a yield rate of chickpea at 1375 kg/ha in Andhra Pradesh, India, which is higher than our estimate of improved pulses. The input use levels for improved pulses are significantly higher except for the use of labour, which is the same. The most striking difference is the seed rate for improved pulse as compared with traditional pulse varieties. The seed rate of improved pulses is almost 10 times higher than the traditional pulse varieties. The improved pulse growers have a significantly higher level of education, agricultural training and extension contacts. The overall adoption rate of improved pulses is 61.72% (Table 4). However, the overall adoption rate of all five types of improved pulses of 61.72% is much higher than the 44% reported by Miah et al. [22] for blackgram, lentil and mungbean combined.

**Table 4.** Comparison of key indicators by pulse varieties.

| Variable Name | Improved Pulse Varieties | | Traditional Pulse Varieties | | Mean Difference (Improved-Traditional) | *t*-Ratio |
|---|---|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation | | |
| Variety selection model | | | | | | |
| Yield (kg/ha) | 1289.13 | 448.06 | 783.32 | 265.03 | 502.82 *** | 32.65 |
| Farming experience (years) | 17.16 | 11.50 | 20.32 | 20.80 | −3.16 *** | −6.64 |
| Education of the farmer (completed years of schooling) | 7.03 | 4.12 | 5.82 | 4.12 | 1.20 *** | 7.36 |
| Subsistence pressure (family size) | 5.20 | 2.10 | 5.60 | 2.18 | −0.40 *** | −4.68 |
| Main occupation is farming (1 if yes, 0 otherwise) | 0.97 | – | 0.99 | – | −0.01 ** | −2.04 |
| Received agricultural training (1 if yes, 0 otherwise) | 0.40 | – | 0.31 | – | 0.10 *** | 5.08 |
| Received extension contacts (1 if yes, 0 otherwise) | 0.67 | – | 0.13 | – | 0.54 *** | 31.98 |
| Medium highland (1 if yes, 0 otherwise) | 0.63 | – | 0.77 | – | −0.14 *** | −7.81 |
| Production function model | | | | | | |
| Land area under pulse (ha) | 1.00 | 1.03 | 0.90 | 0.75 | 0.09 *** | 2.47 |
| Irrigation (BDT/ha) | 284.39 | 688.78 | 120.00 | 589.33 | 164.40 *** | 6.35 |
| Fertilizer (kg of nutrients/ha) | 52.91 | 42.87 | 17.08 | 43.99 | 35.83 *** | 20.88 |
| Seed (kg/ha) | 538.13 | 809.34 | 53.51 | 24.83 | 484.62 *** | 19.20 |
| Mechanical power services (BDT/ha) | 5077.19 | 1856.64 | 2874.36 | 2394.32 | 2202.83 *** | 26.75 |
| Labour (Person days/ha) | 54.59 | 17.98 | 54.40 | 13.99 | 0.19 | 0.29 |
| Pesticide (BDT/ha) | 1308.97 | 1529.99 | 333.04 | 1016.70 | 975.93 *** | 18.14 |
| Organic manure (kg/ha) | 1168.08 | 2130.62 | 218.48 | 904.64 | 949.61 *** | 13.56 |
| Sown during optimum time (1 if yes, 0 otherwise) | 0.60 | – | 0.50 | – | 0.10 *** | 5.08 |
| Used own sourced seed (1 if yes, 0 otherwise) | 0.36 | – | 0.58 | – | −0.22 *** | −11.23 |
| Proportion of lentil (1 if yes, 0 otherwise) | 0.30 | – | 0.04 | – | 0.26 *** | 17.08 |
| Proportion of blackgram (1 if yes, 0 otherwise) | 0.29 | – | 0.14 | – | 0.15 *** | 9.48 |
| Proportion of chickpea (1 if yes, 0 otherwise) | 0.15 | – | 0.23 | – | −0.09 *** | 5.53 |
| Proportion of mungbean (1 if yes, 0 otherwise) | 0.32 | – | 0.00 | – | 0.32 *** | 22.17 |
| Proportion of grasspea (1 if yes, 0 otherwise) | 0.01 | – | 0.31 | – | 0.52 *** | 42.29 |
| Meherpur (1 if yes, 0 otherwise) | 0.11 | – | 0.00 | – | 0.11 *** | 10.81 |
| Natore (1 if yes, 0 otherwise) | 0.20 | – | 0.02 | – | 0.17 *** | 13.73 |
| Jessore (1 if yes, 0 otherwise) | 0.19 | – | 0.03 | – | 0.16 *** | 13.11 |
| Rajshahi (1 if yes, 0 otherwise) | 0.19 | – | 0.04 | – | 0.15 *** | 11.11 |
| Patuakhali (1 if yes, 0 otherwise) | 0.11 | – | 0.17 | – | −0.06 *** | −4.65 |
| Chapainawabganj (1 if yes, 0 otherwise) | 0.02 | – | 0.15 | – | −0.13 *** | −13.69 |
| Jhenaidah (1 if yes, 0 otherwise) | 0.16 | – | 0.11 | – | 0.05 *** | 3.592 |
| Rajbari (1 if yes, 0 otherwise) | 0.17 | – | 0.00 | – | 0.17 *** | 18.81 |
| Faridpur (1 if yes, 0 otherwise) | 0.07 | – | 0.07 | – | 0.00 | 0.19 |
| Madaripur (1 if yes, 0 otherwise) | 0.17 | – | 0.00 | – | 0.18 *** | 18.82 |
| Observations | 1666 | | 1033 | | | |

Note: Exchange rate: USD 1.00 = BDT 81.86 Taka (approximately) during 2012–2013 (World Bank 2013); *** significant at the 1 percent level ($p < 0.01$); ** significant at the 5 percent level ($p < 0.05$).

### 3.4. Determinants of Choosing Improved Pulse Technology

The Chi-squared test statistic in the probit variety selection equation is significant at the 1% level, thereby confirming joint significance of the parameters (Table 5). The McFadden R-squared is estimated at 0.49, which is quite satisfactory. Pulse yield, farming experience, education, extension contact and main occupation as farming are the determinants of the probability of choosing improved pulse technology. The elasticity results show that extension contact is the most important determinant followed by yield, education and experience. A one percent increase in extension contact and yield will increase the probability of choosing improved pulse by 0.19% and 0.18%, respectively, as expected. Subsistence pressure, however, reduces the likelihood of choosing improved pulses. The probit model results econometrically confirmed the findings observed in Table 1.

**Table 5.** Probit elasticities of the factors influencing the decision to adopt improved pulse technologies.

| Variables | Elasticities | t-Ratio |
|---|---|---|
| Constant | −0.0802 | −0.61 |
| Yield | 0.1769 *** | 10.02 |
| Farming experience | 0.0362 * | 1.79 |
| Education of the farmer | 0.0564 *** | 3.45 |
| Subsistence pressure | −0.1422 *** | −5.48 |
| Main occupation is farming | 0.1968 *** | 13.51 |
| Received agricultural training | 0.0180 | 1.40 |
| Received extension contacts | 0.1851 *** | 16.18 |
| Medium highland | −0.0107 | −0.71 |
| Model diagnostics | | |
| Log likelihood | −913.26 | |
| McFadden R-squared | 0.49 | |
| Chi-squared | 1761.39 *** | |
| Degrees of freedom | 8 | |
| Number of total observations | 2700 | |

Note: Marginal effects for dummy variables are computed at P | 1–P | 0 (NLOGIT V. 4, Econometric Software Inc. New York, NY, USA). *** significant at the 1 percent level ($p < 0.01$); * significant at the 10 percent level ($p < 0.10$).

It may be argued that since these pulse types are different, factors influencing their adoption might be different. Therefore, in order to check the robustness of the factors influencing adoption of improved varieties of pulses, we also conducted the same analysis for lentil, blackgram and chickpea individually and the results are presented in Appendix A Table A2. Since growers adopted 100% of mungbean for which the adoption model is not defined, and since only 2.4% of grasspea producers adopted improved varieties, we did not fit a model for these two pulses. It is clear from Table A2, that the factors influencing individual pulse types are largely similar. For example, yield is the dominant factor influencing adoption of improved varieties of all three pulses. Education significantly influences adoption of improved varieties of blackgram. Subsistence pressure significantly reduces adoption of improved varieties of lentil and blackgram. Agricultural training significantly increases adoption of improved varieties of chickpea and grasspea while extension contacts significantly increases adoption of improved varieties of blackgram and grasspea. These results show that the key factors influencing the adoption of improved varieties of different pulse crops are similar, and therefore, combining these into a single model is not a major issue and actually provides a clear picture on the most common/robust factors influencing the adoption of improved varieties of any pulses.

Rahman et al. [28] also noted that gross return, education and access to irrigation significantly increased the likelihood of choosing Jasmine rice in Thailand. Similarly, Rahman [29] noted that gross return and irrigation significantly increased the likelihood of choosing modern rice in Bangladesh but he did not find any significant influence of education and experience.

### *3.5. Productivity Drivers of Improved Varieties of Pulses*

Table 6 presents the results of the stochastic production frontier model corrected for sample-selection bias. The model diagnostics presented at the bottom panel of Table 6 show that the estimates of $\sigma_u$ and $\sigma_v$ are significantly different from zero at the 1% level of significance. Also, the coefficient on the selectivity variable ($\rho_{w,v}$) is estimated at −0.99 and is significantly different from zero at 1% level, which confirms that serious selection bias exists. This result justifies the use of a sample-selection framework for our study and confirms that estimation using observations from only improved pulse or traditional pulse producers will provide biased estimates of productivity, which will then be carried on to the biased estimates of efficiency scores. Rahman et al. [28] and Rahman [29] also noted significant selection bias in choosing Jasmine rice in Thailand and modern rice in Bangladesh, respectively.

It should be noted that in order to take into account varied influences of individual pulse type and growing areas, we included dummy variables of pulse type (i.e., lentil, blackgram and chickpea) and selected regions in our analysis. Therefore, the parameter estimates presented in Table 6 show the net effect of the specified variables while controlling for the influences of individual pulse type and growing areas on productivity of improved pulses included in the model (Table 6).

**Table 6.** Parameter estimates of the stochastic production frontier model for improved pulses corrected for sample-selection bias.

| **Variables** | **Stochastic Production Frontier Model (Jointly Estimated with the Probit Variety Selection Equation)** | |
|---|---|---|
| | **Coefficient** | **t-Ratio** |
| Production frontier function | | |
| Constant | 8.0363 *** | 39.72 |
| ln Land | 0.7678 *** | 19.59 |
| ln Irrigation | −0.0001 | −1.40 |
| ln Fertilizer | 0.1195 *** | 8.42 |
| ln Seed | −0.1507 *** | −7.99 |
| ln Mechanical power | 0.0806 *** | 3.65 |
| ln Labour | 0.0649 ** | 2.17 |
| ln Pesticide | 0.1007 *** | 6.88 |
| ln Organic manure | −0.0259 * | −1.79 |
| Fertilizer users | −0.2714 *** | −5.70 |
| Pesticide users | −0.6638 *** | −6.74 |
| Organic manure users | 0.1872 * | 1.69 |
| Mechanical power user | −0.6083 ** | −2.17 |
| Irrigation users | −0.0785 *** | −3.23 |
| Sown during optimum time | 0.0194 | 1.03 |
| Used own sourced seed | −0.0447 *** | −3.74 |
| Lentil | −0.6887 *** | −7.88 |
| Blackgram | −1.1325 *** | −11.78 |
| Chickpea | −0.5043 *** | −6.52 |
| Meherpur | 0.3772 *** | 6.92 |
| Natore | 0.1591 *** | 3.36 |
| Jessore | 0.1507 *** | 3.68 |
| Rajshahi | 0.0109 | 0.40 |
| Patuakhali | −0.0098 | −0.19 |
| Chapainawabganj | 0.1175 ** | 2.10 |
| Jhenaidah | 0.3162 *** | 3.68 |
| Model diagnostics | | |
| Log likelihood | −808.25 | |
| Chi-square test for Stochastic Frontier vs OLS | −938.83 *** | |
| $\sigma_u$ | 0.4500 *** | 34.71 |
| $\sigma_v$ | 0.2421 *** | 20.01 |
| Sample-selection bias, $\rho_{w,v}$ | −0.99 *** | −3354.44 |
| Number of selected observations | 1666 | |

Note: *** significant at the 1 percent level ($p < 0.01$); ** significant at the 5 percent level ($p < 0.05$); * significant at the 10 percent level ($p < 0.10$).

A total of 21 coefficients for the variables out of a total of 25 are significantly different from zero at the 10% level at least, implying a very good fit of the stochastic production frontier model corrected for sample-selection bias. Since all pulse growers did not use all of the inputs, we have specified the input variables as ln [$Max(X_i, 1–D_i)$] following Battese and Coelli [37]. The model output shows that controlling for non-use of inputs is justified as coefficients for all of the relevant dummy variables were significantly different from zero at 10% level at least. This action also accounts for the possible argument that not all pulses use all inputs. Also, all input variables were mean corrected prior to estimation; therefore, the first-order coefficients can be read directly as elasticities.

Results from the stochastic production frontier for improved pulse, corrected for sample-selection bias, reveal that the significant drivers of pulse productivity are land area, fertilizer, mechanical power services, labour and pesticides. Seed and organic manure seem to be overused and hence reduce pulse productivity. The overuse of these two variables is evident in Table 2 for improved varieties of lentil and mungbean and Table 3 for the overall sample. Land has the highest elasticity value of 0.77, implying that a one percent increase in land area allocated to improved pulses will increase production by 0.77%. The production elasticity of fertilizer was estimated at 0.12 and pesticide at 0.10. The use of own source of seed significantly reduces pulse productivity, perhaps because the level of varietal purity decreases from subsequent planting. Hasan et al. [27] noted a significantly positive influence of labour, pesticides and fertilizers on improved pulse productivity in Bangladesh. Similarly, Rede et al. [35] noted significantly positive influence of seed rate, human labour, machineries, animal power services and phosphate fertilizers on gram productivity in Maharashtra state of India.

Productivity of improved varieties of lentil, blackgram and chickpea is significantly lower as compared to improved mungbean (Table 6). In contrast, Hasan et al. [27] noted significantly higher productivity of improved lentil and blackgram as compared to mungbean for southern Bangladesh. Location does matter. Productivity is significantly higher in five districts. These are Meherpur, Natore, Jessore, Chapainawabganj and Jhenaidah, all of which belong to a single AEZ, i.e., High Ganges River Floodplain.

### 3.6. Production Efficiency of Improved Varieties of Pulses

The summary statistics of technical efficiency scores for improved pulse producers, corrected for sample-selection bias, are presented in Table 7. The mean technical efficiency (MTE) is estimated at 0.73 implying that pulse production can be improved by 27 points by improving technical efficiency alone, which is substantial. Producers exhibit a wide range of production inefficiency ranging from 0.23 to 0.99. Our estimate of MTE for all improved pulses is lower than for individual pulse types, i.e., lentil (MTE = 0.91), blackgram (MTE = 0.85) and mungbean (MTE = 0.76%) reported by Miah et al. (2005) and pulses (MTE = 0.80) reported by Hasan et al. [27] for Bangladesh and gram (MTE = 0.82) reported by Rede et al. [38] but higher than mungbean (MTE = 0.56) reported by Badal et al. [39] for northern India. Observation of wide variation in production efficiency is not surprising and is similar to the results of others [24,27,33,38,39].

**Table 7.** Distribution of technical efficiency scores of improved pulse producers.

| | **Stochastic Production Frontier (Corrected for Sample-Selection Bias)** |
|---|---|
| Efficiency levels | |
| Up to 60% | 17.00 |
| 61–70% | 23.00 |
| 71–80% | 27.60 |
| 81–90% | 25.90 |
| 91% and above | 6.50 |
| Efficiency scores | |
| Minimum | 0.23 |
| Maximum | 0.99 |
| Mean | 0.73 |
| Standard deviation | 0.13 |
| Number of observations | 1666 |

## 4. Conclusions and Policy Implications

The study jointly evaluates the determinants of switching to improved pulse varieties, and the productivity and efficiency for individual producers in Bangladesh by applying a sample-selection framework in stochastic frontier model. The model diagnostics reveal that serious sample-selection bias exists, thereby justifying use of this framework. The implication is that estimation from only single variety producers (i.e., either improved or traditional pulse producers) will provide biased results of the determinants of improved variety adoption, productivity, as well as farm-specific technical efficiency scores, which is clearly demonstrated in this study.

The results confirm that yield, experience, education and extension contacts are the important determinants in choosing improved pulse varieties. As shown in Table 1, the yield from improved pulse variety is significantly higher when compared with traditional pulse variety, and this provides a good incentive to switch, which is further complemented by extension contacts, education and experience. Results from the sample-selection stochastic production frontier reveal that land, fertilizer, mechanical power, labour and pesticides are the main determinants of improved pulse productivity. Productivity is highest for improved mungbean, which explains the 100% adoption rate for this pulse type in Bangladesh. Geographical locations also influence improved pulse productivity, which explains the existing concentration of pulse production in certain areas of Bangladesh, specifically the Ganges Floodplains. A high level of inefficiency exists in improved pulse production, implying that there is substantial scope to increase production by improving technical efficiency alone.

A number of policy implications can be drawn from the results of this study. First, investment in R&D is needed to develop improved varieties for all pulses. Thrust in R&D investment in pulses in the areas of pulse breeding and genetics was recommended in the 10-year Research Strategy for Pulse Crops [4]. Thus far, research is skewed towards developing improved varieties for chickpea, mungbean and lentil. Lack of a wide range of improved varieties for blackgram and grasspea is perhaps responsible for very low or non-adoption of improved varieties of these pulses. Although lentil and mungbean cover a major share of the pulse area, widespread availability of improved varieties for all type of pulses will boost total production of pulses in Bangladesh. In this connection, there is a need to include farmers in the R&D endeavor so that they gain ownership of any improvements in varietal developments, and this will enhance widespread adoption. Second, investment is needed to improve extension services, as contact with extension services is significantly positively associated with a high level of improved pulse adoption. Third, investment in education targeted at farmers will also increase adoption of improved pulses. Recommendation for education targeted for the farming population has been a common feature because of its positive influence in modern technology adoption studies. Our result reinforces the need for education targeted at the farming population. Fourth, investment should be made to enhance availability of high quality improved seed of all pulses. This may be achieved by enhancing farmer-based seed production and distribution schemes (e.g., rice seed producing schemes by BRAC, the largest NGO in Bangladesh), which will ensure widespread availability of improved seed to farmers. Fifth, measures are needed to increase availability of land for improved pulse cultivation, as it is one of the most important determinants of productivity. Since existing tenurial arrangements in Bangladesh are exclusively geared towards facilitating rice farming, which is the main crop, tenancy reform aimed at improving incentives for tenants would enable landless and marginal farmers to increase their farm size and/or enter into improved pulse farming. Although farmers allocate land to various crops according to their own subsistence and cash needs, smooth functioning of the land rental market could result in allocating more land to pulses. Sixth, intervention in facilitating smooth operation of the mechanical power services will also boost pulse productivity. Traditionally, the main sources of tillage and post-harvest operations were draft animal power, which has been gradually replaced by mechanical power, particularly, the use of power tillers. However, the rental market of mechanical power services is not highly developed yet, thereby resulting in variable rates of rental charges for this important production input across regions. Therefore, measures to improve the rental market of mechanical power services will also enhance pulse productivity. As for the fertilizers, the government has already reintroduced subsidies in recent years in order to enhance agricultural growth, which is a step in the right direction, and therefore, no specific policy implication is warranted here.

The complex interplay of these factors perhaps explains the varied level of adoption of improved varieties of pulses despite two decades of serious policy drive and investments aimed at development and diffusion of improved pulse technologies in Bangladesh. The study demonstrated that farmers' socio-economic factors along with yield and input use levels play an important role in determining variety selection decisions as well as productivity performance of pulses. Nevertheless, given the evidence of this study, policies aimed at increasing investments in R&D including involvements of farmers in the process, extension services to develop and disseminate improved pulse technologies including farmer-based seed production and distribution system and farmers' education and tenurial reform to facilitate smooth operation of the land market and mechanical power services will boost pulse production in Bangladesh. The thrust in the government's plan to increase pulse production in Bangladesh commensurate with the plan set out worldwide, which envisages a 10% increase in global pulse production and consumption by 2020 from its 2015 level [5].

A limitation of the present study is that we have focused on the adoption of improved varieties of pulses as the main factor in increasing productivity and production of pulses in Bangladesh, but it should be noted that various management options to address other major constraints faced by farmers are equally important. We have included only two variables, i.e., use of own sourced seed and sowing during optimum time, which are only two of a range of management options available. Therefore, future studies may include various management options undertaken by farmers in studies dealing with the adoption of improved technologies, productivity and production of pulses.

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## Appendix A.

**Table A1.** Name of the improved varieties of pulses grown by the farmers.

| Lentil | Mungbean | Chickpea | Blackgram | Grasspea |
|---|---|---|---|---|
| BARI Masur-3 | BARI Mung-2 | BARI Chola-1 | BARI Mash-1 | BARI Khesari-1 |
| BARI Masur-4 | BARI Mung-3 | BARI Chola-2 | BARI Mash-2 | BARI Khesari-2 |
| BARI Masur-5 | BARI Mung-4 | BARI Chola-4 | BARI Mash-3 | |
| BARI Masur-6 | BARI Mung-5 | BARI Chola-5 | | |
| BARI Masur-7 | BARI Mung-6 | BARI Chola-6 | | |
| BARI Masur-3 | BINA Mung-8 | BARI Chola-9 | | |
| | | BINA Chola-4 | | |
| | | BINA Chola-6 | | |

Note: BARI = Bangladesh Agricultural Institute, BINA = Bangladesh Institute of Nuclear Agriculture.

**Table A2.** Marginal effects of factors influencing the decision to adopt improved pulse technology.

| Variables | Lentil | Blackgram | Chickpea |
|---|---|---|---|
| Constant | 0.0322 | −0.3978 | −0.0059 |
| Yield | 0.0049 *** | 0.0018 *** | 0.0059 * |
| Farming experience | 0.0048 | −0.0014 | 0.0018 |
| Education of the farmer | 0.0006 | 0.0094 * | −0.0058 |
| Subsistence pressure | −0.0030 * | −0.0200 * | −0.0083 |
| Main occupation is farming | 0.0072 | 0.0921 | 0.0078 |
| Received agricultural training | −0.0057 | 0.1373 *** | 0.0965 ** |
| Received extension contacts | 0.0070 | 0.5814 *** | 0.1683 *** |
| Medium highland | 0.0001 | −0.2439 *** | 0.1609 *** |
| Model diagnostics | | | |
| Log likelihood | −123.95 | −249.169 | −303.95 |
| McFadden R-squared | 0.16 | 0.33 | 0.05 |
| Chi-squared | 47.28 *** | 244.30 *** | 32.11 *** |
| Degrees of freedom | | | |
| Number of total observations | 540 | 540 | 540 |

Note: Marginal effects for dummy variables are computed at P | 1–P | 0 (NLOGIT 2007). *** significant at the 1 percent level ($p < 0.01$); ** significant at the 5 percent level ($p < 0.05$); * significant at the 10 percent level ($p < 0.10$).

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