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Estimating the Implicit Value of Crop Stubble as a Barrier to Technology Adoption in Morocco

Nicholas Magnan (npmagnan@ucdavis.edu)

Douglas M. Larson

University of California, Davis

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Nicholas Magnan‡
Douglas M. Larson
Department of Agricultural and Resource Economics
University of California, Davis

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Abstract

For mixed cereal-livestock farmers, cereal production provides a bundle of goods. Grain is consumed by the household or sold at market, and crop residues are used as livestock feed. The straw component of crop residue can be bought and sold at market and therefore has a well-established local market price. Crop stubble, the portion of the crop residue left on the ground, is generally not traded and therefore has no market price. Some agricultural technologies require farmers to forgo using crop stubble as feed, and cultivation of high value crops entails sacrificing residue production altogether. In this paper we apply a structural econometric model to household data from Morocco to estimate the implicit value of crop stubble. We use a sample splitting technique to investigate differences in the value of this resource and find that it is significantly higher for smaller farmers, who therefore face an even larger barrier to technology adoption.

‡Corresponding author: npmagnan@ucdavis.edu
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1. Introduction

Cereal production is widespread throughout Morocco, accounting for about 70 percent of agricultural land (FAO, 2009). It is especially prevalent in rainfed areas, which compose nearly 90 percent of Morocco's agricultural land (Arab Organization for Agricultural Development, 2008). Most small cereal farmers in Morocco are also livestock producers and benefit from complementarities of production. In addition to grain for sale or consumption, cereal cultivation also produces crop residues in the form of straw (residue taken off the ground and baled) and stubble (residue left on the ground). These are valuable inputs towards livestock production.

In Morocco, up to 40 percent of the average ruminant's diet (in terms of biomass) is composed of cereal residues depending on the region (Guessous as cited in Mrabet, 2008), but this percent can be higher for individual herds. The dominance of crop residue in livestock diets is not unique to Morocco; In India, crop residue is estimated to compose 40-60 percent of livestock diet (Rao and Hall, 2003), in Ethiopia 40-50 percent (Keftasa, 1988), and in Sudan 13 percent (Nordblom and Shomo, 1993). In arid and semi-arid cereal growing regions of Morocco crop stubble is typically the sole source of small ruminant (the dominant form of livestock) feed in the summer and fall months following the harvest, so intra-seasonal substitutability between residues and other feed sources may be low (Tarzhouti et al., 2006).

The importance of crop stubble to small farmers has implications for crop and technology choices that impact long-term economic development and agricultural

sustainability. If a farmer adopts no-till cereal production to replace conventional cereal production, or if he[1] adopts high value crops and abandons cereal production altogether, then he must forgo using that crop stubble as animal feed. If the value of crop stubble as animal feed from calculations of the cost of adoption, the full cost of using no-till or planting high value crops instead of cereal will be underestimated. Consequently, farmers may be more hesitant to adopt than development practitioners and policymakers would believe. In this case, policy options that help farmers obtain alternative sources of livestock feed should be considered.

No-till agriculture[2] is a technology farmers can adopt to reduce the cost of cereal production, improve and maintain soil quality, and increase and stabilize yields. Specifically, no-till agriculture allows farmers to forgo plowing by seeding directly through the stubble of previous years' crops, which the farmer is required to leave on the field. Because the farmer does not plow and the field remains covered in stubble, no-till lowers fuel costs (and emissions), prevents erosion, and increases soil moisture and soil organic carbon, making the soil act as a carbon sink (Erenstein, 2003; World Bank, 2010). Despite the perceived benefits, adoption rates worldwide have been low, particularly among small farmers in developing countries (Ekboir, 2002; Pieri et al., 2002; Knowler and Bradshaw, 2007). This is true in Morocco, even though field trials conducted by the Institut National de Recherche Agricolce have been highly successful from an agronomic point of view (Mrabet, 2002; Mrabet, 2008). The adaption and application of no-till to semi-arid areas of

[1] I use masculine pronouns throughout the paper as heads of farming households are nearly exclusively male in Morocco.
[2]No-till is also called conservation agriculture, zero-till, minimum-till, reduced-till, and conservation-till. Throughout this paper I will use the term "no-till". For excellent overviews of no-till agriculture in developing countries see Ekboir, 2002; Erenstein, 2003; and Pieri et al., 2002.

Morocco is a component of the recently released National Plan against Global Warming (Secretary of State of Morocco, 2009). An often cited-but not quantified- reason for low adoption rates is that mixed cereal-livestock farmers face a tradeoff between using crop stubble as animal feed or as an input for no-till agriculture (Antle and Diagana, 2003; Ekboir, 2002; Lal, 2007; Pieri et al., 2002).

Conversion from cereal production to cash crops is thought to have the potential to allow small farmers escape poverty (World Bank, 2008). Cereals are generally considered to be low-value and high-risk compared to cash crops. Currently several major projects are underway in Morocco to help small farmers convert make this conversion. In 2007 the Millennium Challenge Corporation signed a contract with the government of Morocco to improve and expand fruit-tree production, with expansion aimed at land currently in cereals.[3] In a separate effort, the government of Morocco aims to convert 3 million hectares of marginal cereal land to cash crop production to help alleviate rural poverty. In addition to generating more income for small farmers, perennial cash crops can help reduce greenhouse gas emissions through carbon sequestration (World Bank, 2010). However, cash crops generally do not provide stubble that can be used as animal fodder,[4] so the gap between profits from high value crops and cereals might not be as great as perceived when the implicit costs of crop stubble are considered.

Measuring the value of crop residue is complicated. Valuing straw, the residue taken off the field, is fairly straightforward when markets exist, although the value of straw can differ between farmers when transaction costs affect market participation. Stubble, the

[3] See http://www.mcc.gov/mcc/countries/morocco/ma-projects/index.shtml.
[4] A potentially important exception is switchgrass for biofuels. Switchgrass can be grazed in its early growth phases and therefore is a potential cash crop that would also provide animal feed.

residue left on the field, is much harder to value since it is not traded.[5] Furthermore, since stubble markets do not exist, the non-market value of stubble will differ from farmer to farmer. If smaller and/or poorer farmers are more limited in access to marketable animal feed, they could have a higher value for crop stubble, and therefore face a greater barrier to no-till or high value crop adoption than larger farmers.

In this paper we develop and implement a technique to value crop stubble using unique panel data from the Middle Atlas region of Morocco. Applying the data to a highly generalizable production function for livestock, we solve the farmers' cost-minimization problem for maintaining their herd. From the resulting demand and production functions we derive an econometrically estimable system of equations from which the implicit value of crop stubble and other non-traded livestock feed can be estimate. We find that the value of crop stubble is large and significant, particularly when drought decreases supply, and is much higher than the value of other non-marketable feed sources.

Because the value of crop stubble can vary across farmers, we apply a sample splitting technique that tests for differences in crop stubble values and other parameters along key variables (i.e. landholdings). We find that smaller farmers (in terms of cultivated area) value crop stubble twice as much as larger farmers, which suggests that the barrier of forgoing this resource in order to adopt high value crops or no-till technology is much higher for smaller farmers.

The findings of this study highlight that farmers in Morocco depend on crop stubble to supplement marketable feed sources. It is not simply a waste byproduct of crop

[5] In rare instances in the study region, stubble grazing rights are traded but prices vary widely as markets are not well established.

production, but an important input to livestock production with a tangible and measurable implicit value. If farmers lose this resource, they need to increase net purchases of other feed. These complementarities are widely recognized, yet difficult to quantify. The findings of this study indicate that policy makers, researchers, and extension agents need to figure the implicit cost of crop stubble into the farmer's balance sheet when attempting to disseminate no-till agriculture or high value crops.

2. Model

Estimates of the prevalence of crop residue in livestock diets are typically calculated by projecting some estimated average quantity of biomass generated per hectare of cereal production (Nordblom and Shomo, 1993). The method assumes that all crop residues are used as feed. While this method might be appropriate for estimating the quantity of crop residue used as animal feed for the aggregate of a region, it does not lend itself well to calculating the value of crop stubble at the farm level. Existing estimates of the quantity of crop residue used as livestock feed also do not differentiate straw from stubble, which is a serious shortcoming because of possible nutritional differences between the two and because one is marketable and one is not.

During harvest, grain can be knocked off the stalk and fall to the ground amidst the crop stubble. Consequently, crop stubble can include grain whereas straw does not, making stubble more nutritive than straw (Personal communication with Abdelaziz Chergaoui, August 15, 2007). Although crop stubble may be more nutritive than straw, property rights over stubble are much more tenuous. Straw is usually baled, making it transportable. It can be brought to a location where its owner can prevent use by others, or

taken to market and sold at a well-established local price. A farmer who owns a plot of cereal land does not, however, necessarily enjoy full property rights over his crop stubble due to a combination of high enforcement costs, traditions, and social norms (Ekboir, 2002; Pieri et. al, 2002; Wade, 1987). Consequently, some households produce more stubble than they consume, and others consumer more stubble than they produce.

Farmers in the study region use a combination of marketable and non-marketable feed sources to maintain their herd. Some marketable feeds- straw, hay, barley grain, and bran- can either be produced on site or acquired at market. Other marketable feeds- maize, dried beet pulp, and commercial concentrate- are nearly exclusively bought at market. We assume that farmers face zero transport costs for these inputs so that consuming (and consequently not selling) marketable feed produced on-farm is equivalent to buying the same quantity of that feed from market. Farmers are not quantity constrained for marketable resources since they can purchase as much as they wish. We acknowledge that transport costs may be substantial in the study region and elsewhere, but maintain this assumption for simplicity. Incorporating and estimating unobserved transport costs requires substantial changes to the model that would allow us to estimate transport costs, and is something we are exploring elsewhere. Non-marketable feed sources- crop stubble and fallow and pasture- are grazed directly off the ground and have no market price, but are limited in quantity. For our model, we aggregate feed source to the level of the smallest boxes of Table 1, i.e. straw, hay, high-grade feed, stubble, and pasture/fallow.

Our model begins as a cost-minimization problem, where a farmer minimizes the cost of maintaining a herd of size H using some combination of feed $\boldsymbol{z}$, where z_j is the

quantity of feed source *j*. Feed sources *j* = 1…*m* are all marketable at market prices $\boldsymbol{w}$. Feed sources *j*=*m*+1…*M* are "free" in the sense that the farmer does not have to pay out of pocket for these inputs, but is quantity rationed by the availability of these feed sources, $\bar{\boldsymbol{z}}$.

$$\min_{\mathrm{z}} w \cdot z$$
$$\text{s.t.}\, f(\boldsymbol{z}) \geq H, z_j \leq \bar{z}_j \text{ for } j = m+1 \ldots M \tag{1}$$

To model livestock production $f(\boldsymbol{z})$, we use a highly flexible generalized linear production function (Diewart, 1971). This type of production function allows for both substitutability and complementarities between feed types. The farmer's constrained optimization problem is given in equation (2), where $\alpha_{jk} = \alpha_{kj} \geq 0$.

$$L = \sum_{j=1}^{m} w_j \cdot z_j + \lambda \cdot (H - \sum_{j=1}^{M} \sum_{k=1}^{M} \alpha_{jk} \cdot {z_j}^{0.5} \cdot {z_k}^{0.5}) + \sum_{j=m+1}^{M} \rho_j \cdot (z_j - \bar{z}_j) \tag{2}$$

The parameter λ is the marginal cost (and marginal benefit) associated with supporting an additional unit of livestock and ρ_j is the implicit value of input *j* for *j* = *m*+1…*M*. The implicit value for input *j* is zero for farmers who are not quantity constrained for this resource and positive for farmers who are quantity constrained. We cannot identify which households are constrained and unconstrained from the data, but we can test if groups of households are constrained by testing for positive implicit values.

The first order conditions to the optimization problem are:

$$w_j - \lambda \cdot \alpha_{jj} - \textstyle\sum_{k \neq j} \lambda \cdot \alpha_{jk} \left(\frac{z_k}{z_j}\right)^{0.5} = 0 \text{ for } j = 1 \ldots m \tag{3}$$

$$\rho_j - \lambda \cdot \alpha_{jj} - \textstyle\sum_{k \neq j} \lambda \cdot \alpha_{jk} \left(\frac{z_k}{z_j}\right)^{0.5} = 0 \text{ for } j = m+1 \ldots M \tag{4}$$

$$H - \sum_{j=1}^{M} \sum_{k=1}^{M} \alpha_{jk} \cdot z_j^{0.5} \cdot z_k^{0.5} = 0 \tag{5}$$

Equations (3) and (4) can be interpreted as factor demands, and equation (5) as the production function. Because not all farmers used a nonzero quantity of all inputs, we multiply through first order conditions (3) and (4) 3**Error! Reference source not found.Error! Reference source not found.**5**Error! Reference source not found.**3333by $z_j^{0.5}$ and divide through by the Lagrangian multiplierλ. The result is an estimable linear system of *M+1* equations with the cross equation restriction that $\alpha_{jk} = \alpha_{kj}$ for all *j* and *k*.

$$\varphi \cdot w_j \cdot z_j^{0.5} + \alpha_{jj} \cdot z_j^{0.5} + \sum_{k \neq j} \alpha_{jk} \cdot z_k^{0.5} = \varepsilon_j \text{ for } j = 1 \dots m \tag{6}$$

$$\theta_j \cdot z_j^{0.5} + \sum_{k \neq j} \alpha_{jk} \cdot z_k^{0.5} = \varepsilon_j \text{ for } j = m + 1 \dots M \tag{7}$$

$$\sum_{j=1}^{M} \sum_{k=1}^{M} \alpha_{jk} \cdot z_j^{0.5} \cdot z_k^{0.5} - H = \varepsilon_h \tag{8}$$

The system of equations contains the cross-equation restriction that $\alpha_{jk} = \alpha_{kj}$ for all *j*,*k*. It should also be true that $\alpha_{jk} \geq 0$ for all *j* and *k*. From the parameter estimates from (6)-(8) we can estimate the marginal cost of supporting an additional unit of livestock, λ, and the implicit value of non-marketable good *j*, ρ_j, as combinations of reduced form parameters.

$$\lambda = -\frac{1}{\varphi} \tag{9}$$

$$\rho_j = \frac{\theta_j - \alpha_{jj}}{\varphi} \tag{10}$$

3. Data

Survey

The data we use in this study were collected during the summers of 2007 and 2008 in the Middle Atlas Region of Morocco. Surveys were conducted in four rural districts, ranging from 300 meters

above sea level to 1500 meters above sea level in altitude (the urban fringe, low plains, foothills, and mountains). Mixed cereal-livestock farming is the dominant form of livelihood in three lowest zones. Because farming operations are very different in the mountainous zones than the other four regions,[6] data from the mountainous zone is not used in this study. All summary statistics and estimation results given in this paper refer to the three lower zones only. The primary cereals grown in the region are soft (bread) wheat, hard (durum) wheat, and barley. Wheat is used entirely as food, and barely is used as both food and feed. Livestock predominantly consists of sheep, but also includes cows and goats. Many households also have several equines for traction and transport. Farmers generally feed all animals in their aggregate herds the same type of feed, especially in the case of small ruminants.

Within each zone, four to five villages were randomly selected and within each village around 20 households were randomly pre-selected from village rosters, with an average of nearly 13 households per village completing the survey. In the three zones pertinent to this paper, 223 households were surveyed in 2007 and 203 of the same households were resurveyed in 2008. Because stubble availability, pasture and fallow availability, feed prices, and herd size can change from year to year there is substantial variation in the composition and quantity of animal feed from year to year so we pool observations from both years. We limit the sample to households with both land and livestock, leaving 385 observations (196 from 2007 and 189 from 2008).

Respondents were asked a wide variety of questions on their households' economic activities, particularly cereal and livestock cultivation. The survey asked cereal production questions at the plot level, including how much straw was produced and what happened to the crop stubble after the harvest. The survey also included several questions about the farmers' ability to

[6] In the mountainous zone households depend mostly on tree crops for incomes and grow cereal mostly for household consumption. Cereal cultivation is mostly entirely rainfed in the three lower zones, but irrigated on many plots in the mountainous zones. In the lower three zones, small ruminant herds are dominated by sheep, where is in the mountains goats dominate. Common pasture grazing is far more prevalent in the mountain zones than in the lower zones.

prevent others from grazing crop stubble on their land. Livestock questions included an animal inventory and a detailed accounting of quantities of different feed sources used, including a breakdown of what feed was bought at market and what feed was produced on site. Feed prices were gathered as part of a village survey. The most unique data gathered by this survey is on grazing. Household heads were asked how many months their herds (by animal type) were taken to graze on the farmer's own crop stubble, other farmers' crop stubble, fallow fields, and common pasture.

3.2 Descriptive statistics

In the study sample, the average farm size[7] was 10.9 ha. The maximum reported farm size was 112 ha, but 99 percent of respondents reported a farm size of less than 60 ha and 95 percent reported less than 33 ha. In each year, an average of just over three-quarters of cultivated land was planted in cereals, including forage crops. Other crops cultivated include legumes and vegetables. Around 15 percent of land was left fallow. Households had an average herd size of 34.6 sheep, 2.8 cows or cattle, 5.4 goats, and 3.7 equines. To aggregate across livestock types we employed the tropical livestock unit (TLU), assigning a weight of 0.1 TLU for each goat or sheep, and 0.7 TLU for each cow or equine.[8] The sample mean for TLU was 6.6. With the exception of number of equines,[9] all mean values of land and livestock did not differ significantly between years.[10] By most accounts, the majority of farmers in the sample are considered smallholders, although there is substantial heterogeneity in farm size within the sample. We will make use of this heterogeneity to

[7] This includes land rented in and sharecropped, but does not include land rented out. Most land in the study area, however, is owned and cultivated by the same household.
[8] This is the common conversion rate employed by the FAO. See http://www.fao.org/docrep/V1650T/v1650T0d.htm.
[9] The average number of equines went from 1.53 in 2007 to 1.86 in 2008, a small but statistically significant change.
[10] Unless otherwise noted, we use the 0.1 confidence level to denote significance.

examine if the implicit value of stubble is higher for smaller farmers, who would appear to be more constrained for that resource. Descriptive statistics on farm size can be found in Table 2.

Crop stubble use for livestock feed is ubiquitous in the study region. Nearly 95 percent of households with livestock use either crop stubble from their own fields (89 percent), stubble from other households' fields (50 percent), or both as feed. Because farmers do not exclusively graze their own plots, and graze other farmers' plots, they do not know the area of crop stubble they graze except for the rare occasions where a farmer can prevent all others from grazing their herds on his land, and does not graze his herd on others' fields. Farmers do, however, know for approximately how long they grazed their animals on crop stubble (both on their own land and others'). This is the measurement of crop stubble use we captured in the survey. On average, farmers grazed stubble for 71 days. For our estimation, the quantity of stubble used is livestock weighted days (LWD). For instance, a farmer who grazes 2 cows and 6 sheep (2 TLU) on crop stubble for 60 days consumes 120 livestock weighted days of stubble. On average, farmers in our sample used 1,022 LWDs of stubble each year over the two survey years. We used an analogous measure for the number of days spent grazing pasture and fallow land.[11]

Data from 2007 refers to the 2006-2007 agricultural year (August to July) and data from 2008 refers to the 2007-2008 agricultural year. Most stubble grazing occurs in the spring, right after the harvest. Because of the drought of 2007 and the resulting poor harvest, farmers were able to graze their herds on crop stubble significantly longer in 2008

[11] Reports from the survey team and the resulting data indicate that farmers do not easily distinguish pasture land from fallow land. Instances of farmers claiming to use both resources are very rare (6 percent of respondents). We therefore employ the total number of LWDs spent grazing pasture and fallow lands as a single variable.

(1,224 LWDs) than in 2007 (836 LWDs). For pasture/fallow land, low rainfall in 2007 also led to reduced biomass in pastures and fallow fields. Consequently, farmers grazed an average of 2,336 LWDs of pasture/fallow in 2008, compared to only 848 in 2007. To compensate for having less stubble and pasture/fallow available in 2007, farmers used greater quantities, and slightly more variety, of marketable feed in 2007 than 2008. Straw was used by nearly all farmers in both years, but the quantity used was nearly twice as great in 2007. About nine percent of farmers who used hay in 2007 did not in 2008, presumable due to increased availability of non-marketable feed. The same is true for high-grade feeds. Average quantity of hay used was nearly three times as much in 2007 than in 2008 and the quantity of high-grade feed used in 2007 was 75 percent more than in 2008. Table 3 contains descriptive statistics on feed use by year.

Although the main point of this paper is not exploring differences between years, these differences are quite informative about how farmers substitute between marketable and non-marketable feed sources. First of all, households did not appear to alter their herd size from year to year depending on the quantity of non-marketable feed available. Households clearly compensated for reduced availability of non-marketable feeds available in the drought year of 2007 by using more marketable feed. Furthermore, significantly more farmers used high quality marketable feeds (hay and high-grade feed) in 2007 that in 2008. This suggests that straw alone is not a substitute for stubble and pasture/fallow, and that the bundle of feed used to compensate for the lack of non-marketable feed available in 2007 included a variety of marketable feeds.

4. Estimation and results

We estimated the system of equations described (6)-(8)66666666 using 3SLS (Zellner, 1962). Since we are interested in estimating a cost of a rather abrupt technological change- the value of crop stubble as animal feed- we assume some variables that are endogenous in the long run are exogenous in the short run. For instance, a farmer can alter his herd size by buying or selling livestock to respond to input price changes, but we assume that in the short run herd size is exogenous. We also assume the amount of stubble and pasture/fallow land a farmer can use is exogenous, although in the long run a farmer could increase or decrease the amount of stubble and fallow land he has access to by changing his crop portfolio or cultivated area. We assume that prices for marketable crops are exogenous to the farmer.

Quantities of marketable feed consumed, however, is clearly endogenous, even in the short run. This leaves us with three endogenous variables for which we must instrument. In addition to the excluded exogenous variables for the different equations of the system, we also employ exogenous (in the short term) variables from outside the model as instruments: farm size, area of cereal cultivated, household size, car and/or truck ownership, distance to market, and age and education of household head.

Because the quantity of stubble available in 2007 was so much less than the quantity of stubble available in 2008, we control for year fixed-effects in our regression. We assume that the production function parameters are constant over time, but that

parameters that reflect constraints can vary by year. We therefore restructure equations (6) and (7) as:

$$(\varphi + \omega) \cdot w_j \cdot z_j^{0.5} + \alpha_{jj} \cdot z_j^{0.5} + \sum_{k \neq j} \alpha_{jk} \cdot z_k^{0.5} = \varepsilon_j \text{ for } j = 1 \ldots m, \quad \tau = 1 \text{ if year} = 2007 \tag{6'}$$

$$(\theta_j + \omega_j) \cdot z_j^{0.5} + \sum_{k \neq j} \alpha_{jk} \cdot z_k^{0.5} = \varepsilon_j \text{ for } j = m + 1 \ldots M, \quad \gamma_j = 1 \text{ if year} = 2007 \tag{7'}$$

From the reduced form estimates from equations (6'), (7'), and (8) we derive the structural coefficients as (9') and (10') below.

$$\lambda^{2007} = -\frac{1}{(\varphi+\omega)}, \lambda^{2008} = -\frac{1}{\varphi} \tag{9'}$$

$$\rho_j^{2007} = \frac{\theta_j + \omega_j - \alpha_{jj}}{\varphi + \omega}, \rho_j^{2008} = \frac{\theta_j - \alpha_{jj}}{\varphi} \tag{10'}$$

We use a bias-corrected percentile bootstrap of 1,000 pseudosamples to construct confidence intervals (Efron and Gong, 1983) due to the non-linearity of the structural coefficients (Green, Hahn, and Rocke, 1983). The structural coefficients are the marginal cost of (and benefit of) supporting one more TLU, the implicit value of one LWD of crop stubble grazing, and the implicit value of one LWD of pasture/fallow grazing. A positive implicit value for a non-marketable resource implies that farmers are quantity constrained for this resource. A zero value implies that the farmers are not constrained.

Production coefficients

Estimation of the coefficients of the production function is not the primary goal of this paper, but these parameters are informative and can serve as a useful check on our

estimation technique. Table 5 reports these parameter estimates. As expected, straw is far less productive than other marketable feed sources. High grade feed is only slightly more productive per kg than hay, although this difference is not significant.[12] Stubble grazing is 2.5 times more productive than pasture and fallow grazing.

Straw and stubble, hay and stubble, and hay and pasture/fallow grazing exhibit complementarities of production, evidenced by positive estimates of the cross-productivity terms. The estimate of the cross-productivity term between hay and high-grade feed is negative, indicating a discomplementarity between the two. Such a discomplementarity is not theoretically allowed by the functional form chosen (Diewert, 1971). However, a negative estimate of a cross-productivity term is not uncommon when using flexible functional forms (Jacoby, 1993). Overall, the productivity parameter estimates are very reasonable which bodes well for our estimates of the structural parameters.

Marginal cost of livestock and implicit values of non-marketable feed

The average implicit value of stubble is 17.8 Moroccan Dirham (DH)[13] per LWD across all farmers for 2007 and 11.6 DH for 2008. Pasture/fallow grazing has a lower, but still significant value of 6.9 LWD in 2007 and 3 DH per LWD in 2008. We estimate the marginal cost of supporting an additional TLU for one year as 6,974 DH in 2007 and 5,093 in 2008. At first glance, this estimate seems high since the average selling price of a TLU in the study sample ranges from 7,800 DH (three female goats and one cow) to 12,800 DH (three male sheep and one bull). However, this marginal cost includes non-marketable inputs which that do not require the farmer to pay out of pocket, and non-pecuniary

[12] The unit of hay is a bale, which weighs approximately 15 kg. The unit of high-grade feed is a quintal, or 100 kg.
[13] At the time of the study 10 DH equaled approximately 1 USD.

benefits of holding livestock. Regression estimates for the structural coefficients can be found in Table 5.

Taking the implicit value of non-marketable feed sources, we compare the total value of marketable and non-marketable feed used across years (Table 6). In 2007, when a drought severely limited stubble and pasture/fallow grazing, half of total feed by value came from marketable feed. In 2008, just under one-third came from marketable feed. The value of stubble consumed was 40 percent of all feed value in 2007 and over 50 percent in 2008, and in both years was three times the value of pasture and fallow consumed. Stubble is a highly valuable resource and farmers who adopt technologies that preclude stubble grazing would need to drastically increase out-of-pocket expenses in order to compensate.

Differences across farmers

Because crop stubble is not traded, its value is implicit and can vary between farmers depending on the degree to which they are constrained to stubble and other inputs to livestock production. Differences in the implicit value of crop stubble across farmers could be one reason why it is more difficult to smaller farmers to adopt high value crops that replace cereals, or adopt no-till cereal production, which precludes them from using crop stubble as animal feed.

In this portion of this paper we demonstrate that the implicit value of crop stubble, which acts a barrier to agricultural technology, is larger for smaller farmers than larger farmers. Borrowing from Hansen's (2000) threshold estimation technique, we estimate our model allowing some parameters to differ for smaller farmers in the sample, indicated

by a dummy variable D_s where D_s = 1 if farm size < s and zero otherwise (Equations (6'') and (7'')). We continue to allow these same parameters to vary by year, as in equations (6') and (7') and hold the production function constant across farmers and years.

$$(\varphi + \omega + \delta \cdot D_s) \cdot w_j \cdot z_j^{0.5} + \alpha_{jj} \cdot z_j^{0.5} + \sum_{k \neq j} \alpha_{jk} \cdot z_k^{0.5} = \varepsilon_j \text{ for } j = 1 \ldots m \qquad (6'')$$

$$(\theta_j + \omega_j + \delta_j \cdot D_s) \cdot z_j^{0.5} + \sum_{k \neq j} \alpha_{jk} \cdot z_k^{0.5} = \varepsilon_j \text{ for } j = m + 1 \ldots M \qquad (7'')$$

Instead of using an ad-hoc method to determine what constitutes a smaller farm, we allow the data to decide. We estimate equations (6''), (7''), and (8) for all values of s found in the data and compare the objective function of the 3SLS routine to see what value of s best fits the data. There are 81 unique farm sizes in the sample. We find that the threshold that minimizes the objective function is at 4 ha. In our sample, 27.5 percent of households fall below this level (Figure 1).

Hansen (2000) devises a method to rigorously test for the confidence region of threshold estimation in least squares based on a likelihood ratio test. Under the naïve assumption that errors are homoskedastic and normal, the likelihood ratio for the threshold estimator under least squares is:

$$LR(\tau) = n \cdot \frac{S(\tau) - S(\hat{\tau})}{S(\hat{\tau})} \qquad (11)$$

Where $S(\tau)$ is the sum of squared errors with some threshold τ, $S(\hat{\tau})$ is the sum of squared errors at the estimated threshold $\hat{\tau}$, and n is the sample size. Using this likelihood ratio as a convenient test statistic we cannot reject any hypothesis of a threshold between 2.5 ha and

6 ha. In order to split the sample as evenly as possible, we will continue our analysis imposing a threshold of 6 ha, which 34 percent of farmers in the sample fall below.

The threshold estimation results indicate that there are large and significant difference between the parameter estimates for smaller and larger farmers (Table 7). The marginal cost (and benefit) of supporting an additional TLU is 50 percent higher for smaller farmers, and the implicit value of stubble is nearly twice as much. These findings are consistent across both years. There was no significant different in the implicit value of pasture/fallow between the two groups.

5. Conclusions

For mixed cereal-livestock farmers, cereal production produces several goods. Grain is consumed by the household or sold at market, and crop residues are used as livestock feed. Straw, the portion of the residue removed from the field, has a well-established local market price. Stubble, the portion of the residue left on the ground, does not. In this paper we estimate the implicit value of crop stubble as being between 5.75 DH and 18 DH per day for grazing one TLU. The value was significantly higher following a drought year than following an average rainfall year, and higher for smaller farmers than for larger farmers. On average, crop stubble composes between 40-50 percent of the total value of livestock feed used in the study region. Any policy aimed at inducing farmers to adopt no-till agriculture, which precludes using stubble as feed, or high value crops that produce no cereal residue at all, must account for this value by making it easier for farmers to obtain substitute forms of feed.

6. References

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7. Tables and Figures

Marketed (price rationed) $j=1...m$			**Non-Marketed (quantity rationed)** j $j=m+M+1$	
Straw (no grain) ·Wheat ·Barley ·Oat ·Maize*	Hay (grain) ·Barley ·Oat ·Alfalfa*	High-grade feed ·Bran ·Barley grain ·Maize ·Dried beet pulp ·Commercial concentrate	Stubble ·Wheat ·Barley ·Oat ·Maize*	Pasture /Fallow
*Extremely rare in the sample Note: Data aggregation is done at the level of the box.				

Table 1. Livestock Feed sources in the Middle Atlas Region of Morocco

Variable	Mean	Standard deviation
Land (Ha)	10.87	12.44
Sheep	34.57	76.76
Cows	3.73	2.79
Goats	5.43	27.09
Equines	1.70	1.61
TLU	7.80	10.39

Table 2: Farm size and livestock holdings

Feed source	Variable	2007	2008
Straw	Percent farmers using	96.11	97.88
	Bales (1 bale~15kg)	454.98	237.57**
		(448.92)	(231.90)
Hay	Percent farmers using	58.33	48.68*
	Bales (1 bale~15kg)	215.51	81.46**
		(440.06)	(225.78)
High-grade feed	Percent farmers using	90.00	82.0**
	100 kg	28.49	16.13**
		(74.96)	(25.91)
Stubble	Percent farmers using	95.44	94.77
	Livestock weighted days	836.92	1,224.10
		(1,114.19)	(2,031.4)
Pasture/ fallow	Percent farmers using	34.44	62.96**
	Livestock weighted days	847.85	2,335.73**
		(2,089.07)	(4,729.34)

Standard deviations in parenthesis. A * denotes the difference between years is significant at the 0.1 level and ** denotes at the 0.05 level.

Table 3: Feed source use by year

Parameter (α)	Estimate	95 percent confidence interval		Small sample bias‡
		Lower	Upper	
Straw	0.0026	0.0020	0.0032	0.00001
Hay	0.0113	0.0079	0.0173	0.00051
High-grade	0.0832	0.0604	0.1415	0.00301
Stubble	0.0019	0.0014	0.0023	0.00051
Pasture/fallow	0.0007	0.0004	0.0009	-0.00004
Straw x hay	-0.0007	-0.0034	0.0002	-0.00119
Straw x high-grade	-0.0030	-0.0077	0.0036	0.00099
Straw x stubble	0.0008	0.0003	0.0019	0.00015
Straw x pasture/fallow	-0.00002	-0.0001	0.0003	0.00012
Hay x high-grade	-0.03766	-0.0759	-0.0197	-0.00509
Hay x stubble	0.00244	0.0011	0.0047	0.00042
Hay x pasture/fallow	0.00100	0.0002	0.0026	0.00034
High-grade x stubble	0.00159	-0.0015	0.0056	0.00099
High-grade x pasture/fallow	0.00021	-0.0020	0.0028	-0.00025
Stubble x pasture/fallow	-0.00030	-0.0007	0.00003	-0.00002

Confidence intervals are derived using bias-corrected percentile bootstrapping with 1,000 pseudosamples.
‡Small sample bias calculated as the difference between the estimate using the original data and the mean estimate using the pseudosamples (Efron and Gong, 1993).

Table 4: Production function parameter estimates

Parameter	Estimate	95 percent confidence interval		Small sample bias‡
		Lower	Upper	
Marginal cost 2007 (λ^{2007})	6,974.03	5,488.00	8,888.00	-161.37
Marginal cost 2008 (λ^{2008})	5,093.47	4,148.36	5,723.59	-543.38
Stubble value 2007 ($\rho^{2007}_{stubble}$)	17.78	12.67	24.53	-0.30
Stubble value 2008 ($\rho^{2008}_{stubble}$)	11.62	8.00	14.47	-1.13
Pasture/fallow value ($\rho^{2007}_{past/fal}$)	6.92	5.22	11.46	0.64
Pasture/fallow value ($\rho^{2008}_{past/fal}$)	2.96	1.66	3.70	-0.72

Confidence intervals are derived using bias-corrected percentile bootstrapping with 1,000 pseudosamples.
‡Small sample bias calculated as the difference between the estimate using the original data and the mean estimate using the pseudosamples (Efron and Gong, 1993).

Table 5: Regression estimates of structural parameters

	2007	2008	Difference
Value of marketable feed	24,892	11,844	18,486
	(2,515.5)	(1,175.0)	(14,41.7)**
Value of stubble	19,603.3	20,596.4	-933.1
	(1,958.7)	(2,574.3)	(3,220.0)
Value of pasture/fallow	5,740.2	6,913.8	-1,174.5
	(1,020.6)	(1,018.3)	(1,442.2)
Total non-marketable	25,343	27,510	-2,166
	(2826)	(3449.6)	(4,444.8)
Total	50,235.8	39,354.2	10,881.6
	(4441.2)	(4266.1)	(6,164.8)*
Total per TLU	8,151.6	5,132.9	3,018.7
	(434.5)	(254.6)	(508.2)**

Standard deviations in parenthesis. A * denotes the difference between years is significant at the 0.1 level and ** denotes at the 0.05 level.

Table 6. Value of different feeds used across years

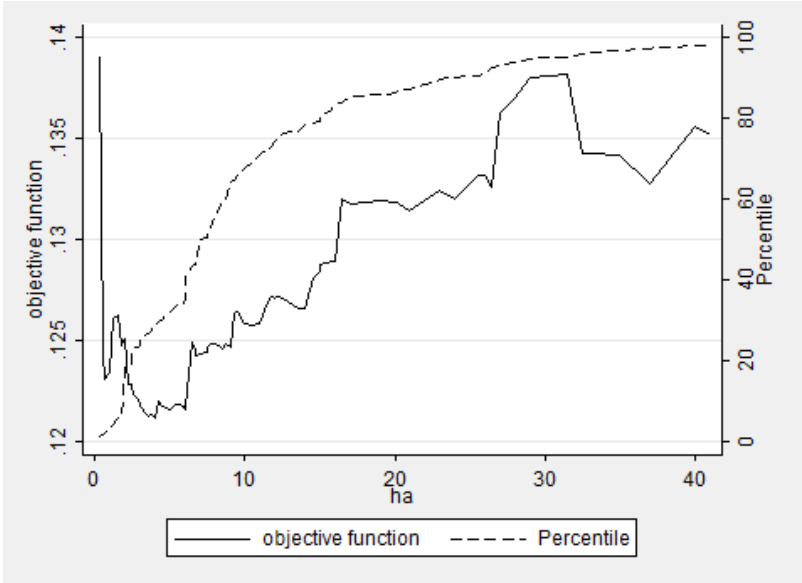

Figure 1: Threshold search over different farm sizes

Parameter	Farm size	Estimate	95 percent confidence interval		Small sample bias‡
			Lower	Upper	
Marginal cost 2007 (λ^{2007})	Small	10,273.54	8,263.77	17,674.46	610.66
	Large	6,219.12	5,218.34	7,943.40	-69.27
Marginal cost 2008 (λ^{2008})	Small	6,232.84	4,909.55	7,549.40	-406.94
	Large	4,476.57	3,713.45	4,934.25	-424.86
Stubble value 2007 ($\rho^{2007}_{stubble}$)	Small	35.24	24.94	82.32	4.03
	Large	16.14	12.42	23.25	0.27
Stubble value 2008 ($\rho^{2008}_{stubble}$)	Small	18.05	12.50	26.44	-0.21
	Large	9.21	6.06	11.53	-0.95
Pasture/fallow value ($\rho^{2007}_{past/fal}$)	Small	7.75	2.80	14.87	0.22
	Large	5.78	4.32	9.09	0.35
Pasture/fallow value ($\rho^{2008}_{past/fal}$)	Small	2.63	-1.26	4.53	-1.23
	Large	2.67	1.28	3.33	-0.55

Confidence intervals are derived using bias-corrected percentile bootstrapping with 1,000 pseudosamples.
‡Small sample bias calculated as the difference between the estimate using the original data and the mean estimate using the pseudosamples (Efron and Gong, 1993).

Table 7: Threshold regression estimates of structural parameters