Economics
Discussion Paper Series
EDP-1215

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September 2012

Economics
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ENVIRONMENTAL REGULATION AND LOCATION OF INDUSTRIALISED AGRICULTURAL PRODUCTION IN EUROPE

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Abstract

This paper analyses empirically the extent to which environmental regulation is an influence on the location of production in the pig industry. The analysis is based on a general empirical location model that captures the interaction between region and sector characteristics in determining the location of production. The empirical model is applied to data on pig production in 43 EU regions (NUTS-1) of six major pig producing European countries over the period 2003 - 2007. The results suggest that while environmental regulation may not have a measurable effect on the location of the pig industry *per se*, it is indeed a strong influence on the sectoral composition of the industry. Relatively highly polluting sectors of the pig industry are attracted to relatively lax jurisdictions which become pollution havens (hot spots of hog waste). Furthermore the increased regional specialisation in the pig industry – driven by differential environmental standards – would be accompanied by increased inter-regional transportation which has an environmental impact of a different kind. These conclusions have important implications for the further harmonisation of environmental regulation related to animal agriculture in the European Union.

Keywords: pollution haven hypothesis; comparative advantage; environmental regulation; industry location; livestock industry.

JEL codes: Q53, Q58, R58.

Acknowledgement

Financial support from the Leverhulme Trust under grant RF-2011-550 is gratefully acknowledged. We also kindly acknowledge the input, data and conceptual support from Robert Hoste (LEI-DLO, The Hague), The Netherlands. We wish to thank Ludwig Lauwers, Alfons Weersink, Tom Vukina, and participants of the 2nd Agrimba Conference in Wageningen, The Netherlands and of the 19th Meeting of the European Association of Environmental and Resource Economists in Prague, the Czech Republic for very helpful comments. The usual disclaimer applies.

Given the growing recognition of the livestock industry's considerable role as a source of water and air pollution, policymakers around the world have introduced a range of environmental regulations. In the United States individual states have adopted a variety of differing regulator measures such as manure disposal procedures and zoning (Metcalfe 2000). In Europe too, despite the common European-level framework for environmental protection measures related to the livestock sector, each country has introduced its own set of policies to deal with livestock externalities (Oenema 2004).

To what extent do such environmental regulations influence the location of production of the livestock industry? The general question of the link between environmental standards and the location of production is a hotly debated issue addressed in what has come to be known as the Pollution Haven Hypothesis (PHH) literature. The PHH purports that a reduction in trade barriers results in a relocation of dirty goods production from jurisdictions with stringent environmental regulation to those with lax environmental regulation creating geographic hot spots with relatively high concentrations of polluters (Levinson and Taylor 2008). Therefore, if true, the PHH has an important policy implication of a potential trade-off between environmental quality and reduced economic activity. From an academic point view also, the PHH is nontrivial because the location of economic activity is determined by several push and pull factors and it is not obvious if environmental policy turns out to be a dominant force (Copeland and Taylor 2004; Taylor 2004).

To date the PHH empirical literature has largely focused on manufacturing whilst neglecting industrialised animal agriculture, a major polluting sector. In many regions around the world, industrialised livestock systems are becoming the standard in meat production. Particularly the swine and poultry industries experienced changing market structures and rapid growth in the 1980s and 1990s. The distancing of animal husbandry from feed-crops has led to a system where there is no longer a direct coupling to a local land base through a feed-crop-manure system (Innes 2000; Naylor *et al*. 2005). Feed is sourced through international markets and production has become clustered in areas where input costs are relatively low and access to international markets are well developed. In combination with the large-scale units favoured by the new supply chains, this has led to vast amounts of animal waste that cannot be processed by the local resource base.

The little empirical research on PHH related to the livestock sector has largely been confined to North America, mainly the US. The typical methodology used in the literature (Metcalfe 2001; Roe *et al*. 2002; Isik 2004; Herath *et al*. 2005; Weersink and Eveland 2006) is some form of location or supply model where one of the explanatory variables is environmental regulation. Sneeringer (2009) uses differences-in-differences and spline models which, the author argues, circumvent the omitted variables and endogeneity caveats in the previous literature. Finally, Sneeringer and Key (2011) employ a regression discontinuity framework to explicitly test for the impact of size-based regulation on regulation avoidance behaviour of firms. To the best of our knowledge, there are only two economic/econometric studies that have investigated the issue of location choice of industrialised animal agriculture in Europe. Larue *et al.* (2011) examine the forces of agglomeration and dispersion in the pig industry using municipal level data in Denmark. Gaigné *et al*. (2012) present a similar study of French *cantons* (US equivalent of counties) investigating whether land limitations driven by regulations on manure application are any influence on the location of hog production and agglomeration economies. The results from these studies are generally mixed (Table 1 presents a summary of the existing literature).

One potential problem with prior studies on animal agriculture is failure to recognise the high level of specialisation that has developed in these production systems. Particularly in the pig industry, producers specialise in specific stages of the animal's lifecycle which has led to sub-sectors. Actually, Roe *et al*.'s (2002, p. 275) observation that "farrowing operations are more labour intensive and, given a fixed resource base, a county with a high percent of sows may be able to sustain fewer total hogs" suggests the trend in specialisation according to factor requirements. Thus weak or no evidence may be a repercussion of pooling sub-sectors that are in fact heterogeneous (*cf.* Jeppersen *et al*. 2002).

< Table 1 about here>

This paper aims to contribute to this fledgling literature on the PHH related to animal production by using a framework that explicitly acknowledges the prevailing specialised operations within the hog industry. The framework employed here also distinguishes this paper from the received literature on the PHH in the context of animal agriculture in another important respect. Stringency of environmental regulation is modelled as one of several motives for location choices. The framework weighs the relative strength of the different motives by analysing the joint role of region and sector characteristics in determining the location of production.

Animal production is highly concentrated in several parts of Europe. Pig production is the main animal production activity in these areas and has become a highly politicised issue. The reason is that on the one hand, regions with high concentration of pig farming are subject to environment damage and consequently further expansion of production is restricted. On the other hand, there are regions with very low level of pig production and growing demand where expansion is appreciated. A similar political trade-off between rural economic development and environmental quality is observed for industrialised pig production in the U.S. (Lawley and Furtan 2008).

With an inventory of 153 million pigs on farms, the EU-25 ranks second in number of pigs in the world, after China (482 million) and ahead of the United States (60 million) (EUROSTAT; FAO Global Livestock Statistics, figures for 2003). From the early 1990s onwards, EU environmental policies have started to overrule national measures. But because of the EU's subsidiary principle, implementation of EU Directives is not the task of the EU; rather this is done at the national, regional or local level. In addition, countries are on different trajectories because of the significant enlargement[1] of the EU over time. Consequently there are large differences in implementation and in the stringency of environmental regulation related to animal agriculture within the EU (see, for e.g., Oenema 2004). Producers may respond to existing or impending regulation by exiting the industry or by changing the location of production. By moving (part of) production to a different EU region a producer might mitigate or bypass the cost of domestic regulations, but adding new capacity at the same site might enable economies of scale and improvements in technical performance that offset additional costs of compliance.

Against this background of differences in stringency of regulation and interest in how regulations affect (the location of) production and the associated pollution, this paper tests the PPH as an explanation for the significant differences in production shares in European pig production. In our empirical model we distinguish between the different subsectors within pig production to reflect the specialization in the stages of the production cycle. The results suggest that while environmental regulation may not have a measurable effect on the location of the pig industry *per se*, it is indeed a strong influence on the sectoral composition of the industry. Relatively lax environmental standards attract relatively highly polluting sectors of the pig industry.

The remainder of the paper is organised as follows. The next section provides a description of pig stock in Europe and regional specialisation. In the third section we present a descriptive material on the geographic distribution of the pig industry in the EU. The fourth section describes the main data used in the econometric analysis. The fifth section presents and discusses the results of our econometric estimation. The final section concludes the paper and elaborates on the implications of our findings for policy and for further research on the PHH in the context of commercialised agriculture.

[1] The European Union began with France, West Germany, Italy and the three Benelux states: Belgium, Luxembourg and the Netherlands in 1951. Since then, the EU's membership has grown to twenty-seven with the recent enlargement from EU-15 to EU-25 in 2004 (Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia) and EU-27 (Bulgaria and Romania).

Pig stocks and geographic distributions in the EU

Pig husbandry has evolved towards specialized units that focus on parts of the animal's lifecycle: sows (piglets), weaned pigs and pigs for fattening. Specialised farrowing-nursery farms and finishing (growing pigs or 'hogs') operations are far more common in the EU than operations that cover the complete lifecycle.[2] The pigs are transported from the farrowing-nursery units to the finishing units. Geographic specialization in the stages of the production cycle discussed above has led to substantial international movement of animals in addition to movements within individual countries. The distinction by animal categories has environmental implication. For a standard pig[3] the growing (fattening) period has by far the major contribution to N-excretion (about 65 %) as compared to piglets and weaners.

< Table 2 about here>

The largest pig producers among the EU-15 are Germany, Spain, The Netherlands, France and Denmark (see Table 2). Of the new members, Poland has by far the largest population of pigs. In most countries, pigs for fattening account for the largest category among total pig stocks as would be expected given the animal's lifecycle.[4] The two producing countries that do not follow this pattern are Denmark and the Netherlands where the largest category in 2002 was piglets (Table 2). Dutch and Danish feeder pigs are to a large extent exported to be finished abroad and this involves long-distance live animal transport.[5] Similarly at NUTS1 regional level there is a clear difference in the composition of the pig inventory in the various regions (see Table 3). It has been suggested that the driving forces of this development which started in the 1990s are higher prices of pigs abroad, higher production cost in the countries of destination and higher environmental compliance costs (Larue *et al*. 2011).

< Table 3 about here>

Our econometric analysis in the next section aims at investigating these suggested driving forces but before that let us evaluate the extent of the claimed specialisation in the pig sector using data on the 42 NUTS1 regions of the six largest pig producers in the EU. We consider standard measures of specialisation and concentration and their changes over time. How specialised is a certain region? Consider the Krugman's specialisation index (Krugman 1991):

$$R_i(t) = \sum_k \left| E_i^k(t) - E_i^{-k}(t) \right|, \qquad R_i \in [0, 2] \tag{1}$$

where E_i^k is the share of category k in the total pig inventory of region i and E_i^{-k} is the share of the same category in the pig inventory of all other regions. The absolute value of the difference between these shares gives us a measure of the difference between the pig structure of region i and all other regions. If the index has a value of two then the region is completely specialised, i.e. has no industries in common with the rest, while if it is zero the region is completely similar to the rest of regions.[6] As shown in Table

2 In the US, highly specialised systems make a further distinction in three separate stages in swine production: farrows-to-wean farms that sell 10-15 pound weaned pigs; wean-to-feeder farms that buy the weaned pigs and sell them as 40-60 pound feeder pigs; and feeder-to-finish farms that finish the feeder pigs to about 260 pounds. This three stage specialisation is less common in Europe.

3 The definition of a standard pig and the pig categories by weight range and age as in Table 2 is common in EU countries (Dourmad *et al*., 1999).

4 From Table 2 it follows that a pig lives about 195 days of which 48 days (25%) as piglet, 53 days (27%) as a weaner and 94 days (48%) as a growing pig (hog).

5 In 2005, 90% of the Danish feeder pigs were exported to Germany and the rest to Italy and Poland. The Netherlands had a more varied export portfolio in 2005: 51% to Germany (2.053.000); Spain (602.000); Italy (230.0000), Belgium/Luxemburg (237.000); Poland (171.000) and Hungary (151.000 pigs) (de Winter, 2008).

6 An alternative specialisation index would be a bi-regional one where each region is compared with each of the rest.

4 the average index has shown a modest change over time: from 0.304 in 2000 to about 0.354 in 2008. The extent of specialisation indicated by these indices of, respectively 15% and 18% are comparable with that of the manufacturing sector in EU of about 17% in 1970s and 19% in the 1990s.[7] There is however quite a variation in the specialization indices across regions and for individual regions over time. The highest indices (above 0.4 in 2008) are those for DEC-Saarland, DE7-Hessen, DE9-Niedersachsen, DEA-Nordrhein-Westfalen, DEF-Schleswig-Holstein, ES4-Centro, ES6-Sur, FR1-Île de France and NL2-Oost Nederland. Some have shown quite a lot of change over time. FR7-Centre-Est, FR1-Île de France, DED-Sachsen and the four Dutch regions (Noord-Nederland, Oost- Nederland, West-Nederland, and Zuid-Nederland) saw their indices rise between 2000 and 2008 by over 40%; whereas ES5-Este and DEG-Thüringen have become less specialized, a decline of the index by 10% and 17%, respectively.

< Table 4 about here>

How concentrated or localised is an industry as a whole or a particular sector? The starting point here is the location coefficient: the share of region *i* in the total inventory of animal category *k* at time *t* that is $s_{i,k}$ defined as:

$$s_{ik}(t) = z_{i,k}(t) \Big/ \sum_{i'} z_{i',k}(t) \tag{2}$$

where $z_{i,k}$ measures the size of category *k* in region *i*, and the region label with prime (*i'*) is used to sum over all regions. We can then construct a simple index of localisation (Overman *et al.* 2003):

$$L_k(t) = \sum_{i'} \left| s_{ik}(t) - area_i \right|, \qquad L_k \in [0, 2] \tag{3}$$

where 'area' represents a region's area as a share of total land area. The rationale for including 'area' here is to control for size. This index has a maximum of two in the case of complete localisation of a category in one region and a minimum of zero in the case of complete similarity, i.e. a category is completely dispersed across regions. The concentration index and the specialisation index are complementary because while the former provides data on the pattern of each category the latter tells us the pattern of regions' structure of the pig industry. As regions become specialised you would expect at least some of the sectors to become concentrated. Table 5 shows that there is considerable concentration in each category. The indexes range from 0.649 (for sows in 2002) to 0.74 (for weaners in 2008). The extent of concentration indicated by these indexes is, respectively, 32% and 37%. Overall, weaners are slightly more concentrated than growing pigs which in turn are more concentrated than sows. Mirroring the evolution of the specialisation index discussed above the average concentration index has shown slight changes over time without a clear pattern.

< Table 5 about here>

It has to be noted that the sample countries under discussion (with a possible exception of Poland) have been well integrated economies for decades and one should not expect any sharp changes in specialisation and concentration over our sample period of 2000-2008. So the limited changes in the calculated regional and concentration indexes are rather remarkable and lend support to the hypothesis of recent developments of differential environmental compliance cost across countries. In general the underlying reasons for regional specialisation are to be found in the characteristics of regions and sectors and in the interactions of these characteristics. Our econometric analysis in the next section will examine these factors.

[7] See Midelfart –Knarvick *et al*. (2000, p .6).

Theory and empirical model

Our aim is to investigate the relevance of various factors in the location of industrialised animal agriculture. In particular, we want to know why some regions attract a high share of a certain category of the pig sector, while other regions have a much lower share. Formally, we investigate the determinants of the localisation variable, $s_{i,k}$ we defined in the previous section as:

$$s_{ik} = z_{i,k} \Big/ \sum_{i'} z_{i',k}$$

where $z_{i,k}$ measures the size of category k in region i, and the region label with prime (i') is used to sum over all regions.

Trade theorists' discussions of industry location are informed by two strands of literature. Comparative advantage arguments based on the role of factor endowments can be derived from Heckscher-Ohlin (HO) models. Recent theoretic work has extended the standard HO models to accommodate environmental factors where cross-country differences in the stringency of environmental regulation play a role in trade patterns (see, for e.g., Antweiler *et al*. 2001 and Copeland and Taylor 2004). New economic geography (NEG), by contrast, stresses the importance of market access. Both the HO and NEG theories rely on the interaction of region characteristics with industry attributes. Thus the HO predicts that industries that use a factor of production intensively will tend to locate in regions which are rich in that factor whereas NEG theories predict that the attraction of a region's market potential is greater the more an industry sells to or buys inputs from other industries. These theories should be regarded as complementary and their relative importance for industrial location outcomes is thus an empirical issue. There are a few variants of location models that are based on such interaction forces and we will employ one variant in this paper.

In these models regions are heterogeneous in various characteristics such as endowments of natural resource and stringency of environmental regulation. Similarly, sectors differ in their various attributes such as the intensity of use of production factors like labour and the extent of pollution intensity. In equilibrium we expect that sectors that highly value a regional characteristic locate there. All else equal, a labour intensive sector will locate in a region with abundant labour, while pollution intensive sectors will be attracted to regions with a relatively lax environmental regulation. In the context of the PHH literature, the relevant empirical question is how strong is the interaction between environmental regulation and pollution intensity, relative to the interaction between other region and industry characteristics.

Such potential interaction channels, indexed j are central in the model. For each interaction channel, we have a vector of associated regional characteristics x_j, and a vector of associated industry attributes y_j. For the pollution interaction channel, x_j measures the regions' stringency of environmental regulation (or its inverse, the laxity), while y_j measures the industries' pollution intensity. For each interaction channel, there is a neutral regional characteristic level χ_j, also referred to as a cut off point, such that a region with this characteristic does not specifically attract industries with high or low levels for the associated industry attribute. Similarly, there is a neutral industry attribute level γ_j, or cut off point, such that an industry with this attribute level does not consider the associated region-characteristic in the selection of its location. Using these parameters our interaction model can be written as (the time subscript is suppressed to avoid clutter):

$$\ln s_{i,k} = \alpha + \sum_j \beta^j \left(x_i^j - \chi^j\right)\left(y_k^j - \gamma^j\right) + \varepsilon_{i,k} \qquad (4)$$

Expanding the equation we obtain the estimating equation as follows:

$$\ln s_{i,k} = \alpha' + \sum_j \left(\beta^j x_i^j y_k^j - \gamma'^j x_i^j - \chi'^j y_k^j\right) + \varepsilon_{i,k} \qquad (5)$$

Adding region and sector dummies would make the linear segments redundant and we will be left with:

$$\ln s_{i,k} = \alpha' + \Sigma_j \beta^j x_i^j y_k^j + \theta_i + \delta_k + \varepsilon_{i,k} \qquad (6)$$

where $\alpha' = \alpha + \sum_j (\beta^j \chi^j \gamma^j)$

The coefficients of the interaction variables β are expected to be positive. This empirical method is quite intuitive. Midelfart-Knarvik *et al*. (2000, 2001) obtain this specification with some benefit from theory. Romalis (2004) derives a similar general empirical trade model from a fully specified trade model. Mulatu *et al.* (2010) employ this specification using cross-section data. Gerlagh and Mathys (2010) also use a variant of this model in the context of energy abundance and intensity. The particular region and sector characteristics that will be employed in this paper are discussed in the following section.

Data

Detailed data description is provided in Appendix I and II. In this section we first describe the definition of the variables used in the interaction model followed by a description of the interaction channels as such. The data discussion is limited to those relevant issues not contained in the Appendix or Tables 6 and 7 that present definition and summary statistics of the variables used in the econometric analysis. We also include a further description of the main variables of interest in this paper, i.e. the environmental variables. We use a panel dataset with 43 NUTS-1 regions of six countries (Germany, Spain, The Netherlands, France, Denmark and Poland) and three time periods (2003, 2004 and 2007). The further restriction of our sample period to these three years is dictated by data availability of the environmental stringency variable. With respect to the econometric analysis, of the 43 regions, three German regions (Berlin, Bremen and Hamburg) are excluded from the analysis because of missing data on feedstuff for all the sample years and one region in France (Méditerranée) is dropped because of missing data on pig inventory. In addition feedstuff data are missing for 2007 for the 7 regions in Spain and the 4 regions in the Netherlands. As is common in the PPH literature our data on input intensity variables are time invariant. These data refer to the period around 2005. It is to be noted that there are benefits and drawbacks of working with a fairly homogenous sample of countries. The benefit is that the possibility of omitted variable bias is minimized owing to the similarities of the countries. The drawback is the difficulty of finding significant results (for lack of sufficient variation), but if these are found, they are more reliable.

Dependent variable

As the focus of our empirical study is on the intensity of a particular category of pig production, the dependant variable is the natural logarithm of a region’s share of pig inventory by category (sub-sector). The definition of a standard pig and the pig categories in Table 2 is common in EU countries but there can still be some differences, particularly in the weight of pigs at slaughter (Dourmad *et al*. 1999).[8] We apply our empirical model for three animal categories: (i) sows (with piglets), (ii) pigs 20-50 kg (weaners), and (iii) fattening pigs (>50 kg).

Regional and sub-sector characteristics and the interaction channels

The region and sector characteristics are summarised in Table 6. We have four regional characteristics that interact with the corresponding sector characteristics (availability of feedstuff, availability of labour,

[8] Traditionally European farmers produced pigs to three different weights to satisfy distinct market requirements: the bacon market (animals at 100 kg), the processing market (70 kg) and the fresh pork market (about 55 kg). In recent years improvements in management, nutrition and pig breeding have meant that animals can be grown onto a larger size without becoming fat, thus remaining suitable for the lower weight markets as well and most pigs are now slaughtered at the higher weight. Pigs finished for traditional products such as cured ham are fed a special diet and are slaughtered at for example 160 kg.

market potential[9] and environmental regulatory laxity). We ignore common region control variables such as a region's share of population, share of land area and climate as they are likely to be captured by region dummy variables in our panel regressions.

< Tables 6 and 7 about here>

Feed is the major production input to the production process — particularly for finishing pigs where it might well account for more than 65 percent of all production expenses. Availability of feedstuff has thus differing importance for the sectors within the pig industry. Availability of feeding-stuff is represented by the tons of harvest of all cereals excluding rice. The corresponding sector characteristic of feed intensity is captured by relative feedstuff consumption of each pig category.

Labour is another major input in the production process and there seem to be differences in labour-intensity among the sub-sectors (Roe *et al*. 2002, p. 275). Availability of labour would therefore be another region characteristic with a potentially differing importance for the sectors within the pig industry. Labour availability is proxied by unemployment rate of the population aged 15 or over. The corresponding sector characteristic of labour intensity is represented by the average annual number of hours required for each sector (see the Appendix for details).

Domestic market potential is represented by Gross Domestic Product (GDP). A major driver of the pig industry in several EU regions has been domestic demand. For example in Spain, annual per capita pork consumption doubled between 1985 and 2002 and in 2003, Spaniards ranked as the world's second-largest consumers of pig meat on a per capita basis behind Austrians. This noticeable increase can be largely attributed to the substantial growth in per capita income after Spain joined the EU and a preference for (more expensive) cured meat products (Lence 2007). The corresponding sector characteristic of scale economies is approximated by the number of farms in the largest size category by pig category.

Compliance to environmental regulations is becoming a major component of production cost, particularly to those sectors that are relatively more pollution-intensive. Thus, once again we have a regional characteristic with differential impact on the sub-sectors of the pig industry. Regulatory laxity can either mean weak rules or no effort to enforce, or lack of institutional or financial capabilities to enforce. Hence constructing an environmental stringency/laxity index based on a description of rules and regulations as such is not very meaningful. We used detailed information on costs to pig producers of regulation in different EU countries for several years constructed by the Agricultural Economics Research Institute in The Hague (see Appendix 1). The Institute conducts research into the production costs of animal agriculture at regular intervals. We have obtained from this institute costs for pork in eurocents per kg slaughter weight (or kg live weight) for 4 regulatory aspects and also a total amount: environmental, animal welfare, public health, spatial planning and total. These costs are available for only the six countries in our sample for 2003, 2004 and 2007. These costs are taken as proxy for the stringency of national environmental stringency (see the Appendix I for further details). Comparison of this proxy measure of stringency with other more general and widely used stringency measures reveals the following. Our 2003 measure is positively correlated with the Environmental Sustainability Index (ESI)[10], the stringency measure of the Global Competitiveness Forum[11] and Environmental Regulation

[9] In some papers the New Economic Geography forces include the interaction between market potential and the share of intermediates in costs, the share of sales to industrial users, and scale economies. We have ignored the first two forces (the linkage effects) because they may not be applicable to the case at hand and if they were there is no reason to expect them to have differential effects on the three categories of the pig industry.

[10] The ESI index is constructed jointly by World Economic Forum, Yale Centre for Environmental Law and Policy, and Center for International Earth Science Information Network, Columbia University. The index refers to the year 2001 and is based on a total of 67 underlying variables (such as environmental regulatory stringency, environmental regulatory innovation and number of EIA guidelines).

[11] This measure is published by the World Economic Forum and refers to the period 2001-2002.

Regime Index (ERRI).[12] The correlation coefficients between our proxy and these measures are, respectively, 0.86, 0.68 and 0.86.

The corresponding sector characteristic of pollution intensity is measured by the inclusive nitrogen loss of each pig category as calculated on the basis of the mean production level in practical pig production and the content in feed and retention according to the work by Jongbloed and Kemme (2005) (details in Appendix II).

The four regional characteristics together with their corresponding sector attributes provide the following three interaction variables: i) feedstuff availability times feedstuff intensity; ii) labour availability times labour intensity iii) regulatory laxity times pollution intensity, and iv) market potential times scale economies. The correlation coefficients among the interaction variables are generally small except the one between the labour and environmental interaction variables which is rather large, 0.78. This presents a potential problem of disentangling the effect of the two interaction terms on location.

Results and discussion

The main results of estimation of Equation 6 are presented in Table 8. In all the regressions, region and sector fixed effects are included. The former absorb the effects of any unobserved regional characteristics that affect all sectors such as geography, culture, regional policy of one sort or another and agglomeration economies.[13] The latter control for the effects of any unobserved sector characteristics such as the slaughter-intensity**,** differences in transportation cost and requirements for more specialised labour by animal category.[14] Remember that the fixed effects are also meant to cover the linear terms of our interaction model in Equation 6. A more complete two-way fixed effects model would be one that has region*year and sector*year dummies (instead of region and sector dummies). However such a model could not be estimated because of multicollinearity which is not surprising considering the large number of dummy variables to be included: about 126.[15]

< Table 8 about here>

The first two columns report the OLS results. In both, the estimated coefficients of the environment, feedstuff and market potential interaction terms have the expected signs and are statistically significant. The labour interaction term is however insignificant, which as we pointed out in Section 4, might have to do with the large inter-correlation between the labour and the environmental interaction terms.

It is possible that environmental policy is endogenous, i.e. such a policy responds to the size and structure of the pig industry. Countries with large production of polluting industries might raise their environmental standards or those with negligible amount of polluting activities may not enact stringent environmental policies (Millimet and Roy 2011). The last two columns present results of the IV/2SLS counterpart of the OLS estimation shown in the first two columns. We use corruption, income and educational attainment as instruments.[16] The standard specification tests

[12] ERRI is reported in Esty and Porter (2002). It is based on a subset of the indexes that form the so called Environmental Sustainability Index (see footnote 11 above) supplemented by data from the World Economic Forum. The index refers to the year 2001.

[13] The literature emphasises the importance of agglomeration/urbanisation economies (see, for e.g., Roe *et al*. 2002, Weersink and Eveland 2006 and Larue *et al*. 2011). But there is no suggestion that such economies are sector-specific and hence covering them in region fixed effects might be plausible.

[14] We have also experimented with ‘land share’ (represented alternatively by ‘total land area’ or ‘utilized agricultural area‘) as an explanatory variable but no sensible results were obtained.

[15] So in effect we are assuming that the unobserved region-specific and sector-sector-specific effects remain constant over time which is hardly a heroic assumption given the time frame of our sample.

[16] These variables are fairly common instruments in the literature and are based on the findings of Pellegrini and Gerlagh (2006); they are, for example, employed in Mulatu *et al*. (2010). We have also experimented with urbanization as an additional instrument but its inclusion led to rejection of the instrument validity test i.e. overidentification (see notes to Table 8 for the various identification tests).

(reported and explained at the bottom of Table 8) suggest that the identification strategy using these instruments works well. For the two IV/2SLS specifications, the Anderson canonical correlation likelihood ratio test firmly rejects the null of model underidentication and the Craig-Donald F-test rejects the null of weak instruments. To test whether the instruments are valid, we performed the Hansen *J*-test for overidentifying restrictions. We find that the null of valid instruments is confirmed at 10% level and thus the models are supported. Finally, the Anderson-Rubin *F*-test readily rejects its null hypothesis and indicates that the endogenous regressors are relevant. The IV results more or less confirm the OLS results. The only considerable change is the coefficient of the labour interaction term which now becomes negative and significant. This counter-intuitive result can be attributable to the mutlti-collinearity problem mentioned above or/and to our inability to capture differences in the quality of labour (specialised labour) required by different pig categories. The IV estimated coefficients of the environmental variable are larger than their OLS counterparts – a result consistent with much of the evidence in the literature (Millimet and Roy 2011). The specifications with period dummies appear to be preferable. A Wald test of a linear restriction of the year dummies (Chi Square with 3 degrees of freedom) indicates that the null hypothesis that the dummies are uniformly zero is easily rejected.

The results reported in Table 8 are with standard errors that are robust (to arbitrary heteroscedasticity). An alternative estimator would be one that allows inter-group correlation between the error terms (specifically, allowing error terms to be clustered by region-sector groups in order to capture persistence). The results are reported in the Appendix (Table A.2) and are fairly similar to those with robust standard errors. The only material difference is that the feedstuff variable is no longer estimated as sharply.

Since the coefficients of the interaction terms capture the joint role of region and sector characteristics in the location of an activity, the positive estimated coefficients of β means that a sector with relatively more (i.e. above average) intensive use of feedstuff is attracted to regions which are relatively more (i.e. above average) abundant in feedstuff. Likewise, a sector that is relatively more pollution intensive (growing pigs/hogs) would be drawn to regions which have relatively lax environmental standards (such as those in Poland). Finally, a sector with above-average scale economies tends to locate in regions with an above-average domestic market potential.

To address the question of the relative strengths of the various interaction effects we need to put the estimated coefficients of the interaction channels in comparable terms, i.e. the dependent variable and independent variables should be normalized. Expressed in this manner, the estimated coefficients are standardized and hence are comparable (the coefficients are what are known as beta coefficients). These coefficients are calculated for our preferred model that is the IV specification (with year dummies) of Table 8 and are presented in Table 9.

< Table 9 about here>

Ignoring the implausible result of the labour variable it can be noticed that the environmental interaction channel has the largest effect on location. The feedstuff interaction channel has a larger impact than the market potential one. We also see that the large effect of the environmental interaction channel is not matched by the two together. It follows that environmental regulation is a dominant influence on the location of pollution intensive pig sectors.

The picture that has emerged in our analysis might not fully come out if one were to rely on analyses of aggregate industry data – a common practice in the existing literature. Table 10 reports the results of regression for the aggregate pig sector. The dependent variable is a region's share of the pig industry as a whole and the dependent variables are the regional characteristics as such (without interaction with the corresponding sector attributes). Note that the regressions include time invariant region fixed effects.

We note that in our preferred model the only regional characteristic that has a statistically significant positive effect on the location of the entire pig industry is feedstuff abundance. The consistently positive significant effect of environmental regulation laxity estimated in the above sectoral (disaggregate) analysis is not born out in the aggregate data. It can also be noted that judging by the identification tests reported in the bottom of the table, the identification strategies are not all working well. Overall the results suggest that while environmental regulation may not affect the overall inventory of pigs in a region it certainly does impact the composition of the industry: fattening pigs being relatively more pollution intensive tend to locate in regions where environmental standards are lax.

< Table 10 about here>

Conclusion

This paper documents the pattern of regional specialisation in European pig industry and presents an econometrics analysis of the determinants of production location in the industry. Given the fact that this industry is increasingly subjected to stringent environmental regulations for its role in water and air pollution, a major focus of this paper is to evaluate the extent to which environmental policy is an influence in the location of production in the pig industry.

We employ a general empirical location model in which environmental regulation is one of several motives for location choices. We analyse data on the different sectors within the pig industry (i.e., sow/piglet, weaner and fattening pig) in 43 NUTS-1 regions in six major pig industry European countries over the period 2003 - 2007.

The results suggest that while environmental regulation may not have a measurable effect on the location of the entire pig industry, it is indeed a strong influence on the sectoral composition of the industry. Regions with relatively lax environmental standards attract relatively highly polluting sectors of the pig industry. This is perhaps reassuring from purely economic/employment point of view because it suggests that differential environmental standards would leave the regional distribution of the hog industry as a whole largely intact. From the point of the environment however there might be two reasons for consternation. The first is the emergence of pollution havens (i.e. hot spots of hog waste) as particularly polluting activities relocate to jurisdictions with lax environmental standards. In analogy with the well known carbon leakage effects one could call this the *hog waste leakage* effect**.** The second reason is that increased regional specialisation in the pig industry – driven by differential environmental regulation – would be accompanied by increased inter-regional transportation which has an environmental impact of a different kind. These conclusions have important implications for the further harmonisation of environmental regulation related to animal agriculture in the EU.

Further work could look into the transportation intensity of the animal categories with an aim to analyse the impact of proposed animal welfare regulations in individual countries that restrict the number of hours in transport.

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Table 1. Overview of studies on the location of animal production

Study	*Sector analysed*	*Geographical focus & period*	*Empirical model*	*Dependant variable*	*RHS variables*	*Environmental variable*	**Results: pollution haven hypothesis**
Abdalla *et al.* (1995)	Animal sector	Whole USA	NA	NA	NA		Plant location and market structure can be a function of environmental policy
Metcalfe (2001)	Hog	18 major hog producing states in USA; 1986-1998	Supply equation	States' share of total US hog inventory	Market price of hogs; input prices for feed and land; environmental input price; & proxies for the costs of transportation	State Water Quality Regulation	Negative effect of environmental regulation on smaller hog feeding operations
Roe *et al.* (2002)	Hog	15 key hog production states in US; 1992 & 1997	Supply equation with a spatial lag structure	Hog inventory, by county; the change in inventories between 1992 & 1997, & average number of hogs per farm	Agglomeration proxies; urban encroachment indicators; local economic variables; specialization indicators; market access measures; regulatory variables	State-level stringency index based on various states' regulations	Increased costs of environmental regulation are associated with smaller total and per farm inventory levels in 1997
Isik (2004)	Dairy	All continental counties except those with no dairy farms in the sample period; 1992 & 1997	Supply equation with a spatial lag structure	Dairy inventories by county; average number of dairy cows per farm, the change in a county's dairy inventories, and the changes in the share of a county in the total cow inventories between 1992 & 1997	Local economic conditions, agglomeration economies, climate conditions, and socioeconomic factors	State level stringency index based the 1998 National Survey of Animal Confinement Policies	Environmental regulation affects dairy inventories
Herath *et al.* (2005a)	Hog, Dairy cows and	eight major Production regions; 1975-	Entropy Measures to compare	[geographical Concentration: a state's share of	[slaughtering/ processing Capacity, population density and environmental regulations]	Conservation Foundation Index; Green Index; and an index based on the presence	Mixed

Study	*Sector analysed*	*Geographical focus & period*	*Empirical model*	*Dependant variable*	*RHS variables*	*Environmental variable*	**Results: pollution haven hypothesis**
	fed-cattle	2000	concentrations & explain them	livestock inventory		or absence of sets of livestock regulations as reported in the State Compendium.	
Herath *et al*. (2005b)	Hog, dairy cows and fed-cattle	48 contiguous states; 1976 – 2000	Supply equation	A state's share of national inventory livestock	Environmental regulation; relative prices; livestock infrastructure; general business climate; and natural endowment	State level stringency cu index based on presence or absence of seven regulations	Environmental regulation affects the hog and dairy sectors but not the cattle-fed sector
Weersink & Eveland (2006)	Hog	42 municipalities in 8 counties, Canada; 1996-2001	Supply equation	Density of total barn building permits, new barn permits, & permits for hog facilities	Environmental regulations; output & input prices; business climate; & agglomeration economies & regional support for farming	local environmental regulation: required manure storage days; minimum distance from waterway; minimum lot size; nutrient management plan requirements; trigger for expansion	No measurable effect of environmental regulation
Sneeringer (2009)	Hog	North Carolina at the county level; 1980-2005	Spline regression models of supply and emissions; Differences in-differences approach	Hog inventories by county; SO2 and PM10.	Income, population, population density, temperature, precipitation, population over 65 of age, unemployment rate, poverty rate and number of residential housing permit	Exemption of swine operations from county zoning restrictions and environmental penalties	Lax (absence of) environmental regulation led to increased presence of the pork industry
Sneeringer (2011)	Hog	US states with 100 or more 'finish' only operations and with the federal regulatory threshold in	Regression discontinuity model	Change in the number of operations by size category over time	NA	Regulatory threshold (2,500 finishing hogs) used in state and federal rules targeting large scale operations	Large % of finish-only hog farms operate at size just below the threshold – avoiding regulation. This effect increased between 1997 and 2007

Study	*Sector analysed*	*Geographical focus & period*	*Empirical model*	*Dependant variable*	*RHS variables*	*Environmental variable*	**Results: pollution haven hypothesis**
		place during 1997, 2002 & 2007: Illinois, Iowa, Kansas, Missouri, Minnesota, Nebraska, Ohio, South Dakota & Wisconsin;					
Larue *et al*. (2011)	Hog	Denmark; 1999 & 2004	Spatial lag model	Municipal pig density	Access to slaughterhouse, feedstuff; population density and distance to the German border	Ratio of demand for land for spreading of manure to available land	Ambiguous
Gaigné *et al*. (2012)	Hog	French *canton* (US equivalent of county); 1988 & 2000	Spatial lag model	Hog production density (number of hogs per hectare)	Access to feed (corn), access to other cereals, access to slaughter facilities, access to final consumers, local degree of urbanization, structure of farms & existence of inter-industry externalities	Availability of land for manure spreading	Land limitations due to regulation on manure application affect the location of hog production

Table 2. Pig stocks in EU-15

Total pig stocks in the member states (1000 heads) – December survey 2002					
	Total (1000 heads)	**Composition in %**			
		Breeding sows	**Piglets**	**Pigs 20-50 kg (weaners-feeder pigs)**	**Pigs for fattening (hogs)**
EU-15	121991	10	28	24	37
10 New member states*	32141	10	30	24	36
EU-25	154737	10	29	24	37
Belgium	6735	10	27	22	41
Denmark	12879	11	32	28	29
Germany	26251	10	27	25	38
Greece	903	15	29	23	32
Spain	23518	11	26	22	40
France	15271	9	28	25	38
Ireland	1782	10	29	28	32
Italy	9166	8	19	20	52
Luxembourg	76	10	28	22	40
Netherlands	11154	10	41	20	29
Austria	3305	10	25	29	36
Portugal	2344	13	29	25	32
Finland	1423	13	27	21	38
Sweden	1989	11	31	23	35
United Kingdom	5330	11	26	27	36
Czechoslovakia	3429	14	29	23	34
Cyprus	491	11	34	22	32
Estonia	340	11	31	24	33
Latvia	453	11	22	21	46
Lituania	1061	9	17	26	48
Hungary	5082	10	24	22	44
Malta	78	9	24	27	39
Poland	18997	13	33	25	33
Slovenia	1882	10	27	22	41
Slovakia	1554	11	29	23	37

* The new member states joined the EU in May 2004 and include: Czechoslovakia, Cyprus, Estonia, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia, and Slovakia.
Source: EUROSTAT.

Table 3. Pig stocks in NUTS 1 regions of EU six countries* (average over 2000-2010 in '000)

Pig Sector / *NUTS1*	All pigs	Growing pigs	Weaners	Sows
DEC - Saarland	17	8	4	1
DE1 - Baden-Württemberg	2206	692	485	273
DE2 - Bayern	3683	1286	825	385
DE4 - Brandenburg	765	239	184	98
DE7 - Hessen	780	333	188	68
DE8 - Mecklenburg-Vorpommern	703	254	185	79
DE9 - Niedersachsen	7877	3586	1993	623
DEA - Nordrhein-Westfalen	6255	2760	1423	508
DEB - Rheinland-Pfalz	318	126	72	28
DED - Sachsen	627	198	165	79
DEF - Schleswig-Holstein	1453	618	337	118
DEG - Thüringen	732	229	215	87
DK - Denmark	12823	3650	3630	1351
ES1 - Noroeste	946	337	206	107
ES2 - Noreste	5298	2099	1215	491
ES3 - Comunidad de Madrid	35	10	7	6
ES4 - Centro	6545	2686	1128	800
ES5 - Este	7492	2978	1850	695
ES6 - Sur	4261	1857	938	431
ES7 - Canarias	68	20	16	11
FR1 - Île de France	11	4	3	0
FR2 - Bassin Parisien	1626	606	413	161
FR3 - Nord - Pas-de-Calais	515	193	139	47
FR4 - Est	322	126	86	31
FR5 - Ouest	10615	4153	2744	870
FR6 - Sud-Ouest	1148	459	296	102
FR7 - Centre-Est	647	262	166	55
FR8 - Méditerranée	100	39	25	10
NL1 - Noord-Nederland	539	166	103	56
NL2 - Oost-Nederland	3869	1222	771	368
NL3 - West-Nederland	580	203	131	50
NL4 - Zuid-Nederland	6879	2071	1270	700
PL1 - Region Centralny	3048	1087	719	276
PL2 - Region Poludniowy	825	280	183	84
PL3 - Region Wschodni	2687	965	621	257
PL4 - Region Pólnocno-Zachodni	5364	1722	1482	476
PL5 - Region Poludniowo-Zachodni	1141	376	280	109
PL6 - Region Pólnocny	3827	1237	965	373

* The six countries include: Denmark, Germany, France, Netherlands, Poland and Spain. For five of the 43 NUTS-1 regions inventory data are missing for one or another of the sample years, hence excluded from the table. There are no inventory data for 2005 and 2006 for any of the regions.
Source: Eurostat.

Table 4. Krugman specialisation index (Pigs inventory data)

Year / NUTS1	2000	2001	2002	2003	2004	2007	2008
DEC - Saarland	0.389	0.449	0.452	0.470	0.434	0.412	0.467
DE1 - Baden-Württemberg	0.236	0.238	0.235	0.208	0.249	0.252	0.298
DE2 - Bayern	0.285	0.278	0.275	0.283	0.298	0.357	0.317
DE4 - Brandenburg	0.242	0.214	0.228	0.217	0.212	0.223	0.283
DE7 - Hessen	0.382	0.393	0.368	0.413	0.387	0.360	0.410
DE8 - Mecklenburg-Vorpommern	0.258	0.275	0.294	0.251	0.261	0.270	0.283
DE9 - Niedersachsen	0.396	0.414	0.372	0.420	0.389	0.417	0.492
DEA - Nordrhein-Westfalen	0.404	0.441	0.400	0.451	0.430	0.373	0.472
DEB - Rheinland-Pfalz	0.369	0.374	0.340	0.344	0.378	0.332	0.368
DED - Sachsen	0.178	0.184	0.172	0.195	0.183	0.223	0.286
DEF - Schleswig-Holstein	0.370	0.397	0.378	0.365	0.380	0.362	0.468
DEG - Thüringen	0.282	0.251	0.257	0.240	0.221	0.245	0.234
DK - Denmark	0.205	0.204	0.204	0.206	0.230	0.229	0.247
ES1 - Noroeste	0.283	0.232	0.294	0.331	0.348	0.283	0.309
ES2 - Noreste	0.292	0.475	0.432	0.473	0.456	0.310	0.345
ES3 - Comunidad de Madrid	0.234	0.256	0.252	0.131	0.278	0.354	0.317
ES4 - Centro	0.377	0.363	0.369	0.382	0.435	0.360	0.466
ES5 - Este	0.419	0.326	0.322	0.317	0.356	0.342	0.379
ES6 - Sur	0.464	0.403	0.398	0.356	0.424	0.379	0.446
ES7 - Canarias	0.144	0.177	0.183	0.199	0.180	0.220	0.203
FR1 - Île de France	0.341	0.380	0.381	0.298	0.313	0.297	0.485
FR2 - Bassin Parisien	0.295	0.305	0.297	0.291	0.320	0.294	0.313
FR3 - Nord - Pas-de-Calais	0.273	0.251	0.272	0.288	0.299	0.316	0.330
FR4 - Est	0.307	0.370	0.346	0.320	0.353	0.300	0.328
FR5 - Ouest	0.347	0.341	0.350	0.354	0.371	0.363	0.392
FR6 - Sud-Ouest	0.324	0.327	0.339	0.350	0.371	0.330	0.346
FR7 - Centre-Est	0.328	0.383	0.348	0.305	0.329	0.358	0.378
FR8 - Méditerranée	0.294	0.333	0.328	0.356	0.359	0.374	0.306
NL1 - Noord-Nederland	0.254	0.297	0.269	0.257	0.289	0.235	0.392
NL2 - Oost-Nederland	0.259	0.335	0.281	0.272	0.295	0.251	0.407
NL3 - West-Nederland	0.293	0.338	0.312	0.291	0.271	0.275	0.408
NL4 - Zuid-Nederland	0.270	0.313	0.291	0.280	0.319	0.254	0.399
PL1 - Region Centralny	0.337	0.281	0.295	0.328	0.328	0.293	0.345
PL2 - Region Poludniowy	0.284	0.314	0.307	0.299	0.314	0.290	0.339
PL3 - Region Wschodni	0.334	0.310	0.292	0.342	0.324	0.314	0.344
PL4 - Region Pólnocno-Zachodni	0.274	0.256	0.264	0.259	0.288	0.274	0.266
PL5 - Region Poludniowo-Zachodni	0.273	0.250	0.262	0.314	0.297	0.262	0.284
PL6 - Region Pólnocny	0.268	0.245	0.255	0.274	0.292	0.246	0.288
Average	0.304	0.315	0.308	0.309	0.323	0.306	0.354
Weighted average	0.215	0.225	0.217	0.226	0.242	0.206	0.278

See text for formula. For five of the 43 NUTS-1 regions inventory data are missing for one or another of the sample years, hence they are excluded from the table. There are no inventory data for 2005 and 2006 for any of the regions.
Source: Eurostat.

Table 5. Index of localisation

	2000	2001	2002	2003	2004	2007	2008
Sow (plus piglet)	0.680	0.660	0.649	0.659	0.791	0.663	0.679
Weaner	0.734	0.726	0.718	0.725	0.736	0.723	0.740
Growing pig	0.711	0.698	0.679	0.682	0.686	0.690	0.723
Average	0.708	0.695	0.682	0.689	0.738	0.692	0.714

See text for formula. For five of the 43 NUTS-1 regions inventory data are missing for one or another of the sample years, hence they are not included in the analysis. There are no inventory data for 2005 and 2006 for any of the regions.
Source Eurostat.

Table 6. Regional characteristics

Variable	*Definition*	*Data source*	*Mean*	*Stand Dev.*	*Min*	*Max*
Availability of feedstuff	Production of cereals (excluding rice) in millions of tons	Eurostat	4.44	4.90	0.00	30.59
Availability of labour	Unemployment rates of the population aged 25-64	Eurostat	10.48	5.27	3.00	24.10
Domestic market potential	GDP in Purchasing Power Standard (million millions) deflated by the price index HICP (2005=100) for EU25	Eurostat	1.87	3.64	0.24	29.00
Environmental Regulation laxity	PORK additional costs due to policy measures (Eurocents per kg slaughter weight): 1-(total cost/20)	Several publications by the Dutch Agricultural Economics Research Institute	0.69	0.17	0.23	1.00
Instrumental variables (for Environmental Regulation Laxity)						
Urbanisation	% of total population living in urban areas	Eurostat	0.94	0.05	0.81	1.00
Corruption	Corruption perception index: (10.5 – corruption score in the index)	Transparency International	3.44	1.56	1.00	7.00
GDP per capita	Per capita income in Purchasing Power Standard (‘0000)	Eurostat	2.33	0.57	1.01	3.31
Educational attainment	% of population with upper secondary education	Eurostat	0.68	0.11	0.44	0.80

Detailed definitions of variables, notes on issues around missing data and data sources are given in Appendix I and II. Of the 43 regions, three German regions (Berlin, Bremen and Hamburg) are excluded from the analysis because of missing data on feedstuff and one region in France (Méditerranée) is dropped because of missing data on pig inventory. In addition feedstuff data are missing for 2007 for the 7 regions in Spain and the 4 regions in the Netherlands.

Table 7. Sector characteristics

Variable	*Definition*	*Data source*	*Mean*	*Stand Dev.*	*Min*	*Max*
Ln Inventory share	Regional share of a pig category in total EU inventory of that category	Eurostat	-5.03	1.74	-11.90	-2.26
Feedstuff intensity	Relative feed consumption ('000 kg feed per animal place per year)	Author's construction on the basis of data on feed per kg gain for each pig category (Hoste and Puister, 2009) and consumption level (Fernandez *et al*. 1999)	0.81	0.45	0.27	1.36
Labour intensity	Labour input per year (hours per average sow + associated piglets, weaners and finishers)	Author's construction based on Hoste and Puister 2009 (based on FADN data)	7.22	7.88	1.53	18.34
Economies of scale	Number of farms in the largest size category (the number of farms as % of the total number of farms)	Eurostat	0.10	0.02	0.08	0.13
Pollution intensity	Nitrogen losses in kg by pig category in Denmark	Fernandez et al. (1999)	11.71	6.98	3.22	20.30

Detailed definitions of variables and data sources are given in Appendix II.

Table 8. Regressions of regional shares of pig inventory (of different categories)

Dependent variable: $\ln(s_{ik})$	OLS	OLS	IV/2SLS	IV/2SLS
Interaction channels (β^j) and other controls				
Labour abundance * Labour-intensity	0.0004	0.0009	-0.0041 **	-0.0028 *
	(0.0011)	(0.0010)	(0.0015)	(0.0013)
Feedstuff abundance * Feed intensity	0.0328	0.0455 **	0.0214	0.0374 *
	(0.0224)	(0.022)	(0.0185)	(0.0184)
Env. Regulatory laxity * Pollution intensity	0.1074 **	0.1204 ***	0.3918 ***	0.3523 ***
	(0.0426)	(0.0399)	(0.0764)	(0.0806)
Market potential * Scale economies	0.2502 *	0.2179 *	0.2576 **	0.2193 *
	(0.1166)	(0.1159)	(0.0947)	(0.1029)
Period fixed effects	No	Yes	No	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Sector fixed effects	Yes	Yes	Yes	Yes
Underidentification			0.000	0.000
Weak Identification			0.000	0.000
Overidentification			0.106	0.149
Joint Significance of Endog. Regressors			0.000	0.000
N	318	318	318	318

Notes:

Robust standard errors in parenthesis. *is significant at the 10% level. ** is significant at the 5% level. *** is significant at the 1% level. Excluded instruments are GDP per capita, corruption and educational attainment. *Underidentification* reports the p-value of Anderson canonical correlations likelihood ratio test of identification and rejection indicates that the model is identified. *Weak Identification* reports the p-value of Cragg-Donald *F* test for the presence of weak instruments (meaning that the model is only weakly identified). *Overidentification* reports the p-value of Hansen J statistic test of instrument validity and rejection casts doubt on the validity. *Joint Significance* reports the p-value of Anderson-Rubin *F* test of joint significance of endogenous regressors in the structural equation.

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Table 9. Beta coefficients (of the IV estimator that included period dummies in Table 8)

Dependent variable: ln(s_{ik})

Labour abundance * Labour intensity	-0.161 *
	(0.075)
Feedstuff abundance * Feed intensity	0.107 *
	(0.052)
Env. Regulatory laxity * Pollution intensity	1.080 ***
	(0.247)
Market potential * scale economies	0.037 *
	(0.018)
Period fixed effects	Yes
Region fixed effects	Yes
Sector fixed effects	Yes

Notes:
Significance is not affected in standardised variables (i.e. beta coefficients). But for the sake of completeness we note the standard errors in parenthesis as follows. *is significant at the 5% level. ** is significant at the 1% level.

Table 10. Regressions of aggregate share of pigs

Dependent variable: $\ln(s_i)$	OLS	OLS	IV/2SLS	IV/2SLS
Regional characteristics and other controls				
Labour abundance	0.054	0.100 *	-0.052	0.052
	(0.042)	(0.047)	(0.059)	(0.063)
Feedstuff abundance	0.376 **	0.742 **	0.383 ***	0.479 ***
	(0.159)	(0.166)	(0.124)	(0.067)
Env. Regulatory laxity	1.377	0.781	6.069 **	2.535
	(0.890)	(0.909)	(2.357)	(2.012)
Market potential	(0.133)	-0.036	0.088	-0.013
	(0.200)	(0.146)	(0.117)	(0.106)
Period fixed effects	No	Yes	No	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Underidentification			0.000	0.033
Weak Identification			0.105	0.112
Overidentification			0.000	0.000
Joint Significance of Endog. Regressors			0.000	0.000
N	106	106	106	106

Notes:
Robust standard errors in parenthesis. *is significant at the 10% level. ** is significant at the 5% level. *** is significant at the 1% level. Excluded instruments are GDP per capita, corruption and educational attainment. *Underidentification* reports the p-value of Anderson canonical correlations likelihood ratio test of identification and rejection indicates that the model is identified. *Weak Identification* reports the p-value of Cragg-Donald *F* test for the presence of weak instruments (meaning that the model is only weakly identified). *Overidentification* reports the p-value of Hansen J statistic test of instrument validity and rejection casts doubt on the validity. *Joint Significance* reports the p-value of Anderson-Rubin *F* test of joint significance of endogenous regressors in the structural equation.

Aappendix I. Environmental Stringency Data

The data on environmental stringency are from several publications by the Dutch Agricultural Economics Research Institute. This Institute conducts research into the production costs of animal agriculture at regular interval (Bondt *et al.,* 2000, 2001, 2004; Hoste *et al*., 2006, 2009). The EU countries included in each of these five studies above are: NL, FR, DE, DK and ES. For 2007, regulation is distinguished in 5 categories: environment, animal welfare, animal health, public health and spatial planning (zoning). In previous reports there were rather fewer categories.

Additional costs for pork in eurocents per kg slaughter weight (or kg live weight) are given for each of the 5 regulatory aspects by country. These costs are for 2003, 2004 and 2007. In addition an outlook is provided of these regulatory cost categories for each of the countries for 2013.

Table A1. PORK Additional costs due to policy measures by year (Eurocents per kg slaughter weight)

2003						
Category of regulation	NL	FR	DE	DK	ES	PL
Environmental	3.8	2.8	1.3	2.4	0.33	..
Animal welfare	..	0.0	0.0	0.0	0.0	..
Public health	..	..	..			..
Spatial planning	0.0	0.0	0.0	0.0	0.0	..
Total	10.25	7.8	6.2	8.0	4.0	..

2004						
Category of regulation	NL	FR	DE	DK	ES	PL
Environmental	9.3	3.2	1.0	2.1	0.5	..
Animal welfare	..	0.0	0.0	0.0	0.0	..
Public health	..	..	..	..	..	..
Spatial planning	0.0	0.0	0.0	3.7	0.0	..
Total	11.1	7.3	7.0	7.1	0.8	..

2007						
Category of regulation	NL	FR	DE	DK	ES	PL
Environmental	11.1	3.3	3.4	1.6	4.1	0.0
Animal welfare	1.7	0.0	0.0	0.0	0.0	0.0
Public health	2.6	2.6	3.6	2.6	3.6	5.6
Spatial planning	0.0	0.0	0.0	3.7	0.0	0.0
Total	15.4	5.9	7.0	7.9	7.7	5.6

2013						
Category of regulation	NL	FR	DE	DK	ES	PL
Environmental	13.2	4.9	6.3	5.4	4.1	0.0
Animal welfare	5.0	0.3	1.2	0.3	0.3	0.3
Public health	2.6	2.6	3.6	2.6	3.6	5.6
Spatial planning	0.9	0.0	0.0	3.7	0.0	0.0
Total	21.7	7.8	11.1	12.0	8.0	5.9

Appendix II. Notes on all other data

Pig inventory

Number of pigs of different category in different regions. The data source is Eurostat: Animal populations (December) [agr_r_animal].
EU25 data are missing for 2000, 2004, 2007 and 2008. We obtained estimates for these missing figures on the basis of a regression of EU25 figures over 2001-2003 on the average figures for the six countries in our sample.

Data are also missing for France (and its regions) for 2000. We obtained an estimate for France as a whole in a similar fashion from a regression of the figures for France for 2001-2003 on the figures for EU 25. For French regions we used regressions of the figures for the respective region over 2001-2010 (excluding 2005-2006 for which data are missing) on the figures for France as a whole.

Regional characteristics

Land use

Total land area. The data source is Eurostat: Land use [agr_r_landuse].
In order to make this data series compatible with the rest of the data we have added rows DEE0 (a region in Germany), ES63 and ES64 (regions in Spain) with no figures for land use, and deleted rows DEE1-DEE3 (regions of Germany).

There are quite a few missing data for some regions and we have completed the series by a simple extrapolation (for example, data for 2000 would be assumed to be the same as that of 2001) – as this is the sort of data that hardly changes over time. Since land use data for EU25 are missing, we have used the total land use of the six countries in our sample to obtain regional shares for the purpose of calculating our 'concentration index'.

Feed availability

Cereals (excluding rice). The data source is Eurostat: Areas harvested, yields, production [agr_r_crops]. In millions of tons. In order to make this data series compatible with the rest of the data we have added rows DEE0 (a region in Germany), ES63 and ES64 (regions in Spain) with no figures for feed, and deleted rows DEE1-DEE3 (regions of Germany).

Labour availability

Total unemployment, age 15 or over. The data source is Eurostat: Unemployment rates by sex and age, at NUTS levels 1, 2 and 3 (%) [lfst_r_lfu3rt].

Market potential

Gross Domestic Product (GDP in PPS (Purchasing Power Standard). The purchasing power standard (PPS) is the name given by Eurostat to the artificial currency unit in which the PPPs and real final expenditures for the EU 25 are expressed – namely, euros based on the EU 25. It is deflated by HICP (2005=100) - from Annual Data (average index and rate of change) [prc_hicp_aind]. The data source is Eurostat: GDP and main components - Current prices [nama_gdp_c].

Environmental laxity

PORK additional costs due to policy measures (Eurocents per kg slaughter weight): 1-(total cost/20). The data sources are several publications by the Dutch Agricultural Economics Research Institute (Hoste *et al*., 2006, 2009). See Appendix I for further details.

Instrumental variables

Urbanisation

The number of people who live in urban areas as a proportion of total population. Source: Eurostat (DS-071619-table).

Corruption

Corruption perception index. Source: http://transparency.org/policy_research/surveys_indices/cpi. This index gives scores which we subtracted from 10.5 to construct our index, thus Denmark with the highest score of 9.5 in 2003 will have an index of 1.

Educational attainment

Persons with upper secondary or tertiary education attainment by age and sex (%). Source Eurostat (edat_lfse_08).

GDP per capita

Gross domestic product at market prices in Purchasing Power Standard per inhabitant (‘0000). Source: Eurostat: (nama_inc_c).

Sector characteristics

Feed intensity

Relative FEEDSTUFF measure of consumption (kg feed per animal place per yr). The data is constructed on the basis of Jongbloed and Kemme (2005) who provides consumption in kgs feed on an annual basis of 1243.00, 245.00 and 743.00 for respectively sow including piglets, weaner and growing pigs. We also have data from Hoste and Puister (2009) feed per kg gain at farm level for our sample of six countries as: Netherlands (NL) =2.75; France (FR)=3.00; German (DE)=3.03; Denmark (DK)=2.90; Spain (ES)=3.14; and Poland (PL)=3.24. We then took the figures from Jongbloed and Kemme (2005) to be for the Netherlands and calculated the figures for others in relative terms on the basis of those from Hoste *et al.* (2006). This gives the figures in the following table

Relative FEEDSTUFF measure of consumption (kg feed per animal place per yr)

	NL	FR	DE	DK	ES	PL	Average	In ‘000
sow (incl piglets)	1243.00	1356.00	1369.56	1310.80	1419.28	1464.48	1360.52	1.36
weaner	245.00	267.27	269.95	258.36	279.75	288.65	268.16	0.27
Growing pigs	743.00	810.55	818.65	783.53	848.37	875.39	813.25	0.81

Labour intensity

Labour input use. Constructed as follows:

Labour input per year (hours per average sow + associated piglets, weaners and finishers) according to Hoste and Puister 2009 (based on FADN data).

A)

NL	FR	DE	DK	ES	PL
11.6	21.5	19.2	15.4	15.8	46.4

The publication Afsluitnormen gives the following information:

B)

Labour costs in EURO per year			
	sow + piglets	weaner	Finisher
	144	14	12

We assume cost per hr is identical for the three categories. In addition it is known that up to 50% of the time on a farrowing farm is spent dealing with the piglets. This gives the following:

C)

	Labour input by pig category			
	sow plus piglets	weaner	Finisher	sum
	144	14	12	170
Relative	0.85	0.08	0.07	1.00

The combination of A and C then results in the following:

Labour Intensity in hours							
	NL	FR	DE	DK	ES	PL	Average
sow plus piglets	9.83	18.21	16.26	13.04	13.38	39.30	18.34
weaner	0.96	1.77	1.58	1.27	1.30	3.82	1.78
Finisher	0.82	1.52	1.36	1.09	1.12	3.28	
Total	11.60	21.50	19.20	15.40	15.80	46.40	1.53

<u>Farm size</u>

Relative size of farms of different pig categories. The data source is Eurostat: Pigs: Number of farms and heads by size of farm (UAA) and size of breeding sow herd [ef_ls_gvsows].

The EUROSTAT publication by Marquer (2010) uses >100 sows and >400 fattening pigs to define large breeding and finishing farms, respectively. This distinction wil be based on economic size. The economic size of agricultural activities is measured in european size units (See http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:European_size_unit_(ESU)).

We follow Marquer's approach and adopt the following: sow including piglets: sows 100 head or more, Growing pigs: pigs for fattening 400 head or more, and weaners: same as for fattening pigs.
There is a slight problem as Eurostat database provides data on farm size only for three categories as follows: piglets under 20kg; breading sows over 50kg; and others. This categorisation is not quite consistent with the one we are working with. So we take these three groupings to correspond respectively to weaners, sows including piglets and fattening pigs.

We considered two alternatives for this variable: the number of large farms as such and the number of farms as a % of the total number of farms with the specific type of pig. These two resulted in different rankings of the three pig categories. And we decided to take the latter because what we would want is a measure that reflects optimal scale of operation which a mere number of farms of a certain size might not reveal (if farms of other sizes are also just as many).

The data used are averages of the six countries over eight years: 1990, 1993, 1995, 1997, 2000, 2003, 2005 and 2007. The resulting figures for the number of large farms as a % of the total number of farms with the specific type of pig are: 0.0837 for sow; 0.13 for weaner; and 0.0842 for fattening pigs.

<u>Pollution intensity</u>

Nitrogen losses. The data source is:
Jongbloed en Kemme (2005) http://library.wur.nl/way/bestanden/clc/1872469.pdf N-emission:

- Sow with piglets till 6 weeks (category 400): 20.3 kg N per yr per animal place
- Weaners 6 wks till 25 kg (category 407): 3.22 kg per yr per animal place
- Fattening pigs 25 kg - about 110 kg (category 411): 11.6 kg per year per animal place.

Table A.2. Regression results with clustered error terms (clustered around Region-Sector)

Dependent variable: $\ln(s_{ik})$	OLS	OLS	IV/2SLS	IV/2SLS
Interaction channels (β^j) and other controls				
Labour abundance * Labour-intensity	0.0004	0.0009	-0.0041 *	-0.0028
	(0.0012)	(0.0013)	(0.0019)	(0.0017)
Feedstuff abundance * Feed intensity	0.0328	0.0455	0.0214	0.0374
	(0.0304)	(0.0326)	(0.0226)	(0.0251)
Env. Regulatory laxity * Pollution intensity	0.1074 **	0.1204 **	0.3918 **	0.3523 **
	(0.0426)	(0.0508)	(0.1295)	(0.1209)
Market potential * Scale economies	0.2502	0.2179	0.2576 **	0.2193 *
	(0.1379)	(0.1269)	(0.1150)	(0.1014)
Period fixed effects	No	Yes	No	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Sector fixed effects	Yes	Yes	Yes	Yes
Underidentification			0.000	0.000
Weak Identification			0.001	0.000
Overidentification			0.038	0.31
Joint Significance of Endog. Regressors			0.046	0.31
N	318	318	318	318

Notes:
Of course the coefficients reported here are identical to those of Table 7; the repetition is for ease of reading. Robust standard errors in parenthesis. *is significant at the 10% level. ** is significant at the 5% level. *** is significant at the 1% level. Excluded instruments are GDP per capita, corruption and educational attainment. *Underidentification* reports the p-value of Anderson canonical correlations likelihood ratio test of identification and rejection indicates that the model is identified. *Weak Identification* reports the p-value of Cragg-Donald *F* test for the presence of weak instruments (meaning that the model is only weakly identified). *Overidentification* reports the p-value of Hansen J statistic test of instrument validity and rejection casts doubt on the validity. *Joint Significance* reports the p-value of Anderson-Rubin *F* test of joint significance of endogenous regressors in the structural equation.