Food Sec. (2016) 8:1011–1028
DOI 10.1007/s12571-016-0611-9

ORIGINAL PAPER

Growing the service economy for sustainable wheat intensification in the Eastern Indo-Gangetic Plains: lessons from custom hiring services for zero-tillage

Alwin Keil[1] · **Alwin D'Souza**[1] · **Andrew McDonald**[2]

Received: 13 November 2015 / Accepted: 1 August 2016 / Published online: 24 September 2016

Abstract Zero-tillage (ZT) is a proven technology for enhancing wheat productivity and, hence, food security in the Indo-Gangetic Plains, while reducing production costs. However, very few farmers possess their own tractors much less the specialized seed drills required to implement the technology. As a consequence, adoption of ZT largely hinges on affordable access to custom hire services. In Eastern India, the service economy for ZT is expanding, but remains in the early stages of growth. ZT service businesses remain largely uncharacterized, and related business dynamics poorly understood. To address this knowledge gap and derive recommendations for an efficient targeting of public sector support for those service providers (SPs) who are poised for growth, we identified factors that influence ZT entrepreneurship, encompassing new business formation and the resulting scale of the enterprise. We used data from a census of 270 ZT SPs in Bihar, as documented by the Cereal Systems Initiative for South Asia (CSISA). To identify determinants of engaging in ZT service provision, the data were pooled with those of 1000 randomly-selected wheat farmers located in the same districts. We applied Heckman's two-step estimation procedure to derive unbiased estimates of determinants of the scale of the ZT service businesses. ZT SPs are generally larger, tractor-owning farmers who have taken up service provision as a side business since 2010 or later. Only 8.3 % of the surveyed farm households owned a tractor, demonstrating the importance of service provision for accessing ZT and other mechanization technologies. ZT SPs expanded their businesses considerably from 2011 to 2012 to an average total of 20 clients and 50 ha serviced per SP. However, larger areas were primarily achieved by servicing larger client farms. Well-educated farmers with larger land holdings and extensive social networks are most likely to become ZT SPs. However, among this stratum, the relatively smaller scale farmers were most likely to provide services at a sizeable scale. To efficiently accelerate the spread of ZT technology, we conclude that these smaller-scale tractor-owning farmers are the most sensible targets for purchase subsidies on ZT drills as well as the primary audience for business development training. Since a considerable fraction of the ZT area expansion resulted from service provision to larger client farms, there is a need to develop business models that enhance the social inclusiveness of ZT services by reducing the transaction costs of reaching smallholders.

Keywords Zero-tillage · Agricultural mechanization services · Business development · Heckman selection model · Bihar

Introduction

Enhancing the productivity of the rice-wheat cropping systems in the Indo-Gangetic Plains (IGP) is of primary importance for ensuring food security for more than 20 % of the global population (Chauhan et al. 2012). The Eastern Indian

✉ Alwin Keil
a.keil@cgiar.org

Alwin D'Souza
alwdsouza@gmail.com

Andrew McDonald
A.McDonald@cgiar.org

1 CIMMYT-India, CG Block, National Agricultural Science Centre (NASC) Complex, DPS Marg, New Delhi 110012, India

2 CIMMYT-Nepal, NARC Agricultural Botany Division, Khumultar, Kathmandu, Nepal

state of Bihar is a net importer of wheat with 868,000 MT purchased against a base of production of just over 5 million MT in 2010–11 (Paulsen et al. 2012). With an average of 2.34 MT ha^{-1} over the period 2012/13–2013/14 (MoA 2015), Bihar has the lowest wheat yields in the IGP. With one of the highest population growth rates in India and without concerted efforts to enhance agricultural productivity (MoA 2015), the gap between consumption and production is poised to widen in this densely populated state of 104 million people (MoA 2015). Furthermore, the regions that currently supply wheat to Bihar, such as the Northwestern state of Punjab where wheat yields averaged 4.79 MT ha^{-1} over the same period (MoA 2015), have comparatively little scope for boosting yields further (Aggarwal et al. 2004). Exacerbating this scenario, there are strong imperatives in Northwestern India to reduce water resource utilization in agriculture in order to arrest the dramatic declines in groundwater levels that are undermining the sustainability and environmental footprint of production (Humphreys et al. 2010). In recognition of the pervasive yield gaps that characterize the Eastern IGP along with a wealth of under-developed water resources (Aggarwal et al. 2004; DoA 2008), Indian policy makers have turned their attention to meeting both state-level and national food needs through intensification in the East through programs such as 'Bringing the Green Revolution to Eastern India' (BGREI; http://bgrei-rkvy.nic.in). Nevertheless, a variety of factors contribute to the currently low yields in the East. Identifying technical entry points and strengthened support systems for innovations that will contribute to agricultural intensification in a manner that is environmentally sustainable, socio-economically tenable, and – just as importantly - broadly scalable among smallholders presents a formidable challenge.

In researcher-managed field trials across South Asia, the combination of zero tillage (ZT) and residue retention ('conservation agriculture') has been found to have considerable agronomic and economic benefits, while improving the environmental footprint of agriculture by reducing energy costs and improving soil and water quality (Erenstein and Laxmi 2008; Chauhan et al. 2012; Gathala et al. 2013; Mehla et al. 2000). ZT wheat is the most widely adopted resource conserving technology in the rice-wheat systems to date, especially in the Northwestern Indian IGP (Derpsch et al. 2010). The prevailing ZT practice uses a zero-till drill[1] attached to a four-wheel tractor to sow wheat directly into unplowed fields with a single pass, whereas conventional-tillage (CT) practices in wheat typically involve 'intensive tillage with multiple passes of the tractor to accomplish plowing, harrowing, planking, and seeding operations' (Erenstein and Laxmi 2008). In ZT wheat, agronomic factors leading to productivity advantages are related to (i) time-savings in crop establishment, allowing earlier sowing and, hence, reducing risks of terminal heat stress during the grain-filling phase; (ii) in cases, better control of damaging weeds, especially the herbicide-resistant *Phalaris minor*; (iii) better nutrient management; and (iv) water savings (Gathala et al. 2013; Mehla et al. 2000). Based on on-farm trials in Haryana, Mehla et al. (2000) estimated a ZT induced yield gain of 15.4 %, which they attributed to timely sowing (9.4 %) and enhanced fertilizer- and water use efficiency, as well as weed suppression (6.0 %). Significant yield increases and cost savings due to ZT wheat have also been confirmed in farmers' fields, both in the Northwestern IGP (Erenstein et al. 2008; Krishna and Veettil 2014) and in the Eastern IGP (Keil et al. 2015), based on household surveys. For Bihar, Keil et al. (2015) estimated a yield gain of 19 % over CT wheat and economic benefits from yield increase and cost savings equivalent to 6 % of the average wheat farmer's annual household income; they concluded that broad-scale adoption of ZT technology could play a major role in making Bihar self-sufficient in wheat.

In India, tractor ownership is confined to relatively wealthy farmers, especially in the less productive states of the Eastern IGP, such as Bihar, where the poverty rate among the rural population is among the highest in India at 33.7 % (MoA 2015). For smallholder farmers in Bihar, access to the productivity enhancing and resource conserving ZT technology hinges on custom hire of ZT services. Hence, the service economy for ZT can play a vital role in closing wheat yield gaps for enhancing wheat self-sufficiency and food security in Bihar. However, the supply side of mechanization has received little attention in the literature, despite the fact that agricultural labor is becoming increasingly scarce due to out-migration to urban centers or engagement in non-agricultural income generating activities, thus driving up rural wages and increasing the economic rationale for agricultural mechanization (Zhang et al. 2010; Agasty and Patra 2014; Mehta et al. 2014; Kienzle et al. 2013). Diao et al. (2012) used the examples of Bangladesh, China, and India to discuss alternative supply models of agricultural mechanization. Mechanization in Bangladesh is largely based on small machines, e.g. two-wheel tractors, that are relatively affordable for smallholder farmers. In China, in addition to small-scale mechanization similar to the case of Bangladesh, there is a rapid spread of specialized entrepreneurs providing mechanization services, especially for harvesting, for the better part of the year, travelling long distances and using larger machinery. India, on the other hand, has not taken the route of small-scale mechanization, but thus far relies heavily on mechanization services being provided by medium- to large-scale farmers who own four-wheel tractors. However, only very few studies investigated the viability of agricultural mechanization services provided by the private sector, such as Houssou et al. (2013) or Yang et al. (2013). To the best of our knowledge, there exists

[1] Refer to Mehla et al. (2000) for technical details of zero-till drills.

no study that examines the development and performance of ZT service businesses in the IGP; in particular, an identification of factors that foster individuals' engagement in ZT service provision and expansion of enterprises that are formed. This kind of information is needed for efficient targeting of development investments (e.g. subsidy allocation, training interventions) to potential service providers (SPs) who are poised for growth and, hence, are more likely than others to provide access to the ZT technology to larger numbers of farmers. To address this important knowledge gap, the objectives of this paper are (1) to characterize ZT SPs and their businesses in Bihar, (2) to analyze the profitability of ZT service provision, and (3) to identify the factors that influence the engagement in ZT service provision and the scale of the business in order to derive recommendations for an efficient targeting of potential ZT SPs and, thus, enhance access to the benefits of ZT technology that would otherwise be out of reach for smallholders.

Research area, sampling procedure, and data collection

Agriculture is the main occupation in Bihar with almost 81 % of its population engaged, whereas its contribution to the state's domestic product is 42 % (DoA 2008). Rice, wheat, pulses, maize, potato, sugarcane, oil seeds, tobacco and jute are the principal crops grown. Although Bihar is endowed with good soil, sufficient rainfall and abundant groundwater, its agricultural productivity is one of the lowest among Indian states (DoA 2008; MoA 2015). The research area is composed of six districts in Bihar where the Cereal Systems Initiative for South Asia (CSISA; www.csisa.org) has focused research and outscaling activities for sustainable intensification technologies since 2009 (Fig. 1). Using a census approach, in May/June 2013 data were collected from all of the 270 ZT SPs who were documented by CSISA in Bihar and who were spread across 231 villages in nine districts; all ZT SPs were farmers who used ZT technology on their own farms and provided custom-hire services at varying scales as a side business. To identify determinants of engaging in ZT service provision, the ZT SP dataset was pooled with a dataset of 1000 randomly selected wheat growing households (users and non-users of ZT), collected from August to October 2013 in 40 randomly selected villages in six districts, which are a subset of the nine SP districts. For the joint analysis, only ZT SPs residing in the six common districts were considered, reducing their number to 230. Since the primary purpose of the wheat farmer dataset was the estimation of ZT induced yield effects (see Keil et al. 2015), the sample was stratified by ZT adoption status, encompassing 400 users of ZT and 600 non-users. To permit sample stratification, a brief census survey was conducted in each of the 40 research villages to elicit households' main occupation, incidence of wheat cultivation (since, in Bihar, ZT is thus far almost exclusively used in wheat), and ZT adoption status. The stratification is unproblematic for our purposes since we are primarily interested in the sample households' common characteristic of *not* providing any ZT services. In Bihar, wheat is by far the most widely grown crop during the winter (*rabi*) season (MoA 2015); based on the village census data, 92.8 % of households in our research villages were wheat growers. Therefore, confining the sampling frame to wheat-growing households is not expected to introduce any significant bias in our analysis.

Data were collected from household heads by a team of 18 professional enumerators through structured interviews.[2] To minimize data entry errors, electronic questionnaires with extensive skip and validation rules were used. From ZT SPs, detailed data were collected on their service provision business, i.e. number of clients and area serviced, costs and returns, and perceived constraints. We collected recall-based panel data spanning three wheat cropping seasons, 2010/11 to 2012/13, during which 71 % of SPs provided ZT services for the first time in the 2012/13 *rabi* season. From all households, information was elicited about asset endowment and rice and wheat growing practices. Furthermore, we assessed the household heads' level of risk aversion using a set of self-assessment and hypothetical yield scenario questions. GPS co-ordinates were recorded for all interviewed households. The comprehensive questionnaire led to an average interview time of 2.5 h both among SP and non-SP households; to avoid respondent fatigue, interviews were usually completed in two sessions.

Methodological approach

Assessing the profitability of ZT service provision: theoretical framework

To assess the profitability of ZT service provision we used a theoretical framework which is based on firm

[2] All ZT SPs were male. Among the wheat growing households, heads were male in 98 % of cases. Due to the non-sensitive nature of the research topic, the male enumerators did not face any problem in interviewing the few female household heads. The enumerators worked for a New Delhi-based consulting firm specialized in research and communications in the social and agricultural sectors.

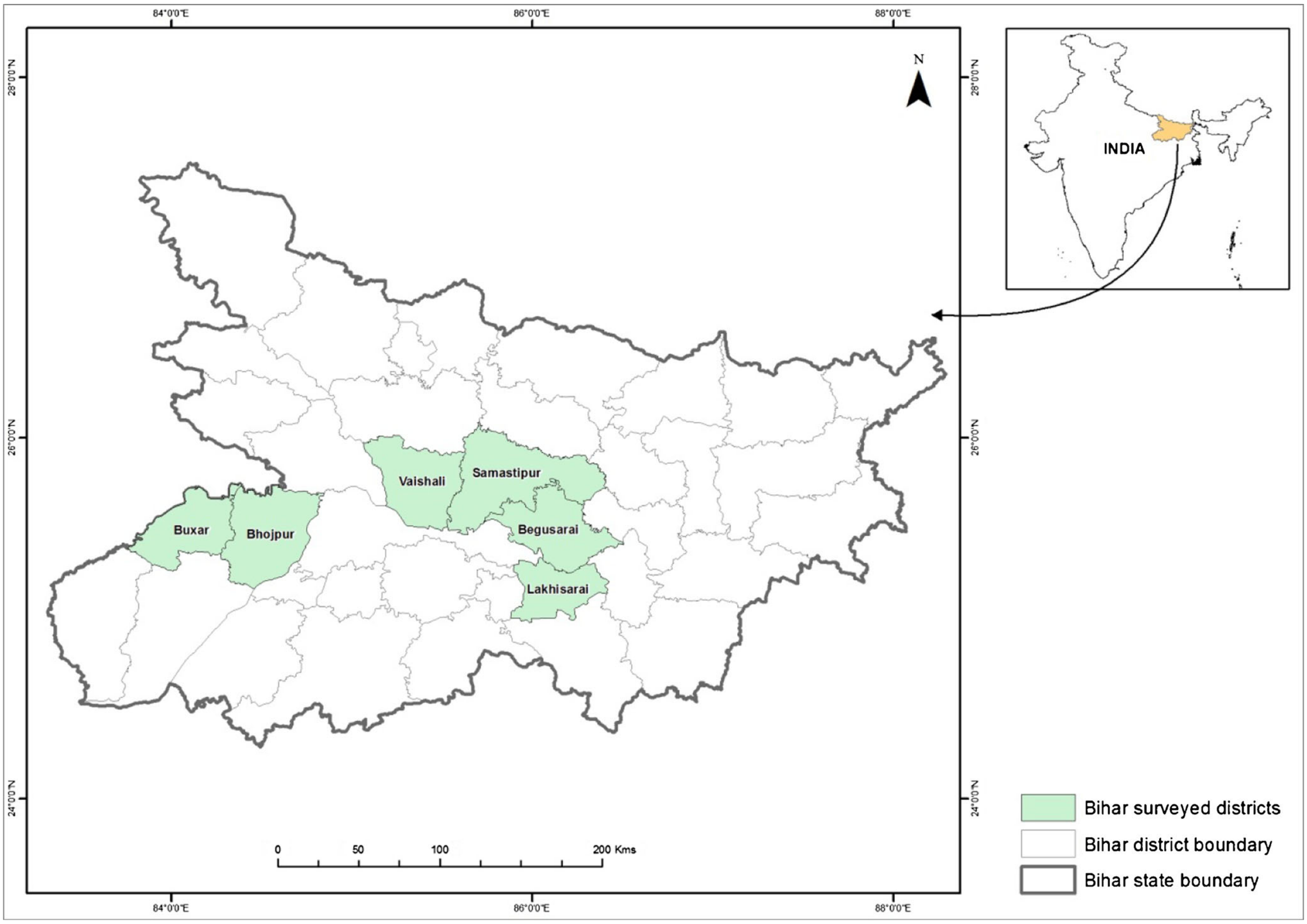


Fig. 1 Map of the state of Bihar in northern India, highlighting the survey districts

investment theory. In the following section, which draws heavily on Houssou et al. (2013), we considered ZT service provision to be a business run by a firm. Conceptually, the firm decides whether to invest in a ZT drill and provide related services or to save the same amount of capital in a bank to earn interest. Our profitability analysis was based on the following assumptions: (1) the investment in the ZT drill is made without taking out a loan, which is confirmed by our data; (2) the firm does not invest in a tractor for the sole purpose of ZT service provision, but rather owns a tractor that is being used for multiple purposes, one of them being ZT service provision; (3) the useful life of the tractor is 10,000 working hours (equivalent to an average daily use for 2.74 h over a 10-year period); (4) the useful life of the ZT drill is 5 years, which is a conservative but reasonable assumption, given the relatively poor build-quality of the ZT drills available in the research area; and (5), with the required annual maintenance, neither the productivity of the tractor nor that of the ZT drill is affected by their depreciation.

The firms' goal is to maximize its intertemporal net profit π across the useful life of the ZT drill, which can be written as follows:

$$\pi = \sum\nolimits_{t=0}^{4} R_t * GM_t - I \tag{1}$$

where

$$R_t = \frac{1}{(1+r)^t} \tag{2}$$

R_t is the discount factor for year t and r is the annual saving interest rate; the definition of R_t represents the standard method of delay discounting by valuing a future cash flow in terms of its net present value (Doyle 2013). I is the initial investment cost of the ZT drill and GM_t is the gross margin, i.e., the annual service provision revenue minus variable costs. The gross margin in year t can be calculated as follows:

$$GM_t = P_t * A_t - A_t(FP_t * FC + T * W_t) - M_t \tag{3}$$

where

- P_t ZT service charge per ha (Indian Rupees, INR)
- A_t Area serviced (ha)
- FP_t Fuel price per litre (INR)
- FC Fuel consumption per ha (litres)
- T Operating time per ha (hours)
- W_t Wage rate of tractor operator per hour (INR)
- M_t Maintenance and repair costs of the ZT drill and tractor (INR)

W_t is zero in the case of owner-operators, which we will consider in our subsequent analysis. M_t includes the proportionate tractor maintenance and repair costs, based on the time share the tractor is used for ZT service provision.

Although π is defined for one investment cycle of 5 years in Eq. 1, we assume that the firm will reinvest in the same kind of ZT drill (and in the same kind of tractor), so that the business is sustained over time. Solving the profit maximization problem yields the following non-arbitrage condition:

$$GM - \delta I = rI \tag{4}$$

where δ is the capital depreciation rate. The non-arbitrage condition requires that the gross margin minus the capital depreciation cost of the ZT drill investment equals the interest earned from saving the same amount of capital in a bank. Beyond this equilibrium point it will be rational for the firm to reinvest in the same kind of ZT service provision business. While Eq. 4 needs to hold over the entire investment horizon of 5 years, but not necessarily in each individual year, in the absence of panel data we make the simplifying assumption that P_t, A_t, FP_t , W_t , M_t, as well as δ and r are constant over time, so that Eq. 4 holds for each year.

For each year, the net profit earned from ZT service provision, i.e., the profit minus the interest that could have been earned by saving the capital rather than investing it in a ZT drill, can be calculated as follows:

$$NP = GM - D_{prop} - (\delta + r)I \tag{5}$$

where

$$D_{prop} = A*T*D \tag{6}$$

D_{prop} denotes the proportionate depreciation of the tractor that is attributable to ZT service provision, which is the product of the area serviced (A), the operating time per ha (T), and the depreciation of the tractor per working hour (D).[3] D is calculated as the investment cost of the tractor divided by the assumed useful life of 10,000 working hours. Substituting GM by the right-hand side of Eq. 3 and D_{prop} by the right-hand side of Eq. 6 and re-arranging yields:

$$NP = P*A - A(FP*FC + T*(W + D)) - M - (r + \delta)I \tag{7}$$

Our profitability analysis in "Characterizing zero-tillage service provision businesses" section is based on Eq. 7. While our calculations are based on the sample means of observed values (for different groups of ZT SPs) for most parameters, the operating time per ha (T) is set to 185 min, which, in focus group discussions with ZT SPs, was elicited as an average value; however, it has to be kept in mind that T will vary with the degree of land fragmentation. Given the assumed five-year useful life of the ZT drill, the capital depreciation rate (δ) is set to 0.2, and the interest rate (r) is set to 0.1. The latter accounts for a 'risk premium' on top of the interest that could be earned by saving the amount of I in the bank (typically 4 % p.a.), hence leading to rather conservative profit estimates.

Given that the variability in purchase prices of ZT drills (I) is limited, fuel prices (FP) and wage rates (W) are given, and, based on assumption (2), also fuel consumption (FC) and tractor depreciation (D) are fixed, the firm can influence the net profit from ZT service provision primarily via the area serviced (A). Hence, as elaborated in the next section, the second part of our analysis identifies factors that influence the area serviced, conditional on a positive decision to engage in ZT service provision.

Identifying determinants of the scale of zero-tillage service provision: model estimation strategy

We assume households' engagement in ZT service provision to be based on two sequential decisions: first, a yes/no decision whether or not to engage in service provision and, second, the decision at which scale to provide services. The identification of factors influencing the first decision is econometrically straightforward: we estimate a probit model with a dichotomous dependent variable which takes on the value of 0 for non-SP households and the value of 1 for SP-households. Our analysis of factors influencing the business scale decision, however, is based on the sub-sample of SP-households only. Unobserved or unobservable characteristics of SPs differentiating them from non-SPs may at the same time influence the scale of their service provision businesses. As a result, the estimated regression coefficients on the hypothesized business scale determinants may be afflicted by sample selection bias (Heckman 1979). In order to account for the non-randomness of the selection rule, Heckman (1979) proposed a two-stage estimation procedure to correct the potential bias. Applying Heckman's approach to the case

[3] Based on assumption (2), the investment in the tractor is not considered part of I.

of ZT service provision, our model estimation strategy can be written as follows: let the equation which determines sample selection, i.e., the decision whether to engage in ZT service provision be

$$Y* = \gamma w + \nu \tag{8}$$

and let the equation determining the scale of the ZT service business be

$$BS = \beta \mathrm{x} + \varepsilon \tag{9}$$

where

$Y*$	Difference in expected returns between engaging and not engaging in ZT service provision
BS	Suitable measure of the business scale
w, x	Vectors of exogenous regressors
γ,β	Vectors of parameters to be estimated
ν,ε	Error terms

I. Selection mechanism

The dependent variable Y* is not directly observable. Each household uses idiosyncratic criteria and will decide to engage in service provision if Y* > 0. A binary variable Y is defined which takes on the value of 1 if the household decides to engage in service provision and the value of 0 otherwise:

$$Y = \gamma w + \nu \tag{10}$$

where Y = 1 if Y* > 0 and Y = 0 otherwise.

Prob(Y = 1) = Prob(Y* > 0) = Prob($\nu > -\gamma$w) = Prob(γw) = Φ(γw), where Φ is the cumulative distribution at γw.

II. Regression model

Equation 9 is observed only if Y = 1; ν,ε are assumed to be distributed according to a bivariate Normal distribution with mean zero, standard deviation σ and correlation ρ. Then:

$$E\left[BS \middle| Y = 1\right] = \beta x + \rho\sigma\lambda(\gamma w) \tag{11}$$

where λ= ϕ (γw)/Φ (γw), where ϕ is the density function at γw.

λ is the Inverse Mills Ratio (IMR), and $\rho\sigma$ equals the regression coefficient on the IMR, β_λ. As shown above, the IMR is the ratio of the value of the density function of a standard normal distribution calculated at γw and the probability of being in the SP sub-sample, which equals the value of the cumulative distribution at γw for SPs and its complement to 1 for non-SPs. The IMR can be interpreted as a variable which captures all unobserved and unobservable characteristics which potentially could have an effect on the final outcome variable of interest, BS. By including the IMR in the second-stage equation, the sample selection bias is corrected for, and OLS can safely be used for the estimation of β (Wooldridge 2006: 619–620). Hence, the second-stage equation is specified as follows:

$$BS = \beta x + \beta_\lambda \lambda + \varepsilon \tag{12}$$

Using the Stata 13 software package (www.stata.com) we estimated a full maximum likelihood variant of Heckman's selection model, which produces heteroskedasticity-consistent standard errors that account for clustering of the sample at the village level.

Model specification

The dataset encompasses 227 SP households and 991 non-SP households with no missing values in any of the variables required for the analysis. As elaborated above, the selection equation uses a binary dependent variable indicating whether or not a household is engaging in ZT service provision. Since ZT services are remunerated on a per-area-unit basis, we use the total number of hectares serviced in the *rabi* season preceding the survey as a measure of the scale of the business. Drawing on the concept of livelihood resources as laid out in the sustainable livelihoods framework (Chambers and Conway 1992; Scoones 1998), we hypothesize the (scale of) engagement in ZT service provision to be determined by households' resource endowment (including access to relevant information) and potential competition with other ZT SPs in the households' vicinity. The households' resources we classify under four types of capital, namely (1) natural capital, (2) human capital, (3) financial capital, and (4) social capital/information access. Under the category of human capital, we include a measure of risk aversion, which remains an unobserved factor in most studies pertaining to the adoption of agricultural innovations. Since farming is the main source of income for both non-SP and SP households, our measure is proxied by the respondents' stated willingness to take risks in farming on a scale from 1 (substantial risk) to 5 (no risk). Moreover, some factors related to the productivity of the SPs' own farm operations enter the model; since a certain level of endogeneity cannot be ruled out, these factors should be viewed as correlates with rather than determinants of the scale of ZT businesses.

With a growing number of ZT SPs, farmers will make their decisions about whether to engage in service provision – and at what scale to do so – in an increasingly competitive environment. Using the recorded GPS co-ordinates, we counted the number of ZT SPs in a given radius around individual sample households, with the radius ranging from 500 m to 20 km. This allowed us to analyze the effects of the concentration of SPs in a given area on the business decisions taken.

The density of ZT SPs varied significantly among districts, and competition effects may vary depending on the SP density. For instance, the marginal effect of an additional ZT SP in a low-density district may be positive, inspiring other households to engage in the same type of business; in a district with an already high density of ZT SPs, however, the marginal effect of an additional SP is more likely to be negative, discouraging others from engaging in the same type of business. Therefore, we interacted the number of proximate ZT SPs with district dummy variables to obtain district-wise estimates of potential competition effects.

Furthermore, district dummies control for location-specific differences, which may be caused, among other factors, by varying timings and intensities of CSISA activities. Table 3 in "Characterizing zero-tillage service providers" section provides the definitions and sample means of the dependent and explanatory variables used in the regression analysis. To gain additional insights in the characteristics of specific groups of observation units, Table 3 displays sample means separately for ZT SPs and non-SPs, as well as for SPs who serviced <10.1 ha in the 2012/13 *rabi* season (bottom quartile) and those who serviced >40.5 (top quartile).

Results

Development of zero-tillage service provision over time

As a precursor to this section it is useful to note that the provision of ZT services is still a relatively novel business, which has taken off since 2012 only. Table 1 shows a sharp increase in ZT SP numbers over the *rabi* seasons 2010/11–2012/13. From 2010 to 2011, their number grew by 359 % from 17 to 78, and it increased by another 238 % to 264 active ZT SPs in 2012. While the average number of farmers serviced per ZT SP remained quite stable around 19 to 20, the median number increased by 50 % from 10 to 15 over the period 2010–2012. A more obvious trend is observed in terms of the area serviced: on the average, from 2010 to 2011, the area serviced per ZT SP increased by 153 % from 13.0 to 32.9 ha, and by another 56 % to 50.2 ha in 2012. The median area serviced increased by 100 % from 10.1 to 20.2 ha over the same time. Furthermore, the last column of Table 1 shows that, while there is a highly significant positive correlation between the number of farmers and the number of acres serviced, the magnitude of the same has declined over the years from 0.65 in 2010 to 0.26 in 2012. This implies that, while ZT SPs started off with a rather similar per-client area in 2010, their businesses have become more differentiated, with some SPs servicing a larger number of relatively small farmers and others concentrating on a smaller number of clients with large farms. Hence, we conclude that a relatively large increase in the area under ZT practices can be associated with a relatively small increase in the number of farmers serviced, and vice-versa.

Characterizing zero-tillage service provision businesses

Only 8.3 % of households in our non-SP sample owned a four-wheel tractor. Among those, per-capita land endowment amounted to 0.51 ha as compared to only 0.22 ha among the remaining households (Mann-Whitney test significant at $P < 0.001$). This empirical finding corroborates our introductory statement that tractor ownership in Bihar is confined to farm households with relatively large land holdings, and that smallholder farmers' access to the ZT technology hinges on the existence of ZT SPs. The use of cheaper two-wheel tractors is limited in Bihar, and ZT seed drills for these tractors are not commercially available at present.

Among ZT SPs, the average investment in a four-wheel tractor amounted to 539,503 INR at 2012 prices[4] ($N = 264$). In the 2012/13 *rabi* season, their tractors were, on average, 6.4 years old (median 4) and had 38.3 hp (median 39). The average sales price of a ZT drill – similarly converted to 2012 prices – was 55,213 INR. However, due to subsidies on ZT drills by the Government of Bihar, which were reduced from 80 % to 50 % in 2013, the SPs' own investment averaged 18,244 INR, which is equivalent to a subsidy of 67 % of the sales price, on the average. At the time of the survey, 88.0 % of ZT SPs did not offer any other mechanized services. The minority who did, offered threshing services (34.4 %), spraying services (18.8 %), land preparation using a rotavator (12.5 %), laser-aided land levelling and combine-harvesting (6.3 % each).

Table 2 displays major characteristics of ZT service provision businesses in the 2012/13 *rabi* season. Since the net profit will largely depend on the area serviced (cf. Eq. 7 in "Assessing the profitability of ZT service provision: theoretical framework" section), we differentiated our findings by area-based quartiles of ZT SPs.[5] Column 1 displays the average ZT area serviced, which amounted to 50.2 ha across the entire sample, ranging from 6.5 ha in the bottom quartile to 163.9 ha in the top quartile. Column 2 shows that, while the mean number of clients increased across quartiles from 10 to 32, only the bottom quartile SPs had a significantly smaller number of clients than the other quartiles. This indicates a high degree of variation in client numbers within the area-based

[4] Indian Rupees. 1 USD = 66.5 INR (Sept. 2013). Purchase prices prior to 2012 were inflated by 5.5 % p.a., a rate which was derived from the average annual price increase of a 35 HP tractor, based on the sample data. Due to its specificity, this approach is deemed more appropriate than a correction using the consumer price index, which is based on a comprehensive basket of goods and services.

[5] A concentration of total area serviced values at 20.2 ha (50 acres; 9.5 %) and 40.5 ha (100 acres; 6.8 %) leads to varying sample sizes across quartiles, in particular to a very large second quartile.

Table 1 Development of zero-tillage (ZT) service provision businesses over time

Rabi season	No. of ZT service providers (SP)	Mean no. of ha serviced per ZT SP (median in parentheses)	Mean no. of farmers serviced per ZT SP (median in parentheses)	Correlation between no. of farmers and no. of ha serviced (Pearson)
2010/11	17	20.4 (10)	13.0 (10.1)	0.645*
2011/12	78	18.7 (12)	32.9 (16.2)	0.482*
2012/13	264	19.9 (15)	50.2 (20.2)	0.255*

*Correlation statistically significant at the 0.1 % level of error probability

quartiles, as is also evidenced by the relatively low correlation between the number of farmers and number of acres serviced (Table 1). Consistent with fewer clients, Column 3 shows that the number of days with ZT service provision was significantly lower in the bottom quartile (15) than in the other three quartiles (23 to 30). As Column 4 demonstrates, the average ZT area per client differed widely across the upper three quartiles: while it is statistically the same in the first and second quartiles at 1.1 and 1.2 ha, respectively, the area was significantly larger among the third quartile (2.3 ha, median 1.5) and yet much larger among the top quartile (11.5 ha, median 6.4). This reveals that the large average area covered by the top quartile SPs resulted from targeting primarily large client farms. The charges for ZT services amounted to 1110 INR per ha on the average (Column 5); while there is no difference in the ZT fees among the lower three quartiles, the top quartile charged significantly more at 1186 INR per ha, on the average. The difference may be explained by the fact that top quartile SPs operated under a relatively less competitive environment and were therefore able to charge more: the number of SPs in a 1 km and 2 km radius is significantly negatively correlated with the ZT fee charged; Pearson correlation coefficients are –0.164 ($P < 0.01$) and – 0.152 ($P < 0.05$), respectively. The SP density around top-quartile SPs was significantly lower than that around third-quartile SPs, at 3.1 versus 4.5 SPs in a 1 km radius ($P < 0.1$) and 3.9 versus 6.7 SPs in a 2 km radius ($P < 0.01$), on the average; differences in greater radiuses up to 20 km were likewise pronounced and statistically highly significant.

Regarding the profitability measures displayed in the remaining columns of Table 2, we differentiate two cases, namely with and without accounting for the cost of hired labor. The reason is that, unlike expenses for fuel and repairs, those for hired labor are not inherent to ZT service provision; rather, SPs may choose whether or not to hire a tractor operator to provide (part of) such services. Columns 6 to 9 are based on the data as collected in the field, whereas columns 6a to 9a exclude labor costs, hence ridding the data of the SPs' individual labor hiring choices and providing a common basis for the comparison of the profitability measures across quartiles.

The average gross margin amounted to 516 INR per ha (Column 6). Subtracting Column 6 from Column 5 yields the average variable costs for fuel, maintenance, repairs, and hired labor, which amounted to 593 INR per ha; omitting labor costs increased the gross margin by 25 INR per ha, on the average (Column 6a). Comparing the values across quartiles reveals that gross margins per hectare are significantly higher in the top quartile than in the lower three quartiles, which can partly be explained by the significantly higher service fees charged. Furthermore, the large per-client area among the top quartile SPs (Col. 4) is likely to contribute to the difference by reducing the operating time per hectare: we find a statistically significant negative correlation between the average client area serviced and the average variable costs per hectare (Pearson correlation coefficient − 0.181, $P < 0.001$, both with and without the inclusion of labor costs).

Column 7 shows the net profit per hectare, which accounts for the depreciation of the tractor and ZT drill, as well as for the opportunity costs of the capital invested in the ZT drill (cf. Eq. 7 in "Assessing the profitability of ZT service provision: theoretical framework" section). Obviously, the net profit per hectare hinges on the area serviced, leading to statistically highly significant differences between the bottom (−778 INR), the top (462 INR), and the two intermediate quartiles, thus indicating substantial economies of scale in ZT service provision. Turning to the profitability of the ZT service provision activity as a whole, Column 8 demonstrates the vast differences in total gross margins across SP quartiles, ranging from an average 3100 INR among the bottom quartile to 117,400 INR among the top quartile. Finally, Column 9 displays the total net profit from ZT service provision, which was, on average, negative for the bottom quartile SPs at −3100 INR, just positive among the second and third quartiles, and very substantial at 84,200 INR among the top quartile SPs. In contrast to the total gross margin, the overall net profit did not differ significantly between the second and the third quartile. Omitting labor costs, i.e. assuming all services to be carried out by an owner-operator, leads to only modest increases in all profitability measures (Columns 6a to 9a). The conclusion remains unchanged, namely that only the top quartile SPs were able to reap a substantial net profit from ZT service provision.

Figure 2 displays the relationship between net profit from ZT service provision and area serviced. It was derived by

Table 2 Major characteristics of zero-tillage (ZT) service provision businesses in the 2012/13 rabi season, differentiated by area-serviced quartiles (sample means)

	1. ZT area serviced (ha)	2. No. of clients serviced	3. Days with ZT service provision	4. ZT area per client (ha)	5. ZT fee per ha (INR[a])	Including cost of hired labor: 6. ZT gross margin per ha (INR)	7. ZT net profit per ha (INR)	8. ZT gross margin 2012 ('000 INR)	9. ZT net profit 2012 ('000 INR)	Excluding cost of hired labor: 6a. ZT gross margin per ha (INR)	7a. ZT net profit per ha (INR)	8a. ZT gross margin 2012 ('000 INR)	9a. ZT net profit 2012 ('000 INR)
Stat. significance	****	****	***	****	*	**	****	****	****	**	****	****	****
<= 10.1 ha ($N = 64$)	6.4[a]	10.1[a]	14.9[a]	1.1[a]	1134[ab]	420[a]	−778[a]	3.1[a]	−3.1[a]	474[a]	−724[a]	3.4[a]	−2.8[a]
> 10.1–20.2 ha ($N = 91$)	15.9[b]	17.1[b]	22.6[b]	1.2[a]	1045[a]	487[a]	−10[b]	7.8[b]	0.1[b]	504[a]	10[b]	8.1[b]	0.3[b]
> 20.2–40.5 ha ($N = 49$)	31.6[c]	22.5[b]	29.2[b]	2.3[b]	1102[ab]	484[a]	109[b]	15.4[c]	3.9[b]	502[a]	124[b]	16.0[c]	4.4[b]
> 40.5 ha ($N = 60$)	164.1[d]	32.3[b]	30.3[b]	11.5[c]	1186[b]	687[b]	462[c]	117.4[d]	84.2[c]	697[b]	472[c]	118.5[d]	85.4[c]
Overall ($N = 264$)	50.2	19.9	23.7	3.7	1110	516	−67	33.0	19.1	541	−42	33.5	19.7

*(**)[***]{****} Means statistically significantly different at the 10 %(5 %)[1 %]{0.1 %} level of alpha error probability, based on multiple Mann-Whitney tests accounting for family-wise error; diverging superscript letters indicate statistical significance *at least* at the indicated level

[a] Indian Rupees. 1 USD = 66.5 INR (Sept. 2013)

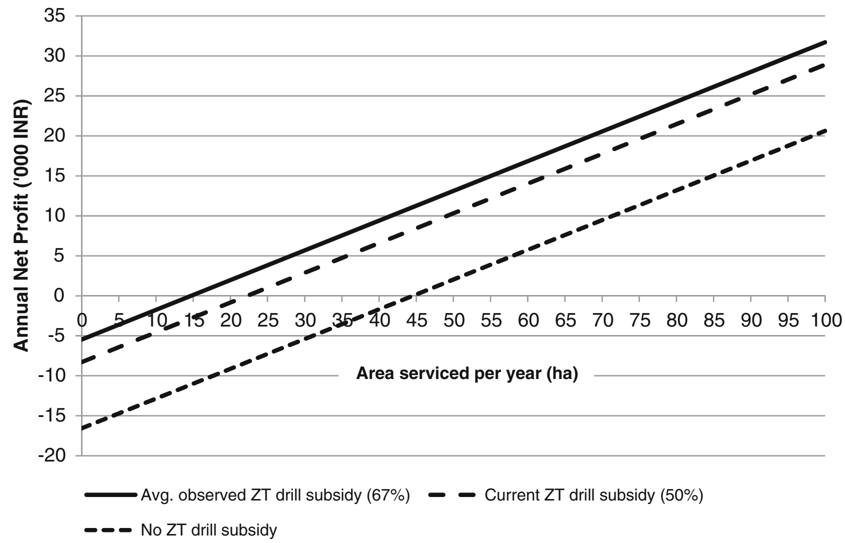
varying the area serviced (A) in Eq. 7 and setting the parameters P, FP, FC, D, M, and I to the overall sample means[6] (see "Assessing the profitability of ZT service provision: theoretical framework" section). Furthermore, ZT services are assumed to be provided by owner-operators ($W = 0$). The figure displays three subsidy scenarios for ZT drills (affecting the value of I), namely (i) the average level of subsidy observed at the time of the survey (67 %), (ii) the current level of subsidy (50 %), and (iii) a potential future no-subsidy scenario. The break-even ZT areas (net profit $NP = 0$) for the three scenarios amount to 14.7 ha, 22.3 ha, and 44.6 ha, respectively. As mentioned in "Assessing the profitability of ZT service provision: theoretical framework" section, our calculation of the net profit is based on an interest rate (r) of 10 %, which accounts for a 'risk premium' on top of the interest that could be earned by saving the amount of I in the bank and therefore leads to rather conservative profit estimates. If we set r to the prevailing savings interest rate of 4 %, the break-even areas in the three subsidy scenarios are reduced to 11.8, 17.8, and 35.7 ha, respectively. In any case, the scenario analysis demonstrates that, under the current subsidy policy, ZT service provision becomes profitable beyond an area of around 20.2 ha only (which is consistent with our quartile-specific results in Table 2). If the subsidy for ZT drills were phased out, this threshold area would double, i.e., only the top quartile ZT SPs would earn a profit.

Characterizing zero-tillage service providers

All of the ZT SPs studied in Bihar were tractor-owning farmers who used ZT technology on their own farms. As demonstrated in the previous section, the scale of ZT service provision varied widely among ZT SPs. Based on the conceptual framework outlined in "Model specification" section, Table 3 lists the means of dependent and explanatory variables used to identify determinants of engaging in ZT service provision and determinants of the scale of this engagement in terms of area serviced. Before presenting the regression results in the next section, the following paragraphs highlight differences in capital endowment between ZT SPs and non-SPs, as well as between large-scale and small-scale ZT SPs. The discussion is based on the disaggregation of sample means by engagement in service provision (non-SPs versus SPs) and scale of service provision (bottom quartile versus top quartile with respect to area serviced) and related statistical tests that are displayed in Table 3. To ensure geographical coherence, only those ZT SPs who reside in the same districts as the sampled non-SPs are considered for this comparison and the

[6] The respective values are: P = 1,109.5 INR/ha; FP = 53.5 INR/l; FC = 8.9 l/ha; D = 166.6 INR/ha; M (ZT drill) = 45.7 INR/ha; M (tractor) = 45.7 INR/ha; I (scenario i) = 18,244 INR; I (scenario ii) = 27,607 INR; I (scenario iii) = 55,213 INR.

Fig. 2 The relationship between annual net profit from zero-tillage (ZT) service provision and area serviced, differentiating three subsidy scenarios. Note: Net profit calculation based on a 5-year useful life of the ZT drill



subsequent regression analysis, leading to a slight deviation of the average area serviced as compared to the previous section, which characterized ZT service provision businesses based on the entire SP dataset available.[7]

Starting with natural capital, Table 3 shows that there are statistically highly significant differences in per-capita land endowment both between non-SPs and SPs, and between small-scale and large-scale SPs: at 1.26 ha per household member, average land endowment of SP households was about five times that of non-SP households at 0.24 ha (total household land endowment amounted to 4.55 ha and 1.36 ha, respectively). Conversely, within the group of SP households we found a negative correlation between land endowment and area serviced (Pearson correlation coefficient − 0.160, $P < 0.05$): at 2.31 ha, bottom-quartile SPs had more than three times as much land per person at their disposal as top-quartile SPs (0.69 ha; total land endowment values were 6.18 ha and 2.82 ha, respectively).

Turning to human capital endowment, we found that the share of farmers who had completed at least 9th grade schooling was significantly higher among SPs (91.6 %) than among non-SPs (52.6 %), while there was no difference between small- and large-scale SPs in this respect. There were also significant differences in caste membership: while, generally, a larger share of SP households belonged to the General caste (an aggregate term for 'forward' castes in India, as opposed to 'backward' castes), the share of large-scale SPs belonging to this category was somewhat smaller than the share of small-scale SPs. With respect to risk aversion, as proxied by the respondents' stated willingness to take risk in farming, we found that, at an average rating of 2.3, SPs were significantly less risk averse than non-SPs (2.8); no significant differences are found between small- and large-scale SPs. Significant differences were also revealed regarding households' endowment with family labor, as measured by the labor-to-land ratio in adult equivalents (AE) per acre: SP households were significantly shorter of labor than non-SP households, at 2.0 versus 4.3 AE ha^{-1}, on the average; among the SPs, the bottom quartile were significantly shorter of labor than the top quartile (2.4 versus 3.2 AE ha^{-1}). The difference in the variable *Own time constraint* shows that, on the average, large-scale SPs felt significantly more time constrained than small-scale SPs.

Income data indicate that small-scale SPs were significantly wealthier than large-scale SPs: while the average total household income of small-scale SPs – exclusive of that from ZT service provision – amounted to 521,000 INR in 2012, it averaged only 301,000 INR among large-scale SPs (Mann-Whitney test significant at $P < 0.01$) Due to its endogenous nature, the income information cannot be directly used as an explanatory variable in the regression analysis and is therefore not shown in Table 3. Instead, we used credit access from formal and informal sources as a longer-term proxy of financial capital endowment. On average, at approximately 520,000 INR, SP households could potentially borrow 4.5 times the amount that non-SP households could access (115,000 INR). The difference between small-scale (718,000 INR) and large-scale (435,000 INR) SPs is also statistically highly significant and consistent with the available income information.

Regarding social capital and information access, we find statistically highly significant differences between SP and non-SP households, indicating that SPs had more extensive social networks and potentially better access to agricultural information. In particular, 27.3 % of SP households were members of the Farmers' Association, as compared to merely 2.4 % of non-SP households. Local farmer groups may serve as important platforms for recruiting new clients for service

[7] A comparison using the entire ZT SP dataset leads to very similar results, which are available on request.

Table 3 Definitions and sample means of dependent and explanatory variables in the Heckman selection model explaining engagement in zero-tillage (ZT) service provision (1st stage) and scale of the ZT business (2nd stage) in Bihar

Variable description			1st Stage (N = 1218)			2nd Stage (N = 227)		Sig. of diff.
		Overall mean (N = 1218)	Non-SPs (N = 991)	SPs (N = 227)	Sig. of diff.	Bottom quartile (N = 45)	Top quartile (N = 56)	
Dependent variables								
Stage 1: ZT SP[a]	= Dummy, = 1 if ZT SP[a]	0.186	0.000	1.000		–	–	
Stage 2: ZT area	= Logged no. of ha serviced in the 2012/13 Rabi season[b]	–	–	53.408		6.322	162.489	****
Natural capital								
Land endowment	= Per capita land endowment (ha)	0.432	0.243	1.260	****	2.314	0.694	***
Human capital								
Age	= Age of HH[a] head	50.348	50.376	50.225	n.s.	52.578	54.964	n.s.
High education	= Dummy, = 1 if educational achievement is at least 9th grade	0.599	0.526	0.916	****	0.889	0.929	n.s.
High caste	= Dummy =1 if HH belongs to General caste[c]	0.470	0.402	0.767	****	0.911	0.679	***
Risk aversion	= Willingness to take risk in farming on scale from 1 (subst. risk) to 5 (no risk)	2.688	2.775	2.308	****	2.667	2.411	n.s.
Labor endowment	= Labor: land ratio (Adult Equivalents ha^{-1})	3.839	4.263	1.988	****	2.449	3.182	****
Own time constraint	= Own time constraint perception on scale from 0 (no constraint) to 5 (very severe)	–	–	2.328		1.978	2.500	***
Financial capital								
Credit access	= Logged max. amount HH could currently borrow ('000 INR)[b]	190.617	115.086	520.361	****	718.111	434.554	****
Social capital/access to information								
Farmers' Association	= Dummy, = 1if any HH member is member of the Farmers' Association	0.071	0.024	0.273	****	0.222	0.607	****
Know Block extension official	= Dummy, = 1 if HH head knows agr. extension employee at Block level	0.185	0.096	0.573	****	0.689	0.732	n.s.
Number off. known	= Total number of officials known at all levels[d]	11.255	4.971	38.687	****	47.711	43.429	n.s.
Extension access	= Access to agr. extension on scale from 0 (no access) to 5 (very good access)	2.652	2.611	2.833	****	3.100	2.563	***
Farm/business characteristics								
ZT business years	= Years ZT service provision	–	–	1.388		1.244	1.321	*
Low productivity	= Dummy, = 1 if agr. productivity was within lowest tercile in 2012	–	–	0.335		0.289	0.732	****
High productivity	= Dummy, = 1 if agr. productivity was within highest tercile in 2012	–	–	0.330		0.333	0.125	**
Neg. agr. income	= Dummy, = 1 if agr. income was negative in 2012	–	–	0.066		0.111	0.107	n.s.
District-wise ZT SP densities								
SP density Begusarai	= No. of ZT SPs in 10 km radius around respondent HH in Begusarai district	1.885	1.423	3.903	****	5.911	3.393	n.s.
SP density Bhojpur	= No. of ZT SPs in 10 km radius around respondent HH in Bhojpur district	23.668	25.999	13.493	****	9.156	8.786	n.s.
SP density Buxar	= No. of ZT SPs in 10 km radius around respondent HH in Buxar district	3.455	3.677	2.485	n.s.	1.444	8.607	****
SP density Lakhisarai	= No. of ZT SPs in 10 km radius around respondent HH in Lakhisarai district	1.849	0.596	7.317	****	9.864	2.411	n.s.
SP density Samastipur	= No. of ZT SPs in 10 km radius around respondent HH in Samastipur district	1.811	1.900	1.423	n.s.	3.867	0.679	****
SP density Vaishali	= No. of ZT SPs in 10 km radius around respondent HH in Vaishali district	0.662	0.724	0.401	**	0.889	0.482	n.s.

Table 3 (continued)

Variable description		1st Stage (*N* = 1218)				2nd Stage (*N* = 227)		
		Overall mean (*N* = 1218)	Non-SPs (*N* = 991)	SPs (*N* = 227)	Sig. of diff.	Bottom quartile (*N* = 45)	Top quartile (*N* = 56)	Sig. of diff.
District dummies								
Lakhisarai	= Dummy, = 1 if HH is located in Lakhisarai district	0.100	0.075	0.211	****	0.067	0.071	***
Vaishali	= Dummy, = 1 if HH is located in Vaishali district	0.065	0.074	0.026	***	0.044	0.036	n.s.

*(**)[***]{****} Means statistically significantly different at the 10 %(5 %)[1 %]{0.1 %} level of alpha error probability, based on Mann-Whitney tests

[a] ZT *SP* Zero-tillage service provider, *HH* Household

[b] For ease of interpretation, sample means are provided for the unlogged variable

[c] Aggregate term for 'forward' castes in India, as opposed to 'backward' castes

[d] Encompasses agricultural extension and other Gov't employees at Panchayat, Block, district, and state level

provision and for maintaining such relationships; this potential role is further substantiated by the fact that membership in the Farmers' Association was more prominent among large-scale SPs (60.7 %) than among small-scale SPs (22.2 %).

Finally, our analysis reveals differences in business ambition between small-scale and large-scale SPs, which are likely to affect the scale of engagement in service provision, but, for reasons of endogeneity, cannot be used as regressors in the following section. In particular, 73.3 % of SPs in the top quartile stated that they were interested in expanding the number of clients further; the respective share was only 58.2 % among the bottom quartile (chi-square test significant at $P < 0.10$). Consequently, while 32.8 % of SPs in the bottom quartile did not make any efforts to actively market their services, only 10.0 % failed to do so in the top quartile (chi-square test significant at $P < 0.01$).

Factors affecting the engagement in ZT service provision and its scale

Table 4 presents the parameter estimates for factors influencing the incidence of ZT service provision (Stage 1) and, conditional on a positive decision to provide such services, for factors influencing the scale of the service provision business (Stage 2). The Heckman selection model does not produce a straightforward goodness-of-fit measure apart from an overall Wald test of model applicability, which strongly rejects the null-hypothesis that all regression coefficients are jointly zero. However, the explanatory power of the first stage was assessed by running it as a separate probit model, which correctly predicted 79.3 % of ZT SPs and 97.3 % of non-SPs (overall, 93.9 % of cases were correctly predicted). The second stage was run as a separate OLS regression (i.e., without accounting for potential selection bias), which produces an R-squared of 0.52. Hence, it can be concluded that the model has considerable explanatory power. Furthermore, a Wald test of independent equations indicates that the error terms of the first- and second-stage regression are correlated ($P < 0.10$), which justifies the use of the Heckman selection model. Despite the inclusion of squared terms of the variables *Land endowment* and *Business years*, which are by definition highly correlated, the maximum Variance Inflation Factor (VIF) amounted to 5.01 in the first-stage and 8.68 in the second-stage regression, indicating no cause for concern with regard to multicollinearity. Myers (1990) suggested that a value of 10 should not be exceeded by individual VIFs. The robustness of the estimates is corroborated by the fact that the exclusion of non-significant explanatory variables leads to only minor changes in the coefficients of the remaining factors and their statistical significance levels. The full maximum-likelihood estimation of the standard errors accounts for the two-stage sampling procedure with village-level clusters.

The variable *Land endowment* is included in the model as a wealth indicator based on agricultural income generating potential; to be an adequate proxy of wealth it is measured on a per-capita basis. Furthermore, *Land endowment* is a factor influencing tractor ownership, which, naturally, is a prerequisite to providing ZT services.[8] The model indicates a statistically highly significant positive quadratic relationship with the propensity to engage in ZT service provision, i.e. farmers with greater land resources are more likely to become ZT SPs, but the marginal effect decreases with increasing *Land endowment*; the magnitude of the coefficients indicates that the marginal effect turns negative beyond a per-capita land endowment of 21.5 ha.[9] In contrast, the second-stage regression shows that the area serviced *decreases* with increasing *Land endowment.* Again, we estimated a statistically highly significant quadratic relationship, i.e., the ZT area decreases at an – in absolute terms - decreasing rate, with a minimum being reached at a per-capita land endowment of 22.5 ha.

With respect to human capital endowment, several factors are statistically significant in the first-stage regression. *High education* and *High caste* increase the propensity to engage in ZT service provision by 1.7 and 4.3 percentage points, respectively. The coefficient on *Risk aversion* shows that the propensity to engage in this business declines with increasing risk aversion. This is plausible since any new business model entails some level of objective and subjective risk. Finally, the decision to become a ZT SP is positively influenced by the household's endowment with family labor (measured as labor-to-land ratio), whereby the magnitude of the effect is very small. A likely explanation is that the opportunity costs of engaging in service provision decrease with more family labor being available to take care of the SP's own farm operations. The second-stage regression shows that *High education* has a large effect on the area serviced, increasing it by approx. 46.7 %[10] if the educational level of the SP is at least 9th grade. The SP's perception regarding his own time constraining the scale of his ZT business is also found to have a considerable effect.

Financial capital, as proxied by *Credit access,* has a small, yet statistically highly significant effect on the decision to provide ZT services. Since the variable enters the model in its logged form, the coefficient indicates that, starting at the sample mean, a one-percent increase in available credit line increases the propensity to engage in ZT service provision by 2.3 percentage points. Credit access is highly relevant with respect to the purchase of a four-wheel tractor rather than the purchase of the ZT drill, which is highly subsidized in Bihar (see "Characterizing zero-tillage service provision businesses" section). The negative (but statistically insignificant) coefficient of *Credit access* in the second stage of the model is consistent with the negative relationship between land endowment and area serviced.

Several variables measuring the households' endowment with social capital have a significant influence on the decision to become a ZT SP. Most importantly, membership of any household member in the Farmers' Association increases the propensity to become a SP by 13.9 percentage points. Furthermore, the second-stage equation coefficient is statistically significant as well, indicating a 56.2 % increase in the area serviced if the ZT SP household is represented in the local farmers' organization. This implies that the Farmers' Association is an important platform for exchanging agriculture-related information and recruiting clients for ZT services. *Know Block extension official* and *Number officials known* are proxies of the extent of a farmer's social network, and the latter is found to positively influence the decision to become a ZT SP. Again, the exchange of information and the potential to recruit clients are likely explanations. The coefficient on *Know Block extension official* is statistically significant at $P < 0.11$, suggesting some effect as well. Interestingly, access to agricultural extension is found to negatively affect the propensity to engage in ZT service provision. Hence, there seems to be more scope for the agricultural extension service to promote ZT service provision as a business model among suitable candidates.

The period of engagement in ZT service provision and the productivity of the SP's own farm operation are important determinants of the scale of the ZT business. The coefficients on the variables *Business years* and its squared term indicate a statistically highly significant positive quadratic relationship between the time of business operation and the ZT service area, i.e. the area increases over time, but at a decreasing rate. In combination, the coefficients indicate that the maximum ZT service area be reached in the eighth business year. Furthermore, the model indicates that ZT SPs whose own farm productivity is among the lowest tercile service a 92.4 % larger area than those who are among the middle tercile (cf. also the descriptive results presented in Table 3). The coefficient on the *High productivity* variable is negative, but not statistically significant. SPs who suffered a loss in their own farm operation in 2012 (*Negative ag. income*) serviced a 63.4 % smaller area. District-specific potential competition effects are captured in the model by including the number of ZT SPs within a radius of 10 km around individual households (see "Model specification" section). The results of the first-stage equation show that in most districts (Begusarai, Bhojpur,

[8] Tractor ownership itself is a very good predictor of engagement in ZT service provision since only 8.3 % of non-SPs own a tractor. However, tractor ownership is obviously endogenous and therefore cannot be used as a regressor: when we replaced the incidence of ZT service provision by the incidence of tractor ownership in the first-stage probit model, 66 % of tractor owners and 95 % of non-owners were correctly predicted.

[9] Condition for maximum fulfilled for Land endowment =0.0228222/ 0.0010619 = 21.49 ha (rounded coefficients are shown in Table 4).

[10] Calculated as 100*[exp(0.3831) – 1], which is the correct interpretation of the marginal effect of an intercept dummy variable in a model with a logged dependent variable (see Giles 2011).

Table 4 Maximum likelihood estimates of Heckman selection model explaining engagement in zero-tillage (ZT) service provision (1st stage) and scale of the ZT business (2nd stage) in Bihar

Variable	Stage 1: Dep. var. ZT SP		Stage 2: Dep. var. ZT area	
	Coefficient[a]	z-value[b]	Coefficient	z-value[b]
Land endowment	0.0228	2.58**	−0.3238	−4.91****
Land end. squared	−0.0011	−2.45**	0.0144	4.64****
Age	−0.0002	−1.09	0.0028	0.62
High education[c]	0.0168	2.09**	0.3831	1.71*
High caste[c]	0.0431	2.49**	−0.0076	−0.05
Risk aversion	−0.0140	−2.71***	0.0573	0.54
Labor endowment	0.0039	2.73***	0.0034	0.15
Own time constraint	–	–	−0.1671	−2.07**
Credit access	0.0227	3.29***	−0.0895	−1.04
Farmers' Association[c]	0.1394	2.15**	0.4457	1.70*
Know Block extension official[c]	0.0289	1.61	0.1317	0.88
Number officials known	0.0010	2.72***	0.0038	1.17
Extension access	−0.0066	−1.82*	−0.1135	−1.49
ZT business years	–	–	0.4524	3.62****
ZT b. yrs. squared	–	–	−0.0539	−3.39***
Low productivity[c]	–	–	0.6544	3.48****
High productivity[c]	–	–	−0.0933	−0.72
Neg. agr. income[c]	–	–	−1.0053	−3.22***
SP density Begusarai	−0.0048	−3.01***	−0.0046	−0.21
SP density Bhojpur	−0.0010	−2.91***	0.0135	2.36**
SP density Buxar	−0.0021	−2.33**	0.0640	3.22***
SP density Lakhisarai	0.0062	2.79***	−0.0085	−1.19
SP density Samastipur	−0.0043	−2.52**	−0.0626	−3.33***
SP density Vaishali	0.0011	0.43	−0.0096	−0.30
Lakhisarai[c]	−0.0310	−2.87***	0.7362	2.39**
Vaishali[d]	−0.0238	−2.83***	0.2111	0.30
Constant	–	–	3.0929	4.17****
Number of observations = 1218				
Number uncensored obs. (2nd stage) = 227				
Wald chi-square (26) = 655.26****				
Wald test of independent equations: chi-square (1) = 2.87*				
1st stage explanatory power:				
Cases of ZT service providers correctly predicted = 79.3 %				
Cases of Non-service providers correctly predicted = 97.3 %				
Overall cases correctly predicted = 93.9 %				

*(**)[***]{****} Significant at the 10 %(5 %)[1 %]{0.1 %} level of alpha error probability

[a] Coefficients are marginal effects derived from 1st stage probit estimates (evaluated at means of all explanatory variables); for dummy variables, marginal effects are for a discrete change from 0 to 1

[b] Based on robust standard errors adjusted for 185 village-level clusters

[c] Dummy variable

Buxar, and Samastipur) the marginal effect of one additional proximate ZT SP is negative, reducing the probability to engage in the business by 0.1 to 0.5 percentage points, depending on the district. In the district of Lakhisarai, however, the marginal effect is positive, indicating a 0.6 percentage point increase in the propensity to engage in ZT service provision. The second-stage equation produces mixed effects, as well: the results for Bhojpur and Buxar indicate that one additional proximate ZT SP leads to an increase in the area serviced by 1.4 and 6.4 %, respectively. In Samastipur, however, we observed the opposite effect, i.e., a 6.3 % decrease in the area serviced.

Finally, the district dummies control for systematic differences between districts, especially with respect to the timing and intensity of ZT related CSISA activities. Due to multicollinearity with the SP density variables for some districts,[11] dummy variables could only be included for Lakhisarai and Vaishali. The negative coefficients in the first-stage equation are likely to reflect the relatively recent project engagement in these districts (Bhojpur and Buxar were the initial target districts), whereas the large positive coefficient for Lakhisarai in the second-stage equation may be related to systematically larger farm sizes in this district, indicating an increase in the area serviced by 109 %.

Discussion

Our profitability analysis shows that only the top quartile SPs (servicing >40.5 ha per year) reap a substantial net profit from ZT service provision. To put this finding into perspective, it has to be acknowledged that smaller-scale SPs may not view service provision as a major business opportunity, as is reflected by the differences between small-scale and large-scale SPs in their willingness to expand and market their services. Smaller-scale SPs may merely aim to offset part of the investment costs incurred for using ZT on their own farm; for these SPs, a positive gross margin may be a sufficient condition for catering to a relatively small number of clients. Social obligations and the prestige associated with the provision of innovative services in one's own village may be other motives for small-scale ZT service provision. Keeping this in mind, the remainder of this section is geared towards ZT service provision as a business opportunity that can be utilized for scaling the technology to a large number of smallholder farmers (Erenstein and Laxmi 2008; Erenstein 2009).

We find land endowment to be an important determinant of both the engagement in ZT service provision and the scale of the business. Since the maximum observed value of per-capita land endowment in the sample is 19.4 ha, which is less than the area at which the estimated quadratic functions reach their extrema (21.5 ha and 22.5 ha in the first and second stage regression, respectively), we conclude that a positive relationship between land endowment and engagement in ZT service provision can be expected in Bihar. Likewise, conditional on a farmer's engagement in ZT service provision, we can expect a negative relationship between the ZT SPs' own land endowment and the area serviced. This is plausible, as ZT service provision may become more attractive the more limited the SPs' own land resources are, which typically constrains income generating potential from agriculture. We obtain very similar results when we replace per-capita land endowment by total farm size, an indicator which is easier to apply for real-life targeting of SPs who are poised for growth. While the per-capita measure is preferred in the regression model due to slightly better explanatory power and conceptual consistence as a wealth indicator, for practical purposes we conclude that targeting the 'small among the large' (tractor owning) farmers should be part of a strategy to maximize the area serviced per SP.

However, apart from farm size, also productivity will determine the agricultural income generating potential. Indeed, our regression analysis indicates a strong correlation between SPs' own farm productivity and the scale of service provision. Farm productivity can be considered an exogenous factor if it is related to agro-ecological conditions rather than farm management. This needs to be explored further, but since the exclusion of productivity related variables leads to only minor changes in the remaining regression coefficients, there appears to be a substantial exogenous component. The relationship found is plausible as comparatively low returns from agriculture reduce the opportunity costs of engaging in service provision, thus making it a relatively more attractive alternative income source. While a low level of agricultural productivity is associated with a larger area serviced, SPs who suffered a loss in their own farm operation are found to service a much smaller area; this finding may indicate an overall lack of entrepreneurship and management skills of the respective farmers.

District-specific potential competition effects are captured in the model by including the number of ZT SPs within a radius of 10 km around individual households (see "Model specification" section). The contradictory effects found in the first-stage regression may be explained by differences in ZT SP densities between districts, as well as differences in prevailing farm sizes: in districts with an already relatively high concentration of SPs (Bhojpur, Buxar), the negative marginal effect indicates that others are discouraged to engage in the same business as they may perceive it as too competitive. On the other hand, in districts with a relatively low ZT SP density, such as Lakhisarai, the few existing SPs may be perceived as a role model to follow. However, as Table 3 shows, at around 1.8 SPs in a 10 km radius, the SP concentrations are very similar in Begusarai, Lakhisarai, and Samastipur, but a positive marginal effect is estimated for Lakhisarai only. The reason may be that average farm size in Lakhisarai amounts to 2.2 ha, whereas it is only 1.4 ha in Begusarai and Samastipur (Mann-Whitney test significant at $P < 0.001$); as our profitability analysis shows, there are substantial economies of scale in ZT service provision (cf. Table 2). For a given total ZT service area, lower transaction costs are incurred when servicing relatively few larger farms with larger plots as compared to a greater number of smaller farms and/or fragmented land. The results for Bhojpur and Buxar in the second-stage regression indicate that a relatively high concentration of SPs, which, as our data show, is associated with a lower fee charged, may encourage a larger scale of the business, likely in order to successfully compete with other SPs. Hence, one can

[11] Multicollinearity was identified by producing variance inflation factors (VIF) for the first- and second-stage regression. District dummies with an associated VIF > 10 were excluded from the analysis, which led to negligible loss in the explanatory power of the model. On the other hand, exclusion of the two remaining district dummies led to a drop of the percentage of SPs correctly predicted from 79 % to 73 %.

hypothesize that, ultimately, an equilibrium number of relatively large, economically sustainable ZT SPs will be established, while smaller SPs may discontinue their business, unless they are guided by motives other than profit maximization, as described above; this corroborates the importance of an efficient targeting of development efforts towards those SPs who are poised for growth.

The fact that ZT facilitates earlier sowing of wheat and, therefore, helps to avoid yield depression due to terminal heat stress has been emphasized in the literature (Erenstein and Laxmi 2008; Chauhan et al. 2012; Gathala et al. 2013; Mehla et al. 2000). Sowing wheat until November 15 had become the official recommendation by the Government of Bihar in 2013 (GoB 2013). As Keil et al. (2015) show, early sowing of wheat may not be practicable in low-lying areas that are prone to waterlogging during November, but the authors do estimate significant yield gains due to early sowing in well-drained areas. At the same time, they also found that in well-drained environments approximately 38 % of ZT wheat plots and 50 % of CT wheat plots were sown later than November 15 in the 2012/13 *rabi* season and conclude that the potential of ZT to facilitate earlier sowing should be better harnessed in such areas. Of course, pursuing the joint benefits of ZT *and* early sowing in such environments raises the bar with respect to the required capacity of ZT service provision, since it limits the time window for wheat establishment to the first half of November, i.e., a 15-day period (sowing wheat before November 01 is not realistic in most cases since the plots are typically still occupied by the preceding rice crop). This provides another argument for fostering relatively large-scale service provision through appropriate targeting and business development training. Given an average operating time of ZT SPs of 185 min per ha and a 10-h working day, sowing 3.2 ha of ZT wheat per day seems feasible; at maximum, a single ZT SP with one ZT drill could therefore service up to 48.0 ha between November 01 to 15, which would be well above the break-even area, even in a zero-subsidy scenario for ZT drills (cf. Fig. 2).

However, are all farmers likely to have equitable access to ZT services in a future scenario with a more extensive network of relatively large-scale ZT SPs? Economies of scale and lower per-acre transaction costs when servicing relatively large farms imply that SPs may give priority to relatively larger farmer clients (Chandra and Prasad 2014), which has been confirmed by in-depth interviews with select SPs.[12] Hence, it may be more difficult for small scale farmers to get (timely) access to ZT services (Erenstein et al. 2007; Tripathi et al. 2013), leading to a trade-off situation between early sowing of wheat and the use of ZT in wheat for this stratum. On the other hand, increasing competition between SPs may make them less selective in choosing their clients in the future.

The fact that ZT service provision is a relatively novel business in Bihar constitutes a potential limitation of this study. Addressing a number of important research questions, such as how ZT service provision businesses and farmers' (differential) access to such services will develop over time, possibly in a more competitive environment, will require panel data covering a longer time period.

Conclusions and recommendations

To increase the number of ZT beneficiaries in the densely populated Eastern IGP and, hence, contribute to enhancing wheat productivity and food security in an environmentally sustainable manner, an expansion of the network of ZT service providers is required since tractor and drill ownership is not a tenable goal for most capital-constrained small and medium-sized farmers. In general, large scale and well-educated farmers with extensive social networks are most likely to engage in ZT service provision. These are the same farmers who are most likely to own a four-wheel tractor for their own farm purposes. However, among this stratum, it is the relatively smaller farmers and those with a relatively low own-farm productivity who are most likely to provide ZT services at a sizeable scale. This is plausible as comparatively low returns from agriculture reduce the opportunity costs of engaging in service provision, thus making it a relatively more attractive additional income source. Due to economies of scale, relatively large-scale service providers are more likely to continue their business over time - even under less favorable subsidy scenarios for ZT drills – corroborating the importance of targeting those potential SPs who are poised for growth. While awareness raising activities with respect to ZT service provision as a novel business opportunity in Bihar might be targeted at tractor owners in general, purchase subsidies and business development training should be targeted at the smaller scale farmers who are tractor owners with service provision expansion in mind; practically, this would likely mean determining a ceiling farm size as an eligibility criterion for receiving these benefits.

While the rapidly increasing number of ZT SPs in Bihar is very promising, the development of service provision businesses over time and the access of different strata of farmers to such services under a more competitive business environment will have to be assessed on the basis of panel data spanning a longer time period.

[12] While detailed information on the time required to service plots of different sizes is not available for the entire sample, recent data collected from four non-randomly selected ZT SPs indicate substantial economies of scale in operating time: for the smallest plots serviced in 2015 (0.19 ha, on average), the average per-ha operating time amounted to 298 min, whereas on the largest plots (1.07 ha, on average) it averaged merely 120 min. For the plot size indicated as 'average' by the four ZT SPs (0.7 ha), the per-ha operating time averaged 148 min.

However, since the present analysis reveals that a large area serviced has resulted especially from targeting large client farms, there is certainly a need to develop business models that enhance the social inclusiveness of ZT services by reducing the transaction costs of servicing small farms. Demand aggregation and service coordination through village-level point persons may be a promising approach towards this end.

Acknowledgments We gratefully acknowledge the willingness of the interviewed farm households to participate in the surveys. We thank USAID and the Bill & Melinda Gates Foundation for funding this research through the Cereal Systems Initiative for South Asia (CSISA).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Agasty, M. P., & Patra, R. N. (2014). Migration, labor supply, wages and agriculture: a case study in rural Odisha. *Developing Country Studies, 4*(16), 91–109.

Aggarwal, P. K., Joshi, P. K., Ingram, J. S. I., & Gupta, R. K. (2004). Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. *Environmental Science & Policy, 7*(6), 487–498.

Chambers, R., & Conway, G. (1992). Sustainable rural livelihoods: Practical concepts for the 21st century. Brighton, UK.: IDS Discussion Paper No. 296. Institute of Development Studies, University of Sussex.

Chandra, S., & Prasad, D. (2014). Mechanization indicating parameters for site selection of farm machine bank in Bihar. *Agricultural Engineering Today, 38*(1), 18–24.

Chauhan, B. S., Mahajan, G., Sardana, V., Timsina, J., & Jat, M. L. (2012). Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. *Advances in Agronomy, 117*(1), 315–369.

Derpsch, R., Friedrich, T., Kassam, A., & Li, H. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural Biological Engineering, 3*(1), 1–25.

Diao, X., Cossar, F., Houssou, N., Kolavalli, S., Jimah, K., & Aboagye, P. O. (2012). Mechanization in Ghana. IFPRI Discussion Paper 01237. Washington, D.C.: Development Strategy and Governance Division, International Food Policy Research Institute.

DoA (2008). Bihar's Agricultural Development: Opportunities and Challenges - A report of the special task force on Bihar New Delhi: Department of Agriculture, Government of India.

Doyle, J. R. (2013). Survey of time preference, delay discounting models. *Judgment and Decision making, 8*(2), 116–135.

Erenstein, O. (2009). Zero tillage in the rice-wheat systems of the Indo-Gangetic Plains. IFPRI Discussion Paper No. 916. Washington, D.C.: International Food Policy Research Institute.

Erenstein, O., & Laxmi, V. (2008). Zero-tillage impacts in India's rice-wheat systems: a review. *Soil and Tillage Research, 100*(1-2), 1–14.

Erenstein, O., Farooq, U., Malik, R. K., & Sharif, M. (2007). Adoption and impacts of zero tillage as a resource conserving technology in the irrigated plains of South Asia. Comprehensive Assessment of Water Management in Agriculture Research Report 19. (pp. 55). Colombo, Sri Lanka: International Water Management Institute.

Erenstein, O., Farooq, U., Malik, R. K., & Sharif, M. (2008). On-farm impacts of zero tillage wheat in South Asia's rice-wheat systems. *Field Crops Research, 105*(3), 240–252.

Gathala, M. K., Kumar, V., Sharma, P. C., Saharawat, Y. S., Jat, H. S., Singh, M., et al. (2013). Optimizing intensive cereal-based systems addressing current and future drivers of agricultural change in the northwestern Indo-Gangetic Plains of India. *Agriculture, Ecosystems and Environment, 177*, 85–97.

Giles, D. E. (2011). Interpreting dummy variables in semi-logarithmic regression models: exact distributional results. Econometrics Working Paper EWP1101. Victoria, Canada: Department of Economics, University of Victoria.

GoB (2013). Advisory for farmers. Government of Bihar.

Heckman, J. J. (1979). Sample selection bias as a specification error. *Econometrica, 47*(1), 153–161.

Houssou, N., Diao, X., Cossar, F., Kolavalli, S., Jimah, K., & Aboagye, P. O. (2013). Agricultural mechanization in Ghana: is specialized agricultural mechanization service provision a viable business model? *American Journal of Agricultural Economics, 95*(5), 1237–1244.

Humphreys, E., Kukal, S. S., Christen, E. W., Hira, G. S., Singh, B., Yadav, S., et al. (2010). Halting the groundwater decline in North-West India - which crop technologies will be winners? *Advances in Agronomy, 109, Chapter 5*, 155–217.

Keil, A., D'souza, A., & McDonald, A. J. (2015). Zero-tillage as a pathway for sustainable wheat intensification in the Eastern Indo-Gangetic Plains: does it work in farmers' fields? *Food Security, 7*(5), 983–1001. doi:10.1007/s12571-015-0492-3.

Kienzle, J., Ashburner, J. E., & Sims, B. G. (2013). Mechanization for rural development: A review of patterns and progress from around the world. Integrated Crop Management Vol. 20–2013. Rome, Italy: Plant Production and Protection Division, Food and Agriculture Organization of the United Nations (FAO).

Krishna, V. V., & Veettil, P. C. (2014). Productivity and efficiency impacts of conservation tillage in northwest Indo-Gangetic Plains. *Agricultural Systems, 127*, 126–138.

Mehla, R. S., Verma, J. K., Gupta, R. K., & Hobbs, P. R. (2000). Stagnation in the productivity of wheat in the Indo-Gangetic Plains: Zero-Till-Seed-Cum-Fertilizer Drill as an integrated solution. In *Rice-wheat consortium paper series 8*. New Delhi: Rice-Wheat Consortium.

Mehta, C. R., Chandel, N. S., Senthilkumar, T., & Singh, K. K. (2014). Trends of agricultural mechanization in India. Economic and Social Commission for Asia and the Pacific (ESCAP) Policy Brief No. 2. Beijing, China: United Nations Centre for Sustainable Agricultural Mechanization.

MoA (2015). *Agricultural statistics at a glance 2014. Department of agriculture and cooperation*. Ministry of Agriculture, Government of India: New Delhi.

Myers, R. (1990). *Classical and modern regression with applications* (Second ed.). Boston: Duxbury.

Paulsen, J., Bergh, K., Chew, A., Gugerty, M. K., & Anderson, C. L. (2012). Wheat value chain: Bihar. *Evans School Policy Analysis and Research (EPAR) Brief No. 202*. Seattle: Evans School of Public Affairs, University of Washington.

Scoones, I. (1998). Sustainable rural livelihoods: A Framework for Analysis. Brighton, UK.: IDS Working Paper No. 72. Institute of Development Studies, University of Sussex.

Tripathi, R., Raju, R., & Thimmappa, K. (2013). Impact of zero tillage on economics of wheat production in Haryana. *Agricultural Economics Research Review, 26*(1), 101–108.

Wooldridge, J. M. (2006). *Introductory econometrics. A modern approach* (Third ed.). Mason: Thomson South-Western.

Yang, J., Huang, Z., Zhang, X., & Reardon, T. (2013). The rapid rise of cross-regional agricultural mechanization services in China. *American Journal of Agricultural Economics, 95*(5), 1245–1251.

Zhang, X., Yang, J., & Wang, S. (2010). China has reached the Lewis turning point. IFPRI Discussion Paper No. 000977. Washington, D.C.: International Food Policy Research Institute.

Dr. Alwin Keil is a Senior Agricultural Economist with the International Maize and Wheat Improvement Center (CIMMYT), working in the Cereal Systems Initiative for South Asia (CSISA) and being based in New Delhi, India. Before joining CIMMYT in January 2013, Alwin held a position as an assistant professor at the Department of Agricultural Economics and Social Sciences in the Tropics and Subtropics at the University of Hohenheim, Germany. From 2006 to 2012 he led a research project investigating poverty dynamics, farm households' risk management, and technology adoption in a marginal maize-based upland area of Vietnam, and prior to this he led an interdisciplinary climate impact research project in Indonesia. Alwin has extensive experience in conducting quantitative research in rural areas of developing countries (Indonesia, Philippines, Vietnam, Zambia, Ethiopia) based on representative household surveys. While his methodological focus is on ex-post econometric analyses, he also has experience in applying qualitative research methods. Alwin holds a Ph.D. in Agricultural Economics and an M.Sc. in Agricultural Sciences from Georg-August University of Goettingen, Germany. He also holds a diploma in Tropical Agriculture from University of Kassel, Germany.

Alwin D'Souza is currently pursuing his Ph.D. at Morrison School of Agribusiness, Arizona State University. He was formerly a Research Associate with the International Maize and Wheat Improvement Centre (CIMMYT), working in the Cereal Systems Initiative for South Asia (CSISA) and being based in New Delhi, India. Alwin has completed his M.Phil. in economics from Jawaharlal Nehru University, New Delhi. He has research experiences from Integrated Research for Action and Development (IRADe), Centre for Civil Society (CCS), and International Food Policy Research Institute (IFPRI).

Dr. Andrew McDonald is systems agronomist with the International Maize and Wheat Improvement Center (CIMMYT) and has contributed to the Cereal Systems Initiative for South Asia (CSISA) since joining CIMMYT in 2010. With funding from USAID and the Bill and Melinda Gates Foundation, CSISA is a regional food security and livelihoods initiative that seeks to accelerate the rate at which farmers adopt and benefit from locally-adapted technologies through research, training, market development and new models of outreach. Andy currently serves as the project leader for CSISA across India, Bangladesh, and Nepal. He is also CIMMYT's research team leader for sustainable intensification in South Asia. Andy's specific research interests and experience involves mixed methods, including dynamic simulation, applied at the field to landscape scales. His program prioritizes process-based investigations of the influence of management and environmental factors on crop yields and yield stability. Prior to joining CIMMYT, Andy was a research scientist at Cornell University specializing in the role of climate and soil on crop growth and interactions with pests.