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The Banning of Anti-Microbial Growth Promoters and Farm Efficiency Effects in Danish Pig Production

Institute of Food and Resource Economics (FOI)

Working Paper 2007/20

The Banning of Anti-Microbial Growth Promoters and Farm Efficiency Effects in Danish Pig Production

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Abstract

This study with focus on the reaction of producers examines the effect of banning antimicrobial growth promoters on efficiency in the production of weaned and finisher pigs using a multi product shadow profit function. We investigated the effect of the ban over time on the changes in total factor productivity (TFP). Our results suggest that there was no effect of the ban on TFP due to outputs and inputs substitution. The high shadow prices for substituting outputs are associated with better export market prices. These findings may have critical implications for the slaughtering plants with over capacity.

JEL: Q1 Q11 Q12 D24

Keywords

Animal health economics, food economics, shadow prices, efficiency, anti-microbial growth promoters, pig production.

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Preface

This Working Paper is among a series of research projects aimed at increasing the knowledge of the impact of discontinuous use of Antimicrobial Growth promoters on the economic efficiency of livestock production in Denmark. The Working Paper complements other projects related to economics of food safety as well as animal health. The basic focus of the paper is to identify how producers react to the ban on use of antimicrobial growth promoters and hence the policy implications of the ban.

The Working Paper has been written by assistant professor Lartey Godwin Lawson in corroboration with associate professor Johannes Sauer, herd of statistics division Peter Vig Jensen both of Institute of Food and Resource Economics, University of Copenhagen and Professor Helen Jensen of the institute of food safety and security, Iowa State University, USA (during the period of her academic visit in 2006). We wish to acknowledge senior researcher Jørgen Dejgaard Jensen from the Institute of Food and Resource Economics, University of Copenhagen for his useful comments on the first version of this Working Paper.

The Working Paper has been reviewed by associate professor Lars Otto

Mogens Lund
Institute of Food and Resource Economics
Copenhagen, December 2007

1. Introduction

Growth promotion in livestock production is defined as the administration of an antimicrobial, as feed additive, over a period of time to growing animals in order to bring about improved physiological performance. Hence the term Antimicrobial Growth Promoter (AGP) is used. For some years the public has been concern about the risk of bacteria resistance transfer from animal foods with subsequent health hazards for humans and livestock. The pig industry in Denmark, the Danish government and as well as the EU in response, implemented a ban on the use of AGPs in livestock production during the period 1995 through 1999. The main reason for these policy actions was the precautionary principle to protect consumers from the risk of increasing bacterial resistance transfer from food animals to humans and other livestock.

Phillips et al (2004), questioned the decision based on the precautionary principle. They argued that the low dosages of AGP used for growth promotion are an unquantified hazard for humans. But the evidence in National Research Council (1999), and the findings of Tsai-Ling et al. (2002), suggested otherwise. Phillips et al. (2004), emphasized the positive economic impact of the use of antimicrobial growth promoters, which includes the positive effects on animal health, reduced mortality and morbidity from bacterial infections, and increase feed efficiency (Buhr and Hayenga, 1994). The positive economic effects are generally accepted to be the reduction in the cost of production with subsequent lower prices for consumers. Nonetheless, the issue raised is how to find the balance between human health considerations and reduced production cost.

The economics of resistance and human health hazards are yet to be completely ascertained. However in the literature the focus has been on the potential impacts of a ban on use of antimicrobials in livestock production on producer and consumer incomes. The papers cited above (Phillips et al., 2004 and National Research Council, 1999) and those in the literature review below provide useful information as to what quantitatively can be expected from an ex-ante evaluation of the use antimicrobials in pig production. Nonetheless the question of how farmers adjust or could adjust to the withdrawal from the benefits of the antimicrobial growth promoter technology still needs to be addressed.

The aim of this study is to evaluate how farmers adjust to the ban on AGP as well as the impact of the ban on the economic efficiency of combined weaned-pig and slaughter-pig producing farms in Denmark. Generally, it is expected that when regulations are passed, for example the restrictions on use of AGP, farmers will react by changing their input and output sets (for cases of multiple outputs). Therefore the reaction of farmers is evaluated by estimating allocative efficiencies and shadow prices, which are expected to capture distortions in market prices. The economic efficiency is evaluated by the total factor productivity changes. The total factor productivity changes captures the impact of anticipated morbidity, mortality, reduced feed efficiency and growth rate on inputs and is more suitable for guiding policy decisions compared to profits, which is more of interest for the individual farmers.

In the following sections a comprehensive literature review of the impacts of a ban in the pig sector; relevant review of the pig production sector and consumption of antimicrobial growth promoters; econometric modelling approach, data as well as the estimation procedure are presented respectively. Results with comments and finally a general discussion of data, results, which are also compared with other works, the implication of our findings and concluding remarks are provided.

2. Literature Review

Mann and Paulsen (1976) formulated and estimated an econometric simulation model for US livestock and poultry to evaluate the impact of a full ban on the use of feed additives and growth hormones on producers and consumers. They compared a basic model to models for with and without replacement technology while adjusting the parameters of the biological relationships. They found no negative consequences for the income of an average pig producer but an initial increase in consumer prices due to the fall in supply prevailed. Three years after, supply increased due to the initial producer price increase only to reduce producer price differentials between before and after the restriction. With replacement technology, price adjustments took 2 years such that after an initial increase, wholesale prices would begin to fall. The paper did not evaluate the trade-off between public health issues and food production costs.

Wade and Barkley (1992) used US data from 1959 to 1989 and specified an econometric model for pork demand and supply to evaluate the impact of a full ban on the use of antimicrobial drugs in livestock production and on consumers. The estimated elasticities were used to calculate changes in economic welfare. Producer and consumer surpluses were estimated to increase by $ 6.87 million and $ 6.19 million respectively under an assumption that consumption increased as a result of increased consumer confidence in the healthfulness of pork.

Hayes et al. (1999) investigated the economic impact of the ban in United States on swine rations. The paper used an economic model that incorporates both biological and economic processes that govern production and consumption. Changes in biological production parameters were derived partly from the changes observed in Sweden after their ban in 1986. The results suggest that a ban in the US would initially increase production costs per head between $5 and $6; net profit would decline $0.79 per head and consumer prices would increase by 5 cents per pound of pork. Hayes et al. (1999) suggested that the impact of the ban would be more severe for US farms that produced weaned-pigs (Hayes and Jensen, 2003) and those that use less effective hygienic practices and that use old continuous flow buildings. Thus, they indirectly suggest that antimicrobial growth promoter tends to be a substitute for production efficiency.

Hayes et al. (2001), using the same model simulation as in Hayes et al. (1999), reported the findings for three US scenarios: best, most likely and worst. The projected net profit, although negative, increases (becomes less negative) as cost falls, with end values of $ -1.89 and $ -0.10 per head for 2000 through 2009 with corresponding industry costs falling from $ -195 million to $ -12 million respectively. A potential price increase of 5 cent per pound for the most likely scenario is estimated to increase consumer expenditure by $ 11 per year for a family of 4.

Mathews (2001) used basic economic assessment to calculate the impact of the ban on producers and consumers using data that accounted for one quarter of the total hogs produced in the U.S. He estimates that producers who use antimicrobials would experience a net loss from a AGP ban of $ 45.5 million whereas the non-user group would gain $52.5 million; consumers would incur a price increase of $0.78 per hundredweight pork after the implementation of the ban.

Hayes, Jensen and Fabiosa (2002), discuss the ban relative to the impact of management, production and market technologies with additional information from the Danish experience. The authors are in line with National Research Council (1999) and suggest that US farmers with less effective management would be more negatively affected by the ban than farmers with new housing and who practice an all-in-all-out production strategy. Their paper further noted that marketing price agreements and trace-back technologies provide the possibility for producers to be compensated for extra costs through the premium gained for antibiotic free meat products.

Brorsen et al. (2002), focused on a ban of antimicrobial agents in pork production. Using three-commodities, beef, pork and poultry market, they investigated the impact of a ban on producer and consumer surpluses. They solved four equations for retail demand, retail supply, industry demand for farm inputs and supply of farm inputs simultaneously by using elasticities based on available literature and then estimating production cost changes due to banning the use of AGP. They found that the total annual society loss in the short run is estimated at $242.5 million, which is the sum beef and poultry producer gains ($21.3 million), pork producer loss of $153.5 million and consumer loss of $110.3 million. The pork consumer loss is estimated at $89.0 million. In the long run pork producers’ losses fell to $62.4 million and pork consumers’ losses increased to $180.0 million.

Clearly the above review suggests that the anticipated impacts of the AGP-ban on producers and consumers are mixed and lack evidence from actual practice. That is, they are ex-ante assessments of the effect of a ban. Although the use of AGPs is meant to increase efficiency, it is possible that the use of AGP may cover for management inefficiency. The ban is likely to encourage the development of new testing technology to enhance consumer confidence and demand for food products produced without the use of AGPs. Furthermore, the review results generally reflect the biological and the market assumptions incorporated in the analysis. The studies to date, lack evidence of producer response relative to their choice of output and input sets from real world experience. Therefore our paper relaxes these assumptions and evaluates farmers' adjustment behaviour using production and market generated data covering the periods before and after the ban. Nonetheless we infer the expected impact of the ban on the economic efficiency of pig production through changes in the total factor productivity. The total factor productivity as indicated earlier, reflects the impact of anticipated morbidity and mortality, reduced feed efficiency and growth rate on input use.

3. The pig sector and the use of antimicrobial for growth promotion and therapy

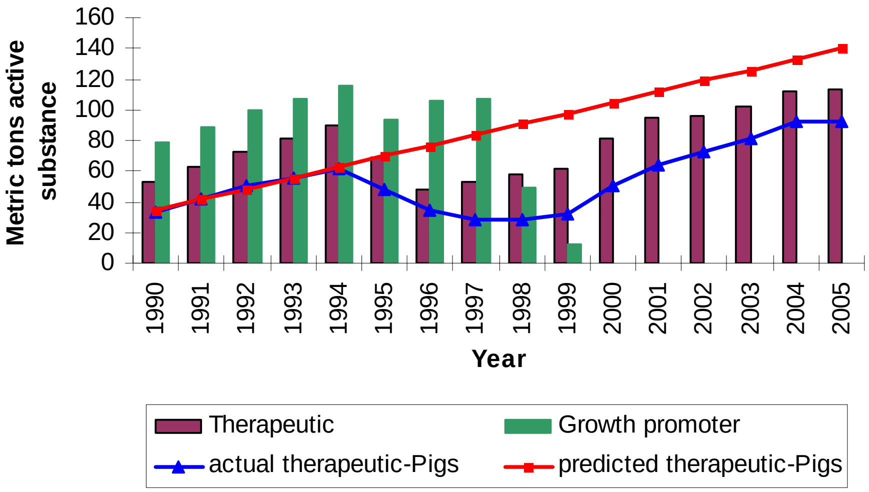
In 2004, Denmark produced about 22 million slaughtered pigs, which is 1.96 million metric tons of pig meat. About 90% of this quantity, i.e. 1.8 million is exported, of which 1.2 million is to the EU market and the remaining 622 thousand metric tons to the rest of the world. On the world market excluding EU, Denmark is the third largest exporter after the US and Canada. In the EU market, Denmark accounts for more than half of the EU exports and thereby the EUs leading exporter of pig meat to the rest of the world (Danske Slagterier, 2004).

The 22 million slaughtered pig output is produced by about 10 000 pig farmers in 2004. This is in contrast to about 27 000 pig farmers producing 19 million slaughtered pigs in 1993. Of the 10 000 pig farmers in Denmark today, about 43% are producers classified as producing both weaned (30kg) and finisher pigs at 80kg (Danske Slagterier, 2004). It is this group of farmers that is the focus of the study. Another 41% of farmers produce only finisher pigs and the rest produce mainly weaned pigs. Two cooperative companies with 12-production plants account for 98% of slaughtering in whiles the rest 2% of pigs are slaughtered by 10 small companies who are best described as butcher companies (Danske Slagterier, 2004).

Concerning the trends in the use of antibiotics, in Denmark, the use of AGPs was discontinued in finishers (slaughter-pigs) in 1998, and in weaned-pig production in 1999. Prior to these years a Danish national ban on the use an AGP, Avoparsin in animal feed, was implemented in 1995 due to its cross-resistance to a critically important human therapeutic antimicrobial, vancomycin. Avoparsin, was predominantly used for pigs from the age 10-12 weeks until slaughter (Wierup, 2001) and was the second largest antimicrobial use in Denmark, by 24 metric tons in 1994 (DANMAP 2004). In 1996 the AGP most used in pigs was tylosin, comprising 68 metric tons of a total of approximately 100 metric tons AGP.

The overall usage of antimicrobials, including AGPs and veterinary therapeutic drugs in livestock production decreased by 33 % from 153 metric tons in 1996 to 103 metric tons in 2003. However, after the ban during the period 1998 and 1999, the total therapeutic use of antimicrobial in livestock production began to increase again. The question raised is whether this increase use of antimicrobial is a result of the ban on the use of AGP, a question also raised by Hayes and Jensen (2003).

Figure 1. Consumption of antimicrobial in livestock and pig production



Briefly, after 1994, the usage of therapeutic antimicrobials in Denmark was almost halved due to implementation of important restrictions in the use of extemporaneously prepared drugs (in July 1995) and elimination of the discounts and other economic incentives for Danish veterinarians to sell medicines. This reduction in use of therapeutic antimicrobials continued during the period from 1995 through 1999. The moderate increases in the consumption of therapeutic antimicrobials from 2001 on appear to be driven by other factors than the AGP. Although the increased use of therapeutic antimicrobial was mainly due to an increased use in pig production, it was confined to certain regions (DANMAP, 2004). As with the Swedish ban experience, after the ban, important clinical problems emerged creating a demand for antibiotic-medicated feed at therapeutic dosages during the initial post weaning period. However the use of antibiotics in swine decreased at a long term (after 6 years) because of improved management and revised production practices for example, feeding regimes (Wierup, 2001).

4. Modelling

To infer on the impact of the ban on the use of AGP at the farm level, we evaluated shadow prices, technical and allocative efficiencies, as well as total factor productivity of the production units.

Shadow Prices

According to the common concept of shadow prices: when determining the optimal input and output vectors, farms compare the benefits of using an additional unit of each input to its cost, the purchase (or 'observed') input price, and compare the benefits of producing an additional unit of each output to its profit, the selling (or 'observed') output price. Depending on whether a primal or a dual approach is taken, these marginal benefits - referred to as the shadow price of the input and the shadow price of the output, respectively - can be measured either in terms of the input's and output's value marginal product, or as the reductions in expenditures on other inputs that can be achieved by using one additional unit of the input as well as the increase in revenue that can be achieved by producing one additional unit of the output. In the absence of market distortions, the optimal amounts of input use and output are intuitive: use an input up to the point where the shadow price and the purchase price are equivalent and produce an output up to the point where the shadow price and the selling price are equivalent. If market distortions are present, farms are unable to equate their shadow prices to the undistorted input and output prices. Due to the vast literature on shadow prices (for an overview see e.g. Khumbhakar and Lovell, 2000), non-observable shadow price ratios have to be considered as the relevant ones for producer decisions in distorted markets. The divergence between the analysed (i.e., estimated) shadow prices and the observed market prices can be interpreted as the sum of allocative inefficiency due to the prevalence of various market constraints, as well as optimization failure by the farm management. Different approaches to model this divergence can be found in the literature: One method consists of additively translating observed prices to create shadow prices (see Kumbhakar and Lovell, 2000). Alternatively, shadow prices can be modeled by multiplicatively scaling observed prices into shadow ones (Lau and Yotopoulos, 1971). We follow the latter approach here and define the relationship between the normalized shadow input and output prices w^*, p^* and the normalized market prices w, p as:

$$w^*_j = \theta_j w_j; \ \mathrm{p}^*_\mathrm{k} = \kappa_k p_k \quad [1]$$

where θ_j and κ_k are (non-negative) price efficiency parameter coefficients and j, k indicate input j and output k respectively. If no market restrictions as well as management failure are the case then $\theta_j = 1$, $\kappa_k = 1$. If market distortions restrict optimizing behaviour then $\theta \geq 0$ and $\theta \neq 1$, $\kappa \geq 0$ and $\kappa \neq 1$. Consequently, a pig producing farm can be regarded as allocatively efficient with respect to observed market prices only if such observed prices reflect the farmer's opportunity cost with respect to inputs and outputs. It is important to note that the price efficiency parameters θ_j and κ_k may reflect both effects of market distortions as well as optimization errors. The shadow price parameters; θ_j and κ_k, following equation [1] imply that the ratio of the shadow price of input or output to its actual price is constant.

Time-Varying Fixed Effects Shadow Profit Model

In a first modelling step we formulate a shadow profit distance function based on the aforementioned concept of shadow prices. In the formulation a measure of producer nonspecific time invariant technical efficiency is additively incorporated by $\ln \phi$ (Kumbhakar and Lovell,2000). Our objective is now to obtain producer specific estimates of technical efficiency varying over the different time periods considered. Obviously with an *I*T* panel it is not possible to obtain estimates of all *I*T* parameters for $\ln \phi_{it}$. However, by adapting the Cornwell, Schmidt and Sickles specification $\ln \phi = \ln(\Omega_{i1} + \Omega_{i2} t + \Omega_{i3} t^2)$ for a profit context, we are able to reduce the number of parameters to be additionally estimated to *I*3*. Consequently we reformulate the model with respect to a fixed effects stochastic profit frontier panel data model with time-varying relative technical efficiency of pig production using the flexible functional form of a translog profit function applied on a balanced panel data set (see Kumbhakar, 1990; Kumbhakar and Lovell, 2000).

As we have only observed prices for the variable inputs feed, labor, 30kg pigs, and sows, we treat the remaining input values for veterinary services and capital, as quasi-fixed, thus including the relevant quantity in the shadow cost function instead of its price (see also e.g. Morrison, 1998 and Morrison and Schwartz, 1996). For our pig production model we use the outputs m = finisher pigs (fp), breeding pigs (bp) and 30kg final pigs (30o) whereas the variable inputs n = feed stuff (fe), labor (l), 30kg input pigs (30i), and sows (s). We further incorporate the quasi-fixed inputs o = veterinary expenses (vet) and capital (cap) as well as the following control variables: r = age of the farmer (age), farming experience (exp), regional location of the farm (reg), total land cultivated (la), total pigs produced (tp), number of pigs used for home consumption (hp), family size (f) and the binary dummy variables livestock production (lp), selling of 7kg piglets (7pl). We normalize the profit system by the finisher pig output price, and the equation system for estimation is then the stated equations:

$$
\begin{aligned}
&\ln \pi = \beta_0 + \sum_m \beta_m \ln(\kappa_m p_{im} \big/ p_{ifp}) + \sum_n \gamma_n \ln(\theta_n w_{in} \big/ p_{ifp}) + 1/2 \sum_n \sum_n \gamma_{nn} (\ln(\theta_n w_{in} / p_{ifp}))^2 + \\
&1/2 \sum_m \sum_m \beta_{mm} (\ln(\kappa_m p_{im} / p_{ifp}))^2 + \sum_k \sum_n \gamma_{kn} \ln(\theta_k w_{ik} / p_{ifp}) \ln(\theta_n w_{in} / p_{ifp}) + \\
&\sum_l \sum_m \delta_{lm} \ln(\kappa_l p_{lm} / p_{ifp}) \ln(\kappa_m p_{im} / p_{ifp}) + \sum_n \sum_m \delta_{nm} \ln(\theta_n w_{im} / p_{ifp}) \ln(\kappa_m p_{im} / p_{ifp}) + \sum_o \chi_o \ln z_{io} + \\
&1/2 \sum_o \sum_o \chi_{oo} z_{io}^2 + \sum_o \sum_s \chi_{os} \ln z_{io} \ln z_{is} + \sum_n \sum_o \chi_{no} \ln(\theta_n w_{in} / p_{ifp}) \ln z_{io} + \sum_m \sum_o \chi_{mo} \ln(\kappa_m p_{im} / p_{ifp}) + \\
&\sum_r \varsigma_r \ln C_{ir} + \ln(1 + \sum_m ((1-\kappa_m)/\kappa_m) R_m * + \sum_n ((1-\theta_n)/\theta_n) S_n *) + \ln(\Omega_{i1} + \Omega_{i2} + \Omega_{i3} t^2)
\end{aligned}
$$

$$
\begin{aligned}
R_m = {} & (\beta_m + \sum_n \delta_{nm} \ln(\theta_n w_n / p_{fp}) + \delta_{30om} \ln(\kappa_{30o} p_{30o} / p_{fp}) + 1/2\beta_{mm} \ln(\kappa_m p_m / p_{fp}) + \sum_o \chi_{om} \ln z_o) / \\
& [(1 + ((1-\kappa_m)/\kappa_m)(\beta_m + \sum_n \delta_{nm} \ln(\theta_n w_n / p_{fp}) + \delta_{30om} \ln(\kappa_{30o} p_{30o} / p_{fp}) + \\
& 1/2\beta_{mm} \ln(\kappa_m p_m / p_{fp}) + \sum_o \chi_{om} z_o) + \\
& (1 + ((1-\kappa_{30o})/\kappa_{30o})(\beta_{30o} + \sum_n \delta_{n30o} \ln((\theta_n w_n)/p_{fp}) + \delta_{30om} \ln((\kappa_m p_m)/p_{fp}) + \\
& 1/2\beta_{30o30o} \ln((\kappa_{30o} p_{30o})/p_{fp}) + \sum_o \chi_{o30o} z_o) + \\
& \sum_n (((1-\theta_n)/\theta_n)(\gamma_n + 1/2\sum_n \gamma_{nn} \ln((\theta_n w_n)/p_{fp}) + \sum_k \gamma_{kn} \ln(\theta_k w_k / p_{fp}) + \\
& \sum_m \delta_{mm} \ln((\kappa_m p_m)/p_{fp}) + \sum_o \chi_{no} z_o)]\kappa_m
\end{aligned}
$$

$$
\begin{aligned}
S_m = {} & -(\gamma_n + 1/2\sum_n \gamma_{nn} \ln(\theta_n w_n / p_{fp}) + \sum_k \gamma_{kn} (\theta_k w_k / p_{fp}) + \sum_m \delta_{mm} \ln(\kappa_m p_m / p_{fp}) \\
& + \sum_o \chi_{on} \ln z_o) / \\
& [(1 + ((1-\kappa_{30o})/\kappa_{30o})(\beta_{30o} + \sum_n \delta_{n30o} \ln((\theta_n w_n)/p_{fp}) + \delta_{30bp} \ln((\kappa_{bp} p_{bp})/p_{fp}) + \\
& 1/2\beta_{30o30o} \ln((\kappa_{30o} p_{30o})/p_{fp}) + \sum_o \chi_{o30o} z_o) + \\
& (1 + ((1-\kappa_{bp})/\kappa_{bp})(\beta_{bp} + \sum_n \delta_{nbp} \ln(\theta_n w_n / p_{fp}) + \delta_{30obp} \ln(\kappa_{30o} p_{30o} / p_{fp}) + \\
& 1/2\beta_{bpbp} \ln(\kappa_{bp} p_{bp} / p_{fp}) + \sum_o \chi_{obp} z_o) + \\
& \sum_n (((1-\theta_n)/\theta_n)(\gamma_n + 1/2\sum_n \gamma_{nn} \ln((\theta_n w_n)/p_{fp}) + \sum_k \gamma_{kn} \ln(\theta_k w_k / p_{fp}) + \\
& \sum_m \delta_{mm} \ln((\kappa_m p_m)/p_{fp}) + \sum_o \chi_{no} z_o)]\,\theta_n \qquad [2]
\end{aligned}
$$

where n, m, o, and r are defined as above, and k = fp, bp, 30o and l = fe, l, 30i, and s.

This quadratic specification of time allows technical efficiency to vary through time, and in a different manner for each producer. The quadratic time term can be interpreted to capture the effects of time invariant technical change. The adjusted shadow profit system [2] is now estimated by applying an iterative seemingly unrelated regression procedure (ITSUR) and adding normally distributed error terms. Subsequently estimates of the ϕ_{it} are created and $\phi_{ot} = \max_i(\phi_{it})$ is defined as the esti-

mated technical efficiency of those farm(s) belonging to the frontier. The technical efficiency of each farm in period t is then estimated as:
$\mathrm{TE}_{it} = \exp(-u_{it})$, where $u_{it} = (\phi_{ot} - \phi_{it})$. Thus according to this approach in each period at least one producer is estimated to be 100% technically efficient, although the identity of the most technically efficient producer(s) can vary through time (Kumbhakar and Lovell, 2000).

By this model specification we are able to measure time-varying pig producer specific technical efficiency, input and output specific allocative efficiency as well as pig producer specific technical change. These measures can then be used to calculate time-varying measures of producer specific Malmquist total factor productivity indexes applying the distance notation based formula given in and following Färe et al., (1994)

$$tfp^{tt}_{it,t+1}(y_{it},x_{it},y_{it+1},x_{it+1}) = \frac{d_i^{t+1}(y_{it+1},x_{it+1})}{d_i^t(y_{it},x_{it})}$$

$$\left[\frac{d_i^t(y_{it+1},x_{it+1})}{d_i^{t+1}(y_{it+1},x_{it+1})} * \frac{d_i^t(y_{it},x_{it})}{d_i^{t+1}(y_{it},x_{it})}\right]^{½} = \mathrm{effch}^{tt}_{it+1} * \mathrm{tch}^{tt}_{it,t+1}$$

[3]

A Bootstrapped Random Effects Panel Tobit Model

To get more empirical evidence on the link between the ban of growth promoters and the development of total factor productivity on farm level finally we apply a random effects panel tobit model. In a random effects model, the unobservable or non-measurable factors differentiating cross-section units are assumed to be best characterised as randomly distributed variables (see e.g. Greene, 2001). The cross-section units of our analysis are the individual pig producers in the respective year of observation. Our regressand is the estimated change in total factor productivity per farm and year following the profit function in equation [2]. We use the change in total factor productivity over time as dependent variable to assure independence with respect to the variance in the explanatory variables as the same regressors were used for the first stage estimation procedure.

The estimated values are in a range between [-1; 1] and consequently we construct the observable left- and right-censored dependent variable TFPch_{it} used in estimation as:
$\mathrm{TFPch}_{it} = \mathrm{TFPch}^*_{it} \text{ if } -1 > \mathrm{TFPch}^*_{it}; 0 \text{ if } \mathrm{TFPch}^*_{it} \le -1; 0 \text{ if } \mathrm{TFPch}^*_{it} \ge 1$.

The random-effects tobit model can then be described as follows:

$$TFPch_{it}^{*} = \beta_0 + \sum_r \varsigma_r C_{ri} + \delta_t t_i + \sum_r \varsigma_{rt} C_{rit} t + \delta_{tt} t_i^{2} + u_{it} + \varepsilon_{it} \qquad [4]$$

where i=1, 2, …, N indexes the pig farms, and t = 1, 2, …, T indexes the time series units, i.e. years of observation. C_{ri} contains explanatory variables r = age, experience, total area, total pigs as well as dummy variables to investigate the effects of the different bans implemented in the years 1995, 1998, and 1999: ban95, ban98, ban99. The variable t as well as t^2 denote the time trend effect, i.e. the share of variance in total factor productivity change devoted to systematic influences over time. Further, the interaction effects of these explanatory variables with time are aimed to be captured by the $C_{rit}t$. Finally the effects of relevant unobservable variables and time-invariant factors characterizing pig farm i for time t are captured by u_{it} whereas the stochastic disturbances for pig farm i are captured by ε_{it} . Since both incorporate randomly distributed stochastic components of the model, the composite error term can be described following a normal distribution i.e. $\omega_{it} = u_{it} + \varepsilon_{it}$ is $N(0,\Sigma)$ where Σ is the variances and the covariance of ω.

We check for the robustness of our model by applying a simple stochastic resampling procedure based on bootstrapping techniques, more specifically the bias corrected bootstrap with the aim to reduce the likely small sample bias in the frontier initial estimates (see e.g. Efron and Tibshirani). This seems to be necessary as our cross-sectional time series sample consists of a limited number of observations.

5. Data and Estimation Procedure

The data for the analysis was provided by the Accounting Statistics Department of the Institute of Food and Resource Economics, a department that collects and maintains a database for 2000 farm units each year. Among this sample are about 220 farms producing weaned (about 30kg) and finisher (about 80kg) pigs. Through the period 1991-2003, an unbalanced rotating panel, stratified random sample of a total of 800 pig farm units with minimum and maximum sampled size being 176 (for 1998) and 266 (for 1994), respectively, was collected. In general, the distribution of the farms in the database represents the national population of farms and the stratification is based on farm size, geographical locations and economic size. For the analytical modelling, a balanced panel for 11 farms for the period of 13 years covered was extracted from the unbalanced rotating panel data. Sample statistics of variables use are provided in table 1.

All prices and monetary values have been equated to 1991 prices. To evaluate the extent to which the subset of the 11 farms represent the 800 farms sampled, prior to the modelling we investigated if the two subsets of data differed in terms of size measured by the number of sows and the output and input prices.

The outlined models are estimated as follows: In a first step the shadow profit system given by [2] is estimated by an iterated seemingly unrelated regression procedure with cross-equation parameter restrictions imposed. Using the estimation of the profit function to calculate the changes in total factor productivity over time in a second step, the random effects tobit model given by [4] is then estimated applying a bootstrap estimation technique based on 500 replications.

Table 1. Definition of variable and sample summary statistics

Variable definitions	Subscripts	Mean	Standard Deviation
Profit			
Net profit DKK' 1000	π	1116	1000
Ln(Net profit)	$\ln \pi$	13.50	1,10
Output prices			
Finisher DKK per 100 kg	*Fp*	1287	85
Breeding pig DKK per N	*Bp*	1358	199
30kg output pig DKK per N	*30o*	439	53
Input prices			
Feed DKK per 100 kg	*Fe*	148	7
Labour DKK per hour	*L*	94	11
30kg input DKK per N	*30i*	450	17
Sow DKK per N	*S*	1160	45
Quasi inputs			
Veterinary expenses DKK' 1000	*Vet*	176	121
Ln(Veterinary expenses)	*Vet*	11.81	0,77
Capital DKK' 1000	*Cap*	813	620
Ln(Capital)	*Cap*	13.31	0,79
Control variables			
Farmers age (years)	*Age*	44	4
Farming experience (years)	*Exp*	20	5
Regional index	*Reg*	7.45	2.54
Total cultivated land (ha)	*La*	97	60
Piglets produced (N)	*Tp*	6160	8151
Home consumption (N)	*Hp*	2.20	2.27
Family size	*Fam*	1.26	0.44
Dummy other livestock (%)	*Lp*	9	-
Dummy 7kg pigs sold (%)	*7pl*	4	-
Profit shares			
Profit share of finisher		5.18	2.71
Profit share of breeding		0.27	0.28
Profit share of 30kg output pig		0.36	0.23
Profit share of feed		2.96	1.77
Profit share of labour		0.74	0.55
Profit share of 30kg input pig		2.65	1.52
Profit share of Sow		0.41	0.25
Size and data			
Farm size (Sows)		241	29
Observations (11 farms x 13 years)		143	-

6. Results and comments

The individual model and parameter estimates are given by table A1 and A2 in the appendix. All model specifications are significant at a satisfying statistical level. For the shadow profit model more than 70% and for the bootstrapped tobit model more than 50% of all estimated parameters are statistically significant. The F-value for the profit model is significant at the 1% level. All estimated shadow price parameter values are shown to be statistically significant. The overall goodness of fit for the random effects tobit model is indicated by the highly significant log-likelihood value as well as the Wald test performed.

Allocative Efficiency, Shadow Prices and impacts on the ban

The essence of the profit model specification in this paper is to estimate the shadow price parameter coefficients κ for outputs and θ for inputs needed to estimate the allocative efficiencies, which are all summarised in Table 2. The shadow price coefficients are all statistically significant. The value for $\kappa < 1$ ($\kappa > 1$) implies that under- (over) production of output *k* (relative to the numeraire) and $\theta < 1$ ($\theta > 1$) implies that the farm mistakenly employs more (less) of input *j* (relative to the *k*th output). As noted earlier the value of 1 for parameters, κ and θ, suggests full allocative efficiency. To express the allocative efficiency relative to the frontier value of 1, the values of κ and θ, greater than one are scaled down between zero and one to reflect the output and input allocative efficiencies. The coefficients (without scaling) multiplied by the corresponding output and input prices reflect the shadow prices given by equation [1] earlier (see table 2).

Table 2. SYSTEMATIC ALLOCATIVE EFFICIENCIES, MEAN SHADOW AND MARKET PRICES

	ALLOCATIVE EFFICIENCY[1]	COEFFICIENTS κ and θ	SHADOW PRICE (SAMPLE MEAN) DKK	MARKET PRICE (SAMPLE MEAN) DKK
OUTPUT 1: FINISHER (KG)	1	1	13	13
OUTPUT 2: BREED (N)	0.751	1.332***	1809	1358
OUTPUT 3: 30S (N)	0.974	0.974***	428	439
INPUT 1: FEED (100 KG)	0.829	1.206***	178	148
INPUT 2: LABOR (H)	0.399	2.506***	235	94
INPUT 3: 30S (N)	0.256	3.902***	1757	450
INPUT 4: SOWS (N)	0.338	2.961***	3443	1163

1: Allocative efficiency estimates are parameter based: no min and max values are available; *,**,*** significance at the 10, 5, and 1% level; κ and θ are for outputs and inputs respectively; N: Number; DKK: Danish Kroner rounded, where 1 DKK = 0.31 Euro.

By comparing the allocative efficiencies estimated relative to the price of finisher pigs, it becomes clear that due to the shadow prices, the average pig producer in the sample produces more breeding pigs and fewer 30kg output pigs as they orient production decisions towards the shadow prices. Similarly, relative to the price of finisher pigs on the inputs side; it is evident that the average pig farmer uses fewer inputs than indicated by the observable market prices.

The κ estimate, 1.332 suggests that the breeder output is over supplied to the market relative to the supply of finisher pigs (numeraire). That is, for farms to increase revenue and profit, given the existing input set, they need to supply more finisher pigs to the market at the expense of breeding pigs. This is because the shadow price value suggests that reducing the sale of the breeding animal by one will increase profit by 1805 DKK.

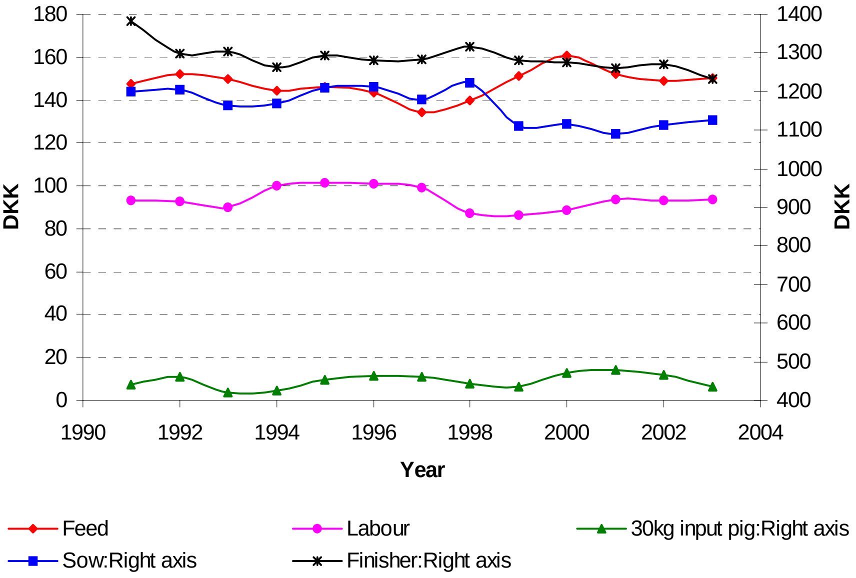
On the input side, as the ratios of $\theta_{feed}/\theta_{labour,\ 30i,\ sows}$ are less than unity (i.e. 0.49, 0.31 and 0.41 for labour, 30kg input pigs (30i) and sows (s), respectively), it is inferred that the input of feed is over-utilised relative to the inputs of labour, 30kg input pigs (30i) and sows (s). Thus for farms to decrease total cost, by estimated shadow prices and given the output set, the farms should use more sows and labour to produce more 30kg input pigs. A reduction in feed use implies that farms should increase the use of other inputs and this should subsequently imply increasing the supplies of 30kg output (30o) pigs and finisher-pigs.

Interpreting the allocative coefficients in terms of the impact of the ban on the use of AGP, the over reaction for breeder supply relative to finisher output suggests that the breeder output is being marketed as a substitute for finisher sales. The sales have been possible due to the demand from the German market where prices offered per kg are more than 15% higher. The utilization of the German market is probably a strategy to avoid the excessive piglet production with subsequent need for antimicrobials. In the pig producing sector, the need for antimicrobials is generally higher for weaned relative to finisher pig production (DANMAP, 2004).

On the input side, feed turns out to be a substitute for 30kg input pig, sow and labour inputs. It is notable that the use of AGP has a direct relevance for feed, 30kg pig and sow inputs and an indirect relevance for labour input (for care taking). The relatively small reaction revealed for 30kg input pig and the subsequent allocative inefficiencies relative to feed input are almost certainly a direct result of the over reaction for breeding pig sales. Thus the available breeding capacity is not utilised to take full advantage of the increasing feed purchases despite the low prices for sows and labour after the ban. Note that total feed cost is expected to increase because of the anticipated decrease in feed efficiency (i.e. without AGP). However, as noted earlier, relative to finisher pig prices, the average pig farmer uses less feed input than indicated by the observable market price for feed. Thus the inefficiencies reflected by the underutilization of inputs are also reflected by an inability of farmers to take advantage of the low price developments, especially for sow and labour inputs after the ban.

The general arguments against the ban have been the expectation that total feed cost is expected to increase because of the anticipated decrease in feed efficiency. The price for 30kg input pig and piglets is expected to increase due to anticipated high mortality and morbidity and possibly low sow efficiency. Under these conditions, the input prices increases should then lead to an increase in retail prices as the excess producer costs are transferred to consumers. However, during the period, the opposite has been the case. Prices paid to producers for finishers fell during the post ban period (Figure 2).

Figure 2. Input prices and finisher output price 1991-2003



The feed price increases shown in Figure 2 reflect more the extra increase in production. As also shown in Figure 2, labour and sow prices fell after the ban was imposed. The price of 30kg input pigs reflects its characteristic moderate fluctuation and thus relatively constant. Sow efficiency, i.e. more piglets per sow, is known to have increased during the post ban period.

The above evidence ironically suggests that farmers overreacted to fears of increased input costs as they based their production decision on the shadow prices. This turns to be unproductive, as is reflected by the allocative inefficiencies.

Technical Efficiency, Technical Change and Total Factor Productivity

The average estimates of technical efficiency (TE) show some variability that could be expected in pig production due to differences in management, farming experience and production structure (National Research Council 1999, Hayes et al. 1999, Hayes et al. 2002). Only one producer had TE peaking and falling after the ban. Farms with the characteristic this producer have less chance of surviving and have to consider market exit. However, the majority of the rest either experienced enhanced TE during and after the ban or had TE constant after peaking before the ban. These farms only need to improve their management. Assuming that the 11 farms are benchmarks for all farms producing weaned pigs at 30kg and finishers pigs at 80kg (i.e. the population of 4300), it is reasonable to suggest that factors other than discontinuing use of AGPs may have resulted in the different impacts for different producers.

The average calculated estimates of TFP shows that it is to a large extent determined by the technical efficiency and not technical change. Technical change is almost the same for all farms except for the single producer with TE peaking and falling after the ban. The adjustment required for not using AGP should be expected to result in a greater variability and impact negatively on technical change and this seems not to be the case.

Factors for the Change in Total Factor Productivity

Table 3 finally summarizes the effects of different policy e.g. the ban, and farm related factors on the development of total factor productivity over time.

Table 3. Estimated factor effects on Total Factor Productivity change

FACTOR	ESTIMATE	SIGNIFICANCE[1]
Age of Farmer	+ 2.14E-03	***
Farming Experience	-2.32E-03	***
Total Land Cultivated	-2.78E-04	***
Total Pigs Produced	-9.86e-08	NS
Ban in 1995	*+ 5.89E-03*	NS
Ban in 1998	*-5.14E-03*	NS
Ban in 1999	*+ 0.063*	NS
Time Trend	-6.41E-03	*
Age x Time Trend	+ 4.36E-05	NS
Experience x Time Trend	+ 1.33E-04	NS
Land x Time Trend	+ 9.88e-06	**
Total Pigs x Time Trend	-1.82e-07	***
Ban95 x Time Trend	*-1.05E-03*	NS
Ban98 x Time Trend	*+ 6.43E-04*	NS
Ban99 x Time Trend	*-5.48E-05*	NS
Time Trend x Time Trend	-1.36E-04	NS

1: *, **, ***: significance at 10, 5, 1 % levels.; NS is non-significant

From table 3, the lack of significance in estimated effects of the ban parameters for 1995, 1998 and 1999 suggests that the ban or the discontinuous use of AGPs among weaned 30kg and finisher pig producers has had no effect on their estimated total factor productivity. That is the discontinuous use of AGP is indifferent to the economic efficiency of pig production. This is partly due to the substitutability among outputs and the exceptional over reaction to input prices. The cost minimization that took place during the post ban period was enough to adjust to the eventual negative impact of the ban but was too much to allow for improvements in allocative efficiencies of production. The negative time trend suggests that the magnitude of the change in total factor productivity decreased during the period as result of the low relative improvement in technical efficiency (table 3).

Other results from equation [4] suggest that increasing age is correlated with increasing total factor productivity among this group of farms. The negative coefficient for experience suggests that farmers who took over ownership of their farms the last few years turn out to have high productivity compared to farmers with longer ownership. We do not have a direct explanation for this finding but it can be deduced that farmers with less experience are more market price oriented in their production decisions compared to the more experienced ones.

It is noted that the shift parameter coefficients for the periods of the bans in the profit function [2] suggest that on average, profit was both negatively and positively affected. This result seems to reflect the short run effect of the discontinuous use of AGP, which in turn shows that while the profit function describes an underlying production structure, the total factor productivity captures the optimal combination of outputs and inputs.

7. Discussion and Concluding Remarks

The final section considers the data, limitations and results in comparison to work of other researchers, and provides implications of our findings and concluding remarks.

The approach used in this paper is based on a shadow price profit system formulated and estimated to evaluate the adjustment made by farmers during the post AGP ban era. We also investigated if the ban had negative implications for 30kg weaned and finisher pig producers. In arriving at our results, we use data for only 11 farms with panel of 13 years. One question that arises is whether the 11 farms fully represent the 800 farms sampled through the years and thereby the population of 4300 farms producing 30kg weaned and 80kg finisher pigs. Investigation of the available data suggested no differences in output and input prices faced by the subset of 11 farms and the other farms in the sample. However, it should be noted that the average farm size measured by the number of sows is higher for the subset of 11 farms but the rate of increase in the farm size during the period is lower compare to the rest of the sampled farms. This may limit the generalization of our results.

We partly used substitutability among output and inputs to explain why the ban has no effect on total factor productivity changes. However one can argue that substitutability should be seen in terms of an increasing use of therapeutic antimicrobials to replace the need for AGPs. As generally known, a largest share of the increase in the post ban consumption of therapeutic antimicrobials is in the pig sector. On one hand it is argued that the increase is associated with discontinuous use of AGP. On the other hand, others argue that the increase is due to the appearance of a new viral infection, Post-weaning Multi-systemic Wasting Syndrome (PMWS), which was first diagnosed in 2000 within specific regions (DANMAP, 2004). In this case, the increase in consumption of therapeutic antimicrobials was necessary to guard against eventual bacterial infections due to reduced immunization on the farms infected with PMWS.

It is notable that the rate of increase in the consumption of therapeutic antimicrobials since the year 2001 is not unusual. The rate of increase since the year 2001 is lower than the increasing rate observed during 1990 through 1994, i.e., just before the first ban was imposed. During the period 1990 to 1994, the consumption of AGP also increased. This suggests that the increased consumption after the year 2001 is not compensating for discontinuous use of AGP but rather for the unusual fall in therapeutic use during period of the ban i.e. the years 1995 through 2000 (see Figure 1), in addition to the effects of treatment for PMWS.

Comparing our results to those of other researchers, Mann and Paulsen (1976), Wade and Barkley (1992), Buhr and Hayenga (1994), Mathews (2001), suggested that producers would gain due to increase market prices. We found no effect of the bans on total factor productivity changes, but did find that producers reacted to the positive shadow prices of substituting toward breed output. The shadow price for the substituting toward breeder output is 1.33 times greater than the market price (table 2). The shadow price effect seems to reflect the impact of the high prices offered in Germany for Danish exports of live animals, which was increasing during the period analysed (Danske Slagterier, 2004). But the German prices were less than expressed by the shadow prices. The shadow price effect could also reflect producer reactions to increasing environmental requirements for a balance between acreage land and head size. Thus our results suggest that economic efficiency is determined by factors other than restrictions on the use of AGPs, including producer input and output choices.

It is relevant to note that other researchers (Hayes et al., 1999, Hayes et al. 2002, Brorsen et al. 2002) who anticipated producer losses ascertained that the losses would be short term effects. The short-term impact is captured by the positive and negative estimates reflected by the ban shifters in the profit function. This is to be expected in a dynamic and competitive production sector. Hayes et al. (1999, 2003) and McBride, Key (2006) and Mathews (2001) suggest that the ban would likely have greater negative impacts on inefficient producers compared to the ones with higher efficiency. This seems to be the case for producers represented by the farm in our analysis such that for these farms, technical efficiency falls sharply after its peak prior to the imposition of the first ban in 1995. The results suggest that inefficient producers incur relatively more of the losses in the industry and will struggle to stay in business after a ban.

Prior to this paper, an earlier Danish study by Jacobsen, Jensen and Lawson (2006) investigated the sector and economy-wide effect of terminating the use of AGP in Denmark using the Agricultural Applied General Equilibrium model. Their results suggested that pig production output would decrease moderately by 0.1% relative to the baseline production increase of 30.5% over the 15 years period of their analysis. However, they also reported that the decrease in production would benefit some other sectors of economy. Among these sectors is the poultry industry, which is also covered by the discontinued use of APG. It is important to note that the paper by Jacobsen, Jensen and Lawson (2006), focuses on cost estimation, which involve other sectors of the economy. In contrast, our paper focuses on economic efficiency defined

by technical and allocative efficiencies and total factor productivity changes for a group of pig producers who represent 43% of the total pig producer population.
In the economic literature it has been suggested that consumers will lose as a result of the discontinuous use of AGP through higher prices. Hayes et al. (2001) estimated consumer expenditure to increase by $ 11 per family of four. Jacobsen, Jensen and Lawson (2006) reported that the per capita cost for the consumer is DKK 68, which is about US $ 12 at the current exchange rate (US $1 = 5.5 DKK). Although consumers are not the focus of this paper, it is noted that the price increase is what consumers will be required to pay to cover the additional costs incurred (and receive the benefits) from being free from antibiotic residues and possible transfer of resistance attributed to antibiotic use in livestock production. Lusk, Norwood and Pruitt (2006) estimate US consumers would be willing to pay a premium (up to 76%) for antibiotic-friendly pork and assign a positive value to the indirect benefit of reduced risk from possible transfer of antibiotic resistance. Clearly the increase in the estimated consumer prices should be within an affordable range for consumers.

With the above caveats in mind, we found that farmers react to shadow prices when making production decisions. In our case the ban on the use antimicrobial growth promoters created the condition for pig farmers to intensify cost minimisation efforts to counter an eventual input price increases. At the same time they search for high prices for their outputs, which were offered for breeding pigs in the export market for live animals. But in each case they under or over reacted to input and output prices respectively and thus were unable to utilise the low input prices to increase the production of 30kg weaned and finisher pigs. The implication for farmers is that they have not been able to capture extra profit embodied in efficient allocation on input and outputs. By farmers not taking advantage of the potential to increase production of 30kg weaned and finisher pig outputs, the result has been lower capacity utilisation at slaughterhouses. We found no impact of the ban on total factor productivity over time as producers' made adjustment in the combination of outputs. Instead, farmers shifted emphasis from producing finishers and 30kg weaned pigs to producing breeding pigs and substituting feed input efficiency for labour, sows and 30kg input pig inputs.

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Appendix

Table A1. **PARAMETER ESTIMATES SHADOW PROFIT FRONTIER SYSTEM**

PARAMETER	ESTIMATE	STERR	PARAMETER	ESTIMATE	STERR
β_0	-1.410	0.145***	γ_{fe30i}	-3.791	2.519
β_{bp}	1.804	0.015***	γ_{fes}	-0.284	0.389
β_{30out}	-1.578	0.294***	γ_{l30i}	-2.335	4.420
γ_{fe}	-1.690	0.080***	γ_{ls}	0.511	8.392
γ_l	8.405	2.252***	γ_{30is}	0.044	2.125
γ_{30i}	-4.579	1.373***	χ_{vet}	4.001	1.352***
γ_s	-3.970	3.151	χ_{cap}	-1.271	1.692
β_{bpbp}	2.546	0.671***	χ_{vetvet}	-9.339	6.355*
β_{30o30o}	-10.446	0.485***	χ_{capcap}	-3.678	4.625
γ_{fefe}	-3.357	0.074***	χ_{vetcap}	10.461	12.478
γ_{ll}	-2.667	0.017***	χ_{vetbp}	-0.745	1.992
γ_{30i30i}	9.527	3.947**	χ_{vet30o}	-13.213	15.337
γ_{ss}	-0.316	1.188***	χ_{vetfe}	-2.365	4.075
δ_{bp30o}	0.461	17.820	χ_{vetl}	24.606	1.433***
δ_{bpfe}	7.358	2.332***	χ_{vet30i}	-19.899	1.268***
δ_{bpl}	-3.279	24.514	χ_{vets}	-17.229	24.436
δ_{bp30i}	4.096	12.570	χ_{capbp}	-8.872	1.562***
δ_{bps}	0.279	0.024***	χ_{cap30o}	12.889	1.371***
δ_{30ofe}	-17.728	0.016***	χ_{capfe}	1.746	4.145
δ_{30ol}	18.598	4.064***	χ_{capl}	14.029	0.705***
δ_{30o30i}	-24.994	11.198*	χ_{cap30i}	-15.545	1.409***
δ_{30os}	-7.034	18.932	χ_{caps}	-12.475	3.596***
γ_{fel}	-0.321	6.488	ς_{hp}	-0.228	0.586

ς_{age}	16.506	0.065***	$\Omega_{3\,farm3}$	0.008	2.19E-03
$\varsigma_{\exp}$	0.387	0.164	$\Omega_{1\,farm4}$	-6.131	2.18E-03***
ς_{reg}	1.893	0.290***	$\Omega_{2\,farm4}$	0.747	3.12E-04***
ς_{la}	-1.738	0.188	$\Omega_{3\,farm4}$	-0.121	2.19E-03***
ς_{tp}	-0.075	0.024***	$\Omega_{1\,farm5}$	0.132	2.18E-03***
ς_{lp}	4.412	0.061**	$\Omega_{2\,farm5}$	-0.151	3.12E-04***
$\varsigma_{7\,pl}$	-3.497	0.053***	$\Omega_{3\,farm5}$	0.002	1.91E-03
ς_{ban95}	-0.686	0.365**	$\Omega_{1\,farm6}$	-1.536	1.91E-03***
ς_{ban98}	1.567	0.073***	$\Omega_{2\,farm6}$	-0.027	2.39E-04***
ς_{ban99}	-1.322	0.449***	$\Omega_{3\,farm6}$	0.005	2.39E-04***
ς_{fam}	2.012	0.449***	$\Omega_{1\,farm7}$	1.239	1.91E-03***
κ_{bp}	1.332	0.015***	$\Omega_{2\,farm7}$	0.134	2.39E-04***
κ_{30o}	0.974	0.209***	$\Omega_{3\,farm7}$	-0.021	0.015
θ_{fe}	1.205	0.191***	$\Omega_{1\,farm8}$	0.271	1.92E-03***
θ_{l}	2.507	0.260***	$\Omega_{2\,farm8}$	-0.027	2.39E-04***
θ_{30i}	3.902	0.625***	$\Omega_{3\,farm8}$	-0.012	1.91E-03***
θ_{s}	2.961	0.148***	$\Omega_{1\,farm9}$	5.449	1.92E-03***
$\Omega_{1\,farm1}$	-4.152	0.543***	$\Omega_{2\,farm9}$	-0.251	1.88E-04***
$\Omega_{2\,farm1}$	-0.049	0.364	$\Omega_{3\,farm9}$	-9.61E-03	1.71E-03***
$\Omega_{3\,farm1}$	0.009	0.015	$\Omega_{1\,farm10}$	-3.771	1.70E-03***
$\Omega_{1\,farm2}$	-8.099	2.18E-03***	$\Omega_{2\,farm10}$	0.082	1.88E-04***
$\Omega_{2\,farm2}$	0.169	3.12E-04***	$\Omega_{3\,farm10}$	-3.53E-03	1.71E-03*
$\Omega_{3\,farm2}$	-5.97E-03	1.91E-03**	$\Omega_{1\,farm11}$	7.436	1.70E-03***
$\Omega_{1\,farm3}$	-5.662	2.19E-03***	$\Omega_{2\,farm11}$	-0.603	1.89E-04***
$\Omega_{2\,farm3}$	-0.168	2.58E-06***	$\Omega_{3\,farm11}$	0.014	1.88E-04***
ADJR^2	0.382				
F-VALUE	5.94E+07				
P>|F|	0.0000				

*,**,***: significance at 10,5, and 1 % -level.

TABLE A2. PARAMETER ESTIMATES BIAS CORRECTED BOOTSTRAPPED RANDOM EFFECTS TOBIT MODEL

Parameter	Estimate	StErr	Bias Corrected Conf. Interval
β_0	0.029	0.038	[-0.061; 0.091]
ς_{age}	2.14E-03	9.15E-04***	[6.63E-04; 4.14E-03]
$\varsigma_{\exp}$	-2.32E-03	9.43E-04***	[-3.35E-03; 3.19E-03]
ς_{area}	-2.78E-04	1.01E-04***	[-4.45E-04; -3.40E-05]
ς_{tp}	-9.86e-08	1.80e-06	[-4.11e-06; 2.43e-06]
ς_{ban95}	5.89E-03	0.023	[-0.039; 0.046]
ς_{ban98}	-5.14E-03	0.039	[-0.167; 4.70E-03]
ς_{ban99}	0.063	0.125	[-0.182; 0.309]
δ_t	-6.41E-03	4.95E-03*	[-0.016; 2.34E-03]
ς_{aget}	4.36E-05	8.76E-05	[-6.0E-05; 4.81E-04]
$\varsigma_{\exp t}$	1.33E-04	1.33E-04	[-4.50E-04; 3.01E-04]
ς_{areat}	9.88e-06	5.16e-06**	[2.43e-06; 2.04E-05]
ς_{tpt}	-1.82e-07	1.16e-07***	[-5.10e-07; -6.25e-09]
ς_{ban95t}	-1.05E-03	5.19E-03	[-0.010; 9.18E-03]
ς_{ban98t}	6.43E-04	5.31E-03	[-1.87E-03; 0.022]
ς_{ban99t}	-5.48E-05	4.49E-03	[-0.010; 9.66E-03]
δ_{tt}	-1.36E-04	7.49E-04	[-1.73E-03; 1.15E-03]
ρ	0.851	0.027***	[0.792; 0.897]
σ_u	0.014	1.09E-03***	[0.011; 0.016]
σ_e	5.73E-03	3.91E-04***	[4.97E-03; 6.50E-03]
LL	389.98141		
Wald Chi^2(15)	1354.94***		
Replications	500	N = 108	

*,**,***: significance at 10, 5, and 1 % -level.

Table A3. Relative Technical Efficiencies (relative to frontier farm#11)

Year	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11
1991	0.33	0.23	0.28	0.29	0.50	0.43	0.58	0.52	0.85	0.35	1
1992	0.35	0.24	0.29	0.32	0.52	0.46	0.61	0.54	0.87	0.37	1
1993	0.37	0.26	0.31	0.34	0.55	0.48	0.65	0.57	0.89	0.39	1
1994	0.39	0.28	0.32	0.36	0.57	0.51	0.68	0.59	0.91	0.42	1
1995	0.41	0.30	0.33	0.36	0.59	0.53	0.71	0.61	0.92	0.44	1
1996	0.43	0.31	0.34	0.36	0.60	0.56	0.74	0.63	0.93	0.46	1
1997	0.45	0.33	0.35	0.34	0.63	0.58	0.76	0.64	0.93	0.48	1
1998	0.47	0.34	0.37	0.32	0.64	0.61	0.77	0.65	0.93	0.50	1
1999	0.50	0.36	0.38	0.29	0.65	0.64	0.78	0.66	0.93	0.52	1
2000	0.52	0.37	0.39	0.26	0.67	0.66	0.79	0.67	0.92	0.54	1
2001	0.54	0.39	0.40	0.22	0.68	0.69	0.79	0.67	0.90	0.56	1
2002	0.57	0.40	0.41	0.19	0.69	0.71	0.78	0.67	0.88	0.57	1
2003	0.59	0.41	0.42	0.15	0.70	0.74	0.77	0.66	0.86	0.59	1
Average	0.46	0.32	0.35	0.29	0.62	0.58	0.72	0.62	0.90	0.48	1

Table A4. Total Factor Productivity (relative to frontier farm)

Year	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11
1991	0.3348	0.2266	0.2838	0.2557	0.5043	0.4337	0.5649	0.5098	0.8389	0.3473	1
1992	0.3533	0.2434	0.2959	0.281	0.5256	0.4581	0.6017	0.5357	0.8627	0.3699	1
1993	0.3725	0.2602	0.308	0.3006	0.5464	0.483	0.6363	0.56	0.8829	0.3926	1
1994	0.3924	0.2772	0.3202	0.313	0.5667	0.5084	0.668	0.5823	0.8993	0.4152	1
1995	0.413	0.294	0.3324	0.3173	0.5862	0.5341	0.6964	0.6023	0.9116	0.4375	1
1996	0.4342	0.3106	0.3446	0.313	0.6049	0.56	0.7208	0.6197	0.9196	0.4594	1
1997	0.4505	0.3267	0.3568	0.3006	0.6356	0.5861	0.7408	0.6342	0.9232	0.4807	1
1998	0.4787	0.3424	0.369	0.2809	0.6393	0.6124	0.7559	0.6457	0.9224	0.5011	1
1999	0.5018	0.3573	0.3811	0.2555	0.6548	0.6386	0.7658	0.6538	0.9172	0.5206	1
2000	0.5256	0.3714	0.393	0.2263	0.6689	0.6647	0.7703	0.6586	0.9076	0.5389	1
2001	0.55	0.3844	0.4048	0.195	0.6817	0.6906	0.7694	0.6599	0.8939	0.5558	1
2002	0.5749	0.3963	0.4163	0.1636	0.6929	0.7162	0.7629	0.6578	0.8761	0.5712	1
2003	0.6005	0.4069	0.4277	0.1336	0.7026	0.7413	0.7512	0.6521	0.8545	0.585	1
Average	0.4485	0.3159	0.3505	0.2669	0.6089	0.5738	0.7044	0.61	0.8963	0.4659	1

Table A5. Total Factor Productivity Change (relative to frontier farm)

Year	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11
1991/92	0.0554	0.0737	0.0423	0.0991	0.0423	0.0564	0.065	0.0509	0.0284	0.0651	0
1992/93	0.0544	0.0694	0.0409	0.0698	0.0397	0.0544	0.0575	0.0453	0.0234	0.0613	0
1993/94	0.0534	0.065	0.0396	0.0413	0.0371	0.0525	0.0499	0.0398	0.0185	0.0576	0
1994/95	0.0524	0.0607	0.0382	0.0135	0.0345	0.0505	0.0425	0.0343	0.0136	0.0538	0
1995/96	0.0514	0.0564	0.0368	-0.0135	0.0319	0.0486	0.0351	0.0289	0.0088	0.05	0
1996/97	0.0374	0.0521	0.0354	-0.0398	0.0507	0.0467	0.0277	0.0234	0.0039	0.0463	0
1997/98	0.0625	0.0478	0.0341	-0.0654	0.0058	0.0447	0.0204	0.018	-0.0009	0.0425	0
1998/99	0.0484	0.0436	0.0327	-0.0903	0.0242	0.0428	0.0131	0.0127	-0.0057	0.0388	0
1999/00	0.0474	0.0394	0.0313	-0.1145	0.0216	0.0409	0.0059	0.0073	-0.0104	0.0351	0
2000/01	0.0464	0.0351	0.0299	-0.1381	0.0191	0.039	-0.0012	0.002	-0.0152	0.0314	0
2001/02	0.0454	0.0309	0.0286	-0.1611	0.0165	0.037	-0.0083	-0.0033	-0.0199	0.0277	0
2002/03	0.0444	0.0268	0.0272	-0.1835	0.014	0.0351	-0.0154	-0.0086	-0.0246	0.0241	0
Average (%)	4.99	5.01	3.48	-4.85	2.81	4.57	2.43	2.09	0.17	4.45	0

Documentation for Modelling

To infer on the impact of the ban on the use of AGP at the farm level, we evaluated shadow prices, technical and allocative efficiencies, as well as total factor productivity of the production units.

Shadow Prices

According to the common concept of shadow prices: when determining the optimal input and output vectors, farms compare the benefits of using an additional unit of each input to its cost, the purchase (or ‘observed’) input price, and compare the benefits of producing an additional unit of each output to its profit, the selling (or ‘observed’) output price. Depending on whether a primal or a dual approach is taken, these marginal benefits - referred to as the shadow price of the input and the shadow price of the output, respectively - can be measured either in terms of the input’s and output’s value marginal product, or as the reductions in expenditures on other inputs that can be achieved by using one additional unit of the input as well as the increase in revenue that can be achieved by producing one additional unit of the output. In the absence of market distortions, the optimal amounts of input use and output are intuitive: use an input up to the point where the shadow price and the purchase price are equivalent and produce an output up to the point where the shadow price and the selling price are equivalent. If market distortions are present, farms are unable to equate their shadow prices to the undistorted input and output prices. Due to the vast literature on shadow prices (for an overview see e.g. Khumbhakar and Lovell 2000), non-observable shadow price ratios have to be considered as the relevant ones for producer decisions in distorted markets. The divergence between the analysed (i.e., estimated) shadow prices and the observed market prices can be interpreted as the sum of allocative inefficiency due to the prevalence of various market constraints, as well as optimization failure by the farm management. Different approaches to model this divergence can be found in the literature: One method consists of additively translating observed prices to create shadow prices (see Kumbhakar and Lovell 2000). Alternatively, shadow prices can be modeled by multiplicatively scaling observed prices into shadow ones (Lau and Yotopoulos 1971). We follow the latter approach here and define the relationship between the normalized shadow input and output prices w^*, p^* and the normalized market prices w, p as

$$w^*_j = \theta_j w_j \qquad p^*_k = \kappa_k p_k \qquad [1]$$

where θ_j and κ_k are (non-negative) price efficiency parameter coefficients and j, k indicate input j and output k respectively. If no market restrictions as well as management failure are the case then $\theta_j = 1,\ \kappa_k = 1$. If market distortions restrict optimizing behaviour then $\theta \geq 0$ and $\theta \neq 1$, $\kappa \geq 0$ and $\kappa \neq 1$. Consequently, a pig producing farm can be regarded as allocatively efficient with respect to observed market prices only if such observed prices reflect the farmer's opportunity cost with respect to inputs and outputs. It is important to note that the price efficiency parameters θ_j and κ_k may reflect both effects of market distortions as well as optimization errors. The shadow price parameters, θ_j and κ_k following equation [1] imply that the ratio of the shadow price of input or output to its actual price is constant.

Shadow Profit Distance Model

In a first modelling step we formulate a shadow profit distance function based on the aforementioned concept of shadow prices. Following an output oriented approach with respect to the measurement of technical efficiency, observed normalized profit is

$$\frac{\pi}{p_1} = y_1 + \sum_{m>1}\left(\frac{p_m}{p_1}\right)y_m - \sum_n\left(\frac{w_n}{p_1}\right)x_n = \phi\pi\left[(p,w)^*,\beta\right]\left\{1+\sum_m\left(\frac{1-\kappa_m}{\kappa_m}\right)R^*_m + \sum_n\left(\frac{1-\theta_n}{\theta_n}\right)S^*_n\right\} \qquad [2]$$

where $\pi = \left[(p,w)^*,\beta\right]$ is the normalized shadow profit function, $(p,w)^* = \left[\kappa_m(p_m/p_1),(\theta_n/\phi),(w_n/p_1)\right]$ is a normalized shadow price vector incorporating output oriented technical inefficiency $0 < \phi \leq 1$ and systematic allocative inefficiency (κ_m, m = 2, …, M and θ_n, n = 1, …, N). The corresponding output and input shadow profit shares (R_m and S_n) are respectively

$$R_m^* = \frac{\partial \ln \pi\left[(p,w)^*;\beta\right]}{\partial \ln p^*_m}, \text{ m} = 2, ..., \text{M} \qquad [3]$$

$$S_n^* = \frac{\partial \ln \pi\left[(p,w)^*;\beta\right]}{\partial \ln w^*_m}, \text{ n} = 1, ..., \text{M} \qquad [4]$$

Note that estimation could be also based on the system of observed output supply and input demand equations. Observed normalized profit is related to shadow normalized profit by

$$\ln\frac{\pi}{p_1} = \ln \pi\left[(p,w)^*,\beta\right] + \ln H + \ln \phi \qquad [5]$$

where

$$H = \left\{ 1 + \sum_m \left(\frac{1-\kappa_m}{\kappa_m} \right) R_m^* + \sum_n \left(\frac{1-\theta_n}{\theta_n} \right) S_n^* \right\} \qquad [6]$$

and the observed profit shares can be related to the shadow profit shares simply by

$$R_m = \frac{p_m y_m}{\pi} = \frac{1}{H} * \frac{1}{\kappa_m} R_m *, m = 2, \ldots, M \qquad [7]$$

$$S_n = \frac{w_n x_n}{\pi} = -\frac{1}{H} * \frac{1}{\theta_{\mathrm{n}}} \mathrm{S}_{\mathrm{n}} *, n = 1, \ldots, N \qquad [8]$$

whereas producer invariant output oriented technical efficiency is measured by the additive parameter ϕ. Well known for its empirical accuracy as well as functional flexibility the translog functional form is used here. A translog normalized shadow profit function is given by

$$\ln \frac{\pi}{p_1} \left[(p, w)*; \beta \right] = \beta_0 + \sum_m \beta_m \ln p_m * + \sum_n \gamma_n \ln w_n * + \frac{1}{2} \sum_j \sum_m \beta_{jm} \ln p_j * \ln p_m * +$$
$$\frac{1}{2} \sum_k \sum_n \gamma_{kn} \ln w_k * \ln w_n * + \sum_m \sum_n \delta_{mn} \ln p_m * \ln w_n *$$
$$[9]$$

and the associated shadow profit shares can be written as

$$R_m * = \beta_m + \sum_j \beta_{jm} \ln p_j * + \sum_n \delta_{mn} \ln w_n *, \ m = 2, \ldots, M \qquad [10]$$

$$S_n * = \gamma_n + \sum_k \gamma_{kn} \ln w_k * + \sum_m \delta_{mn} \ln p_m *, \ n = 1, \ldots, N \qquad [11]$$

This system of equations to be estimated consists then of

$$\ln \frac{\pi}{p_1} = \ln \pi \left[(p, w)*; \beta \right] + \ln H + \ln \phi \qquad [12]$$

$$R_m = \frac{R_m *}{H * \kappa_m}, m = 2, \ldots, M \qquad [13]$$

$$S_n = \frac{-S_n *}{H * \theta_n}, n = 1, \ldots, N \qquad [14]$$

by simply using equations [9], [6], [10] and [11]. As we have only observed prices for the variable inputs feed, labor, 30kg pigs, and sows, we treat the remaining input values for veterinary services and capital, as quasi-fixed, thus including the relevant quantity in the shadow cost function instead of its price (see also e.g. Morrison 1988 and Morrison and Schwartz 1996). For our pig production model we use the outputs m = finisher pigs (fp), breeding pigs (bp) and 30kg final pigs (30o) whereas the variable inputs n = feed stuff (fe), labor (l), 30kg input pigs (30i), and sows (s). We further incorporate the quasi-fixed inputs o = veterinary expenses (vet) and capital (cap) as well as the following control variables: r = age of the farmer (age), farming experience (exp), regional location of the farm (reg), total land cultivated (la), total pigs produced (tp), number of pigs used for home consumption (hp), family size (f) and the binary dummy variables livestock production (lp), selling of 7kg piglets (7pl). We normalize the profit system by the output finisher pigs, the equation system for estimation is then

$$
\begin{aligned}
\ln \pi = {} & \beta_0 + \sum_m \beta_m \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_n \gamma_n \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \\
& \frac{1}{2}\sum_n \sum_n \gamma_{nn} \left[\ln\left(\frac{\theta_n w_n}{p_{fp}}\right)\right]^2 + \frac{1}{2}\sum_m \sum_m \beta_{mm} \left[\ln\left(\frac{\kappa_m p_m}{p_{fp}}\right)\right]^2 + \\
& \sum_k \sum_n \gamma_{kn} \ln\left(\frac{\theta_k w_k}{p_{fp}}\right) \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \sum_l \sum_m \delta_{lm} \ln\left(\frac{\kappa_l p_l}{p_{fp}}\right) \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \\
& \sum_n \sum_m \delta_{nm} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_o \chi_o \ln z_o + \frac{1}{2}\sum_o \sum_o \chi_{oo} \ln z_o{}^2 + \\
& \sum_o \sum_r \chi_{or} \ln z_o \ln z_r + \sum_n \sum_o \chi_{no} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) \ln z_o + \sum_m \sum_o \chi_{mo} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) \ln z_o + \\
& \sum_r \varsigma_r \ln C_r + \ln\left\{1 + \sum_m \left(\frac{1-\kappa_m}{\kappa_m}\right) R_m{}^* + \sum_n \left(\frac{1-\theta_n}{\theta_n}\right) S_m{}^*\right\} + \ln \phi
\end{aligned}
$$

[15]

$$
R_m = \frac{\left(\beta_m + \sum_n \delta_{nm} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \delta_{30om} \ln\left(\frac{\kappa_{30o} p_{30o}}{p_{fp}}\right) + \frac{1}{2}\beta_{mm} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_o \chi_{om} \ln z_o\right)}{\left[\begin{array}{l}
\left[1 + \left(\frac{1-\kappa_m}{\kappa_m}\right)\left(\beta_m + \sum_n \delta_{nm} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \delta_{30om} \ln\left(\frac{\kappa_{30o} p_{30o}}{p_{fp}}\right) + \frac{1}{2}\beta_{mm} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_o \chi_{om} \ln z_o\right)\right] + \\
\left[1 + \left(\frac{1-\kappa_{30o}}{\kappa_{30o}}\right)\left(\beta_{30o} + \sum_n \delta_{n30o} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \delta_{30om} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \frac{1}{2}\beta_{30o30o} \ln\left(\frac{\kappa_{30o} p_{30o}}{p_{fp}}\right) + \sum_o \chi_{o30o} \ln z_o\right)\right]\kappa_m \\
\sum_n \left(\left(\frac{1-\theta_n}{\theta_n}\right)\left(\gamma_n + \frac{1}{2}\sum_n \gamma_{nn} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \sum_k \gamma_{kn} \ln\left(\frac{\theta_k w_k}{p_{fp}}\right) + \delta_{nm} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_o \chi_{no} \ln z_o\right)\right)
\end{array}\right]}
$$

[16]

$$S_m = \frac{-\left(\gamma_n + \frac{1}{2}\sum_n \gamma_{nn} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \sum_k \gamma_{kn} \ln\left(\frac{\theta_k w_k}{p_{fp}}\right) + \sum_m \delta_{mm} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_o \chi_{om} \ln z_o\right)}{\left[\begin{array}{l} \left[1 + \left(\frac{1-\kappa_{30o}}{\kappa_{30o}}\right)\left(\beta_{30o} + \sum_n \delta_{n30o} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \delta_{30obp} \ln\left(\frac{\kappa_{bp} p_{bp}}{p_{fp}}\right) + \frac{1}{2}\beta_{30o30o} \ln\left(\frac{\kappa_{30o} p_{30o}}{p_{fp}}\right) + \sum_o \chi_{o30o} \ln z_o\right)\right] + \\ \left[1 + \left(\frac{1-\kappa_{bp}}{\kappa_{bp}}\right)\left(\beta_{bp} + \sum_n \delta_{nbp} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \delta_{30obp} \ln\left(\frac{\kappa_{30o} p_{30o}}{p_{fp}}\right) + \frac{1}{2}\beta_{bpbp} \ln\left(\frac{\kappa_{bp} p_{bp}}{p_{fp}}\right) + \sum_o \chi_{obp} \ln z_o\right)\right] + \\ \sum_n \left(\left(\frac{1-\theta_n}{\theta_n}\right)\left(\gamma_n + \frac{1}{2}\sum_n \gamma_{nn} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \sum_k \gamma_{kn} \ln\left(\frac{\theta_k w_k}{p_{fp}}\right) + \delta_{nm} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_o \chi_{no} \ln z_o\right)\right) \end{array}\right]\theta_n}$$

[17]

where n, m, o, and r are defined as above, and k = fp, bp, 30o and l = fe, l, 30i, and s.

Time-Varying Fixed Effects Shadow Profit Model

The assumption maintained in time-invariant stochastic efficiency models (see e.g. Fried et al. 1993, and Greene 1993) that efficiency is constant through time is a relatively unrealistic modelling restriction with respect to a competitive agricultural production environment. Consequently, we model the relative efficiency of pig production by applying a fixed effects time varying stochastic approach (see Kumbhakar et al. 1991, Kumbhakar and Lovell 2000) using the flexible functional form of a translog profit function applied on a balanced panel data set. We start from our shadow profit distance model described above by [9] and [15], and reformulate it with respect to a fixed effects stochastic profit frontier panel data model with time-varying technical efficiency. In the formulation [15], a measure of producer nonspecific time invariant technical efficiency is additively incorporated by $\ln\phi$. Our objective is now to obtain producer specific estimates of technical efficiency varying over the different time periods considered. Obviously with an IxT panel it is not possible to obtain estimates of all $I*T$ parameters for $\ln\phi_{it}$. However, by adapting the specification by Cornwell et al. (1990) for a profit context

$$\ln\phi = \ln\left(\Omega_{i1} + \Omega_{i2} t + \Omega_{i3} t^2\right) \qquad [18]$$

we are able to reduce the number of parameters to be additionally estimated to $I*3$. Consequently the profit distance function becomes

$$
\begin{aligned}
\ln \pi = {} & \beta_0 + \sum_m \beta_m \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_n \gamma_n \ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \\
& \frac{1}{2}\sum_n \sum_n \gamma_{nn}\left[\ln\left(\frac{\theta_n w_n}{p_{fp}}\right)\right]^2 + \frac{1}{2}\sum_m \sum_m \beta_{mm}\left[\ln\left(\frac{\kappa_m p_m}{p_{fp}}\right)\right]^2 + \\
& \sum_k \sum_n \gamma_{kn} \ln\left(\frac{\theta_k w_k}{p_{fp}}\right)\ln\left(\frac{\theta_n w_n}{p_{fp}}\right) + \sum_l \sum_m \delta_{lm} \ln\left(\frac{\kappa_l p_l}{p_{fp}}\right)\ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \\
& \sum_n \sum_m \delta_{nm} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right)\ln\left(\frac{\kappa_m p_m}{p_{fp}}\right) + \sum_o \chi_o \ln z_o + \frac{1}{2}\sum_o \sum_o \chi_{oo} \ln z_o{}^2 + \\
& \sum_o \sum_r \chi_{or} \ln z_o \ln z_r + \sum_n \sum_o \chi_{no} \ln\left(\frac{\theta_n w_n}{p_{fp}}\right)\ln z_o + \sum_m \sum_o \chi_{mo} \ln\left(\frac{\kappa_m p_m}{p_{fp}}\right)\ln z_o + \\
& \sum_r \varsigma_r \ln C_r + \ln\left\{1 + \sum_m \left(\frac{1-\kappa_m}{\kappa_m}\right) R_m{}^* + \sum_n \left(\frac{1-\theta_n}{\theta_n}\right) S_m{}^*\right\} + \ln\left(\Omega_{i1} + \Omega_{i2} t + \Omega_{i3} t^2\right)
\end{aligned}
\tag{19}
$$

This quadratic specification of time allows technical efficiency to vary through time, and in a different manner for each producer. The quadratic time term can be interpreted to capture the effects of time invariant technical change. The adjusted shadow profit system (equations [16], [17] to [18]) is now estimated by applying an iterative seemingly unrelated regression procedure (ITSUR) and adding normally distributed error terms. Subsequently estimates of the ϕ_{it} are created and $\hat{\phi}_{ot} = \max_i \left\{\hat{\phi}_{it}\right\}$ is defined as the estimated technical efficiency of those farm(s) belonging to the frontier. The technical efficiency of each farm in period t is then estimated as $TE_{it} = \exp\left\{-\hat{u}_{it}\right\}$, where $\hat{u}_{it} = \left(\hat{\phi}_{ot} - \hat{\phi}_{it}\right)$. Thus according to this approach in each period at least one producer is estimated to be 100% technically efficient, although the identity of the most technically efficient producer(s) can vary through time (Kumbhakar and Lovell 2000).

By this model specification we are able to measure time-varying pig producer specific technical efficiency, input and output specific allocative efficiency as well as pig producer specific technical change. These measures can then be used to calculate time-varying measures of producer specific Malmquist total factor productivity indexes applying the distance notation based formula given in [19]

$$tfp_{it,t+1}^{tt}(y_{it}, x_{it}, y_{it+1}, x_{it+1}) = \frac{d_i^{t+1}(y_{it+1}, x_{it+1})}{d_i^t(y_{it}, x_{it})}\left[\frac{d_i^t(y_{it+1}, x_{it+1})}{d_i^{t+1}(y_{it+1}, x_{it+1})} * \frac{d_i^t(y_{it}, x_{it})}{d_i^{t+1}(y_{it}, x_{it})}\right]^{½}$$

$$= \text{effch}_{it+1}^{tt} * \text{tch}_{it,t+1}^{tt}$$

[20]

and following Färe et al. (1994).

A Bootstrapped Random Effects Panel Tobit Model

To get more empirical evidence on the link between the ban of growth promoters and the development of total factor productivity on farm level finally we apply a random effects panel tobit model. The Tobit model is known as a censored regression or limited dependent variable regression model as a limiting restriction holds with respect to the values taken by the regressand. In a random effects model, the unobservable or non-measurable factors differentiating cross-section units are assumed to be best characterised as randomly distributed variables (see e.g. Greene, 2001). The cross-section units of our analysis are the individual pig producers in the respective year of observation. Our regressand is the estimated change in total factor productivity per farm and year following [18] and [19]. We use the change in total factor productivity over time as dependent variable to assure independence with respect to the variance in the explanatory variables as the same regressors were used for the first stage estimation procedure. The estimated values are in a range between [-1; 1] and consequently we construct the observable left- and right-censored dependent variable TFPch_{it} used in estimation as:

$$TFPch_{it} = \begin{Bmatrix} TFPch_{it}^{*} \text{ if } -1 > TFPch_{it}^{*} < 1 \\ 0 \text{ if } TFPch_{it}^{*} \leq -1 \\ 0 \text{ if } TFPch_{it}^{*} \geq 1 \end{Bmatrix} \qquad [21]$$

The random-effects tobit model can then be described as follows

$$TFPch_{it}^{*} = \beta_0 + \sum_r \varsigma_r C_{ri} + \delta_t t_i + \sum_r \varsigma_{rt} C_{rit} t + \delta_{tt} t_i^2 + u_{it} + \varepsilon_{it} \qquad [22]$$

where i=1, 2, …, N indexes the pig farms, and t = 1, 2, …, T indexes the time series units, i.e. years of observation. C_{ri} contains explanatory variables r = age, experience, total area, total pigs as well as dummy variables to investigate the effects of the different bans implemented in the years 1995, 1998, and 1999: ban95, ban98, ban99. The variable t as well as t^2 denote the time trend effect, i.e. the share of variance in total factor productivity change devoted to systematic influences over time. Further, the interaction effects of these explanatory variables with time are aimed to be captured by the $C_{rit}t$. Finally the effects of relevant unobservable variables and time-invariant factors characterizing pig farm i for time t are captured by u_{it} whereas the stochastic disturbances for pig farm i are captured by ε_{it} . Since both incorporate randomly distributed stochastic components of the model, the composite error term can be described following a normal distribution

$$\omega_{it} = u_{it} + \varepsilon_{it}$$

$$\omega_{it} \sim N(0,\Sigma) \qquad \Sigma = \begin{bmatrix} \sigma_u^2 & \sigma_u \sigma_\varepsilon \\ & \sigma_\varepsilon^2 \end{bmatrix} \qquad [23]$$

We check for the robustness of our model by applying a simple stochastic resampling procedure based on bootstrapping techniques (see e.g. Efron and Tibshirani 1993). This seems to be necessary as our cross-sectional time series sample consists of a limited number of observations. If we suppose that $\hat{\Psi}_n$ is an estimator of the parameter vector ψ_n including all parameters obtained by estimating [22] based on our original sample of 108 observations (12 annual observations for 11 farms minus the frontier farm minus an outlier farm) $X = (x_1,...,x_n)$, then we are able to approximate the statistical properties of $\hat{\Psi}_n$ by studying a sample of 500 bootstrap estimators $\hat{\Psi}_n(c)_m, c = 1,...,C$. These are obtained by re-sampling our 108 observations – with replacement – from X and re-computing $\hat{\Psi}_n$ by using each generated sample. Finally the sampling characteristics of our vector of parameters are obtained from

$$\hat{\Psi} = \left[\hat{\Psi}_{(1)m}, \dots, \hat{\Psi}_{(500)m} \right]$$

As is extensively discussed by Efron and Tibshirani (1993), the bias of the bootstrap as an estimator of $\hat{\Psi}_n$, $B_{\tilde{\psi}} = \tilde{\Psi}_n - \hat{\Psi}_n$, is itself a feasible estimator of the bias of the asymptotic estimator of the true population parameter ψ_n . Hence the bias-corrected estimator of ψ_n can be computed by $\hat{\psi}_n - B_{\tilde{\psi}} = 2\hat{\psi} - \tilde{\psi}$. This holds also for the standard deviation of the bootstrapped empirical distribution providing a natural estimator of the standard error for each initial parameter estimate. By using a bias corrected bootstrap we aim to reduce the likely small sample bias in the frontier initial estimates.

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