Lina BJERKE*

Knowledge in agriculture: a micro data assessment of the role of internal and external knowledge in farm productivity in Sweden

This study examines the impact of internal and external knowledge on firm productivity in the Swedish agricultural sector. It combines theories from regional economics about the geographical aspects of knowledge with traditional theories on the role of knowledge in productivity in agriculture. The study is a firm-level analysis using an unbalanced panel between the years 2002 and 2011 in Sweden. The results show that these firms are positively affected by employees with formal education related to the sector. Higher knowledge levels have a greater impact than lower levels. External knowledge, such as localised spillovers, is also important, but the results on this factor are more ambiguous.

Keywords: agriculture, competitiveness, productivity, accessibility

* Jönköping International Business School and the Swedish Board of Agriculture, Box 1026 551 11, Jönköping, Sweden. lina.bjerke@ju.se; http://orcid.org/0000-0002-1221-1054

Introduction

Knowledge is acknowledged as the most valuable resource for creating long-term competitiveness (Caloghirou *et al*., 2004). Although the extent to which low levels of knowledge are responsible for low growth and low innovativeness in the agricultural sector is not yet fully established, the European Commission heavily emphasises investments in 'knowledge generating assets' and considers these to be key drivers of future productivity growth (EC, 2008).

Since the 1970s, farms in Sweden have decreased in number, increased in size and, consequently, have often increased in output. The number of farms decreased by 6 per cent from 2005 to 2010. This is a smaller decrease than in comparable countries, but the number of farms larger than 100 acres has increased dramatically in Sweden, while aggregate production has remained stable (Manevska-Tasevska and Rabinowicz, 2015). The reason for this could be, for example, restrictions in land access, infrastructure, market access and type of labour supply.

While the Swedish agricultural sector is therefore no exception with respect to low growth, information on the factors that separate high- and low-performing firms is, to a large extent, still missing (Latruffe *et al*., 2008). Variations in physical production conditions cannot describe the whole story since differences are found in the same geographical area. This paper aims to identify the role of knowledge within firm control, i.e. *internal knowledge,* and knowledge outside firm control, i.e. *external knowledge*, in farm competitiveness, which is measured as total factor productivity (TFP). It combines the theoretical framework from regional economics on geographical knowledge spillovers with more traditional theories on agricultural productivity. By doing so, this study differentiates the concept of knowledge in agriculture by looking at internal knowledge and the impact of the knowledge milieu, and this is the main contribution of the paper.

All individuals have a number of characteristics, such as formal education, training and experiences that, in sum, is their accumulated human capital (Becker, 1962; Andersson and Beckmann, 2009). Human capital is widely accepted as an important part of productivity. In agriculture, such a positive effect of knowledge has grown over time as it has evolved from a traditional to a technical- and capital-intensive sector. The technical progress and rapid shifts in production techniques now require a type of knowledge that is different from that required 30 years ago. This not only means a higher level of knowledge but also a good ability to absorb new knowledge from external sources. Agglomeration, knowledge spillovers, regional specialisation and regional diversification characterise the regional milieu and can be important for firms' competitiveness. To the author's knowledge, no previous study has evaluated the Swedish agricultural sector from this perspective.

Returns to internal knowledge

Within firms, human capital can be referred to as *internal knowledge*. Human capital gives people the cognitive skills with which to interpret information and adapt to external knowledge, skills which are highly important in times of rapid internationalisation and technical development (Posner, 1961; Vernon, 1966). Human capital affects productivity at all levels of the economy and all types of industries, but 'labour quality' is often more important than magnitude (Griliches, 1957; Blundell *et al*., 1999; Fox and Smeets, 2011). Improved technology creates situations in which low-skilled labour is substituted for high-skilled labour. In the short term, all sectors compete for the same pool of highly skilled labour, and labour is a slowly adjusted factor of production. Thus, all industries need to be attractive alternatives with a sufficiently high rate of return on education. This is a challenge for industries with large fluctuations and low returns on education. The risk may become too high to engage in higher education related to these types of industries.

Agriculture has traditionally been a sector in which experience is more valuable than formal schooling, but technological progress has increased industry returns on schooling substantially (Becker, 1993; Huffman, 2001). Primarily, education becomes more significant when management requires a deeper and wider understanding of technology and business (Huffman, 2001). In the Swedish agricultural sector, approximately 19 per cent of workers have a postgraduate education and 9 per cent have a university degree. These figures are similar to those in the food processing industry but only half of those for all types of manufacturing. Makki *et al*. (1999) show that United States farm operators with higher education positively affect productivity. The effect of education is primarily derived from a higher absorptive capacity and better adaptability to new conditions (e.g. leadership, strategies and market knowledge). One additional year of education increases farm productivity by 30 to 60 per cent. Furtan and Sauer (2008) obtained similar results when they showed that education has a significant effect on value added in the Danish food industry.

External knowledge

The surrounding milieu is an essential part of the picture when explaining a firm's accessible knowledge. In a dynamic economy with competition at the local, regional and global scales, firms must continually obtain new knowledge to stay competitive. However, most firms are small actors in large markets and are unable to manage all parts of renewal and firm development. Thus, firms combine internal knowledge with external knowledge, which creates opportunities for knowledge spillovers.

External knowledge can come from other individuals with related or unrelated knowledge or via specific business services (e.g. consultancies, economists, accountants, lawyers), and is found locally and from distant areas. Some types of knowledge sharing are very sensitive to geographical distance, which is explained in theories on agglomeration and New Economic Geography (Krugman, 1991). Knowledge is more complex than information and involves more friction when it is transferred. Space remains one type of friction that can still hinder very complex knowledge sharing across long distances (Polese and Shearmur, 2004; Boschma, 2005; Andersson and Beckmann, 2009). Being located near a supportive system and a network of potential collaborators facilitates knowledge generation, spread and absorption (Fischer and Fröhlich, 2001).

The rapid technological development and globalisation of agriculture speaks in favour of the more important role played by external knowledge. Despite this, agriculture has received little attention in theories of agglomeration. The presence of place-specific and immobile resources in agriculture is indeed a valid explanation for why it is different from some other industries. Nonetheless, technical advancements and increased dependence on cognitive skills makes it problematic to be located in the periphery, far from where high-end knowledge is created (Gruber and Soci, 2010).

External knowledge can also be obtained from international linkages (Bathelt *et al*., 2004; Shin *et al*., 2006). There is, for example, increasing evidence that firms combine local and global sources in their product renewal and innovation processes (Asheim and Isaksen, 2002; Simmie, 2003; Moodysson *et al*., 2008; Trippl, 2011). Extra-regional and global linkages take many forms, such as trade networks. Exports and imports are important sources of ideas for new products from all over the world, although this is often related to agglomeration (Jacobs, 1969; Bjerke *et al*., 2013).

Firm characteristics and their role in competitiveness

Firm age and firm size are factors that are shown *not* to perform uniformly over the firm life cycle (Jovanovic, 1982). On the one hand, as firms age, they rely on experience and act based on accumulated human capital (Cohen and Levinthal, 1990; Acemoglu *et al*., 2007). An older firm has also had more time to find a solid base on which to rely and thereby also has a lower failure rate. Thus, failure rates are higher earlier in firms' evolution (Jovanovic, 1982; Jovanovic and MacDonald, 1994). On the other hand, age can cause inertia, leading to lower innovativeness and creativity (Huergo and Jaumandreu, 2004).

In terms of firm size, the previous literature does not offer a coherent picture. Dahwan (2001) uses a panel of firms in the United States and shows that heterogeneity exists among industrial firms. Smaller firms have higher profit rates but lower survival probability. They also tend to be more productive, but their actions are also riskier. They encounter larger market uncertainties and capital constraints that force them to generate higher productivity as long as they survive in the market. International trade is also related to firm size: large firms are more likely to export than smaller firms (Mittelstaedt *et al*., 2003).

Related to agriculture, Latruffe *et al*. (2004) show that, irrespective of production type, size matters for efficiency in the Polish agricultural sector. A number of studies on agricultural firm size and firm performance have addressed this topic from a policy perspective, as well as the effect of technological progress and structural change. However, the vast majority of these studies exclude the matter of human capital and how firms are affected by different types of internal knowledge and localised knowledge spillovers.

Methodology

The data are an unbalanced panel of Swedish firms in the agriculture industry between 2002 and 2011 and are provided by Statistics Sweden. The data cover all firms and all employees in Sweden and include information on account data and detailed information on individuals. Individuals and firms can be linked together and located in a specific area, which means that it is possible to control for the surrounding milieu. Data are organised as an unbalanced panel with approximately 248,000 observations.

Total factor productivity (TFP) and estimated model

Productivity is a reliable measure of long-term competitiveness (EC, 2008; Latruffe, 2010). This paper adopts the standard procedure of a two-step TFP. Human capital is excluded in the first step, corresponding to previous studies. Islam (1995) shows that human capital affects TFP but cannot explain output. Similarly, Benhabib and Spiegel (1994) show that human capital does not enter the production function as an input but rather as an explanatory variable for the growth of TFP.

The model is restricted to constant returns to scale due to industry structure and data restrictions. Firstly, data cannot control for firm diversification or the value of arable land.[1] This poses a restriction on how to interpret capital but also on the relationship between labour and capital. Firms in the data are heterogeneous in terms of capital and relatively homogenous in terms of labour. However, the vast majority of firms has only *one* registered person in the firm (usually the owner). Therefore, some small firms are highly capital intensive. The industry shift towards fewer but larger Swedish agricultural firms with low profitability is not fully explained. Increasing return-to-scale economies may apply to the entire industry (or a within-industry group) rather than to individual firms. Sheng *et al*. (2015) use Australian broad acre firm data and find that higher productivity within larger firms is not a result of increasing returns to scale but rather constant or mildly decreasing returns. The larger firms achieve higher productivity through changes in technology rather than scale. Smaller firms tend to improve their productivity through the ability to access and absorb advanced technologies rather than growing in size.

While the sector is growing, it is profitable for it to absorb new technology. This allows increased production and reduced costs for the entire sector, while each firm encounters constant returns to scale and acts as a price taker, i.e. *external economies* of scale (Hallam, 1991). Thus, firms remain small in the global market, and one can use the mindset of a competitive equilibrium.

TFP is the average product of inputs, and the Cobb-Douglas production function with capital and labour as factors of production is as follows:

$$Y = AK^{\alpha}L^{\beta}\text{, where } \alpha + \beta = 1 \text{ for firm } i \tag{1}$$

where Y is the firm output, K is the total stock of physical capital, L is the labour forces measured as the number of workers in the firms. A is subsequently the TFP.

Dividing equation (1) by L gives:

$$y = Ak^{\alpha}L^{\beta}\text{, } where\ \beta = (1-\alpha) \tag{2}$$

where y is the output (value added) per worker and k is the per worker capital. Taking the natural logarithm, equation (3) is obtained:

$$\hat{y} = \ln TFP = \ln y = \ln A + \alpha \ln k + \beta \ln L \tag{3}$$

The elasticity of output with respect to the within-firm physical capital is 0.4 and is strongly significant. With a constant return to scale, the elasticity of the output with respect to labour is 0.6.

Subsequently, $\hat{y}$ determines the effect of internal and external knowledge on total factor productivity, TFP. The estimated model will then be as follows:

$$\ln TFP_{i,t} = a_1 + [Firm_{i,t}]'a_2 + [Internal\ Knowledge_{i,t}]'a_3 + [External\ Knowledge_{i,t}]'a_4 + \varepsilon_{i,t}$$

[1] Data on land are available at the municipal level. This has been controlled for in all estimations with robust results.

where $t = 2002, \ldots \ldots, 2011$. The model consists of three vectors of variables: one related to firm characteristics, one related to internal knowledge and one related to external knowledge variables. The following section gives more detailed descriptions of these variables.

Variables and descriptives

Measuring knowledge in the surrounding milieu has its origin in the knowledge production function proposed by Griliches (1979). Knowledge is partly distance sensitive, which means that knowledge spillovers are affected by distance but also by types and magnitudes and can, in total, be summarised as knowledge accessibility. Weibull (1976) developed a measure of this gravity potential problem, which is further developed and applied by, for example, Johansson and co-workers (Johansson *et al*., 2002, 2003).

Sweden has 290 municipalities, and the accessibility of municipality i to itself and the $n-1$ surrounding municipalities is defined as the sum of the internal accessibility to a given opportunity D and its accessibility to the same opportunity in other municipalities:

$$A_i^D = D_1 f(c_{i1}) + \ldots + D_i f(c_{ii}) + \ldots + D_n f(c_{in}) \tag{4}$$

A_i^D is the sum of the accessibility of municipality i, and D_i is the amount of opportunity for face-to-face contact. $f(c)$ is the distance decay function that determines how the accessibility value is related to the costs of reaching this specific knowledge. An approximation of this is an exponential function, such as:

$$f(c_{ij}) = \exp\{-\lambda t_{ij}\} \tag{5}$$

where λ is a time distance parameter and t_{ij} is the travel time distance between location i and location j. Consequently, total accessibility is a function of the sums of internal and external accessibility, where the potential opportunities are negatively related to distance:

$$A_i^D = \sum D_j \exp\{-\lambda t_{ij}\} \tag{6}$$

The independent variables are described in Table 1, beginning with the variables related to the firm characteristics and internal knowledge. Data contain information on age but only if the firm was established after 1986. To control for age bias, a dummy variable for firms with an establishment year of 1986 is used. Data also allow us to control for firm size in terms of net sales and trade activity and also whether the firm engages in trade (export and/or imports).

Measures of internal knowledge are divided into those of a general character and those directly related to agriculture. To control for human capital accumulated through ways other than education, experience in other unrelated industries and in the agricultural sector are also added.

The third section of Table 1 contains all accessibility variables, i.e. external knowledge. Firstly, these are divided into types of knowledge, such as access to employees with related and unrelated college or university degrees. Variables aiming to capture the effect of larger access to support busi-

Table 1: Variables, their descriptions and motivations.

Variable name	Description
Firm characteristics	
Firm age$_{i,t}$	Age at year *t*
Old$_{i,t}$	1: if registered as established in 1986; 0: otherwise
Firm size$_{i,t}$	Net sales at year *t*
Trade$_{i,t}$	1: if exporter and/or importer; 0: otherwise
Internal knowledge	
GenColleg$_{i,t}$	Share of employees in firm *i* with college degrees (except those with *AgriColleg*)
AgriColleg$_{i,t}$	Share of employees in firm *i* with agricultural college education*
GenHigh$_{i,t}$	Share of employees in firm *i* with ≥3 years of university education (except those with *AgrHigh*)
AgrHigh$_{i,t}$	Share of employees in firm *i* with ≥3 years of university, agricultural-related, education
BAHigh$_{i,t}$	Share of employees in firm *i* with university degrees in business and administration**
ShareAccount$_{i,t}$	Share of employees with main work tasks within accounting and/or marketing
AgriExpert$_{i,t}$	Sum of employee years (last ten years) in agriculture
(*AgriExpert*$_{i,t}$)^2	
GenExpert$_{i,t}$	Sum of employee years (last ten years) in other industries
(*GenExpert*$_{i,t}$)^2	
External knowledge	
TotAccAgriColleg$_{i,t}$	Total accessibility to individuals with college education in agriculture
TotAccHighAgri$_{i,t}$	Total accessibility to individuals with higher education in agriculture
LocalAccAgr$_{i,t}$	Local accessibility to employees with an agricultural education employed in business support firms****
RegAccExpAgr$_{i,t}$	Intra-regional accessibility with an agricultural education employed in business support firms****
ExtAccExpAgr$_{i,t}$	Extra-regional accessibility with an agricultural education employed in business support firms****
TotAccKIBS$_{i,t}$	Total accessibility to KIBS (NACE 72-74)

* Codes 620z-629z according to Sun2000Inr; ** codes 340a-349z according to Sun-2000Inr; *** occupations are classified according to the Swedish standard for occupational classification, SSYK; **** Employees with education within 340a-349z according to Sun2000Inr classification

Source: own composition

nesses also exist. Access to agricultural support is measured as the number of people with formal education in agriculture who work in business support. Access to KIBS is correspondingly all employees in knowledge intensive business services (KIBS).

Figure 1 presents the localisation of employees in Sweden, divided into the 290 existing municipalities. Figure 1a presents each municipality's share of employees with a college degree related to agriculture, and these are relatively well distributed across Sweden. Figure 1b shows the share of employees with higher education (at least three years of university education) within agriculture. These are more clustered in space, as is also the case for all other individuals with higher education (Figure 1c).

The third section of Table 1 presents variables related to external knowledge. Knowledge accessibility is differentiated into local, inter-regional, and extra-regional, as described above (this can also be measured as total accessibility when all three are added together). Owing to the tendency towards knowledge clustering in space irrespective of type, some accessibility variables capture the effect of population density. Knowledge intensive businesses in particular tend to be distance sensitive and are located in dense areas; they could therefore have difficulties reaching more peripheral areas. This also implies that accessibility to KIBS and accessibility to agricultural support have a bivariate correlation of 0.83.[2]

Results

The results are displayed in Tables 2 and 3; the latter focuses on the effect of external knowledge and thoroughly disentangles the accessibility measure.

[2] Bivariate correlations can be provided by the author upon request.

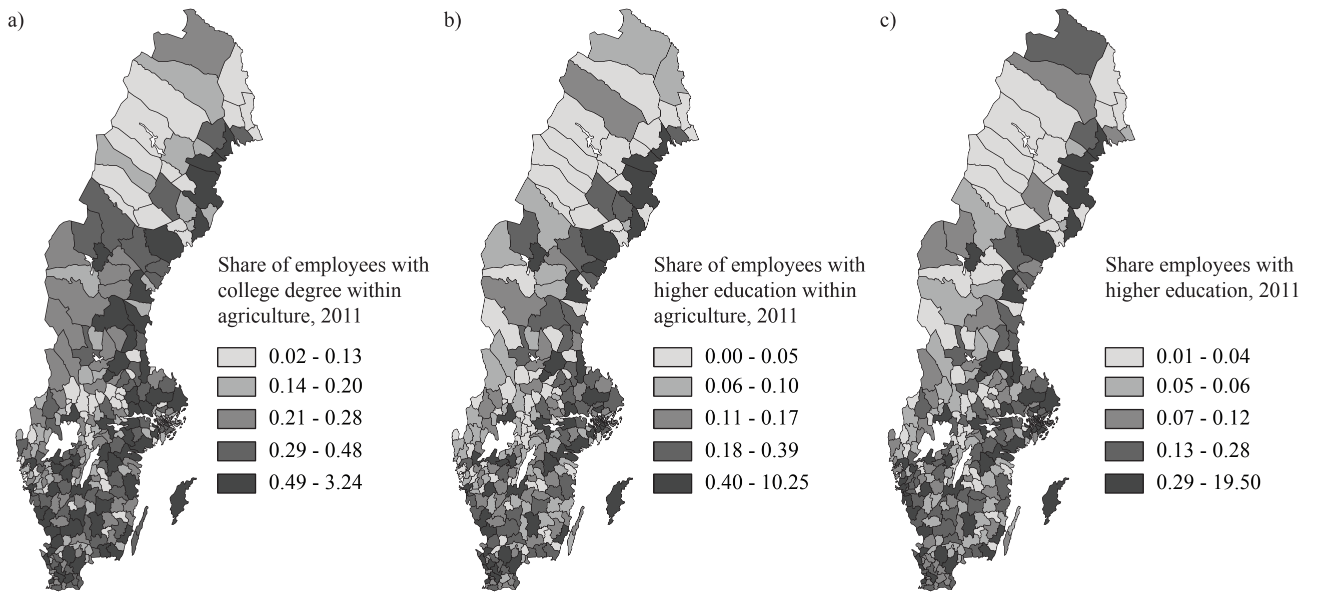

Figure 1: Municipality's share of Sweden's employees with (a) agricultural college degree; (b) agricultural university degree; and (c) all with university degree.

Source: own composition

Table 2: Unbalanced panel regression results, fixed effect.

Variable name	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Firm age$_{i,t}$		0.004*** (0.000)	0.004*** (0.000)	0.004*** (0.000)	0.004*** (0.000)	0.004*** (0.000)
(*Firm age*$_{i,t}$)^2		$-9.17e^{-5}$*** ($1.78e^{-5}$)	$-9.16e^{-5}$*** ($1.78e^{-5}$)	$-9.20e^{-5}$*** ($1.78e^{-5}$)	$-9.17e^{-5}$*** ($1.78e^{-5}$)	$-9.09e^{-5}$*** ($1.78e^{-5}$)
Firm size$_{i,t}$		-0.055*** (0.000)	-0.055*** (0.000)	-0.055*** (0.000)	-0.055*** (0.000)	-0.055*** (0.000)
(*Firm size*$_{i,t}$)^2		$1.15e^{-4}$*** ($2.51e^{-6}$)	$1.15e^{-4}$*** ($2.51e^{-6}$)	$1.15e^{-4}$*** ($2.51e^{-6}$)	$1.15e^{-4}$*** ($2.51e^{-6}$)	$1.15e^{-4}$*** ($2.51e^{-6}$)
Trade$_{i,t}$		0.036*** (0.008)	0.036*** (0.008)	0.036*** (0.008)	0.036*** (0.008)	0.036*** (0.008)
Old$_{i,t}$		-0.013** (0.007)	-0.014** (0.007)	-0.013* (0.007)	-0.013** (0.007)	-0.014** (0.007)
GenColleg$_{i,t}$	-0.022*** (0.005)	-0.013*** (0.005)	-0.013*** (0.005)	-0.013*** (0.005)	-0.013*** (0.005)	-0.013*** (0.005)
AgriColleg$_{i,t}$	0.032*** (0.005)	0.018*** (0.005)	0.018*** (0.005)	0.018*** (0.005)	0.018*** (0.005)	0.018*** (0.005)
GenHigh$_{i,t}$	-0.021* (0.012)	-0.013* (0.012)	-0.013* (0.012)	-0.013* (0.012)	-0.013* (0.012)	-0.012* (0.012)
AgrHigh$_{i,t}$	0.081*** (0.023)	0.060*** (0.023)	0.060*** (0.023)	0.060*** (0.023)	0.060*** (0.023)	0.060*** (0.023)
BAHigh$_{i,t}$	$4.29e^{-4}$ (0.010)					
ShareAccount$_{i,t}$	$9.86e^{-6}$*** ($1.27e^{-6}$)	$5.75e^{-6}$*** ($1.26e^{-6}$)	$6.15e^{-6}$*** ($1.26e^{-6}$)	$5.22e^{-6}$*** ($1.35e^{-6}$)	$5.79e^{-6}$*** ($1.29e^{-6}$)	$7.69e^{-6}$*** ($1.44e^{-6}$)
AgriExpert$_{i,t}$	-0.010*** (0.001)	-0.006*** (0.001)	-0.006*** (0.001)	-0.006*** (0.001)	-0.006*** (0.001)	-0.006*** (0.001)
(*AgriExpert*$_{i,t}$)^2	0.003*** ($9.56e^{-5}$)	0.002*** ($9.65e^{-5}$)	0.002*** ($9.65e^{-5}$)	0.002*** ($9.65e^{-5}$)	0.002*** ($9.65e^{-5}$)	0.002*** ($9.65e^{-5}$)
GenExpert$_{i,t}$	-0.008*** (0.001)	-0.008*** (0.001)	-0.008*** (0.001)	-0.008*** (0.001)	-0.008*** (0.001)	-0.008*** (0.00117)
(*GenExpert*$_{i,t}$)^2	$-7.60e^{-4}$*** ($8.87e^{-5}$)	$-7.74e^{-4}$*** ($8.77e^{-5}$)	$-7.76e^{-4}$*** ($8.77e^{-5}$)	$-7.72e^{-4}$*** ($8.77e^{-5}$)	$-7.74e^{-4}$*** ($8.78e^{-5}$)	$-7.98e^{-4}$*** ($8.82e^{-5}$)
TotAccAgriColleg$_{i,t}$			$-1.17e^{-5}$*** ($4.18e^{-6}$)			
TotAccAgriHigh$_{i,t}$				$4.12e^{-5}$*** ($3.99e^{-5}$)		
TotAccAgrSup$_{i,t}$					$-7.86e^{-5}$*** ($5.25e^{-5}$)	
TotAccKIBS$_{i,t}$						$-5.13e^{-6}$*** ($1.84e^{-6}$)
N	248,148	248,148	248,148	248,148	248,148	248,148
R^2 within	0.08	0.08	0.08	0.08	0.08	0.08
R^2 between	0.02	0.02	0.02	0.02	0.02	0.02
R^2 overall	0.01	0.01	0.01	0.01	0.01	0.02

Source: own calculations

Internal knowledge

Model 1 focuses on internal knowledge. A larger share of employees with 'non-related' college degrees has a negative effect on productivity. A larger share of employees with agricultural-related college degrees affects productivity positively. These two types of employees may have a crowding-out effect on each other if they are substitutes, but they may also be two complementary labour inputs. The bivariate correlation between these two is negative but small (-0.3), indicating that they are substitutes for each other, but not with a predominant crowding-out effect.

Higher education variables show similar effects in which 'related' education positively affects productivity. The size of this is slightly larger than that of agricultural college degree. The effect of formal education within business and administration has no significant effect in this model and is excluded in the subsequent analysis. Having a larger share of employees within marketing and/or accounting has a positive effect, and this is robust with only minor variations.

The average years of experience per employee are initially negative when the experience is within other agricultural firms, but the effect changes direction relatively quickly (after one and a half years). Thus, related experience can be considered as positive for productivity, although it should be emphasised that this, to some extent, also captures the age of the employees. However, the effect of experience does not behave the same when measured as average years employed *outside* the sector. In this case, the effect on productivity is continuously negative. As for education, these two types of employees can affect each other negatively with a slight crowding-out effect. They are tested separately but are robust.

What clearly emerges from Table 2 is that knowledge acquired from formal education is closely related to agriculture and is important for productivity. Moreover, higher education appears to have a slightly larger effect than hiring more employees with 'only' an agricultural college degree. It is also important to emphasise that employees with college degrees are more evenly distributed geographically, and higher knowledge is more clustered in space. This is true for all types of higher knowledge, and one can possibly therefore assume that the marginal effect of higher knowledge varies in space.

Firm characteristics

Firm age and size are robust across all models. Firm age is positive, but the squared version is negative with the interpretation that productivity increases as the firm ages. This effect becomes negative when the firm has existed for slightly more than 20 years. This result is strengthened by the dummy controlling for the older firms, which is negative across all models. Firm size is, on the other hand, initially negative and thereafter positive. It is plausible to assume an effect of the appearance of the product life cycle in which the firms need to become a certain size to dedicate resources to *increase* productivity. Whether an agricultural firm engages in trade is highly robust and positive across all models.

One part of external knowledge is international trade, and the results show that firms that engage in trade have higher productivity. Trade offers a channel of knowledge and facilitates awareness of, for example, international production techniques, processes, services and logistic solutions. The effect of trade should not be neglected; even though further research is needed with regard to agriculture. This sector is exposed to greater competition from abroad, which increases the pressure to increase productivity through innovation and renewal. This is a way to maintain a present market position or even attain a new position in the market.

External knowledge

Firms have few possibilities for influencing external knowledge except changing location, which per se is impossible for production that is based on immobile resources. Given the potential for the endogeneity of these external knowledge variables, the findings should be interpreted with care even though the fixed effect should remedy the issue substantially.

Table 1 presents the external knowledge variables as the

Table 3: Unbalanced panel regression results controlling for external knowledge, fixed effect.

Variable name	Model 7	Model 8	Model 9	Model 10	Model 11
Controlling for firm variables as in Table 2, model 2. Results are robust.					
$LocAccAgriColleg_{i,t}$	$1.23e^{-5}$***				
	($8.71e^{-6}$)				
$RegAccAgriColleg_{i,t}$	$-2.12e^{-5}$***				
	($4.54e^{-6}$)				
$ExtAccAgriColleg_{i,t}$	$1.18e^{-4}$**				
	($1.94e^{-5}$)				
$LocAccAgriHigh_{i,t}$		$-2.87e^{-4}$***			
		($5.24e^{-5}$)			
$RegAccAgriHigh_{i,t}$		$4.68e^{-5}$***			
		($5.60e^{-5}$)			
$ExtAccAgriHigh_{i,t}$		0.006***			
		(0.003)			
$LocAccGenHigh_{i,t}$			$-2.84e^{-6}$***		
			($4.06e^{-7}$)		
$RegAccGenHigh_{i,t}$			$5.51e^{-7}$***		
			($3.48e^{-7}$)		
$ExtAccGenHigh_{i,t}$			$1.91e^{-5}$***		
			($2.28e^{-6}$)		
$LocAccAgrSup_{i,t}$				-0.002***	
				(0.001)	
$RegAccAgrSup_{i,t}$				0.002*	
				(0.001)	
$ExtAccAgrSup_{i,t}$				0.017***	
				(0.004)	
$LocAccKIBS_{i,t}$					$-2.16e^{-5}$***
					($3.20e^{-6}$)
$RegAccKIBS_{i,t}$					$2.12e^{-7}$***
					($2.51e^{-6}$)
$ExtAccKIBS_{i,t}$					$1.27e^{-4}$***
					($1.57e^{-5}$)
N	248,148	248,148	248,148	248,148	248,148
R^2 within	0.09	0.09	0.08	0.08	0.08
R^2 between	0.02	0.02	0.02	0.02	0.02
R^2 overall	0.02	0.02	0.01	0.02	0.02

Source: own calculations

sums of all three levels of accessibility. Accessibility presented in this way can also describe other characteristics of a region (Figure 1). Models 3 and 4 control for total accessibility to employees with agricultural college degrees and agricultural university degrees. Access to employees with college degrees has a negative effect on productivity, while greater access to university agricultural knowledge is positive. Models 5 and 6 control for total accessibility to agricultural support businesses and knowledge-intensive business support services. As expected, these two have the same sign, which indicates that both cluster in space in a similar way. A dense location may be favourable, regardless of the location of clients, which often has the effect that headquarters tend to be located in larger cities. However, employees are assessed at their workplaces, which implies that the risk of underestimating employees 'out in the country' diminishes substantially.

External knowledge is further explored in Table 3. Models 7 to 11 control for accessibility in more detail, i.e. local, intra-regional and extra-regional accessibility.

Model 7 controls for the accessibility of employees with college degrees related to agriculture. In Table 2, this was negative when aggregated as total accessibility. In model 7, local accessibility is significantly positive for firm productivity. Intra-regional accessibility is, on the other hand, negative, while extra-regional access is positive. Again, one has to consider that these firms are highly dependent on place-specific resources, and this may be captured in these separated versions of accessibility. Being located close to a large pool of employees with agricultural college degrees is possibly also an effect of being located in a prosperous milieu for production. However, a local milieu with high access to employees with higher agricultural education is not prosperous, probably because that type of knowledge tends to cluster in places other than rural areas.

Model 8 isolates the effects of local, intra-regional and extra-regional access to higher agricultural knowledge. Total accessibility in Table 2 was positive, but the local accessibility is now negative. However, the intra- and extra-regional access is positive, which again may show location advantages. Being too distant from knowledge is disadvantageous, but being too close means not being near rural prosperous land. The similarity between the location of greater agricultural knowledge and the location of knowledge in general is further accentuated by model 9.

The remaining two models in Table 3 measure accessibility to agricultural business support and other knowledge-intensive business support services. In terms of the direction of effects, they turn out similarly with a negative local effect and positive regional effects. The effect of accessibility to agricultural business support is substantially greater than the effect of KIBS access.

All models have relatively low R^2 values. This is of minor concern in this analysis. Firstly, this is a study on human capital and its effect on productivity, not a study on the type of variables that affect TFP in total. A low R^2 does not mean that the effect is 0. Secondly, this is a panel data estimation with R^2 values, which should not be compared to those of time series. Thirdly, the analysis is a study of a population and not a sample.

Discussion

This study analyses the performance of Swedish agricultural firms between 2002 and 2011. The goal is to determine how different types of internal and external knowledge, conditional on firm characteristics, affect productivity. The way in which this study applies theories on return on education, knowledge agglomeration and knowledge spillovers is a somewhat novel perspective in agricultural economics. However, this approach is highly relevant in times in which agricultural labour is being substituted by capital, human capital and technology.

The paper primarily investigates the effect of formal education, both related and unrelated to agriculture, at the college level and at the university level. The analysis of internal knowledge is accompanied by variables on external knowledge, which represent knowledge accessibility. From the previous literature, one would expect that formal education has a positive effect on firm performance. The expected effect of external knowledge is not as straightforward to estimate in advance. Other producing industries can take advantage of co-locating with other firms that are more or less related. The case of agriculture is more difficult to predict since the industry is highly dependent on place-specific and immobile resources. However, at a time when technology and knowledge have become a principal part of agriculture and its competitiveness, knowledge in the surrounding milieu has become even more interesting to study.

The econometric analysis finds that formal education has a positive effect on productivity as long as the education is related to agriculture. Agricultural college and university education are both positive, but the latter has a slightly larger effect than the former. It appears to be profitable to hire an employee with higher formal education, even though the relatedness to agriculture is the most important factor. Although a larger share of other formal education has a negative effect, this should not be interpreted as the answer to how to balance the two types of employees within a firm. This should be further explored in future research.

The conclusion from this is that knowledge matters for the Swedish agricultural sector, just as it does for other sectors. Formal education is important and has a higher value added if it is related to the sector itself. This supports having well-established and high-quality structured educational programmes for the agricultural sector. However, this does not mean that other competences are insignificant, as shown in the positive effect of having high levels of access to business support, i.e. external knowledge.

External knowledge appears to be important, with the caveat that some locational advantages are difficult to separate from an otherwise prosperous knowledge milieu. Nevertheless, accessible knowledge is also advantageous for agriculture. Agriculture is an industry that is characterised by a well-established support system (agricultural consulting) in Sweden. The results show that access to these types of services matter, but it is again difficult to distinguish this effect from that of knowledge agglomeration and the tendency for knowledge intensive business services to be located in relatively dense urban areas. This type of 'urbanisation', in which knowledge is located far from its 'end consumer', is an important policy message itself: knowledge demand fails to match knowledge supply. This is particularly true for agriculture, which has a predominantly rural location with immobile production. It is a dilemma if knowledge tends to cluster in dense areas while the agricultural industry has an increasing demand for this specific high-end knowledge. The inability to relocate affects industry attractiveness and competitiveness.

References

Acemoglu, D., Aghion, P., Lelarge, C., Van Reenen, J. and Zilibotti, F. (2007): Technology, Information and the Decentralization of the Firm. The Quarterly Journal of Economics **122** (4), 1759-1799. http://dx.doi.org/10.1162/qjec.2007.122.4.1759

Andersson, Å.E. and Beckmann, M.J. (2009): Economics of Knowledge: Theory, Models and Measurements. Cheltenham: Edward Elgar.

Asheim, B.T. and Isaksen, A. (2002): Regional Innovation Systems: The Integration of Local 'Sticky' and Global 'Ubiquitous' Knowledge. The Journal of Technology Transfer **27** (1), 77-86. http://dx.doi.org/10.1023/A:1013100704794

Bathelt, H., Malmberg, A. and Maskell, P. (2004): Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. Progress in Human Geography **28** (1), 31-56. http://dx.doi.org/10.1191/0309132504ph469oa

Becker, G.S. (1962): Investment in Human Capital: A Theoretical Analysis. The Journal of Political Economy **70** (5), 9-49. http://dx.doi.org/10.1086/258724

Becker, G.S. (1993): Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education (3rd edition). Chicago IL: University of Chicago Press. http://dx.doi.org/10.7208/chicago/9780226041223.001.0001

Benhabib, J. and Spiegel, M.M. (1994): The role of human capital in economic development evidence from aggregate cross-country data. Journal of Monetary Economics **34** (2), 143-173. http://dx.doi.org/10.1016/0304-3932(94)90047-7

Bjerke, L., Karlsson, C. and Andersson, M. (2013): Import flows: extraregional linkages stimulating renewal of regional sectors? Environment and Planning A **45** (12), 2999-3017. http://dx.doi.org/10.1068/a45732

Blundell, R., Dearden, L., Meghir, C. and Sianesi, B. (1999): Human Capital Investment: The Returns from Education and Training to the Individual, the Firm and the Economy. Fiscal Studies **20** (1), 1-23. http://dx.doi.org/10.1111/j.1475-5890.1999.tb00001.x

Boschma, R. (2005): Proximity and Innovation: A Critical Assessment. Regional Studies **39** (1), 61-74. http://dx.doi.org/10.1080/0034340052000320887

Caloghirou, Y., Kastelli, I. and Tsakanikas, A. (2004): Internal capabilities and external knowledge sources: complements or substitutes for innovative performance? Technovation **24** (1), 29-39. http://dx.doi.org/10.1016/S0166-4972(02)00051-2

Cohen, W.M. and Levinthal, D.A. (1990): Absorptive Capacity: A New Perspective on Learning and Innovation. Administrative Science Quarterly **35** (1), 128-152. http://dx.doi.org/10.2307/2393553

Dhawan, R. (2001): Firm size and productivity differential: theory and evidence from a panel of US firms. Journal of Economic Behavior and Organization **44** (3), 269-293. http://dx.doi.org/10.1016/S0167-2681(00)00139-6

EC (2008): European Competitiveness Report 2008. Brussel: European Commission.

Fischer, M.M. and Fröhlich, J.E. (2001): Knowledge, Complexity and Innovation Systems. Berlin-Heidelberg-New York: Springer-Verlag. http://dx.doi.org/10.1007/978-3-662-04546-6

Fox, J.T. and Smeets, V. (2011): Does input quality drive measured differences in firm productivity? International Economic Review **52** (4), 961-989. http://dx.doi.org/10.1111/j.1468-2354.2011.00656.x

Furtan, W.H. and Sauer, J. (2008): Determinants of Food Industry Performance: Survey Data and Regressions for Denmark. Journal of Agricultural Economics **59** (3), 555-573. http://dx.doi.org/10.1111/j.1477-9552.2008.00164.x

Griliches, Z. (1957): Specification Bias in Estimates of Production Functions. Journal of Farm Economics **39** (1), 8-20. http://dx.doi.org/10.2307/1233881

Griliches, Z. (1979): Issues in Assessing the Contribution of Research and Development to Productivity Growth. The Bell Journal of Economics **10** (1), 92-116. http://dx.doi.org/10.2307/3003321

Gruber, S. and Soci, A. (2010): Agglomeration, Agriculture, and the Perspective of the Periphery. Spatial Economic Analysis **5** (1), 43-72. http://dx.doi.org/10.1080/17421770903511353

Hallam, A. (1991): Economies of Size and Scale in Agriculture: An Interpretive Review of Empirical Measurement. Review of Agricultural Economics **13** (1), 155-172. http://dx.doi.org/10.2307/1349565

Huergo, E. and Jaumandreu, J. (2004): How Does Probability of Innovation Change with Firm Age? Small Business Economics **22** (3), 193-207. http://dx.doi.org/10.1023/B:SBEJ.0000022220.07366.b5

Huffman, W.E. (2001): Human capital: Education and agriculture, in L.G. Bruce and C.R. Gordon (eds), Handbook of Agricultural Economics **1** (A), 333-381. Amsterdam: Elsevier.

Islam, N. (1995): Growth Empirics: A Panel Data Approach. The Quarterly Journal of Economics **110** (4), 1127-1170. http://dx.doi.org/10.2307/2946651

Jacobs, J. (1969): The Economy of Cities. New York NY: Random House.

Johansson, B., Klaesson, J. and Olsson, M. (2002): Time distances and labor market integration. Papers in Regional Science **81** (3), 305-327. http://dx.doi.org/10.1007/s101100200000

Johansson, B., Klaesson, J. and Olsson, M. (2003): Commuters' non-linear response to time distances. Journal of Geographical Systems **5** (3), 315-329. http://dx.doi.org/10.1007/s10109-003-0111-2

Jovanovic, B. (1982): Selection and the Evolution of Industry. Econometrica **50** (3), 649-670. http://dx.doi.org/10.2307/1912606

Jovanovic, B. and MacDonald, G.M. (1994): The Life Cycle of a Competitive Industry. The Journal of Political Economy **102** (2), 322-347. http://dx.doi.org/10.1086/261934

Krugman, P. (1991): Increasing Returns and Economic Geography. The Journal of Political Economy **99** (3), 483-499. http://dx.doi.org/10.1086/261763

Latruffe, L. (2010): Competitiveness, Productivity and Efficiency in the Agricultural Sector and Agrifood Sectors OECD Food, Agriculture and Fisheries Papers No.30. Paris: OECD publishing. http://dx.doi.org/10.1787/5km91nkdt6d6-en

Latruffe, L., Balcombe, K., Davidova, S. and Zawalinska, K. (2004): Determinants of technical efficiency of crop and livestock farms in Poland. Applied Economics **36** (12), 1255-1263. http://dx.doi.org/10.1080/0003684042000176793

Latruffe, L., Davidova, S. and Balcombe, K. (2008): Productivity change in Polish agriculture: an illustration of a bootstrapping procedure applied to Malmquist indices. Post-Communist Economies **20** (4), 449-460. http://dx.doi.org/10.1080/14631370802444708

Makki, S., Tweeten, L. and Thraen, C. (1999): Investing in Research and Education versus Commodity Programs: Implications for Agricultural Productivity. Journal of Productivity Analysis **12**

(1), 77-94. http://dx.doi.org/10.1023/A:1007855224376

Manevska-Tasevska, G., and Rabinowicz, E. (2015): Strukturomvandlingen och effektivitet i det svenska jordbruket [The structural change and efficiency in Swedish agriculture]. Lund: Agri-Food Economics Centre.

Mittelstaedt, J.D., Harben, G.N. and William, W.A. (2003): How Big is Big Enough? Firm Size as a Barrier to Exporting in South Carolina's Manufacturing Sector. Journal of Small Business Management **41** (1), 68-84. http://dx.doi.org/10.1111/1540-627X.00067

Moodysson, J., Coenen, L. and Asheim, B.T. (2008): Explaining spatial patterns of innovation: analytical and synthetic modes of knowledge creation in the Medicon Valley life-science cluster. Environment and Planning A **40** (5), 1040-1056. http://dx.doi.org/10.1068/a39110

Polese, M. and Shearmur, R. (2004): Is Distance Really Dead? Comparing Industrial Location Patterns over Time in Canada. International Regional Science Review **27** (4), 431-457. http://dx.doi.org/10.1177/0160017604267637

Posner, M.V. (1961): International Trade and Technical Change. Oxford Economic Papers **13** (3), 323-341.

Sheng, Y., Zhao, S., Nossal, K. and Zhang, D. (2015): Productivity and farm size in Australian agriculture: reinvestigating the returns to scale. Australian Journal of Agricultural and Resource Economics **59** (1), 16-38. http://dx.doi.org/10.1111/1467-8489.12063

Shin, M.E., Agnew, J., Breau, S. and Richardson, P. (2006): Place and the Geography of Italian Export Performance. European Urban and Regional Studies **13** (3), 195-208. http://dx.doi.org/10.1177/0969776406065430

Simmie, J. (2003): Innovation and Urban Regions as National and International Nodes for the Transfer and Sharing of Knowledge. Regional Studies **37** (6), 607-620. http://dx.doi.org/10.1080/0034340032000108714

Trippl, M. (2011): Regional Innovation Systems and Knowledge-Sourcing Activities in Traditional Industries – Evidence from the Vienna Food Sector. Environment and Planning A **43** (7), 1599-1616. http://dx.doi.org/10.1068/a4416

Vernon, R. (1966): International Investment and International Trade in the Product Cycle. Quarterly Journal of Economics **80** (2), 190-207. http://dx.doi.org/10.2307/1880689

Weibull, J.W. (1976): An axiomatic approach to the measurement of accessibility. Regional Science and Urban Economics **6** (4), 357-379. http://dx.doi.org/10.1016/0166-0462(76)90031-4