Adoption of BMPs and technical inefficiency in Canadian canola production

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Abstract

This study examines the BMP adoption and technical efficiency for canola producers in the Canadian Prairie Provinces. A Just-Pope stochastic frontier production function is estimated using data from a survey of canola producers conducted in early 2012. Yield is modeled as a function of nutrients and precipitation. A linear inefficiency function includes farm specific variables and a set of binary variables representing BMP adoption. These include use of environmental farm plans and soil testing, precision farming techniques or nutrient management practices. Model results indicate that BMP variables for soil tests, nutrient management planning and precision farming are positively related to technical efficiency while other BMP indicators are not significant. Producer characteristics such as experience and off-farm income tend to have the expected relationship with technical efficiency. Model results appear to be significantly influenced by moisture problems that occurred through the Prairie region during the 2011 cropping year.

The results in this paper suggest that for Western Canadian canola producers, there is potential complementarity for some BMPs in terms of improving technical efficiency while simultaneously advancing environmental stewardship. This study extends the limited literature that combines stochastic production frontier analysis with flexible risk specifications to incorporate environmental stewardship practices in the inefficiency model.
Adoption of BMPs and technical inefficiency in Canadian canola production

Adoption of beneficial management practices (BMPs) by agricultural producers has been encouraged as a means of mitigating the impact of agricultural production on environmental quality. BMPs are farming practices that contribute to reducing potential negative environmental impact from agricultural production (AAFC 2013). However, the resulting effects of BMP adoption on farm performance are uncertain; limited evidence suggests that many BMPs contribute to lower returns for adopting producers (e.g., Jeffrey et al. 2012).

One way in which BMP adoption may affect financial performance of adopting agricultural firms is through changes (positive or negative) in the efficiency of production. However, little attention has been given to this question. This study examines the effects of BMP adoption on technical efficiency for canola producers in Western Canada. Canola production is important to Canadian Prairie agriculture, both in terms of quantity of production and economic value (LMC International 2011). The objective of this study is to assess whether adoption of agricultural BMPs by canola producers in the Canadian Prairie region has any effect on technical efficiency levels. BMPs adopted by producers may include development of environmental farm plans, soil testing, reduced or zero tillage systems, application of precision farming techniques and various nutrient management practices.

Understanding the relationship between BMP adoption and technical efficiency levels can provide insights into the likelihood of BMPs being economically viable for producers. This in turn has implications for the likelihood of government intervention being needed to encourage significant adoption of these practices. Studies that consider the effects of environmental stewardship practices on efficiency are currently lacking and it is in this respect that the current analysis makes a contribution.

There is a rich literature in the area of technical efficiency of agricultural production. However, only a limited number of studies have examined technical efficiency.

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1 Tamini et al. (2012) represents a recent study that does examine the link between BMPs and technical efficiency.
2 For example, in 2011 the three crops with the greatest seeded area in the Canadian Prairie Provinces were wheat (8,136,000 ha), canola (7,596,000 ha) and barley (2,478,000 ha) (Statistics Canada nd).
efficiency for field crops in developed countries (e.g., Giannakas et al. 2001; Kumbhakar et al. 2013; Wilson et al. 2001). Even fewer studies of efficiency in canola are available. Mousavi-Avval et al. (2011) and Unakitan and Lorcu (2011) are two examples, but neither study examines North American production of canola and both use deterministic efficiency methods (i.e., Data Envelope Analysis).

There is a growing literature that makes use of a more flexible specification for output variability in production function estimation, based on original papers by Just and Pope (1978, 1979). Given the importance of risk in crop production, this approach has been used in crop production function analysis. Examples of studies include Boubacar (2012), Cabas et al. (2010), Carew et al. (2009), Gardebroek et al. (2010) and Roberts et al. (2004). Carew and Smith (2006) examine production risk for Manitoba canola yields using a Just-Pope production function.

Papers such as Kumbhakar (1993; 2002) and Battese et al. (1997) demonstrate how stochastic production frontiers and efficiency analysis can be combined with the Just-Pope framework. However, relatively few empirical studies have examined both efficiency and risk together in the same analysis although the literature is growing in size and scope. Examples of papers that combine efficiency and production risk include Bokusheva and Hockmann (2006), Jaenicke et al. (2003), Ogundari and Akinbogun (2010) and Villano and Fleming (2006).

**Research Methodology**

A stochastic frontier production function is estimated for a sample of canola producers located in Western Canada. Production is influenced by farm specific characteristics such as soil type, along with levels of variable inputs (e.g., fertilizer) and so these factors are included in the analysis. Canola production is inherently risky due to uncertainty in the production environment (e.g., weather), thus making it important to explicitly incorporate risk in the estimation procedure as well. Therefore, the estimation

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For example, papers by Bravo-Ureta et al. (2007), Darku et al. (2013), Gorton and Davidova (2004) and Thiam et al. (2001) provide extensive lists and reviews of empirical technical efficiency studies. However, a review of Table 1 in Bravo-Ureta et al. (2007) results in a relatively low count of studies that examine technical efficiency for grains and other field crops in developed countries.
involves using a production function with flexible risk properties; that is, a Just-Pope specification.

Maximum likelihood procedures are used to estimate a model that simultaneously considers expected production, production risk and inefficiency functions. Yield is modeled as a function of plant nutrients (e.g., nitrogen and phosphorus), precipitation, soil type and other farm specific variables for expected yield and production variability functions. A linear inefficiency function includes farm and farmer specific variables (e.g., age, experience, location, off farm income) as well as a set of binary variables that represent evidence of BMP adoption. These BMP variables include use of environmental farm plans and soil testing, type of tillage system, and use of precision farming techniques or nutrient management practices.

Production Function Model

As noted earlier, risk is an important consideration in canola production. This has two implications for the analysis undertaken in this study. First, the stochastic nature of yield response to discretionary inputs suggests the need to examine technical efficiency through a stochastic frontier framework; that is, allowing for the existence of a random component of deviations from the production frontier. Secondly, given the restrictive assumptions made with respect to the effects of input levels on yield variability (Just and Pope 1978, 1979) when using standard production function analysis a flexible functional risk specification is warranted (i.e., a Just-Pope formulation).

The stochastic frontier model of production and related estimation of technical efficiency is well established and widely used in agricultural economics research. A number of seminal papers (e.g., Aigner et al. 1977; Meeusen and van den Broeck 1977; Battese and Coelli 1995) have contributed to a rich empirical literature in this area. The stochastic frontier production function estimated in this study is defined and constructed so as to be consistent with the approach taken in this literature. Consider the following production function:

\[
\ln(y_i) = f(x_i, \beta) + v_i - u_i
\]  

(1)
where $y_i$ is output for the $i^{th}$ firm, $x_i$ is the vector of observed inputs and $f(x_i, \beta)$ is the deterministic part of the frontier, with $\beta$ being a vector of parameters to be estimated. The function has a composed error term ($v_i - u_i$); $v_i$ captures random effects while $u_i$ is the inefficiency component ($u_i \geq 0$).

Consistent with discussion in papers such as Battese et al (1997), Wang (2002) and Jaenicke et al. (2003) the stochastic frontier model in equation (1) may be modified to be consistent with the Just-Pope framework, as follows:

$$\ln(y_i) = f(x_i, \beta) + v_i - u_i$$

$$v_i \sim N(0, \sigma^2_v)$$

$$\sigma^2_v = \exp(z^v\gamma^v)$$

$$u_i \sim N^+(\mu_i, \sigma^2_\mu)$$

$$\mu_i = z^u\delta^u$$

In equation (2), $v_i$ and $u_i$ are defined as before, with $v_i$ being distributed normally and $u_i$ being a non-negative truncation of a normal distribution with mean $\mu_i$ and variance $\sigma^2_\mu$. As defined here, $\mu_i$ is a function of a vector of explanatory variables ($z^u_i$) assumed to be associated with technical inefficiency; $\delta^u$ is a vector of parameters. The Just-Pope production function framework is incorporated through the specification of variance $\sigma^2_\nu$ as a function of explanatory variables, $z^\nu_i$, with $\gamma^\nu$ being a vector of parameters. The vectors of explanatory variables for the three functional components of the model (i.e., $x_i, z^\nu_i, z^u_i$) are distinct from each other although in empirical analysis the explanatory variables for the expected production $f()$ and the variance of output functions ($\sigma^2_v$) tend to be similar if not identical.

Given this model specification, mean output is conditional on the technical inefficiency effect, $u_i$ and can be expressed as:

$$E[\ln y_i | x_i, u_i] = f(x_i, \beta) - u_i$$

(3)
This is the average (deterministic) production function. Given the way in which the random error is defined, specification of marginal risk in production is flexible:

\[
\frac{\partial \sigma_y^2}{\partial z_i^v} \leq 0
\]  
(4)

In other words, individual elements of \( z_i^v \) can be risk increasing or risk decreasing depending upon coefficient estimates in the risk function \( \tilde{\gamma}^v \).

Technical efficiency (TE\(_i\)) for each observation is the ratio of the average production function to the efficient output level corresponding to \( u_i = 0 \), as follows:

\[
TE_i = \frac{E[lny_i|x_i,u_i]}{E[lny_i|x_i,u_i = 0]} = \frac{f(x_i,\beta) - u_i}{f(x_i,\beta)} = 1 - TI_i
\]  
(5)

where TI\(_i\) is the level of technical inefficiency. Technical inefficiency levels can be determined using the estimator for \( \hat{\mu}_i \) derived by Jondrow et al. (1982):

\[
\hat{\mu}_i = E[u_i|e_i],
\]  
(6)

where \( e_i = v_i - u_i \)

based on a distributional assumption for \( u_i \). In the case of the current study, it is assumed that \( (u_i, v_i - u_i) \) is distributed normally with mean \( \mu_i \) and variance \( \sigma_u^2 \), truncated at zero. Given these assumptions:

\[
\hat{\mu}_i = \frac{-(v_i - u_i)\sigma_u^2}{(1 + \sigma_u^2)}
\]  
(7)

\[
\hat{\sigma}_\mu^2 = \frac{\sigma_u^2}{(1 + \sigma_u^2)}
\]  
(8)

\[
\hat{u}_i = E[u_i|v_i - u_i] = \hat{\mu}_i + \hat{\sigma}_\mu \Phi(\hat{\mu}_i/\hat{\sigma}_\mu) - \mu_i \Phi(\hat{\mu}_i/\hat{\sigma}_\mu)
\]  
(9)
where $\phi(\cdot)$ and $\Phi(\cdot)$ are the density and cumulative distribution functions, respectively, for a standard normal random variable.

**Empirical Analysis**

The empirical model used in this study, based on the conceptual model outlined above, consists of three equations:

\[
\ln(y_i) = \beta_0 + \sum_{j=1}^{J} \beta_j^* \ln(x_j^i) + \sum_{k=1}^{K} \beta_k D_k^i + \epsilon_i \tag{10}
\]

\[
\sigma^2_v = \gamma_0 \prod_{j=1}^{J} (x_j^i)^{y_j^i} \prod_{k=1}^{K} (D_k^i)^{y_k^i} + \varphi_i \tag{11}
\]

\[
u_i = \delta_0 + \sum_{m=1}^{M} \delta_m z_m^i + \omega_i \tag{12}
\]

where in equation (10) $y_i$ and $x_j^i$ are levels of output and $j^{th}$ input ($j=1,\ldots,J$), respectively, for the $i^{th}$ producer, and $D_k^i$ ($k=1,\ldots,K$) are producer-specific dummy variables hypothesized to affect expected production (e.g., soil zone). In equation (11), $\sigma_v^2$ is the production variance which is modeled as a function of the same variables used in the expected yield portion of the production function. While in principle there is no reason to suppose that exactly the same set of factors affect both expected production and variability in production, it is often the case in empirical Just-Pope production analysis that a common set of explanatory variables is used. In equation (12), $u_i$ is the inefficiency term and $z_m^i$ ($m=1,\ldots,M$) are variables hypothesized to explain/influence technical (in)efficiency (e.g., experience, BMP usage). The error terms are $\epsilon_i$, $\varphi_i$ and $\omega_i$, with $\epsilon_i$ being the composed error term $(v_i - u_i)$ and $\omega_i$ being restricted such that
\( \omega_i \geq -\left( \delta_0 + \sum_{m=1}^{M} \delta_m z_m^i \right) \); that is, \( u_i \geq 0 \). Maximum likelihood methods are used to simultaneously estimate equations (10)-(12) with associated parameters \( \beta \) s, \( \gamma \) s and \( \delta \) s.

Both the expected yield and production variance functions are estimated using Cobb-Douglas formulations. While the Cobb-Douglas functional form is associated with some restrictive technical properties, it continues to be used extensively in estimating both production frontiers and Just-Pope production functions. Ogundari and Akinbogun (2010) and Kumbhakar (2002) are examples of studies combining efficiency and flexible production risk specifications that estimate Cobb-Douglas functions. Carew et al. (2009) and Carew and Smith (2006) are examples of recent studies that use the Cobb-Douglas form to estimate Just-Pope production functions for field crops in Western Canada. In addition, there is limited evidence that the choice of functional form has limited impact on relative efficiency levels (Mbaga et al. 2003; Murillo-Zamorano 2004; Yélou et al. 2010).

**Data**

Cross-sectional data for a sample of canola producers in the Canadian Prairie Provinces are used in this analysis. Agriculture and Agri-Food Canada (AAFC) commissioned a survey of canola producers to seek information about decision making and production practices for the 2011 growing season. A representative sample of 996 Prairie canola producers was surveyed in early 2012.\(^4\) Survey data included information on production and management systems (e.g., tillage, seeding, fertilizer and pesticide practices), as well as information used in decision making (e.g., soil testing). Detailed responses were collected from each respondent for a representative 2011 canola field on their farm. Input levels (i.e., seeding rates, fertilizer application rates, etc.), production practices (e.g., tillage operations, crop protection, etc.) and output levels (i.e., canola yield) for the representative field were recorded. General information about the farm operation (e.g., province, soil zone, 2011 growing season precipitation) and farm operator (e.g., age, education, experience) was also gathered.

\(^4\) A detailed discussion of survey methods and a complete summary of producer responses are provided by Blacksheep Strategy Inc (2012).
For the production function analysis, output was defined as canola yield given as bushels harvested per acre. Inputs included in the expected yield and production variance functions were nitrogen (N), phosphorus (P) and sulphur (S), all measured in pounds of nutrient applied per acre, along with growing season precipitation (in inches). The decision regarding what variables to include in the estimation was based on previous studies, expert opinion, and availability of data. These types of variables have been used in other production function estimations for Canadian Prairie crops (e.g., Carew and Smith 2006; Carew et al. 2009). Potash (i.e., potassium) was not included in the analysis as it is not considered to be a limiting nutrient in much of the Prairie region, and was not found to be significant in previous analysis for canola in the region (Carew and Smith 2006). Other variables often considered in crop production function analyses are soils and temperature. Temperature data were not available for this producer sample. Variables representing soil type and soil problems were both considered in the analysis, but neither was statistically significant in initial estimation results.

Observations with missing data for any of the production function variables were removed from the survey data. This resulted in a final sample size of 643 observations. As noted earlier, the original survey sample was selected to be representative of canola producers, both by province and soil type. Table 1 provides a comparison of the estimation sample and the total survey sample, with respect to these two criteria. From Table 1, the distribution of estimation observations by province and soil type is consistent with the original survey sample. Also, the average farm size for the estimation sample is approximately 2344 acres (Table 3). This is only slightly larger than the average farm size of 2286 acres for the entire survey sample (Blacksheep Strategy Inc 2012). Table 2 provides summary statistics for explanatory variables included in the expected yield and production variance equations.

As noted in equations 10 and 11, dummy variables are also included as explanatory variables in the Just-Pope production function estimation. Both soil type and provincial dummy variables were considered in the analysis. As noted earlier, the

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5 In the survey itself, producers were asked to report the types of fertilizers used and associated application rates. These responses were used to calculate nutrient application rates for the production function estimation.
soil type variables were not statistically significant. Two versions of the production function model were estimated; a basic model (Model 1) with no dummy variables, and a second model (Model 2) that included provincial dummy variables.\textsuperscript{6}

The third equation in the estimated system is the inefficiency model equation (i.e., equation 12). Inefficiency models in cropping technical efficiency studies often include variables such as firm size, decision maker age, education and/or experience, ownership structure, income sources, etc. (e.g., Giannakas et al 2001; Kumbhakar et al 2013; Wilson et al 2001) as explanatory variables. Similar variables were considered for inclusion in the current analysis of Canadian Prairie canola producers. In particular, farm size (acres), canola growing experience (i.e., number of years growing canola) and the presence of off-farm income (i.e., whether off-farm income was used to assist the farm business financially) were all included as explanatory variables for inefficiency.\textsuperscript{7} Table 3 provides summary statistics for the canola experience, off-farm income and farm size variables.

Explanatory variables were also incorporated into the inefficiency model to examine the relationship between adoption of BMPs and efficiency. The producer survey elicited information about practices associated with canola production that could be characterized as “environmental stewardship” (e.g., existence of an environmental farm plan, use of precision farming techniques). If present, these may indicate adoption of BMPs by the producers. Based on responses to relevant questions, five variables were defined and used in the inefficiency model as evidence of environmental stewardship. In all cases, the variables were dichotomous categorical (i.e., yes/no) variables. Definitions for these variables are discussed below. Table 3 provides a summary of the distribution of values for each of these variables.

The first BMP variable is “environmental farm plan”, which is completion of an environmental farm plan (EFP). Until 2009, an EFP program was part of the Agricultural Policy Framework in Canada. Participating producers undertook a supervised self-

\textsuperscript{6} Dummy variables were included for Manitoba, Saskatchewan, and Alberta-Peace, which included observations from the Peace region of Alberta and British Columbia. The provincial dummy for Alberta was omitted from the estimation.

\textsuperscript{7} Besides canola experience, the survey data also included variables for age and overall farming experience. Canola experience was used in the inefficiency model because it was deemed the most relevant measure of “experience”. As well, all three measures were strongly positively correlated.
assessment to identify potential environmental issues and risks on farms. Completion of an EFP resulted in eligibility for participation in cost sharing programs for implementation of BMPs. The national program was terminated in 2009, but EFP programs are still present in some provinces (e.g., Alberta). A “yes” response to this question may indicate that the producer has recognized environmental issues associated with the farm business and is taking steps to address them.

Also included as an explanatory variable is “crop plan”. Producers were asked if a crop plan was completed for each canola field prior to planting, where this referred to creating a formal plan for inputs or production practices. This may include seed variety/hybrid, fertility program, field scouting, herbicides, fungicides, etc. (Blacksheep Strategy Inc 2012). This variable was included because a “yes” response may be an indication of practices such as nutrient management, integrated pest management, etc.

A variable representing use of precision farming techniques was included as an indicator of environmental stewardship. Precision farming includes variable rate fertilizer and/or pesticide application rates, which may indicate adoption of nutrient management planning or integrated pest management. It also includes other practices not as closely related to environmental stewardship (e.g., autosteering, variable rate seeding, GPS guidance, etc.), and so is not a perfect indicator.

The use of soil tests may also be an indication of environmental stewardship practices. Soil test results can be used as the basis for determining fertilizer rates for individual fields. This would form part of nutrient management planning. One of the survey questions asked producers whether they have soil tests done for their canola fields and, if so, how often. The responses to this question were used to define a “soil test” variable, included in the inefficiency model.

Nutrient management planning (NMP) is a BMP in which producers adjust fertilizer application rates to account for nutrient availability from other sources (e.g., carryover from previous year) and nutrient needs of crops to be seeded in the current year (Brethour et al. 2007). The previous four variables (environmental farm plan, crop plan, precision farming, soil test) each hint at possible producer use of NMP. However, there were three additional questions that provided more direct evidence of NMP adoption by producers. The first of these asked whether the fertilizer program was the
same for all canola fields or if it varied from field to field. Varying fertilizer rates by field is an indication of NMP. The second question asked how the producer decided upon the rate of fertilizer for the representative canola field. Possible responses included using soil test recommendations, general fertilizer guidelines, past yield or other experience, price considerations or expert advice. The use of soil test recommendations is a potential indicator of NMP. Finally, producers were asked about records kept for each field (e.g., seeding dates and conditions, tillage practices, herbicide applications, etc.). Three responses that may indicate use of NMP were maintaining soil test results, maps of soil sampling locations, and the nutrient program for each field. A “nutrient management planning” variable was created using these three questions. If a producer answered with any of the “NMP indicator” responses for any of these three questions, that observation was deemed to be “yes” for the NMP variable.

**Empirical Results**

Table 4 provides the parameter estimates for two versions of the Just-Pope stochastic production frontier model. Model 1 is the “basic” model that includes the explanatory variables discussed in the previous section. Model 2 also includes provincial dummy variables in the expected yield and production variance equations, to capture any regional effects on expected canola production and variability in production.

*Expected Yield Equation*

The majority of variables in the expected yield equation are statistically significant at a 5% or 1% level, and most have the expected sign (Table 4). Interestingly, N is insignificant in Model 1, although the coefficient is positive, but N is positive and significant at a 10% level of significance when provincial dummies are included (i.e., Model 2). Due to other factors such as precipitation (discussed below), it may be the case that N was not a very limiting factor in canola production during the 2011 growing season. Another possibility is that in the range of N use exhibited by many of the sampled producers, the production function is relatively “flat” with respect to N response.
The coefficient for precipitation in the expected yield equation is (unexpectedly) negative and significant in both versions of the model. However, this result is indicative of moisture conditions in the Canadian Prairie region during the 2011 growing season. Many areas in the southern and eastern Canadian Prairies experienced very wet spring conditions, including “extreme” spring flooding in parts of Manitoba and Saskatchewan (AAFC 2012). This caused significant problems for seeding, germination and development of crops due to delayed seeding, flooding of seeded fields, etc. There was also a significant precipitation event in the Prairie region in late spring that exacerbated the situation in many regions. Complicating matters, at least in terms of modeling the impact of precipitation, is the fact that later in summer much of that same area of the Prairies experienced very dry conditions. Under these circumstances, it is therefore not surprising that the coefficient on precipitation is opposite-signed to what would be expected. It may be the case that a more flexible specification of precipitation than is provided for in a Cobb-Douglas functional form would provide different results.

The provincial dummy variables in the expected yield equation (Model 2) are significant and negative (Table 4). This suggests that expected yields in other regions of the Prairies were lower, relative to Alberta (i.e., the excluded provincial dummy variable). There are two explanations for this result. First, canola yields in Alberta tend to be higher than for the Canadian Prairie region as a whole. Secondly, during 2011 Manitoba and Saskatchewan were most heavily affected by the unusual moisture conditions (discussed earlier) and these same areas (particularly Manitoba) experienced very dry (and even drought) conditions later in the summer; both of these factors would have adversely affected yields.

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8 During the period 2003-2012, average canola yield in the three Prairie Provinces was 1720 kg per ha. The individual provincial average yields over that period were 1750, 1590 and 1940 kg per ha for Manitoba, Saskatchewan and Alberta, respectively (Statistics Canada nd).

9 It should be noted that despite the adverse moisture conditions in the region, the average canola yield for the producer sample used in estimating the production frontier was 38.71 bushels per acre. This converts to approximately 2169 kg per ha (AARD nd), which is higher than the overall 2011 average of 1900 kg per ha for the Prairie Provinces (Statistics Canada nd).
Production Variance Equation

In studies for which Just-Pope crop production functions are estimated, it is often hypothesized that fertilizer inputs are risk increasing. This corresponds to positive coefficients in the production variance equation. This dates back as far as the original Just-Pope analysis (Just and Pope 1979) and has been confirmed in at least some subsequent studies (e.g., Roberts et al. 2004; Bokusheva and Hockmann 2006).

In the current analysis, the results are mixed. As shown in Table 4, P is risk increasing (i.e., positive coefficient) while S is risk decreasing (i.e., negative coefficient). The coefficient for N in both models is positive but statistically insignificant. The results for N and P are consistent with previous analysis for canola by Carew and Smith (2006). The result for N is also consistent with analysis by Carew et al. (2009), where the impact of N on yield variability for wheat in Manitoba was muted when the effects of weather were incorporated in the model. They also found S to be risk reducing.

Precipitation is risk increasing in terms of production variance. The explanation for this result is the same as for the negative precipitation coefficient in the expected yield equation. Precipitation was also found by Carew and Smith (2006) to be risk increasing for canola production in Manitoba. When growing conditions are dry, yields for crops from dryland production systems will be limited by moisture and will generally be low with limited variability. With ideal precipitation, other factors (genetics, fertility, management) will limit yield and because these factors vary across farms yield will also vary across farms.

As with the expected yield equation, both soil type and provincial dummy variables were initially included in the production variance equation estimation. Soil type did not have a statistically significant impact and so was removed from Model 2.¹⁰ As shown in Table 4 for Model 2, the provincial dummy variables are statistically significant, with production variance being lower for Saskatchewan and Manitoba. This may be attributable to the lower expected yields for those two provinces; that is, if the sample yields for those provinces are lower, resulting in a lower expected yield, the

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¹⁰ Carew and Smith (2006) also found no significant relationship between soil quality and production variability for Manitoba canola yields.
variance may also be lower. However, all three provincial dummy coefficients are
significant only at a 10% level.

Inefficiency Equation

Inefficiency equation coefficient estimates are provided in Table 4. For these
coefficients, a negative sign indicates that the variable has a negative effect on
technical inefficiency; that is, greater levels of that variable are associated with
improved technical efficiency. As shown in Table 4, experience in canola production is
positively related with technical efficiency, although the coefficient is not significant in
Model 1 and is significant at a 10% level in Model 2 (with provincial dummies). This
result is generally consistent with findings in previous studies (e.g., Wilson et al. 2001;
Kumbhakar et al. 2013) in which more experienced producers (defined in various terms
including age, years of farming, etc.) tend to be more efficient.

Conversely, off-farm income is negatively related to technical efficiency, although
the statistical significance varies by model (Table 4). This result is also consistent with
previous analyses (e.g., Goodwin and Mishra 2004; Kumbhakar et al. 2013). Off-farm
employment takes away time that could be otherwise used for crop production and
management activities.

The sign on the farm size coefficient is positive for Model 1 and negative for
Model 2, but neither coefficient is statistically significant. In both cases, the standard
error is greater than the estimated coefficient. This result is somewhat surprising as
there are a significant number of studies that have found positive relationships between
farm size and technical efficiency (e.g., Wilson et al. 2001; Olson and Vu 2009; Zhu and
Oude Lansink 2010; Mugera and Langemeier 2011). This is not the case for the canola
producers in the survey sample. However, the evidence from previous literature is not
entirely consistent. For example, while finding a statistically significant positive
relationship between farm size and technical efficiency, Giannakas et al. (2001)
concluded that the relationship was not economically significant. As well, Rasmussen
(2010) determined the relationship between farm size and technical efficiency from
Danish cropping farms to be negative. If there is a link between efficiency and farm
size, perhaps it is being captured by other variables in this analysis. Farm size may
also have a greater impact on economic efficiency (e.g., through economies of size) than on technical efficiency.

As discussed earlier, there are five explanatory variables in the inefficiency equation that are indicators of environmental stewardship practices or BMPs; soil test, precision farming, crop plan, environmental plan and nutrient management planning. The parameter estimates for all of these variables in both models are negative indicating a positive relationship with technical efficiency, although not all coefficients are statistically significant. The use of precision farming techniques, nutrient management planning and soil testing (in Model 1) are all shown to be statistically significant and positively related to technical efficiency. These results make sense, given the nature of the variables. In all cases, they represent investing time and/or money in practices that result in more “accurate” input levels; that is, tailoring input levels according to need (e.g., variable fertilizer rates, variable seeding rates, weed scouting to determine need for pest management). There is therefore a direct link between the practice and improved technical efficiency. It is for these reasons that producers likely adopt the practices. The environmental stewardship benefits (e.g., reduced fertilizer use resulting in lower potential for nutrient leaching and/or runoff) are mainly positive externalities.

In the case of the other two “environmental” variables, crop plan and environmental plan, while there are positive relationships with technical efficiency, the coefficients in the inefficiency equation are not statistically significant. For the crop plan variable, responding producers may be interpreting the term loosely with respect to what constitutes a crop plan. Alternatively, it may be the case that other variables in this model are explaining the variability in efficiency that would otherwise be attributed to the effects of using crop planning (e.g., nutrient management planning variable picking up the fertility management aspect of crop planning). In the case of the environmental plan variable, there is no guarantee that developing an environmental farm plan will result in any further action by producers. As well, if actions are taken in terms of environmental stewardship practices, they may not impact significantly on efficiency in crop production (e.g., buffer strips around wetlands).
Technical Efficiency Estimates

A summary of technical efficiency estimates is provided in Table 5. The average technical efficiency level for the producer sample is 0.622 (i.e., 62.2% efficient). Individual technical efficiency estimates range from 0.40 to 0.78. This suggests a significant level of technical inefficiency in the sample. As well, the results indicate that the sample is relatively homogeneous with respect to efficiency, with a relatively limited range of efficiency values. The average technical efficiency is low, given a review of previous efficiency studies. As well, it is surprising that there are no observations that are “highly efficient” (i.e., no efficiency levels greater than 0.9 or even 0.8).

While unexpected, possible explanations exist for the pattern in technical efficiency results. There is some evidence that the choice of functional form does not significantly affect relative efficiency levels (i.e., rank correlations) (e.g., Mbaga et al. 2003; Murillo-Zamorano 2004), but this may be data specific and does not necessarily apply to absolute efficiency estimates. As well, the choice of distributional assumption for the inefficiency term may affect technical efficiency levels.\footnote{Analysis has been undertaken for the current study to examine the effects of changing the distributional assumption for the inefficiency effects. Initial results suggest that if an exponential distribution is assumed, technical efficiency levels for the sample producers are significantly increased.} In a review of technical efficiency studies, Bravo-Ureta et al. (2007) determined that stochastic frontier models estimated with cross-sectional data (as is the case in the current study) result in lower mean technical efficiency levels than if panel data are used.

The average technical efficiency level calculated for this sample is low relative to much of the literature but the results are not unprecedented. Bravo-Ureta et al. (2007) provide a summary for 117 studies that used stochastic frontier methods to estimate technical efficiency in agricultural production. While the overall mean technical efficiency level calculated over the 117 studies is 0.766, there are a number of studies in the list where average technical efficiency is less than 0.7 (Table 1 in Bravo-Ureta et al. 2007). The vast majority of these studies are for crop production agriculture, so perhaps there is something in the nature of crop production that results in a greater likelihood of lower efficiency estimates. As well, in a more recent study of technical and environmental efficiency for Quebec crop and livestock farm operations (Tamini et al. 2012) the average technical efficiency score was 0.426.
Finally, it may just be the case that for this particular set of producers growing canola in 2011, average technical efficiency levels were low. Including precipitation as an explanatory variable in the Just-Pope formulation was intended to explain the effects of moisture on expected yield and production variance. However, perhaps the magnitude of the impact of moisture problems on crop production during the 2011 growing season was such that the effects were not all captured in the frontier and that contributed to lower efficiency levels for the producer sample.

Table 5 also provides a breakdown of technical efficiency estimates, by province and by soil zone. Consistent with earlier discussion regarding soil zone and the Just-Pope model results, soil zone does not appear to have an effect on technical efficiency. Mean technical efficiency values are similar between soil zones. Giannakas et al (2001) did find soil quality to have a significant (positive) influence on technical efficiency for Saskatchewan wheat producers, but perhaps the moisture issues (discussed earlier) muted any potential effect of soil quality.

While not tested statistically, there did seem to be provincial differences in technical efficiency (Table 5). Average technical efficiency for Alberta (0.654) was higher and the standard deviation lower than for the other three areas. The minimum technical efficiency value for the Alberta sample was also higher than for the other regions. This may provide further evidence that weather issues were influencing the technical efficiency estimates, given the distribution of moisture problems in the Prairie region (AAFC 2012).

**Concluding Comments**

This study estimated technical efficiency for a cross-section sample of canola producers in the Canadian Prairie Provinces who were surveyed in early 2012. A stochastic Just-Pope production frontier was estimated, assuming a Cobb-Douglas functional form for both the expected yield and production variance equations, and a truncated normal distribution for the inefficiency terms. The results for the expected yield model were (for the most part) consistent with expectations as nutrient levels contribute positively to output. There were mixed results in the production variance equation in terms of the whether fertilizer inputs were risk increasing or risk decreasing.
Soil type did not significantly affect either expected yield or production variance, but there were significant provincial effects.

The effects of growing season precipitation in the Just-Pope production frontier estimates were unexpected. Precipitation had a negative relationship with expected canola yield and was risk increasing in the production variance equation. These results were likely attributable to significant moisture problems and issues that occurred during the 2011 growing season, which formed the basis for producer responses to the canola survey. This may also have contributed to lower than expected levels of technical efficiency calculated for the sample from the estimated production frontier model.

In terms of environmental stewardship and BMP adoption, the impact on technical efficiency of canola production appeared to be either neutral or positive. In particular, evidence of adoption of nutrient management planning, precision farming techniques and (to a lesser extent) soil testing was positively related to technical efficiency. There was no evidence from the results in this analysis that adoption of cropping BMPs by Canadian Prairie canola producers was detrimental to efficiency levels. If there is a negative relationship between farm financial performance and BMP adoption, the cause of that relationship may lie somewhere other than the impact of BMPs on technical efficiency.

However, only a limited number of practices were addressed in the current study. In particular, the survey did not ask producers about their use of environmental stewardship practices that are not directly related to canola production decisions; for example, land use change BMPs such as restoration of wetlands or implementation of buffer strips. If these types of BMPs were considered, the effects might have been different. If wetlands in canola fields were restored for example, there may be an impact on efficiency of field operations due to nuisance costs (Cortus et al. 2011) that would negative affect overall technical efficiency of production.

Given the results generated in this analysis, there are additional avenues of work that could and should be explored. The use of a Cobb-Douglas functional form, while still common in efficiency analyses, does result in restrictive assumptions (e.g., constant production elasticities) that may have influenced the results in the current study. A more flexible specification may allow better modeling of the complex relationship
between expected yield or production variability and precipitation. Technical efficiency values may also be affected by the choice of functional form and distributional assumption for inefficiency effects.

Finally, given the nature of the problem examined in this study (i.e., environmental stewardship and efficiency), it would be useful to undertake an assessment of environmental efficiency. For example, Tamini et al. (2012) examine technical and environmental efficiency for a sample of Quebec agricultural producers, including the impact of BMP adoption. In the case of canola producers in the Canadian Prairies, an analysis of environmental efficiency would require estimates of not only canola yield but also environmental outputs such as unaccounted for nitrogen that may have been lost due to leaching or run off. This type of assessment would permit a more complete picture of the impact of environmental stewardship, including potential tradeoffs between technical and environmental efficiency. Further analysis of this type is warranted.

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References


Table 1. Distribution of observations by province and soil zone, sample used in estimation and total survey sample

<table>
<thead>
<tr>
<th>Province</th>
<th>Estimation Sample</th>
<th>Survey Sample&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percentage</td>
</tr>
<tr>
<td>Alberta</td>
<td>167</td>
<td>25.97</td>
</tr>
<tr>
<td>Alberta-Peace</td>
<td>44</td>
<td>6.84</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>294</td>
<td>45.72</td>
</tr>
<tr>
<td>Manitoba</td>
<td>138</td>
<td>21.46</td>
</tr>
<tr>
<td>Total</td>
<td>643</td>
<td>100.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Estimation Sample</th>
<th>Survey Sample&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percentage</td>
</tr>
<tr>
<td>Black</td>
<td>281</td>
<td>43.70</td>
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<tr>
<td>Brown</td>
<td>81</td>
<td>12.60</td>
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<tr>
<td>Dark Brown</td>
<td>156</td>
<td>24.26</td>
</tr>
<tr>
<td>Gray</td>
<td>73</td>
<td>11.35</td>
</tr>
<tr>
<td>Dark Gray</td>
<td>52</td>
<td>8.09</td>
</tr>
<tr>
<td>Total</td>
<td>643</td>
<td>100.00</td>
</tr>
</tbody>
</table>

<sup>a</sup> The survey sample distributions are taken from Blacksheep Strategy Inc. (2012).

Table 2. Summary statistics for variables used in Just-Pope production function

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>S.D.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola yield (bushels/ac)</td>
<td>38.71</td>
<td>12.18</td>
<td>1</td>
<td>86</td>
</tr>
<tr>
<td>Nitrogen (pounds/ac)</td>
<td>91.29</td>
<td>28.59</td>
<td>9.00</td>
<td>199.90</td>
</tr>
<tr>
<td>Phosphorus (pounds/ac)</td>
<td>29.02</td>
<td>10.82</td>
<td>3.00</td>
<td>76.50</td>
</tr>
<tr>
<td>Sulphur (pounds/ac)</td>
<td>18.02</td>
<td>12.49</td>
<td>2.50</td>
<td>140.00</td>
</tr>
<tr>
<td>Precipitation (inches)</td>
<td>11.96</td>
<td>5.73</td>
<td>1</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 3. Summary statistics for variables used in the inefficiency model

<table>
<thead>
<tr>
<th>Quantitative Variable</th>
<th>Mean</th>
<th>S.D.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola experience (years)</td>
<td>24.39</td>
<td>10.86</td>
<td>1</td>
<td>51</td>
</tr>
<tr>
<td>Farm Size (acres)</td>
<td>2343.82</td>
<td>2051.00</td>
<td>160</td>
<td>15000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Categorical Variable&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-Farm Income</td>
<td>202</td>
<td>441</td>
</tr>
<tr>
<td>Soil Test</td>
<td>388</td>
<td>255</td>
</tr>
<tr>
<td>Precision Farming</td>
<td>527</td>
<td>116</td>
</tr>
<tr>
<td>Crop Plan</td>
<td>311</td>
<td>332</td>
</tr>
<tr>
<td>Environmental Plan</td>
<td>445</td>
<td>198</td>
</tr>
<tr>
<td>Nutrient Management Planning</td>
<td>453</td>
<td>190</td>
</tr>
</tbody>
</table>

<sup>a</sup> The values for categorical variables represent the numbers of observations for which the variables were coded “1” (i.e., yes) and “0” (i.e., no) for use in the inefficiency model estimation, based on the definitions for the variables.
Table 4. Maximum likelihood parameter estimates: stochastic Just-Pope canola production function frontier

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1: Basic Model</th>
<th>Model 2: Provincial Dummies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>S.E.</td>
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<tr>
<td>Expected Yield Equation</td>
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<tr>
<td>Constant</td>
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<td>5.487</td>
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<tr>
<td>Nitrogen</td>
<td>1.225</td>
<td>1.217</td>
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<tr>
<td>Phosphorus</td>
<td>3.015**</td>
<td>1.248</td>
</tr>
<tr>
<td>Sulphur</td>
<td>2.670***</td>
<td>0.931</td>
</tr>
<tr>
<td>Precipitation</td>
<td>-2.268**</td>
<td>0.948</td>
</tr>
<tr>
<td>D&lt;sub&gt;AB-Peace&lt;/sub&gt;</td>
<td>-4.634**</td>
<td></td>
</tr>
<tr>
<td>D&lt;sub&gt;MB&lt;/sub&gt;</td>
<td>-7.952***</td>
<td></td>
</tr>
<tr>
<td>Production Variance Equation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-11.785**</td>
<td>4.790</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.003</td>
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<tr>
<td>Phosphorus</td>
<td>2.109**</td>
<td>0.840</td>
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<tr>
<td>Sulphur</td>
<td>-1.308**</td>
<td>0.573</td>
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<tr>
<td>Precipitation</td>
<td>2.658***</td>
<td>0.795</td>
</tr>
<tr>
<td>D&lt;sub&gt;AB-Peace&lt;/sub&gt;</td>
<td>1.293*</td>
<td></td>
</tr>
<tr>
<td>D&lt;sub&gt;MB&lt;/sub&gt;</td>
<td>-2.730*</td>
<td></td>
</tr>
<tr>
<td>D&lt;sub&gt;SK&lt;/sub&gt;</td>
<td>-1.264*</td>
<td></td>
</tr>
<tr>
<td>σ&lt;sub&gt;u&lt;/sub&gt;</td>
<td>4.620***</td>
<td>0.0982</td>
</tr>
<tr>
<td>Inefficiency Equation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>37.712***</td>
<td>3.109</td>
</tr>
<tr>
<td>Canola Experience</td>
<td>-0.0197</td>
<td>0.0413</td>
</tr>
<tr>
<td>Off Farm Income</td>
<td>1.090</td>
<td>0.992</td>
</tr>
<tr>
<td>Size</td>
<td>0.0600</td>
<td>0.237</td>
</tr>
<tr>
<td>Soil Test</td>
<td>-2.337**</td>
<td>1.007</td>
</tr>
<tr>
<td>Precision Farming</td>
<td>-3.585***</td>
<td>1.210</td>
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<td>Crop Plan</td>
<td>-0.739</td>
<td>0.936</td>
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<td>1.011</td>
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<td>Nutrient</td>
<td>-2.586**</td>
<td>1.116</td>
</tr>
<tr>
<td>Management Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-2465.775</td>
<td></td>
</tr>
<tr>
<td>Number of observations</td>
<td>643</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Nitrogen, Phosphorus, Sulphur and Precipitation are variables are natural logarithms (ln). Provincial dummies are for Manitoba (MB), Saskatchewan (SK), and the Peace region of Alberta and British Columbia (AB-Peace). The provincial dummy for Alberta is excluded.

<sup>b</sup> Values in parentheses are standard errors. *, ** and *** denote statistical significance at 10%, 5% and 1% levels, respectively.
Table 5. Descriptive statistics for technical efficiency estimates

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Min</th>
<th>Max</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sample</td>
<td>0.622</td>
<td>0.061</td>
<td>0.396</td>
<td>0.776</td>
<td>643</td>
</tr>
<tr>
<td>By Province</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alberta</td>
<td>0.654</td>
<td>0.048</td>
<td>0.507</td>
<td>0.757</td>
<td>167</td>
</tr>
<tr>
<td>Alberta-Peace&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.611</td>
<td>0.058</td>
<td>0.396</td>
<td>0.731</td>
<td>44</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>0.613</td>
<td>0.061</td>
<td>0.442</td>
<td>0.735</td>
<td>294</td>
</tr>
<tr>
<td>Manitoba</td>
<td>0.604</td>
<td>0.062</td>
<td>0.460</td>
<td>0.776</td>
<td>138</td>
</tr>
<tr>
<td>By Soil Zone&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>0.624</td>
<td>0.059</td>
<td>0.453</td>
<td>0.776</td>
<td>281</td>
</tr>
<tr>
<td>Browns</td>
<td>0.621</td>
<td>0.064</td>
<td>0.396</td>
<td>0.757</td>
<td>237</td>
</tr>
<tr>
<td>Grays</td>
<td>0.618</td>
<td>0.057</td>
<td>0.483</td>
<td>0.731</td>
<td>125</td>
</tr>
</tbody>
</table>

<sup>a</sup> Alberta-Peace refers to observations from the Peace region of Alberta and British Columbia.

<sup>b</sup> “Browns” refers to observations located in the brown and dark brown soil zones. “Grays” refers to observations located in the gray and dark gray soil zones.