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The relationship between animal welfare and economic outcome at the farm level

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DEPARTMENT OF FOOD AND RESOURCE ECONOMICS
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IFRO Report

The Relationship between Animal Welfare and Economic Outcome at the Farm Level

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The Relationship between Animal Welfare and Economic Outcome at the Farm Level

Authors: Tomasz Gerard Czekaj, Aske Schou Nielsen, Arne Henningsen, Björn Forkman, Mogens Lund

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Preface

This report contains statistical studies of the empirical relationship between animal welfare and economic outcome at the farm level for pig production in Denmark. Herd level data from the inspection of the animal welfare legislation at Danish pig farms in 2010 and 2011 was obtained from the Danish Veterinary and Food Administration and analyzed together with accounting data received from the Danish Pig Research Centre in cooperation with the Danish Knowledge Centre for Agriculture. The statistical analyses were carried out during 2012 and 2013.

We are grateful for receiving permission to analyze the data from the Danish Veterinary and Food Administration, as well as from the Danish Pig Research Centre and the Danish Knowledge Centre for Agriculture. The project is financed by the Danish Centre for Animal Welfare under the Danish Veterinary and Food Administration.

The report was written by Tomasz Gerard Czekaj, Aske Schou Nielsen, Arne Henningsen and Mogens Lund from the Department of Food and Resource Economics, Faculty of Science, University of Copenhagen and Björn Forkman from the Department of Large Animal Sciences, Faculty of Health and Medical Sciences, also University of Copenhagen. The authors accept full responsibility for the content of the report.

Mogens Lund, project leader
September 2013

Abstract

This report investigates the empirical relationship between animal welfare and economics among pig producers in Denmark. We apply data derived from inspections of Danish pig farms to check animal welfare legislation. While this data is on legislative compliance rather than a direct measure of animal welfare, we assume that it is also of relevance for animal welfare assessments. Based on this data, we propose several indicators of animal welfare which are then used in the economic analyses.

The economic analyses consist of three parts. The first part presents the results of descriptive analyses where possible correlations between economic variables and the constructed indicators of animal welfare are investigated. The results show that farm size and experience are uncorrelated with animal welfare. Good animal welfare on integrated pig farms is correlated with higher gross margins per pig unit, despite significantly higher medicine and veterinary costs per pig unit. Good animal welfare on specialized slaughter pig farms is correlated with low medicine and veterinary costs per pig unit. These results indicate that the relationship between animal welfare and the economic outcome of pig producers should be interpreted within the context of the production type.

The second part presents the results of regression analyses which generally confirm the relationships found in the descriptive analyses. However, the number of identified significant correlations is smaller in the regression analysis than in the descriptive analyses.

In the third part, the method of econometric analysis of technical efficiency is applied to investigate the relationship between animal welfare and the technical efficiency of Danish pig producers. The results show that farms with good animal welfare management are on average more technically efficient.

Dansk sammendrag

Projektets formål og baggrund

Projektets overordnede formål er at undersøge, om der kan identificeres signifikante sammenhænge mellem overholdelse af lovgivningen på dyrevelfærdsområdet, her brugt som indikator for dyrevelfærd, og økonomi på bedriftsniveau. Den almindelige antagelse er, at højere dyrevelfærd er forbundet med større omkostninger. Imidlertid må det forventes, at sammenhængene mellem dyrevelfærd og økonomi er mere komplekse. Det kan eksempelvis ikke udelukkes, at god dyrevelfærd i besætningen, målt som overholdelse af lovgivningen, er positivt korreleret med de økonomiske resultater som fx størrelsen af dækningsbidraget, idet god (dårlig) management kan øge (mindske) både dyrevelfærd og økonomiske resultater. Projektet analyserer denne og andre hypoteser om sammenhængene mellem dyrevelfærd og økonomi på bedriftsniveau.

Analyser af sammenhængene mellem dyrevelfærd og økonomi kan bidrage med større indsigt i de driftsøkonomiske incitamenter til at sikre en bedre dyrevelfærd i den enkelte besætning. Større viden om de økonomiske incitamenter – og eventuelle barrierer – til øget dyrevelfærd blandt forskellige husdyrproducenter kan også bidrage til øget regelefterlevelse samt en mere målrettet og omkostningseffektiv offentlig regulering af den fremtidige dyrevelfærd.

Endvidere kan sådanne analyser give større indsigt i, hvad en forbedret dyrevelfærd må koste i forskellige situationer, uden at det går ud over landbrugets indtjening og konkurrenceevne. Såvel dyrevelfærd som omkostningerne til dyrevelfærd er vigtige konkurrenceparametre. Det gælder ikke mindst svinekød og smågrise, hvor Danmark har en stor eksport.

Der findes i dag ingen systematiseret empirisk viden om, hvorvidt god dyrevelfærd er en økonomisk gevinst eller omkostning i landbruget. Det skyldes blandt andet, at dyrevelfærd er et særdeles sammensat begreb, som er vanskeligt at definere og kvantificere. Øget dyrevelfærd drejer sig ikke kun om at forbedre dyrenes sundhedsstatus, men også om i andre henseender at give dem et bedre liv, fx ved at mindske forekomsten af frustration og frygt og ved at give dyrene mulighed for at udfolde naturlig adfærd. Landmanden har et klart økonomisk incitament til at sikre dyrenes basale behov og sundhed, i det omfang disse påvirker produktiviteten, men derudover véd vi meget lidt om landmandens motivation og holdninger til at forbedre den samlede dyrevelfærd i sin besætning.

Projektets gennemførelse

Projektets gennemførelse har omfattet fire faser:

- Samkøring af databaser
- Beskrivende analyser
- Multivariate analyser
- Effektivitetsanalyser

Samkøring af databaser

Det anvendte datamateriale bygger på en samkøring af regnskabsdata fra økonomidatabasen på Videncentret for Landbrug og databaser i Fødevarestyrelsen. De anvendte databaser i Fødevarestyrelsen er dyrevelfærdskontrollen for 2010 og 2011 og den nulpunktsundersøgelse, som blev gennemført i efteråret 2011. (Som tidligere nævnt så bruges overholdelse af lovgivningen som indikator for niveauet af dyrevelfærd i denne studie.) Velfærdskontrollen gennemføres årligt på 5 procent af alle landbrug med mere end 10 landbrugsdyr eller heste og er baseret på en kombination af risikovurdering og en tilfældig udvælgelse af Fødevarestyrelsen. Nulpunktsundersøgelsen er gennemført som en tilfældig stikprøveundersøgelse blandt alle danske svinebesætninger. I nærværende projekt er derfor udelukkende undersøgt statistiske sammenhænge mellem dyrevelfærd og økonomi i svineproduktionen.

For de bedrifter i velfærdskontrollen og nulpunktsundersøgelsen, hvor der konstateres overtrædelser af velfærdsreglerne, er der oplysninger om arten af overtrædelserne og karakteren af de relaterede påbud, indskærpelser o.l. Disse oplysninger er blevet suppleret med økonomiske data fra de samme bedrifter for regnskabsåret 2011. De økonomiske data er stillet til rådighed af Videncenter for Svineproduktion i samarbejde med afdelingen for Økonomi & Virksomhedsledelse på Videncentret for Landbrug. For hver bedrift er følgende regnskabsmæssige oplysninger blevet modtaget fra Videncentret: Antallet af producerede grise, dækningsbidraget pr. dyreenhed (svin), dyrlægeomkostningerne pr. dyreenhed (svin), landmandens alder samt hans antal år som selvstændig landmand (som proxy for landmandens erfaringer). Endvidere er for hver bedrift modtaget input- og outputdata til de gennemførte effektivitetsanalyser. Disse data er omtalt senere.

Uanset hvilke data, som er til rådighed, vil en præcis definition af dyrevelfærd altid være en vanskelig opgave. Dyrevelfærd er ikke nogen eksakt størrelse. Staldforhold og miljøfaktorers påvirkning af dyrevelfærden kan tolkes på forskellig måde bl.a. afhængig af, hvilke indikatorer for dyrevelfærd der gøres brug af. En litteraturgennemgang viser ingen entydige sammenhænge mellem dyrevelfærd og økonomi, måske fordi de fleste produktionsøkonomiske studier af dyrevelfærd kun benytter et enkelt mål for dyrevelfærd, fx halthed, eller beregner omkostningerne til forskellige produktionssystemer med forskellig velfærd ud fra modelbaserede standarder. Det betyder, at de empiriske sammenhænge mellem dyrevelfærd og

produktionsøkonomi fortsat er uklare og dermed ikke videnskabeligt dokumenteret. Et samlet mål for dyrevelfærd kræver principielt et overordnet indeks, som inkluderer alle relevante aspekter af dyrevelfærd. Et sådant mål er ikke udarbejdet i nærværende projekt.

I denne undersøgelse er benyttet forskellige indikatorer for dyrevelfærd, som alle kan beregnes ud fra de tilgængelige data i velfærdskontrollen og nulpunktundersøgelsen. Den første indikator er en binær variabel, som angiver, hvorvidt der er sket overtrædelser af dyrevelfærdslovgivningen eller ikke, og det uanset antallet og betydningen af de konstaterede overtrædelser. Den anden indikator angiver derimod det totale antal overtrædelser af velfærdslovgivningen, og det gælder igen uanset betydningen af overtrædelserne. Den tredje anvendte indikator, som er en kategorisk variabel, angiver den mest alvorlige overtrædelse af dyreværnslovgivningen. Indikatoren siger ikke noget om arten eller antallet af overtrædelser.

Hverken indikatoren for, hvorvidt der er sket en overtrædelse, antallet af overtrædelser eller den mest alvorlige overtrædelse siger noget direkte om det konkrete niveau af dyrevelfærd i en besætning. For at analysere en mere direkte sammenhæng til dyrevelfærd er der tillige lavet indikatorer, som angiver, hvorvidt der er observeret overtrædelser af dels dyrevelfærdsreglerne vedr. henholdsvis rode- og beskæftigelsesmateriale, dels reglerne for håndtering af syge dyr.

En aggregering af data har været nødvendig for at beregne indikatorerne for alle de bedrifter, som indgår i analysegrundlaget. Det skyldtes især, at de økonomiske data er opgjort på bedriftsniveau, mens data i velfærdskontrollen og nulpunktsundersøgelsen er opgjort på besætningsniveau. Det giver problemer med aggregeringen af data på de bedrifter med flere besætninger, der hver har sit eget nummer i det Centrale Husdyr Register (CHR).

Det er vigtigt at være opmærksom på, at de anvendte indikatorer alle er meget simple, og at de ikke nødvendigvis afspejler den samlede dyrevelfærd i den enkelte besætning.

Statistiske analyser viser, at data fra henholdsvis velfærdskontrollen og nulpunktsundersøgelsen på visse områder er signifikant forskellige. Antallet af kontrollererede besætninger pr. bedrift er forskellige i de to undersøgelser, men antallet af kontrollerede besætninger pr. bedrift har ingen indflydelse på størrelsen af de valgte indikatorer for dyrevelfærd. Det indikerer, at den valgte metode til aggregering af dyrevelfærddata fra besætnings- til bedriftsniveau ikke har ført til signifikante skævheder i analyserne. Derimod er den relative fordeling af bedrifter i forhold til driftsformen forskellige i velfærdskontrollen og nulpunktundersøgelsen. Der er relativt færre bedrifter med integreret svineproduktion i nulpunktundersøgelsen, men der er en tendens til, at der sker hyppigere overtrædelser på disse bedrifter, og at de også har flere overtrædelser i forhold til de sammenlignelige bedrifter i velfærdskontrollen. Endvidere viser analyserne, at bedrifterne med integreret

svineproduktion i nulpunktsundersøgelsen har mere alvorlige lovovertrædelser end de tilsvarende bedrifter i velfærdskontrollen. Bedrifter klassificeret som integrerede svinebrug omfatter 58 procent af alle observationer i det samlede datasæt (dvs. både data i velfærdskontrollen og i nulpunktsundersøgelsen under ét). Såvel forskelle i fordelingen på driftsformer som i antallet af bedrifter gør, at data i velfærdskontrollen og nulpunktsanalysen ikke kan analyseres som et samlet datasæt. Som tidligere nævnt er data i nulpunktundersøgelsen baseret på en tilfældig udvælgelse, hvilket ikke gælder i velfærdskontrollen. De statistiske analyser af sammenhængen mellem indikatorer for dyrevelfærd og økonomi er derfor udelukkende baseret på data fra nulpunktsundersøgelsen.

Beskrivende analyser

De beskrivende analyser omfatter 67 bedrifter med integreret svineproduktion og 39 bedrifter udelukkende med slagtesvineproduktion. Der var ikke tilstrækkelige data til at analysere andre driftsformer, som fx bedrifter med ren smågriseproduktion. For at være klassificeret som en bedrift med svineproduktion, og dermed indgå i analyserne, skal mindst 66 procent af de samlede indtægter stamme fra svineproduktionen.

Ved brug af forholdsvis simple beskrivende analysemetoder er følgende hypotetiske sammenhænge mellem de definerede indikatorer for dyrevelfærd (defineret som forskellige typer af overtrædelser af dyreværnslovgivningen) og

- antal producerede grise
- dækningsbidrag pr. dyreenhed (for svin)
- dyrlægeomkostninger pr. dyreenhed (for svin)
- indtægter pr. dyreenhed (for svin)
- foderomkostninger pr. dyreenhed (for svin)
- andre omkostninger pr. dyreenhed (for svin)
- landmandens alder
- antal år som selvstændig (som proxy for landmandens erfaring)

analyseret. Det er valgt at fokusere på disse sammenhænge ud fra en gennemgang af den eksisterende relevante litteratur og i dialog med en række eksperter på dyrevelfærdsområdet.

Tabel 1 og 2 viser resultaterne for de statistiske tests af sammenhængene mellem de ovennævnte 8 socioøkonomiske variable og de 5 indikatorer for dyrevelfærd for bedrifter med henholdsvis integreret svineproduktion og ren slagtesvineproduktion. De identificerede signifikansniveauer er vist i noter til de to tabeller. Hvis testresultatet ikke viser nogen signifikans, er det angivet som ”Ingen” i tabellerne.

Studier refereret i den økonomiske litteratur har identificeret statistiske sammenhænge mellem indikatorer for dyrevelfærd og størrelsesforhold, men de fundne sammenhænge er langt fra entydige. De gennemførte statistiske analyser i dette projekt viser derimod ingen signifikante sammenhænge mellem antallet af svin på den ene side og på den anden side antallet og/eller karakteren af overtrædelser. Det anvendte datamateriale giver dermed ikke belæg for at hævde, at der er en generel sammenhæng mellem besætningsstørrelse og overholdelse af dyrevelfærdslovgivningen på bedrifter med svineproduktion.

Dækningsbidraget fra svineproduktion indeholder både indtægterne fra salg af svin og omkostningerne til bl.a. foder og dyrlæge. Det kan derfor forventes, at der er en sammenhæng mellem størrelsen af dækningsbidraget og niveauet af dyrevelfærd i besætningen. Sammenhængen kan imidlertid gå begge veje. Det kan hævdes, at god management kan føre til såvel et højt dækningsbidrag som høj dyrevelfærd. Omvendt kan der også argumenteres for, at høj dyrevelfærd kræver større omkostninger, som mindsker dækningsbidraget. Sammenhængene mellem de produktionsøkonomiske resultater og niveauet for dyrevelfærd i husdyrproduktionen er ikke dokumenteret i litteraturen, selvom nogle få studier har fundet evidens, som peger på en negativ sammenhæng mellem økonomisk produktivitet og dyrevelfærd.

Når det gælder bedrifter med integreret svineproduktion, ses en signifikant tendens til, at der opnås et lavere dækningsbidrag, såfremt der har været en overtrædelse af dyrevelfærdslovgivningen (jf. anden række i tabel 1), hvorimod dette ikke er tilfældet for bedrifter med rene slagtesvinebesætninger (jf. anden række i tabel 2, som angiver ”Ingen” korrelation mellem dækningsbidraget og de 5 indikatorer for overtrædelser af dyrevelfærdsreglerne). Det kan muligvis forklares med, at god management (som også giver højere dyrevelfærd) er af større økonomisk betydning i integreret svineproduktion end i slagtesvineproduktionen.

De statistiske resultater viser en betydelig forskel, når det gælder sammenhængene mellem dyrlægeomkostningerne pr. dyreenhed på den ene side og på den anden side antallet og typen af overtrædelser i henholdsvis integrerede svinebesætninger og slagtesvinebesætninger. I de integrerede besætninger er der en tendens (signifikant på 10 procents-niveauet) til, at dyrelægeomkostningerne er lavere i de besætninger, hvor der er konstateret mindst en overtrædelse (jf. de tre sidste rubrikker i tredje række i tabel 1). De gennemsnitlige dyrlægeomkostninger er estimeret til 1.061 kr. pr. dyreenhed svin på bedrifter, hvor der ikke er observeret overtrædelser af reglerne vedrørende håndtering af syge svin. På bedrifter, hvor der er konstateret mindst en overtrædelse, er de gennemsnitlige dyrlægeomkostninger derimod beregnet til 857 kr. pr. dyreenhed. En mulig forklaring kan være, at producenter på de integrerede bedrifter, som investerer relativt mest i forebyggelse og god medicinsk behandling af syge dyr, også har en højere dyrevelfærd.

Tabel 1. Testresultater for bedrifter med integreret svineproduktion

	Totale antal overtrædelser	**De mest alvorlige overtrædelser**	**Overtrædelser af enhver slags**	**Overtrædelser vedr. rode- og beskæftigelses-materiale**	**Overtrædelser vedr. syge dyr**
Antal svin	Ingen	Ingen	Ingen	Ingen	Ingen
Dækningsbidrag (DB)	Lavere DB hvis overtrædelser[a]	Der er en forskel[a]	Lavere DB hvis overtrædelser[a]	Lavere DB hvis overtrædelser[b]	Ingen
Dyrlægeomkostninger	Ingen	Ingen	Lavere omkostninger hvis overtrædelser[a]	Lavere omkostninger hvis overtrædelser[a]	Lavere omkostninger hvis overtrædelser[b]
Indtægter	Ingen	Der er en forskel[a]	Ingen	Lavere indtægter hvis overtrædelser[c]	Ingen
Foderomkostninger	Ingen	Ingen	Ingen	Ingen	Ingen
Andre omkostninger	Ingen	Ingen	Ingen	Ingen	Ingen
Landmandens alder	Ingen	Ingen	Ingen	Ingen	Ingen
Landmandens erfaring	Ingen	Ingen	Ingen	Ingen	Ingen

a) Signifikans på 10 pct.'s niveau; b) Signifikans på 5 pct.'s niveau; c) Signifikans på 1 pct.'s niveau.

Tabel 2. Testresultater for bedrifter med ren slagtesvineproduktion

	Totale antal overtrædelser	**De mest alvorlige overtrædelser**	**Overtrædelse af enhver slags**	**Overtrædelser vedr. rode- og beskæftigelses-materiale**	**Overtrædelser vedr. syge dyr**
Antal svin	Ingen	Ingen	Ingen	Ingen	Ingen
Dækningsbidrag (DB)	Ingen	Ingen	Ingen	Ingen	Ingen
Dyrlægeomkostninger	Ingen	Der er en forskel[a]	Højere omkostninger hvis overtrædelser[a]	Ingen	Højere omkostninger hvis overtrædelser[a]
Indtægter	Højere indtægterhvis overtrædelser[c]	Ingen	Lavere indtægter hvis overtrædelser[a]	Ingen	Ingen
Foderomkostninger	Ingen	Ingen	Ingen	Ingen	Ingen
Andre omkostninger	Højere andre omkostninger hvis overtrædelser[a]	Ingen	Højere andre omkostninger hvis overtrædelser[a]	Ingen	Højere andre omkostninger hvis overtrædelser[a]
Landmandens alder	Ingen	Ingen	Ingen	Ingen	Ingen
Landmandens erfaring	Ingen	Ingen	Ingen	Ingen	Mindre erfaring hvis overtrædelser[a]

a) Signifikans på 10 pct.'s niveau; b) Signifikans på 5 pct.'s niveau; c) Signifikans på 1 pct.'s niveau.

Det omvendte er delvist tilfældet i de rene slagtesvinebesætninger, hvor dyrlægeomkostningerne er signifikant højere, når der er konstateret mindst en overtrædelse af de samlede regler, og der er sket en specifik overtrædelse af reglerne for håndtering af syge dyr (jf. række 3 i tabel 2). Bedrifterne uden overtrædelser har

gennemsnitlige dyrlægeomkostninger på 173 kr. pr. dyreenhed, mens bedrifter med overtrædelser af reglerne for håndtering af syge slagtesvin har dyrlægeomkostninger på 232 kr. i gennemsnit pr. dyreenhed. Denne forskel er signifikant på 10 procents-niveauet. Det kan muligvis forklares med, at slagtesvinebedrifter med dårlig dyrevelfærd har flere syge svin og derfor højere dyrlægeomkostninger.

Sammenhængene mellem indikatorerne for dyrevelfærd og landmandens erfaring er også blevet statistisk analyseret. To forskellige indikatorer for erfaring er blevet benyttet. Den ene er landmandens alder ud fra den antagelse, at landmandens alder er proportional med hans erfaring med landbrugsdrift. Den anden indikator er antallet af år som selvstændig landmand. For det meste ejer landmanden den eller de samme bedrifter indtil han eller hun går på pension. Derfor vil antal år som selvstændig landmand være en troværdig indikator for landmandens professionelle erfaring.

Som det fremgår af tabel 1 og 2 er der dog ingen eller kun en meget svag indikation af nogen sammenhæng mellem overtrædelser af dyreværnslovgivningen og landmandens erfaring. For bedrifter med integreret svineproduktion kunne ikke findes nogen statistisk signifikante sammenhænge overhovedet. For rene slagtesvinebesætninger er sammenhængen mellem erfaringsniveauet og velfærdsindikatorerne også svag. Den eneste sammenhæng, der er identificeret gennem de statistiske analyser, er, at slagtesvineproducenter med mindre landbrugserfaring tilsyneladende har flere overtrædelser af reglerne for håndtering af syge dyr i forhold til landmænd, hvor sådanne overtrædelser af dyrevelfærdsreglerne ikke er blevet observeret. Det indikerer, at jo større landbrugserfaring, jo større sandsynlighed for at kunne håndtere syge dyr i overensstemmelse med den gældende lovgivning på området.

Multivariate Analyser

Den beskrivende analyse har kun set på sammenhænge mellem to variable hver gang, selvom det må forventes, at både de økonomiske resultater og dyrevelfærd afhænger af mange faktorer. Derfor er også gennemført multivariate statistiske analyser, der giver mulighed for simultan analyse af indflydelsen af mange forskellige faktorer.

De multivariate analyser omfatter 135 bedrifter (som også omfatter bedrifter med andre driftsformer end integreret svineproduktion og slagtesvineproduktion). Både faktorer, der kan have en indflydelse på dyrevelfærd, og faktorer, der kan påvirke de økonomiske resultater, er blevet undersøgt.

Hovedkonklusionen fra analyserne med indikatorer for dyrevelfærd som afhængige variable er, at overtrædelsen af lovgivningen om dyrevelfærd afhænger af driftsformen, men derimod stort set ikke afhænger af andre faktorer så som besætningsstørrelsen og landmandens erfaring.

Resultaterne af den multivariate analyse med dækningsbidraget som den afhængige variabel viser en negativ sammenhæng mellem dækningsbidraget og overtrædelser af dyrevelfærdslovgivningen med hensyn til syge dyr; dvs. bedrifter, der overtræder lovgivningen vedrørende håndtering af syge dyr, har i gennemsnit et lavere dækningsbidrag end bedrifter, der ikke overtræder denne lovgivning. Ingen andre af de anvendte indikatorer for dyrevelfærd har nogen statistisk signifikant sammenhæng til dækningsbidragets størrelse.

Regressionsanalysen af dyrlægeomkostningerne viser, at denne omkostning stort set ikke afhænger af dyrevelfærd, men derimod af driftsformen.

De signifikante sammenhænge, som er fundet gennem de multivariate analyser, er generelt i overensstemmelse med de fundne resultater i de beskrivende analyser, men antallet af identificerede signifikante sammenhænge er mindre i de multivariate analyser end i de beskrivende analyser. De multivariate analyser sammenligner bedrifter, der har de samme karakteristika (dvs. de tager højde for ikke kun forskelle i driftsformen, men også forskelle i fx besætningstørrelse og landmandens alder og erfaring). I modsætning hertil tager de beskrivende analyser udelukkende hensyn til forskelle i driftsformen. Det er med til at forklare, hvorfor der er fundet færre signifikante sammenhænge mellem indikatorerne for dyrevelfærd og de socioøkonomiske variable i de multivariate analyser end i de beskrivende analyser.

Effektivitetsanalyser

I modsætning til de beskrivende og multivariate økonomiske analyser er det gennem effektivitetsanalyser muligt at lave en benchmarking af bedriftens samlede produktivitet og relatere denne benchmarking til de definerede indikatorer for overholdelse af dyreværnslovgivningen. Herved kan det analyseres, om der er statistisk sammenhæng mellem den samlede produktivitet og niveauet for dyrevelfærd på bedrifter med svineproduktion. Den anvendte statistiske metode betegnes som ”Stochastic Frontier Analysis” eller kort SFA.

Effektivitetsanalysen omfatter 120 bedrifter (idet 15 bedrifter er udeladt pga. manglende oplysninger om dyrket areal og/eller arbejdsindsats). Den estimerede SFA-model inkluderer 2 output-variable og 6 input-variable. De 2 output-variable består af dels det samlede nettoudbytte i den animalske produktion i kr., dels udbyttet fra planteproduktion og forskellige serviceydelser i kr. De 6 input-variable består af: Foderforbrug i kr.; de veterinære omkostninger og diverse andre variable input i svineproduktionen opgjort i kr.; andre diverse variable omkostninger i planteproduktionen eller ikke delelige omkostninger opgjort i kr.; dyrket areal i ha; anvendt arbejdskraft i timer; og anvendt landbrugskapital i kr.

SFA-resultaterne viser, at der en negativ sammenhæng mellem antallet af overtrædelser af dyreværnslovgivningen og bedriftens samlede effektivitet (dvs. bedrifter med flere overtrædelser har en lavere

samlet effektivitet). Bedrifter, som overtræder reglerne vedrørende håndtering af syge dyr, har en endnu lavere teknisk effektivitet (sammenlignet med bedrifter, som har det samme totale antal af overtrædelser, men inden for andre områder af dyrevelfærdslovgivningen). Overtrædelser af reglerne vedrørende rode- og beskæftigelsesmateriale er muligvis positivt korreleret med bedriftens tekniske effektivitet, men denne sammenhæng er ikke statistisk signifikant. Samlet set falder bedriftens indtægter i gennemsnit med 0,2 procent pr. observeret overtrædelse. Hvis der er overtrædelser af velfærdsreglerne vedrørende håndtering af syge dyr, er bedriftens indtægter i gennemsnit reduceret med yderlige 2,5 procent.

Afslutning

Der er knyttet en række begrænsninger til de gennemførte analyser. Den første drejer sig om validiteten af målet for dyrevelfærd, som diskuteret tidligere. En anden begrænsning er, at såvel dækningsbidraget som dyrlægeomkostningerne er aggregerede økonomiske størrelser. Dyrlægeomkostningerne, og især dækningsbidraget, er aggregerede størrelser i den forstand, at de begge består af mange underposteringer gennemført i løbet af regnskabsåret. Til gengæld giver data i både velfærdskontrollen og nulpunktsundersøgelsen et øjebliksbillede. Dette billede kan være stærkt påvirket af tilfældigheder. Disse data repræsenterer derfor ikke niveauet for dyrevelfærd i en besætning i et helt år. Samlet set kan de dog godt give et retvisende billede af det gennemsnitlige velfærdsniveau i svineproduktionen, hvis det kan antages, at negative og positive tilfældigheder i velfærdskontrollen og nulpunktsundersøgelsen nogenlunde udligner hinanden.

Det skal også bemærkes, at de gennemførte analyser vedrører statistiske sammenhænge, men ikke årsagssammenhænge (dvs. kausalitet) mellem dyrevelfærd og økonomiske resultater. Resultaterne viser, at der kun er en svag statistisk sammenhæng mellem dyrevelfærd og økonomiske resultater. Ifølge analyserne afhænger overtrædelser af dyrevelfærdslovgivning af driftsformen, men fx ikke af besætningsstørrelsen. Bedrifter, der overtræder dyrevelfærdslovgivningen, har en tendens til at have et lavere dækningsbidrag (især i integreret svineproduktion) og en lavere teknisk effektivitet end de bedrifter, der overholder dyrevelfærdslovgivningen. Samlet set tyder det på, at landmænd, der har styr på økonomien og har en effektiv produktion, også har bedre styr på overholdelsen af dyrevelfærdsreglerne, men mere detaljerede analyser (baseret på flere og mere detaljerede data) er nødvendige for at kunne undersøge kausaliteten mellem dyrevelfærd, de økonomiske resultater og andre relevante faktorer.

1. Introduction

1.1. Background

Farm animal welfare is continually being debated in the Danish media, and it involves consumers, livestock producers, retailers and the government. Animal welfare can be important both for producers, who regularly have to make production decisions that influence their animals' welfare, and for consumers, who regularly have to make decisions about which animal products to buy (e.g. conventional products, products with an animal welfare label, organic products, or no animal products at all). The government is willing to implement new regulations on animal welfare, and retailers have started to brand products based on animal welfare attributes (Dyrenes Beskyttelse 2013). The relevance of animal welfare in Denmark is apparent when one looks at the number of articles and opinion pieces in the major newspapers (e.g. Gjerris 2012, Politiken 2013b). In Denmark, the debate about farm animal welfare often uses the pig industry as an example, because of its relative importance in Danish livestock production. The production value of Danish animal production in 2012 was 49 billion DKK, of which the pig sector accounted for almost 23 billion DKK (Hansen and Andersen 2013). This level of production requires a population of 12 million pigs in Danish stables (Danmarks Statistik 2013). These issues make the study of animal welfare relevant for society, and the importance of the pig sector makes it a relevant case study of animal welfare.

Animal welfare has traditionally been studied by ethicists, ethologists and veterinarians, but it has recently also gained the attention of economists. In general, there are four areas within the field of economics that could be of particular use for the discussion of animal welfare. These are public economics, welfare economics, consumer economics and production economics (Lusk and Norwood 2011). Public economics studies market failures, e.g. whether animal welfare has public good characteristics, which would justify government intervention such as stricter welfare legislation. Welfare economics examines the effects of different policies or initiatives on consumers, taxpayers and producers and makes use of both consumer economics and production economics. The aspect of animal welfare that has been most frequently analyzed by economists is consumers' preferences for improved animal welfare (Lusk and Norwood 2011, for a review see Lagerkvist and Hess 2011).

Production economics can aid understanding of the producer's economic incentives for improving animal welfare. The producer is the caretaker of farm animals and his decisions regarding the housing system, feed quality, health management, etc. reflect his values on animal welfare, but also his desire to maximize profits. Knowledge on the relationship between economics and animal welfare can aid farmers, consultants and policy makers in discussions on management strategies or in the implementation of new welfare legislation. According to McInerney (2004), Lawrence (2009) and Lusk and Norwood (2011), there is a gap in the economic

literature concerning animal welfare, especially in the field of production economics. Several studies within production economics use a modeling approach and calculate the costs of housing systems with different welfare attributes (e.g. Guy *et al.* 2012; Bornett *et al.* 2003; Lund *et al.* 2010; Seibert and Norwood 2011; Majewski *et al.* 2012; Den Ouden *et al.* 1997). Jensen et al. (2008) used a log-linear variance model to investigate the effect of diseases on the profit margin[1] of the slaughter pig production in Denmark. Jensen *et al.* (2012b) studied the severity of pain and profit losses associated with different causes of lameness. The authors used statistical simulations to quantify the animal welfare consequences (i.e. pain) and losses in profitability based on expert opinions. Ahmadi *et al.* (2011) and Stott *et al.* (2012) used linear programming to study the effects on profits of pen systems with different welfare attributes, and extensive sheep farming systems with different welfare scores. All these studies use data from the literature, questionnaires, interviews, and expert opinions, and most use a model farm as the outset for the calculations. A a few studies use a technical efficiency framework, e.g. Lawson *et al.* (2004a), Lawson *et al.* (2004b) and Barnes *et al.* (2011). Lawson *et al.* (2004a) and Lawson *et al.* (2004b) study the relationship between animal health and technical efficiency in dairy cattle production. They apply stochastic frontier analysis to a large farm accountancy data set that includes veterinary treatment records. Barnes *et al.* (2011) employ data envelopment analysis.

1.2. Purpose

The relevance of the animal welfare debate, the importance of the pig sector in Danish animal production, and the lack of knowledge on animal welfare within production economics are the main reasons for addressing this issue. The aim of this study is to deliver new insights into farm animal welfare from an economic perspective. The datasets on animal welfare inspections conducted in Denmark in 2011 have been merged with farm level accountancy data on Danish pig producers. The outcome is a unique data set that allows us to study the relationship between aspects of farm animal welfare and the economic outcome of Danish pig producers.

1.3. Problem Statement

The research objective of this report is to analyze the relationship between pig welfare (using the proxy of legislative compliance in the area of animal welfare) and the economic outcome of farmers. More specifically, the research objective is to answer the following question:

Is there a relationship between animal welfare and economic results at the farm level?

This question is addressed by answering the following sub questions:

[1] The authors define profit margin (PM) in following way: PM = Revenue – Feed cost – Medicine cost – cost of piglets, where all measures are per pig unit. Since they do not account for total costs of pig production (i.e. fixed costs), their measure should be called gross margin instead of profit margin.

- Is there a relationship between the number of pigs produced by a farmer and pig welfare?
- Is there a relationship between gross margin per pig unit[2] and pig welfare?
- Is there a relationship between medicine and veterinary cost per pig unit and pig welfare?
- Is there a relationship between the age or experience of the farmer and pig welfare?
- Is there a relationship between the technical efficiency of a farm and pig welfare?

1.4. Methodology

In order to answer these questions, we use descriptive analysis to investigate the possible relationship between the animal welfare indicators and the following socio-economic variables: the number of produced animals, gross margin per pig unit, veterinary costs per pig unit, age of the farmer and experience. Descriptive analyses can be used to detect obvious relationships between two variables. They are used because of the explorative nature of the research question. Additionally, we use linear regression methods to investigate these relationships while taking into account the effects of other variables and allowing for interactions between the explanatory variables.

Furthermore, we investigate the relationship between technical efficiency and pig welfare using a stochastic output distance function. Technical efficiency in economics is often defined as the ratio of observed output to the maximum potential output. In the analysis of technical efficiency, two approaches are often used: the nonparametric Data Envelopment Analysis (DEA) and parametric Stochastic Frontier Analysis (SFA). The advantage of the SFA over the deterministic DEA is that it distinguishes between inefficiency and noise in the data and the estimation process. Stochastic events play an important role in agriculture (e.g. due to weather conditions), which can generate noise in the data. Therefore, the SFA method is chosen for the analysis of technical efficiency. Most often, the concept of a primal production function is used to estimate the technical efficiency in the stochastic frontier analysis framework. However, the primal specification of a production function requires either that producers produce a single output or the researcher needs to aggregate the multiple outputs into a single aggregated output. The alternative approach that allows for the multiple-output and multiple-input production technology is the estimation of the output distance function. Economic data for these analyses is provided by the Pig Research Centre, and is based on accountancy data from Danish farmers in 2011.

As we do not have data from an overall animal welfare assessment, we use the farm's compliance with the legislation in the area of animal welfare as a proxy of animal welfare in our analysis. The data on compliance is

[2] One pig unit corresponds to 4.3 sows with piglets up to 7.3 kg; or 36 slaughter pigs from 32 kg to 107 kg; or 200 piglets between 7.3 kg and 30 kg.

provided by the Danish Veterinary and Food Administration and the Danish AgriFish Agency. The data from the Danish Veterinary and Food Administration is from a randomly sampled welfare inspection performed in 2011. This data is referred to as "nulpunkt" data. The data from the Danish AgriFish Agency is also based on welfare inspection data from 2011. However, this is a risk-based inspection which means that the data has not been randomly sampled. The data will be referred to as welfare control data.

Animal welfare is a complex concept. Therefore, the report begins by presenting the different aspects of animal welfare, which is followed by a discussion of animal welfare research in the context of of production economics literature in section 2. The data derived from the animal welfare inspections and its relation to pig welfare is described in section 3. In section 4, the proposed indicators of animal welfare are described, and their strengths and weaknesses discussed. The aggregation of animal welfare data that was necessary to combine the animal welfare and economic datasets is described in section 5. Section 6 presents the theory relating to the stochastic output distance function. Before we proceed with the economic analysis (section 7), the two samples of animal welfare inspections are tested for potential biases in the aggregation procedure, and their poolability is assessed. The results of the conducted analyses (descriptive analyses, regression analyses and analysis of technical efficiency) of the relationship between animal welfare indicators and economic outcomes are presented in section 8. Section 9 discusses the results of the conducted analyses and section 10 concludes.

1.5. Delimitation of the Research Scope

The report takes an empirical approach to the research question, and most sections are therefore directed towards handling the data and the economic analyses. The availability of data was a determining factor for the choice of hypothesis, and the formulation of the animal welfare indicators. All conclusions are entirely based on the available data.

We focus on the connection between production economics and farm animal welfare. Therefore, we need to mention that we do not study animal welfare from any of the perspectives offered by public economics, welfare economics, or consumer economics. The knowledge presented in this report can be used to further understanding of Danish farmers' economic incentives for complying with animal welfare legislation.

2. Reviewing Animal Welfare

2.1. The Concept of Animal Welfare

The industrialization and intensification of modern agriculture, which started in the 1950s, has resulted in changes in animal housing and animal management. Although many of these changes have led to improved animal health, at the same time they have resulted in animals being kept in artificial environments (Keeling 2005). The debate on animal well-being or animal welfare started in the 1960s and was initiated by R. Harrison's book ``The Animal Machines'' in which she introduced the term ``factory farms`` comparing animals to machines in factories. The first research paper on animal welfare was the report of the "Brambell Committee" (Brambell 1965) that provided a number of recommendations which set the benchmark for the entire European development within animal welfare (Sandøe et al. 2012).

According to Sandøe (2010), research on animal welfare is mainly undertaken by natural scientists (in ethology, pain and stress-physiology and veterinary medicine). However, more studies on animal welfare by other disciplines, notably sociology, economics and ethics, need to be conducted in order to identify and overcome the factors which hinder improvements in animal welfare (Appelby 2004).

Animal welfare is a wide-ranging, and often value-laden, term that is used with somewhat different meanings by different people (Sandøe 2010). In our study, we adopt Broom's (2008) approach to defining animal welfare. Broom (2008) discusses different concepts of pig welfare, which he puts into five categories: needs, feelings, stress, health and pain. These categories cover different aspects of good and poor welfare, and make a good starting point for grasping the different elements that constitute animal welfare.

2.1.1. Needs

Animals have different needs, such as suitable environmental conditions that allow their bodily functions to control body temperature, feed of sufficient quantity and quality in order to maintain a satisfactory nutritional state, social interactions, etc. The environment surrounding a pig is important for satisfying these needs. A pig's body temperature, its nutritional state and social interactions need to be above a certain level in order for the pig to be able to fully cope with its environment. The stables should therefore provide certain conditions to allow these needs to be fulfilled. The needs of a pig can be characterized "*as a requirement, which is part of the basic biology of an animal, to obtain a particular resource or respond to a particular environmental or bodily stimulus"* (Broom 2008, p. 19). There are two kinds of needs. Some needs must be satisfied if life is to continue (e.g. food), while others the animal wishes to satisfy (e.g. to root in soil or straw). If an animal strongly expresses a wish to fulfil a certain need, it is usually an indication that the need is important for the animal's biological success, and is therefore important when assessing welfare (Broom 2008). Needs are closely linked

with feelings, because when a need is unsatisfied, the individual probably experiences negative feelings, and positive feelings when the need is satisfied.

2.1.2. Feelings

The functional role of feelings is debated, with suggestions ranging from them being an epiphenomenon to having a direct causal effect on behavior. Irrespective of the explanation, empirical findings indicate that feelings are often seen in situations where animals are attempting to cope with their environment (Duncan and Petherick 1991; Broom 2008). Broom (2008, p.21) states that:" *(...) whenever a situation exists where decisions are taken which have a big effect on the survival or potential reproductive output of the individual, it is likely that feelings be involved*". Contrary to other aspects of welfare, data on feelings are difficult to obtain, and have primarily been derived from preference studies, or indirect sources such as physiological and behavioral responses in different situations (Dawkins 1983; Broom 2008).

2.1.3. Stress

Stress involves the failure of an animal to cope with a given situation (Broom 2008). Controllability and predictability are significant factors for assessing whether an animal can cope with a given situation. For example, the absence of food may cause an animal stress, but if the animal is able to solve the problem by finding food, then the event is controllable, and the stress associated with the event does not have long term consequences. Predictability can help the animal mitigate the effects of the stressful situation, even though it might not be able to control the situation (Wiepkema and Koolhaas 1993). Stressful situations occur when predictability and controllability are not possible, e.g. when housing conditions mean that a pig can not escape from being attacked by a littermate. Chronic stress is present when an adverse situation is permanent, or when a stressful element has a lasting negative effect on the animal. Stereotypes (repeated movements) and harmful behavior, e.g. tail-biting, are typical symptoms of chronic stress (Wiepkema and Koolhaas 1993).

2.1.4. Health

Health refers to the physical state of the animal and it is an important part of welfare. Indeed, according to many definitions of welfare, health is a prerequisite for good welfare (Broom 2008). A healthy animal can, however, have bad welfare, e.g. when its needs are not fulfilled. The advantage of using health problems as an indicator of welfare is that in many cases the connection to suffering is clear, and health status is often recorded (Rushen 2003).

2.1.5. Pain

Pain is part of an animal's control response to adversity during life, and can be a signal that the animal is having difficulty coping with its environment. Acute pain can result in behavioral avoidance, while the repeated experience of acute pain can result in learning so that potential injury can be avoided. Chronic pain can result in changed behavior, which can in itself have adverse effects, e.g. lameness (Broom 2008).

The 5 elements of animal welfare can overlap as pain, stress, poor health and unfulfilled needs are connected to negative feelings. Poor health can cause stress, while pain can signal poor health, etc. In sum, these elements represent different aspects of what constitutes animal welfare.

2.2. Indicators of Animal Welfare

One of the big issues with regards to the economic analysis of animal welfare is the acquisition of quantifiable data. Some authors argue that animal welfare should be based on how an animal feels (Duncan and Petherick 1991), while others suggest it should be determined by an absence of behavioral problems (Ladewig 2005). However, both are very difficult to measure.

Curtis (2007) promotes the use of animal-based indicators (e.g. the animal's health), primarily because these are measurable, and moreover changes in animal-based indicators signal changes in the animal's state of being, and therefore in their welfare. The advantage of animal-based indicators is that they are closely connected to animal welfare, but it should be noted that they require more resources to measure than environment-based indicators of animal welfare (e.g. sufficient space), which are simple to measure, but their possible relationship with animal welfare is less straightforward to determine (Botreau *et al.* 2007b). Several authors argue for the use of a variety of indicators to be able to cover the multidimensional nature of animals' welfare (Broom 1991; Rushen 2003; Christensen *et al.* 2012).

2.3. Animal Welfare and Production Economics

Several studies within animal science have focused on the productivity of farm animals in relation to animal welfare, whereas the literature on animal welfare and production economics is scarce (Lusk and Norwood 2011). In the following, we survey the indicators that have been adopted in the literature, and how they relate to economics.

2.3.1. Environment-based Indicators

A commonly used indicator of animal welfare is space allowance, or simply m^2 per pig. The larger the area per pig, the better the welfare. Greater space allows pigs to perform their natural behavior, as their movements are less constrained. A lack of space can stress pigs if they are unable to escape dangerous situations and can

provoke stereotypy (repeated movements), which is commonly seen in animals which are kept in confinement. A lack of adequate space can also lead to tail-biting, which is painful and may result in infections and reduced welfare both for the biting and the bitten pig. When space is inadequate, hygiene deteriorates as it becomes difficult for the pig to keep the dunging and resting areas separate (Jensen *et al.* 2012a). Jensen *et al.* (2012a) investigated whether the financial costs of increased space is compensated by the more efficient growth of pigs, or by reduced labor costs due to a reduction in manual cleaning. They analyzed the effect of space per animal on the cleanliness of the pens and based on this analysis, they derived the need for cleaning of the pen. Jensen et al (2012a) found that an increase in the amount of available space did not have any statistically significant affect on the cleanliness of the pens or on the gross margin per pig.

Pigs spend 80% of their time lying down, so it is important that they are comfortable when in this position; otherwise their welfare is negatively affected (Ekkel *et al.* 2003). Providing pigs with straw, or similar rooting material such as peat or soil, is generally considered to improve the comfort and welfare of the animals (Arey and Franklin 1995). Even a small quantity of straw can keep a pig busy most of the time, but there is a tendency that straw-related behavior increases with quantity (Day *et al.* 2002). The main function ofstraw for growing pigs is that it provides a stimulus for the mouth and snout, which would otherwise be directed towards other objects in the pen or pen-mates. Therefore, straw-related behavior reduces aggression, tail biting and stereotypy (Beattie *et al.* 1995). Despite these benefits, the use of straw can have a negative effect on hygiene in the pen as it increases the likelihood of the pig coming into contact with manure, and getting infections, although the prevalence of movement disorders, hoof damage, and other leg injuries is lower on concrete floors with straw bedding (Tuyttens 2005). The use of straw is more expensive than slatted housing systems, as straw has to be bought, stored, while cleaning is also required, all of which entail labor costs (Tuyttens 2005). A study by Sinisalo *et al.* (2012) showed that tail biting reduces average daily gain by 1% to 3%. Therefore, the cost of straw should be seen in relation to the dynamic effects from e.g. a reduction in tail bites and leg injuries. Enrichment of the animals' environment with playing and rooting material tends to reduce undesirable behavior, but it also depends on factors such as space allowance and housing type.

Bornett *et al.* (2003) studied the costs of four different housing systems by applying model calculations. The housing types studied were: fully-slatted, partly-slatted, Freedom Food housing with increased straw and space allowance, and an outdoor free-range system. The partly-slatted floor was found to be better for the hooves of the pig than the fully-slatted, while the Freedom Food and free-range systems were considered to be better for pig welfare than the slatted housing systems. The results of the study showed that feed costs were lowest in the partly-slatted floor housing system, and highest in the outdoor system. The opposite tendency was true for the housing costs. Labor costs were found to be highest in the Freedom Food system, while they were higher in

the partly- and fully-slatted floor systems than the outdoor system. The authors concluded that the partly-slatted flooring reduced costs and improved pig welfare compared to the fully-slatted flooring, and that the outdoor system had the highest rearing costs as a result of an increase in feed costs (Bornett *et al.* 2003). The higher feeding cost in the outdoor system was due to a poorer feed conversion ratio, which was probably caused by higher activity levels, and increased energy consumption by pigs in order to maintain body temperature (Bornett *et al.* 2003; Lebret *et al.* 2002; Millet *et al.* 2005). Several studies apply a similar approach to Bornett *et al.* (2003) and study housing systems with regards to animal welfare and production economics (Guy *et al.* 2012; Seibert and Norwood 2011; Lund *et al.* 2010).

2.3.2. Animal-based Indicators

Jensen *et al.* (2012b) studied the relationship between lameness and profitability. Lameness was used as a measure of pain, and nine different causes of lameness were investigated. The degree of pain associated with the diseases/injuries, and the different treatment probabilities, were based on expert opinions. The probability of treatment methods was used to model the expected reductions in gross margins resulting from the diagnosis. Jensen *et al.* (2012b) showed that bone fractures caused the highest level of pain and the greatest reduction in gross margins. The authors conclude that it is important for the farmer to recognize the different types of lameness in the herd, because it can improve profitability and animal welfare. Lawson *et al.* (2004a) studied how lameness and metabolic and digestive disorders affected technical efficiencies in dairy herds. The most efficient producers in their study reported more incidences of lameness, ketosis and digestive disorders, whereas less efficient producers reported more incidences of milk fever. The expected negative correlation between lameness, ketosis and digestive disorders and technical efficiency was outweighed by the productivity of inputs. Lawson *et al.* (2004b) studied the relationship between technical efficiency and reproductive disorders in a dairy herd. The authors did not find a negative relationship between milk production efficiency and reproductive disorders as expected, because management decisions compensated for the negative biological impact of the reproductive disorders on milk production. Barnes *et al.* (2011) analyzed the effect of lameness on technical efficiency in dairy herds by considering lameness as an input to production. They found that dairy herds with a low prevalence of lameness had higher technical efficiencies, which is contrary to the results of Lawson *et al.* (2004a). According to Barnes et al (2011), farms with a low incidence of lameness were characterized by lower labor productivity and lower stocking density, however this was overshadowed by higher productivity of feed and forage, and an increase in milk yields compared to the farms with higher levels of lameness. Therefore, the authors argue that a whole farm perspective, rather than partial indicators, are required once noneconomic factors (such us lameness or other welfare indicators) are used to assess the technical efficiency of the farm.

Perinatal mortality rates are high in Danish pig production, where approximately 24% of a litter dies before the age of 4 weeks, which is the normal weaning age in Denmark (Pedersen *et al.* 2010). Complications which result in the death of newborns, as opposed to still births, can generally be assumed to involve severe suffering. Typical causes of neonatal deaths are breathlessness, hypothermia, hunger and sickness. These complications can arise because of e.g. a cold environment, competition for the sow's teats or a lack of maternal care (Mellor and Stafford 2004). Pedersen *et al.* (2010) suggest that the Danish breeding system is one reason for the high perinatal mortality rate as it emphasises the economic results of genetic characteristics, such as a sow's ability to give birth to large litters, which in turn is correlated with perinatal mortality rates. Guy *et al.* (2012) analyzed different high welfare farrowing crates, where piglet survival rates, straw-bedding for the sow and space were among the welfare parameters. They found that the high welfare farrowing system increased costs by 1.6% compared to the frequently used farrowing crate with lower welfare. However, if piglet mortality rates could be reduced from 12% in the low welfare farrowing crate system to 9% in the high welfare system, then costs would be comparable, although this would depend on improved management.

2.3.3. Management as an Indicator

The farmer or the stockperson is responsible for feeding, identifying sick and aggressive pigs, and choosing the housing system. Management is therefore closely connected to the welfare of the pigs, and several studies have found that proper management is important for animal welfare. Ózsvári *et al.* (2012) found that the relationship between the management strategy and veterinary practice was positive and significant, and that better veterinary practice improved the performance of the farm. Therefore, they conclude that the commitment of the management to upgrading the animal health status of the farm (through veterinary practices) improves the performance of the farm. Munsterhjelm *et al.* (2006) evaluate the reproductive performance of sows. They use an overall measure of animal welfare, where `health and stockmanship´ is one of the indicators used. They use health-related attributes and record keeping, hygiene and maintenance of pens, as proxies for `health and stockmanship´, to evaluate animal welfare. The conclusion of their study is that stockmanship has a positive effect on the reproductive performance of sows, which is similar to the conclusion of the Scientific Veterinary Committee (1997).

2.3.4. Multidimensional Indicators

Rushen (2003) states that many animal welfare studies rely on too few measures, and therefore discusses the use of an overall welfare assessment. He points out that, when integrating different measures of welfare, there are typically trade-offs between them. This complicates the interpretation of such an overall measure in terms of how the weighting of each indicator should be resolved. Nonetheless, Rushen (2003) argues that: *"(…) the*

approach to welfare assessment which involves documenting the full range of specific problems that exist in housing systems, is more promising" (Rushen 2003, p. 211). A study by Stott *et al.* (2012) uses an overall welfare assessment to evaluate the relationship between gross margin and animal welfare in extensive sheep farming systems. The authors analyzed the relationship between welfare scores assigned to the farms based on experts' opinions and gross margins obtained from linear programming models. The results showed that there was no correlation between gross margin and welfare scores.

2.4. Summary

This section has shown that the definition of animal welfare is multidimensional. The discussion on the indicators of animal welfare shows that conditions in the pigs' stable and environment can affect welfare in several ways. From the discussion on animal welfare, welfare indicators and economics it is clear that there is a connection between animal welfare and economics. However, this connection is not straightforward, as the economic results of improved welfare depend on dynamic effects, which are often unclear. Therefore, the economic costs and benefits are not straightforward to evaluate. Most production economic studies on animal welfare use a single measure, e.g. lameness as an indicator of an animal's welfare, or calculate the costs of housing systems with different welfare standards. However, in order to measure animal welfare, an overall indicator which takes into account the multidimensionality of animal welfare should be used.

3. The Animal Welfare Inspection

The Danish inspection of the welfare of farm animals is based on departmental order nr. 1358 from December 15th 2009. Danish laws on animal welfare are grounded in EU directives, but the Danish laws are in general stricter than the minimum requirements set by the EU directives, especially in the case of pigs (Ministry of Food, Agriculture and Fisheries of Denmark 2011a).

3.1. Inspection in Practice

Inspections of animal welfare are performed at the herd level[3] and are unannounced, so the farmer cannot influence the findings of the inspection beforehand. The farmer, or his representative, is required to be present during the inspection. The presence of the daily stock keeper promotes dialogue on potential violations, so that misunderstandings do not occur, and therefore increases the credibility of the findings (Ministry of Food Agriculture and Fisheries of Denmark 2011b). There are a number of inspectors who visit farms which means a consistent evaluation of the checklist measures cannot be guaranteed. The ministry seeks to limit this through seminars, dialogue with inspectors, and by establishing guidelines for the inspection (Ministry of Food Agriculture and Fisheries of Denmark 2011b). In practice, the inspection is conducted with the aid of a checklist and if a violation occurs, the circumstances are noted and the severity of the violation is determined for each specific checkpoint. The Animal Protection Act applies to individual animals, so a violation does not consider the number of animals affected by a particular checkpoint (Ministry of Food, Agriculture and Fisheries of Denmark 2013). This means that only one violation is noted even if a checkpoint is violated in the case of, e.g. 10 pigs. The chance of violating the legislation therefore increases for producers with larger herds. This illustrates how inspections do not assess of animal welfare *per se*, but rather compliance with animal welfare legislation (Department of Large Animal Sciences 2012).

3.2. Welfare Control Inspection

Inspections of animal welfare are conducted on 5 % of all herds with more than 10 farm animals or horses in Denmark, and are based on a combination of risk assessment and random sampling by the Danish Veterinary and Food Administration.

3.3. "Nulpunkt" Inspection

In 2011, a separate inspection of animal welfare was conducted on pig farms. This inspection was named "Nulpunktsundersøgelsen" (base-line analysis). Pig farms were randomly selected in order to obtain an unbiased sample to be used as a baseline for comparison with the Welfare control. In connection with the

[3]The inspection is done according to the CHR number, which is an abbreviation for the Central Husbandry Register. A CHR number is an identification number given to a herd belonging to a livestock farm. A farmer can have several CHR numbers.

"Nulpunktsundersøgelsen," inspectors attended a meeting to align their assessments of the checkpoints on the checklist, so that individual assessments would be comparable (Department of Large Animal Sciences 2012).

3.4. Grading of Violations

A violation of a checklist measure can be categorized into four different degrees of severity: significant disadvantage, neglect, serious neglect and abuse (Ministry of Food, Agriculture and Fisheries of Denmark 2011a). Assessment criteria for the animal welfare inspection and available sanctions are presented in table 3.1.

Table 3.1: Assessment criteria for the animal welfare inspection and available sanctions

Assessment criteria	**Available sanctions**
Significant disadvantage	Admonition Injunction or reported to the police
Neglect	Injunction Reported to the police
Serious neglect	Reported to the police
Abuse	Reported to the police

A significant disadvantage is defined as conditions that cannot be categorized as neglect, but which are disadvantageous to the animals' welfare. If the conditions in the stable comprise a significant disadvantage to the pigs, then farmers receive an admonition ("indskærpelse"). If a specific violation, characterized as an admonition, is observed for the same farmer within two years of the first occurrence, the farmer receives an injunction or be reported to the police ("politianmeldelse").

Neglect is defined as conditions which do not warrant the involvement of the police as long as the conditions are corrected immediately. An injunction ("påbud") is given when neglect is not serious. In some cases, neglect can get reported to the police if the inspection authority wishes to emphasize matters of particular importance. Neglect is also reported to the police if a farmer fails to comply with an injunction within the stated time limit.

Serious neglect should always be reported to the police by the inspector. Serious neglect includes, e.g. a chronic ailment which has not been treated.

Abuse is covers the most severe cases of maltreatment and neglect, and should also be reported to the police.

3.5. The Level of Animal Welfare in the Inspection

3.5.1. The Checklist

The checklist mainly evaluates environment-based measures. These are easier and more reliable to measure than animal-based measures. Assessing whether or not a farmer has provided pigs with rooting material is easy to check, and assessments should therefore be consistent between inspectors, whereas an animal-based measure, such as behavior, is more difficult to assess. In the following, we present an overview of the criteria in the checklist and their relation to animal welfare.

3.5.2. Management of Sick Pigs

There are several criteria in the checklist concerning proper management with regards to sick animals. Several checkpoints concern sick animals and the provision and use of sick pens. This ensures that sick animals have proper conditions to cope with their illness. Aggression between pigs is an issue when they live in densely populated pens. Several criteria exist to ensure that procedures limit aggression, and that aggressive pigs are isolated. Aggression can cause stress amongst pigs.

3.5.3. Management in general

This category of criteria concerns the stock keeper's handling of the pigs. The farmer should ensure that pigs are able to see other pigs, that pigs are moved correctly, that no pigs are tethered, and that pigs are regularly checked. Some of these criteria are difficult to assess during an inspection, e.g. whether or not the pigs are checked regularly. A central criterion in this category is the proper provision of rooting material, which is often mentioned in the literature as being an important stimulus for the pigs and their welfare.

3.5.4. Housing/Pens

This category includes requirements for minimum space requirements, cleanliness of pens, the condition of the floors, and climatic conditions such as temperature. Clean floors ensure that poor hygiene does not negatively affect health, and that pigs can move around without slipping and potentially incurring injuries. In general, these indicators ensure that the pigs' surroundings do not cause discomfort, which could lead to stress.

3.5.5. Stables

This category concerns the condition of the stables and requires the presence of clean inventory, proper lighting, and the absence of potentially injurious objects. This category concerns conditions which do not directly affect the pigs' conditions and are therefore less obviously related to animal welfare.

3.5.6. Feed and Water

This category requires that all pigs have access to clean feed and water at all times. It seems counterintuitive that a farmer would violate these requirements, because he is interested in fattening pigs. However, there are many things to attend to in a pig stable and therefore it is possible for a farmer to be negligent in this respect. Clearly, adequate nutrition is central to a good standard of welfare.

3.5.7. Mutilation

This category concerns procedures for castration, tail docking, tooth grinding, etc and ensures that they are performed correctly. The procedures themselves cause pain to the pigs. Having no violations within this category is therefore not analogous to the pigs' good welfare, but it may limit the degree of pain associated with the procedures.

3.5.8. Record keeping

Record keeping consists of requirements for keeping medical records, and a self-monitoring scheme. Record keeping does not affect the welfare of the pigs, but it is considered a tool for raising the farmer's awareness of the welfare of his or her animals.

This review shows that the animal welfare inspection checks central elements of animal welfare. Not all criteria are immediately relevant for welfare, but in general they concern several different welfare aspects and can, therefore, be used as data on animal welfare. In order to apply the data, it is important to be aware of the level of welfare measured.

3.6. Relationship between Animal Welfare Inspections and Animal Welfare

The legislation determines the minimum requirements for animal welfare, but the legislation is not solely the result of a concern for animal welfare and ethics, but also political and economic interests. A proper welfare assessment should solely involve assessing the true state of the animals, which means considering the negative and positive aspects of their welfare and combining these into an overall assessmentwhich in turn means that good welfare, on some parameters, can compensate for poor welfare on others (Forkman 2010).

The welfare inspection is not in itself an assessment of the state of animal welfare (Forkman 2010) as it entails inspecting the requirements set out by the legislation. Therefore, a farmer who is abiding by the requirements of the legislation does not have violations. However, this does not necessarily translate into good welfare and it may be possible that the animals have good welfare even though the legislation is violated and vice versa, which can be illustrated by the checkpoints concerning mutilations mentioned above. An inspection of animal welfare evaluates each requirement in the legislation, so a farmer can not compensate a violation by improving

animal welfare in other areas. The requirements in the legislation exist to deter and prevent poor animal welfare, and therefore risk factors are included, which are important because the regular welfare control inspections are only conducted on a sample of farms. The welfare control inspection of a risk-based sample of farms (described in section 3.2.) and the "nulpunkt" inspection of a random sample of farms (described in section 3.3.) check the same animal welfare regulations, although Forkman (2010) argues that the "nulpunkt" inspection is stricter than the regular welfare control inspections.

3.7. Theoretical Considerations about the Relationship between Animal Welfare and Productivity

McInerney (2004) discusses the connection between animal welfare levels and livestock productivity (see figure 3.1). He argues that there is an unacceptable level of animal welfare, which is represented by the line between point W_{min} to point D. This level of animal welfare symbolizes neglect, abuse and cruelty, and any point below this line is unacceptable. Point "A" on figure 3.1 shows the natural welfare of the animals. In this situation, the animals live in the wild and exhibit their natural behavior. Livestock producers could theoretically improve the animals' welfare above the natural level to point "B", e.g. by providing them with shelter from predators, and sufficient food at all times. However, livestock producers are businessmen and wish to increase productivity. Therefore, they make efficient use of inputs, such as limiting the space per animal and maximizing turnover rates in the stables. Such activities decrease the welfare of the animals towards point C, D or E in figure 3.1. McInerney (2004) further argues that livestock producers are required to secure a minimum level of animal welfare, because both the individual farmer and the public have an interest in setting an acceptable limit, so that the welfare of livestock is at least acceptable. The level of animal welfare that is desired by different actors (e.g. consumers, producers, animal rights activists, politicians, etc.) is likely to be higher than the minimum welfare. Figure 3.1 illustrates this point, and that the desired level is somewhere around point C, i.e. below maximal welfare and above minimal welfare. We have used this figure to show the connection between livestock productivity and animal welfare. The level of animal welfare which is governed by animal welfare legislation lies in the region of point C.

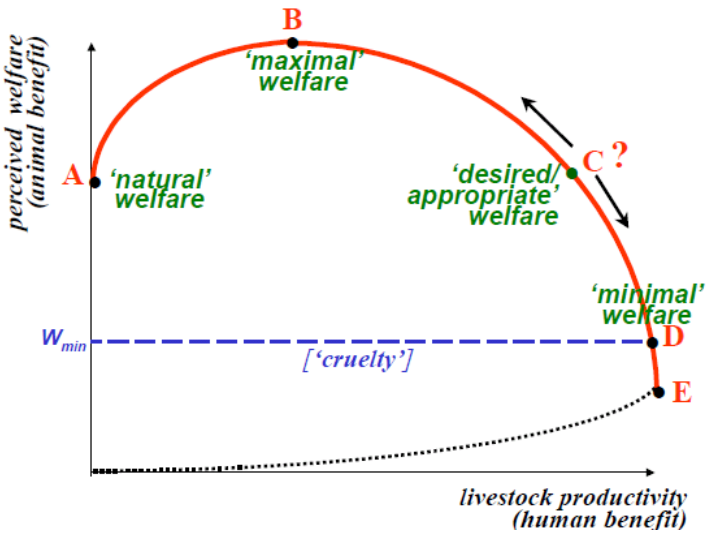


Figure 3.1: Conflicts between animal welfare and productivity (Source: McInerney 2004).

As discussed previously, a welfare inspection cannot be compared to a welfare assessment, but we can argue that it can be used as an indicator of animal welfare, as long as the caveats of the data are understood. According to the argumentation above, farmers with no violations can have a level of animal welfare corresponding to point C or above.

In the figure 3.2, we present a slightly modified theoretical model of the relationship between productivity and animal welfare which we find more helpful as a theoretical basis for our empirical analysis. For instance, figure 3.2 does not show a unique "unacceptable level of animal welfare," because it is impossible to objectively define this level in practice, as different people have different perceptions of what is acceptable and unacceptable treatment. Productivity is defined as the ratio of the output quantity to the input quantity. In case of multiple outputs and/or multiple inputs, an aggregated output quantity and/or an aggregated input quantity can be used. At an extremely low animal welfare level, the animals are suffering so much that productivity is very low (i.e. low output quantities and relatively large input quantities, e.g. due to sickness, mortality, etc.). With increasing animal welfare up to a certain level W_1, the animals are doing better, which results in higher productivity, e.g. due to higher growth rates, higher reproductive rates, lower mortality and lower veterinary costs. But if animal welfare has to be increased above level W_1 (point "E" in figure 3.2), an increase in inputs (e.g. more space per animal, more opportunities for playing and rooting) results in a less-than-proportional increase in the output (or even an unchanged (constant) or reduced (lower) output) so that productivity decreases.

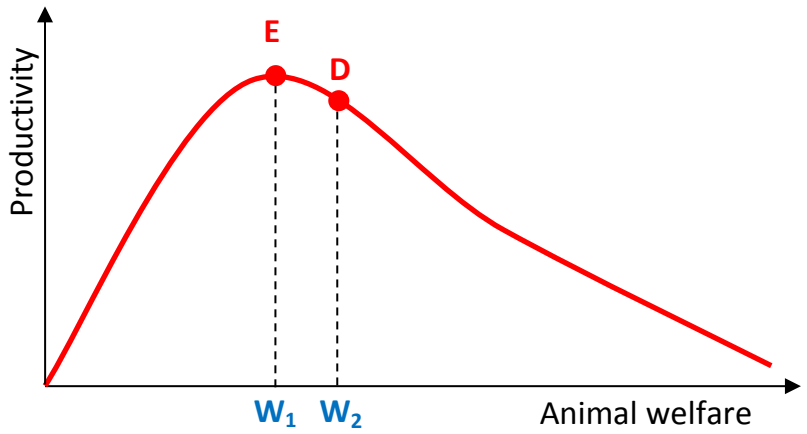


Figure 3.2: Relationship between animal welfare and productivity

If farmers are price takers and appropriate weights are used for aggregating outputs and inputs, productivity corresponds to profitability. Therefore, in the absence of animal welfare regulations, rational farmers who have no intrinsic motivation to comply with animal welfare regulations and just maximize their profit, choose the animal welfare level W_1 that results in the highest productivity (point "E" in figure 3.2). Thus, farmers have an economic incentive to have an animal welfare of at least level W_1. It is fair to assume that many people desire a higher level of animal welfare than level W_1. Hence, the regulator (e.g. policy makers at the national or international level) introduces minimal requirements regarding the animal welfare that are higher than level W_1, e.g. level W_2 in figure 3.2. If farmers follow these animal welfare regulations, their productivity and economic profit is lower than at the animal welfare level W_1. Farmers could only gain from further increasing animal welfare, if they get a price premium (e.g. if the final products are labeled as animal welfare friendly and some consumers are willing to pay a price premium for these products).

Welfare inspections check whether farmers are complying with animal welfare regulation, i.e. whether the actual animal welfare is below the legally required level of animal welfare. Thus, these data do not indicate how much the animal welfare level is above the legally required minimum level W_2 (corresponding to point D in figure 3.1). However, there is a strong indication that farmers who violate animal welfare legislation have animal welfare levels below level W_2. The distance between the actual level of animal welfare and the legally required level of animal welfare depends on the type of violation and its severity. As mentioned above, violating animal welfare regulations does not rule out the possibility that the animals have good welfare, because the inspection solely checks the legislation and does not account for potential substitutability between different aspects of animal welfare. By identifying the importance of the different requirements and the

number and severity of violations, it is possible to obtain a clearer image of the state of animal welfare on farms which are not abiding by the requirements.

If the animal welfare on all farms corresponds to level W_1 denoted in figure 3.2, there would be (everything else equal) a negative relationship between animal welfare and productivity. However, if some farmers have animal welfare levels that are significantly below W_1, there may be (everything else equal) no relationship, or even a positive relationship, between animal welfare and productivity.

The (observed) relationship between animal welfare and productivity can also be affected by other variables that affect both animal welfare and productivity. This indirect relationship between animal welfare and productivity could be caused, for instance, by the quality of the management (see figure 3.3). If good (bad) herd managers are (not) able to achieve a high productivity, as well as a sufficiently high level of animal welfare, and if there is not a direct relationship between animal welfare and productivity, we would find a positive relationship between animal welfare and productivity. If both direct and indirect relationships between animal welfare and productivity are present, the observed relationship is their combination. Thus, if our results indicate that there is no (clear) relationship between animal welfare and productivity, there may be significant direct and indirect relationships, although these relationships would balance out.

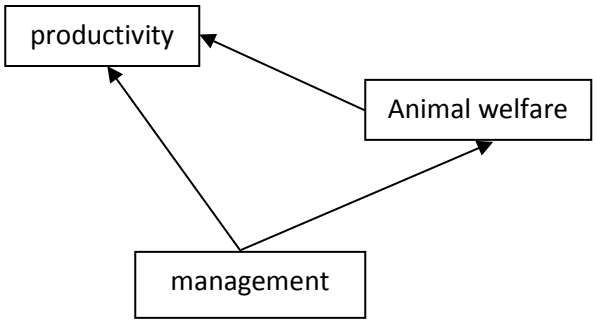


Figure 3.3: Relationship between management quality, animal welfare, and productivity

Figure 3.4 presents a more detailed model of the relationship between management, animal welfare and productivity. Animal welfare depends on herd management and input quantities (e.g. space per animal, medicine for preventing and curing diseases). Output quantity depends on input quantities (e.g. stable, labor, feed, medicine), the level of animal welfare (for explanations, see above) and the quality of the management.

Productivity is just the ratio of the output quantity to the aggregate input quantity (for explanations, see above). We assume that productivity does not have a direct causal effect on animal welfare.[4]

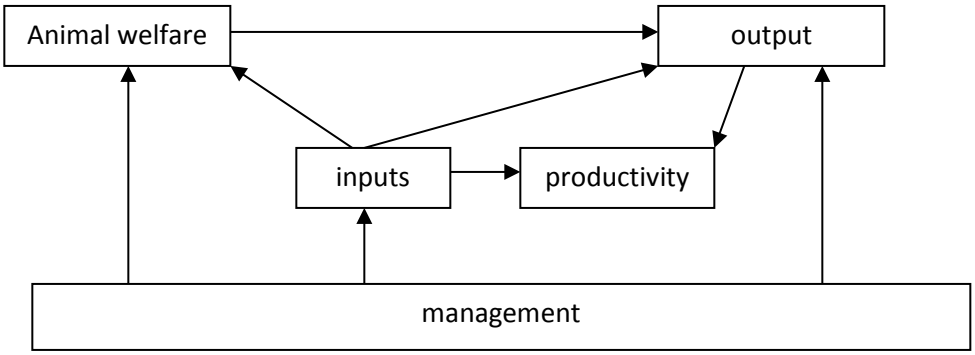


Figure 3.4: Detailed relationship between management quality, animal welfare, and productivity

[4] It might be argued that high or low productivity might affect the farmer's motivation and his/her decisions which in turn affect animal welfare. However we consider such effects to be negligible.

4. Proposed Indicators of Animal welfare

In order to exploit the data in the best way, we propose several indexes of the animal welfare data. The constructions of these variables are essential for evaluating animal welfare. In the following, we list and discuss the traits of potential indicators of animal welfare.

4.1. Any Violation

One way to investigate the economic differences between livestock producers is to compare producers with or without violations of the animal welfare legislation (AnyViolation). This is a simplistic way of evaluating differences between producers as the indicator does not account for the severity of sanctions, how the violation is related to animal welfare, or the number of violations. This variable is therefore not an ideal indicator of animal welfare, but can instead be used to indicate whether there is a difference between producers who abide by the animal welfare legislation and those who do not.

4.2. Total Number of Violations

Another indicator of animal welfare is the total number of violations, which is obtained by counting all violations of the animal welfare legislation for each farmer. In contrast to the indicator AnyViolation, this indicator accounts for differences among violators, while it also captures the effect of violations within different dimensions of animal welfare, and therefore comes closer to the ideal of a multidimensional index of animal welfare (Botreau *et al.* 2007a; Rushen 2003). However, simply counting the violations assigns less importance to the dimensions of animal welfare that are described by fewer checklist points (Botreau *et al.* 2007b). Hence, using the total number of violations as an indicator of animal welfare may be problematic if the importance of the different dimensions of animal welfare does not correspond to the number of checklist points. For instance, for slaughter pigs, five checklist points concern sick pigs while only one concerns playing and rooting material, but both are important for welfare.

Counting the total number of violations does not account for the severity of the sanctions or how the violations are related to animal welfare. This means that there could be instances where a farmer has several violations with minor sanctions for violations, and where the violations are only weakly related to animal welfare. The opposite scenario could also be true, i.e. a farmer having few violations with severe sanctions, and where the violations are strongly related to animal welfare. Under these circumstances, the total number of violations would be a poor indicator of animal welfare. However, the variable could be used as an indicator of the management of animal welfare, because one could argue that the more violations, the less emphasis a farmer puts on the animal welfare legislation.

4.3. Most Severe Violation

Using the most severe violation as a variable provides a categorical variable, which does not take into account the way in which the violation is related to animal welfare or the number of violations. On the other hand, it does take into account the severity of the sanction. There are differences amongst the sanctions when interpreting this variable in connection to animal welfare. An admonition for a violation with a weak connection to animal welfare is not a strong indicator of animal welfare, because it could have been given for an unfortunate one-time event. In order to be reported to the police, a farmer has to severely disregard animal welfare, or violate the same checklist point more than once. Therefore, a police report is a stronger indicator of bad animal welfare than an admonition. Another caveat is the possibility that farmers may have several violations that are of the same severity as his or her most severe violation. This could reduce the comparability between farms that have the same most severe violation, because some of these farms may have several violations of this severity, while other farms have no other violations of this severity.

Table 4.1 lists the traits of the different indicators which illustrates that none of the indicators ensures a direct focus on the connection to animal welfare. It is possible to construct a composite indicator that takes account of all the traits by constructing a weighting scheme. However, adding weights to the number of violations, severity of sanctions, and the different checklist points would require much knowledge and judgment on animal welfare. Weighting schemes typically require experts to do the weighting, and the final index would depend largely on their weightings (Botreau *et al.* 2007a). As mentioned in Botreau *et al.* (2007a), the background of the expert, veterinarian or ethologist, may affect his/her weighting. Therefore, we choose not to construct a composite indicator, but settle with the already mentioned variables, which are simple, objective and independent of weightings.

Table 4.1: Proposed Indicators of animal welfare and their traits

Traits of variable / Name of variable	Number of violations	Severity of sanctions	Ensures a direct connection to animal welfare
AnyViolation	No	No	No
Total violations	Yes	No	No
Most severe violation	No	Yes	No

4.4. Rooting Materials and Sick Animals

Table 4.1 illustrates that none of these indicators ensures a direct connection to animal welfare. This could be overcome by choosing some checklist points that have a clear connection to animal welfare, and using them as indicators of animal welfare. The most relevant checklist points are those concerning sick animals and access to rooting and playing material[5]. The indicator AnyRooting indicates whether a farmer has violated any animal welfare regulations concerning rooting and playing material, while the indicator AnySick indicates whether the farmer has violated any regulations concerning sick animals. It would have been preferable to construct two additional indicators by taking into account the most severe violations in these parts of the animal welfare regulations, but there is not enough variation in the severity of the violations in our data to account for severity in the statistical analysis.

[5] Proper care and the avoidance of suffering was also selected, but since less than 5% of farms had violations according to this indicator (6 farms in Nulpunkt and 5 in Welfare control) it was not used in the analyses.

5. Aggregation

5.1. Merging Animal Welfare Data with Economic Data

Economic data is registered on the CVR[6] number which is the identification number of a company. Within agriculture, this is comparable to the use of the term "farm". The welfare inspection data is registered on the CHR number, which is attached to a specific property (a herd) and not the entire farm. A farmer can have several herds with farm animals, and therefore several CHR numbers. If a farmer has four CHR numbers attached to the CVR number, animal welfare inspection can be conducted on, e.g. two CHR numbers out of four. This means that there is not inspection data on all the pigs at a farm, which is important for the economic analysis in the following sections, because the economic data is registered for the entire farm, i.e. at the CVR number. The welfare data needs to be aggregated to the CVR number in order to perform the economic analysis. In the following, we describe the different conceptual issues of the data, and how these are solved.

In order to illustrate the different checklists and the different sanctions in table 5.1-5.4, we have randomly chosen the checklist points A15, C131, C145 and H321, and some sanctions for pedagogical reasons. These sanctions are abbreviated so that no violation is equivalent to "OK", an admonition is "IND", an injunction is "Paab", and a police report is "PA". The indicators "total number of violations,""most severe violation" and "AnyViolation" are included to illustrate the effect of the aggregation procedure. In this case, there are two different CVR numbers, and each has one CHR number with 3000 and 2000 pigs, respectively. Table 5.1 illustrates the structure of the animal welfare dataset in the first case of relevance for the aggregation procedure.

5.1.1. Aggregation when one out of one CHR number belonging to the CVR number is inspected

This is the simple situation where one CVR number has only a single CHR number. It also symbolizes the ideal and final situation where animal welfare data is aggregated to the CVR number. Table 5.1 illustrates that the CVR (1) has 3 violations, the most severe violation is "police report", and it is "TRUE" that CVR (1) has violations of the checklist points.

[6] CVR is an abbreviation of the Danish 'Central VirksomhedsRegister' (Central Business Register), while CHR is an abbreviation of the Danish 'Central HusdyrbrugsRegister' (Central Husbandry Register). In order to avoid confusion, in this section we use the terms CVR and CHR number, and not farm and herd, respectively.

Table 5.1: Aggregation when one out of one CHR number belonging to the CVR number is inspected

CVR	CHR	Pigs	A15	C131	C145	H321	Total number of violations	Most severe violation	AnyViolation
1	1	3000	OK	IND	Paab	PA	3	PA	TRUE
2	1	2000	OK	IND	OK	OK	1	IND	TRUE

5.1.2. Aggregation when two out of two CHR numbers belonging to the CVR number are inspected

This situation is similar to the situation in section 5.1.1, because the welfare inspection was conducted on all the CHR numbers belonging to the CVR number. The inspection at two different CHR numbers could be argued to be similar to an inspection performed at a single CHR number having the same number of pigs as CHR (1) and CHR (2) together. This would suggest that the most severe violations for each checkpoint are kept after aggregating the two CHR numbers. This is illustrated in the final row of the table below. It is worth noting that the total number of violations has increased and the most severe violation has changed in this example.

Table 5.2: Aggregation when two out of two CHR numbers belonging to the CVR number are inspected

CVR	CHR	Pigs	A15	C131	C145	H321	Total number of violations	Most severe violation	AnyViolation
1	1	1000	OK	IND	IND	IND	3	IND	TRUE
	2	2000	Paab	OK	Paab	IND	3	Paab	TRUE
Aggregation of CHR 1 and 2									
1	1+2	3000	Paab	IND	Paab	IND	4	Paab	TRUE

5.1.3. Aggregation when one out of two CHR numbers belonging to the CVR number is inspected

An animal welfare inspection is often not conducted on all herds (all CHR numbers) on a specific farm (CVR number). In this case, only the animal welfare data from the inspected herd is used in the aggregation procedure. This implies that a hypothetical inspection of the “uninspected” herd (CHR 2) would not result in any violation of the animal welfare regulations that have not already been violated in the inspected herd.

Table 5.3: Aggregation when one out of two CHR numbers belonging to the CVR number is inspected

CVR	CHR	Pigs	A15	C131	C145	H321	Total number of violations	Most severe violation	AnyViolation
1	1	2000	OK	IND	Paab	Paab	3	Paab	TRUE
	2	3000	-	-	-	-	-	-	-
Aggregation									
1	1+2	5000	OK	IND	Paab	Paab	3	Paab	TRUE

5.1.4. Aggregation when 2 out of 4 CHR numbers belonging to the CVR number are inspected.

In this case, information on all CHR numbers is lacking, although information on more than one CHR number exists. In order to simplify the missing data problem, the aggregation approach from section 5.1.2 is applied to aggregate the inspected herds (CHR numbers). This result can be seen in the final two rows. In the example, there is inspection data on the CHR numbers 1 and 4, and therefore these are merged. The CHR numbers 2 and 3 are also merged, but there is only data on the number of pigs. This result reduces to a situation similar to the situation in section 5.1.3 with two CHR numbers.

Table 5.4: Aggregation when 2 out of 4 CHR numbers belonging to the CVR number are inspected

CVR	CHR	Pigs	A15	C131	C145	H321	Total number of violations	Most severe violation	AnyViolation
1	1	1000	OK	IND	Paab	Paab	3	Paab	TRUE
	2	2000	-	-	-	-	-	-	-
	3	1500	-	-	-	-	-	-	-
	4	2500	OK	IND	OK	Paab	2	Paab	TRUE
Aggregation of CHR 1 and 4, of 2 and 3, and of all four herds									
1	1+4	3500	OK	IND	Paab	Paab	3	Paab	TRUE
	2+3	3500	-	-	-	-	-	-	-
1	1+2+3+4	7000	OK	IND	Paab	Paab	3	Paab	TRUE

6. Methodology

6.1. Multivariate regression analysis

The purpose of regression analysis is to evaluate the effects of one or more explanatory variables on a single dependent variable. This is achieved by evaluating the conditional expectation of the dependent variable given the explanatory variables: $\mathrm{E}[\mathrm{y}|\mathrm{x}]$, which can be expressed as:

$$y=f(x;\alpha)+\varepsilon,$$

Where y is the dependent variable, x is a set of explanatory variables, α is a vector of parameters to be estimated, f(.) denotes the unknown regression function and ε is a random error term.

The advantage of multivariate regression over correlation analysis is that multivariate regression analysis can investigate the relationship between many variables, accounting both for direct and indirect relationships. If the regression function is linear (in parameters), the ordinary least squares (OLS) method is the most straightforward approach for estimating the unknown parameters. However, once the dependent variable is a non-continuous count variable (i.e. only containing positive integer values), the basic OLS model is not appropriate. In such cases, count data models such as the Poisson model or its generalizations, e.g. the negative binomial regression model, are the most suitable model specifications.

If the number of outcomes of the dependent variable is limited to only two alternatives (e.g. success and failure), discrete response (binary outcome) models are most suitable. In these models, the interest lies in the response probability of success given the values of independent variables:

$$p(x)\equiv P(y=1|x)=G(x;\alpha),$$

where p(x) is response probability distribution, P(.) denotes probability, x is a vector of explanatory variables and G(.) is a cumulative distribution function (cdf).

Often, G(.) is specified either as a standard normal cdf (probit model) or as logistic cdf (logit model), and the method of maximum likelihood estimation (MLE) is applied to obtain estimates of the parameters of interest.

6.2. Stochastic Frontier Output Distance Function

This section describes the framework that we use to estimate the technical efficiencies of the pig producers in our data set. In order to achieve this, we present the distance function and some intuition on the term “technical efficiency”, which provides a basis for the discussion of the estimation of the output distance function within a Stochastic Frontier Analysis (SFA) framework.

In applied production analysis, either production functions or cost functions are usually used to estimate the efficiency at the sector level or the individual (e.g. farm) level. The production function only allows for the estimation of a single output. However, most pig producers in Denmark also produce crops. Since Danish pig farmers produce multiple outputs, an estimation procedure that can model multiple outputs is required. The cost function is often used in these cases. However, as input prices do not substantially differ between regions in Denmark, it is impossible to estimate a cost function without cross-sectional data. In such cases, an output distance function that can handle multiple inputs and multiple outputs and does not require price data is often used. For these reasons, the output distance function is used in the analysis.

In the following, we describe the output distance function and its properties that can be derived from microeconomic production theory. This section is based on Coelli *et al.* (2005) and Bogetoft and Otto (2010). We use the Shephard's definition of an output distance measure (i.e. $TE = y/y^* \leftrightarrow y = TE \cdot y^*$, where TE denotes technical efficiency, y is the observed output and y^* is the output at the frontier), as opposed to using the Farrell distance measure (Bogetoft and Otto 2010).

For a given production technology set, P, defined by:

$$P=\{(x,y): x \text{ can produce } y\}$$

the output set, P(x), given by:

$$P(x)=\{y:x \text{ can produce } y\}=\{y:(x,y)\in P\}$$

represents the set of all output vectors, y, which can be produced using the input vector, x.

The Shephard's output distance function D_o is defined on the output set, P(x), as:

$$D_o(x,y)= \min\left\{\delta>0: \left(\frac{y}{\delta}\right) \in P(x)\right\}$$

The properties of the output distance function are given in Coelli *et al.* (2005):

1) $D_o(x,0)=0$ for all non-negative x;
2) $D_o(x,y)$ is non-decreasing in y and non-increasing in x;
3) $D_o(x,y)$ is linearly homogeneous in y;
4) $D_o(x,y)$ is quasi-convex in x and convex in y;
5) if y belongs to the output set (production possibility set) of x, then $D_o(x,y)\leq 1$; and
6) if y belongs to the frontier of the production possibility set, then $D_o(x,y)=1$.

Property 1 states that it is possible to produce nothing from a given set of inputs, and in this case, the distance measure is zero. Property 2 states that the output distance function does not decrease when y increases and it does not increase when x increases. A producer can therefore not be less efficient if he produces more with the same inputs. Property 3 implies linear homogeneity in output quantities and requires:

$$D_o(x,t\cdot y)= \min\left\{\delta \middle| \left(x,\frac{t\cdot y}{\delta}\right)\in P(x)\right\}$$

$$D_o(x,t\cdot y)= \min\left\{\lambda\cdot t \middle| \left(x,\frac{y}{\lambda}\right)\in P(x)\right\},\quad \left(\frac{\delta}{t}=\lambda\right)$$

$$D_o(x,t\cdot y)=t\cdot \min\left\{\lambda \middle| \left(x,\frac{y}{\lambda}\right)\in P(x)\right\}$$

$$D_o(x,t\cdot y)=t\cdot D_o(x,y)$$

Property 4 implies that if inputs x^1 and x^2 can produce y, any weighted average of these inputs can also produce y (quasi-convexity in x), and that if two combinations of outputs y^1 and y^2 can be produced using input vector, x, any weighted average of these output can be also produced (convexity in y). Therefore, convexity serves the role of enlarging the technology (Bogetoft and Otto 2010, p. 64).

Property 5 and 6 state that the distance function does not exceed the value of 1, because the frontier represents the maximum attainable output.

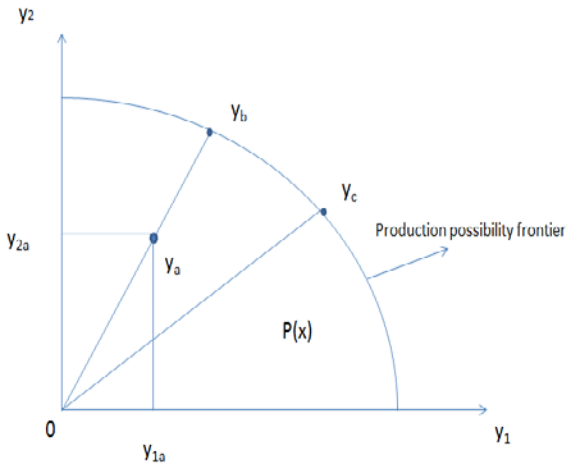


Figure 6.1: Output distance function and the production possibility set Coelli *et al.* (2005)

Figure 6.1 shows the production possibility set, P(x), which is bounded by the production possibility frontier. It shows output y_1 and y_2, which is produced with the use of an input vector x. Given the input vector x, it is not possible to produce outside the production possibility set (property 5 and 6), and therefore the frontier

displays the maximum attainable output combinations. The value of the distance function for the output combination y_a is

$$\delta = 0y_a / 0y_b.$$

This value is below 1, because it is the actual output combination y_a compared to the maximum attainable combination of output y_b. This is a measure of technical efficiency. The reciprocal of this factor is when all output quantities at point y_a can be increased without increasing input use, i.e. if the producer became more efficient. Technical efficiency is measured along a ray from the origin to the observed point of production. This means that the proportions of outputs are held constant along the ray, and therefore that a change in the unit of measurement does not affect technical efficiencies. The efficiency measurement is therefore unit invariant (Coelli *et al.* 2005).

6.2.1. The Stochastic Frontier Model

The linearized form of the Cobb-Douglas production function that is often used for regression analysis can be written as the following:

$$\ln(y_i) = \ln(f(x_i;\beta)) + \varepsilon_i,$$

where ε_i is an error term that accounts for random noise and differences in technical efficiencies. In regression analysis, the method of Ordinary Least Squares (OLS) is often used, but this method interprets all deviations from the estimated regression function as noise, and the inefficiency cannot be identified. Estimating the production function with OLS means that observations can lie above the regression function, because it minimizes the sum of squared vertical distances between the predicted outputs and the observed outputs. Using OLS may therefore contradict the definition of the production frontier, because the production frontier represents the maximum attainable output at a given input vector.

The stochastic frontier model, which was independently proposed by Aigner *et al.* (1977) and Meeusen and Broeck (1977), can be used to estimate a production function that accounts both for random noise and producers' inefficiencies:

$$\ln(y_i) = \ln\big(f(x_i;\beta)\big) + v_i - u_i \text{ with } u_i \geq 0,$$

where v_i accounts for noise and u_i accounts for technical inefficiency. One reason for estimating a stochastic frontier model is to obtain predictions of the technical inefficiencies while allowing for noise in the model. Noise can have a positive or a negative effect on output, and can therefore cause observations to lie above or

below the frontier. The frontier represents the maximum attainable output and inefficiency therefore always has a negative effect on the output of a producer.

In the SFA model, it is assumed that v_i's are independently and identically distributed and have zero means and variances σ_v^2, i.e. $v_i \sim$ iid $N(0,\sigma_v^2)$. It is assumed that the u_i's follow a truncated normal distribution, i.e. $u_i \sim$ iid $N^+(\mu_i,\sigma_u^2)$ (Battese and Coelli 1995). The stochastic frontier model can be estimated using the Maximum Likelihood method, which maximizes the match between the statistical model and the dataset by choosing the value of the parameters that make the values of the actual observations as likely as possible. The Maximum Likelihood estimation is done through an iterative optimization procedure. In order to separate the effect of the u_i's and v_i's for all producers, two additional parameters are estimated, γ and σ^2. These are related in the following way:

$$\gamma=\frac{\sigma_u^2}{\sigma^2} \text{ where } \sigma^2=\sigma_v^2+\sigma_u^2 \text{ and } \gamma\in[0,1]$$

When γ tends to 0, deviations from the frontier are due to the dominance of noise in the data, σ_v^2, and there are no technical inefficiencies. In this case, the estimation result would approach that of the ordinary least squares estimation procedure. On the other hand, when $\gamma\rightarrow1$, deviations from the frontier are due to the dominance of, σ_u^2, and therefore technical inefficiencies (Coelli *et al.* 2005).

6.2.2. Stochastic Output Distance Function

In order to enable the econometric estimation of the stochastic frontier production model with multiple outputs, we need to specify the output distance function. The functional form that is used for the estimation be linearly homogeneous in the output quantities (property 3):

$$D_o(x,y)=f(x,y)$$

$$f(x,t\cdot y)=t\cdot f(x,y)$$

If $t=\frac{1}{y_1}$, then the function can be written as:

$$f\left(x,\frac{y}{y_1}\right)=\frac{f(x,y)}{y_1}$$

$$f(x,y)=f\left(x,\frac{y}{y_1}\right)\cdot y_1$$

Substituting this into the equation of the output distance function, we get:

$$D_o(x,y) = f\left(x, \frac{y}{y_1}\right) \cdot y_1$$

$$\frac{D_o(x,y)}{y_1} = f\left(x, \frac{y}{y_1}\right)$$

$$\frac{1}{y_1} = \frac{f\left(x, \frac{y}{y_1}\right)}{D_o(x,y)}$$

Taking the natural logarithm on both sides of this equation yields, we get:

$$-\ln(y_1) = \ln\left(f\left(x, \frac{y}{y_1}\right)\right) - \ln(D_o(x,y))$$

Remember that $0<D_o(x,y)\leq 1$ as long as the firm is producing a positive quantity of at least one output. This implies that $-\infty < \ln(D_o) \leq 0$ so that we can set $u=-\ln(D_o)\geq 0$. Substituting u for $-\ln(D_o)$ gives:

$$-\ln(y_1) = \ln\left(f\left(x, \frac{y}{y_1}\right)\right) + u$$

The random error term v is then added to the equation to turn it into a stochastic model:

$$-\ln(y_1) = \ln\left(f\left(x, \frac{y}{y_1}\right)\right) + u + v$$

This equation is now of the form of the stochastic frontier model. Therefore, SFA estimation methods can be applied to estimate this equation, i.e. a multiple-output and multiple-input production technology.

6.2.3. Cobb-Douglas Stochastic Output Distance Function

The choice of functional form is important for the estimation and description of the production technology. Many studies within production economics apply the translog functional form, because it is second order flexible. This also means that more parameters need to be estimated than in less flexible functional forms (e.g. Cobb-Douglas), and therefore more observations are required for the estimation. We chose to apply the Cobb-Douglas functional form, because it relies on fewer parameters to be estimated. This comes at a cost, because the distance elasticities of the inputs and outputs are constant, and do not vary across observations, so that the elasticity of scale, which is defined as the negative sum of the distance elasticities of the inputs, is also constant (Coelli *et al.* 2005).

The estimable equation is:

$$-\ln(y_{1i}) = \alpha_0 + \sum_{k=2}^{M} \alpha_k \ln\left(\frac{y_{ki}}{y_{1i}}\right) + \sum_{k=1}^{N} \beta_k \ln(x_{ki}) + \sum_{m=1}^{L} \rho_m H_{mi} + v_i + u_i,$$

where the subscript i indicates the producer, M is the number of outputs (y), N is the number of inputs (x), H is a set of L further explanatory variables that may affect the frontier, and α, β and ρ are the parameters to be estimated. A model of the technical inefficiencies and its explanatory variables can be estimated simultaneously with the stochastic frontier model (Battese and Coelli 1995). The model for the technical inefficiency is given by:

$$\mu_i = \delta_0 + \sum_{n=1}^{O} \delta_n z_{ni} \text{ with } u_i \sim N^{+}(\mu_i, \sigma_\mu^2),$$

where *z* are the explanatory variables, *δ* are parameters to be estimated, and O is the number of z-variables. The actual prediction of the technical efficiencies is not described in this report, but we refer to Coelli *et al.* (2005) for a detailed description. The inefficiency equation above appears simple, but the interpretation of the coefficients is not straightforward. The sign of the coefficient can be interpreted, but not the magnitude. The formula for the marginal effect of a z-variable is derived in Olsen and Henningsen (2011), and the marginal effects can be retrieved using the add-on package "frontier" (Coelli and Henningsen 2012) for the statistical software "R".

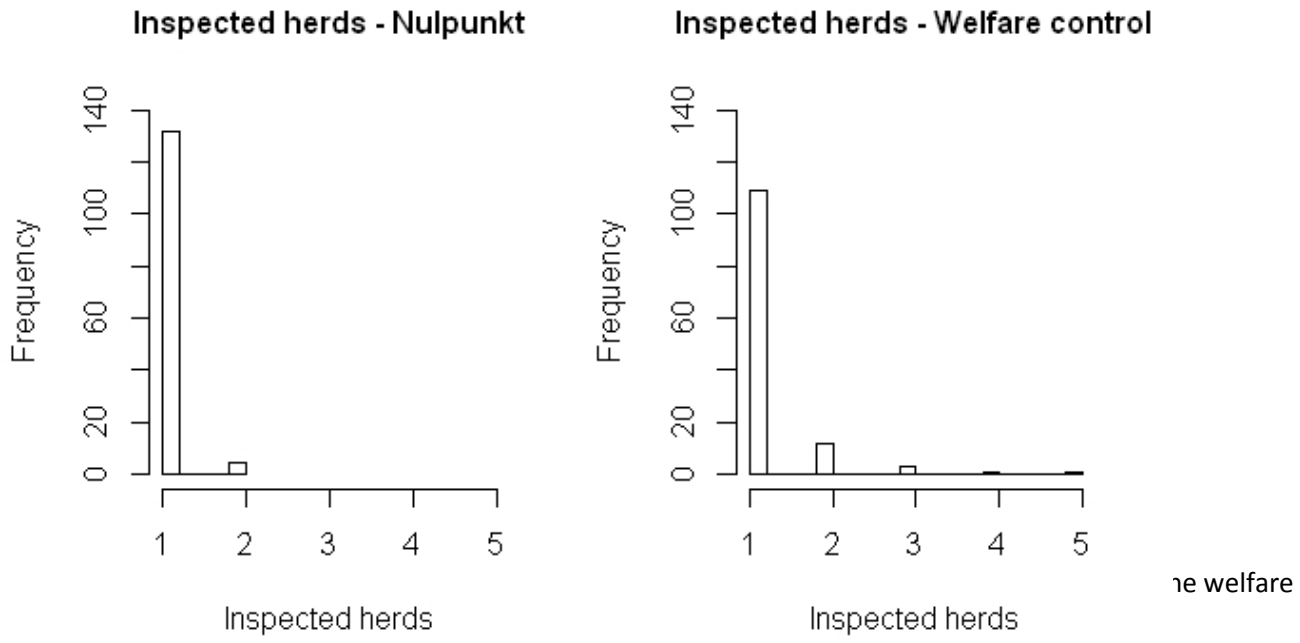
7. Analyzing Animal Welfare Data

As previously discussed, the animal welfare data are based on the "nulpunkt" data and the welfare control data. There are some potential biases in the data, which are common for both datasets. Several farms in the sample have more than one herd, whereas the proportion of inspected herds varies between farms. We investigate whether the proportion of inspected herds affects the number or severity of violations. The distributions of the animal welfare indicators are assessed across the datasets in order to decide whether it is reasonable to pool the data, and approach it as one sample. In the welfare control data, there are 126 observations, while there are 138 observations in the "nulpunkt" data.

7.1. Testing for Bias

7.1.1. Herds Inspected

In the "nulpunkt" data set, only one herd is inspected at most farms, whereas in the welfare control data set, more than one herd is more frequentlyinspected. As discussed in section 5.1.3, concerning the aggregation procedure, it is assumed that farms where more than one herd is inspected can be approached as if one large herd had been inspected. This may be a strong assumption, and it is therefore tested. Figure 7.1 shows the number of herds inspected on the farms in the two samples.



ıe welfare

The number of violations registered for a farm should be considered as a count variable. It is an ordered variable, because it is better to have no violations than to have 5. We wish to test whether farms wheremore

than one herd was inspected have different inspection results than farms where only one herd was inspected. Therefore, we test whether the indicators "total number of violations" and "most severe violation" depend on the number of herds inspected at the farm. This is performed with the non-parametric Mann Whitney U test for ordered categorical variables (see section A.4 in the appendix for further information on this test). When tTesting for differences in the total number of violations, the null hypothesis is:

H_0: There is no difference in the distribution of the total number of violations between farms where one herd is inspected and farms where more than one herd is inspected.

H_1: There is a difference.

This is tested for the pooled dataset including both "nulpunkt" data and welfare control data[7]. The test yields a Z-score = -0.295, and a p-value = 0.771 and therefore the null hypothesis cannot be rejected. There is no difference between the distributions when testing for the number of violations.

The indicator "most severe violation" is also an ordered categorical variable. It is clearly an ordered variable, because it is better to have no violations, than to receive an injunction. Therefore, we use the same approach to test whether there is a difference in the distributions of the most severe violation. The null and alternative hypotheses are similar, and so is the result of the test with a Z-score = 0.088 and p-value = 0.943. This means that the null hypothesis cannot be rejected.

Additionally, we tested to see whether there is a difference in the distribution of the indicators "total number of violations" and "most severe violation" when all herds at the farm were inspected or not. When testing for the indicators "total number of violations" and "most severe violation," the null hypothesis is:

H_0: There is no difference in the distribution of the total number of violations (most severe violation) between farms where all herds are inspected and farms where not all the herds are inspected.

H_1: There is a difference.

The test statistics Z-score = -0.476, and a p-value = 0.635 and Z-score = -0.172, and a p-value = 0.868 for the total number of violations and the most severe violation, respectively. In both cases, we fail to reject the null hypotheses. Therefore, the fact that more than one herd is inspected on some farms does not cause any significant bias in the data. The internal consistency in the datasets is therefore not seriously biased due to this problem.

[7] We do not test this within individual samples because there are only a few farms in the "nulpunkt" data where more than one herd has been inspected.

7.1.2. Share of Pigs Inspected

A related issue is that all pigs are inspected on some farms, whereas only some pigs are inspected on others. As discussed in section 5.1.3, it is not possible to overcome this issue in the aggregation procedure, and this may lead to bias. The non-parametric Mann Whitney U test is used to test whether this affects the results of the inspections. Testing for the total number of violations, the null hypothesis is:

H_0: There is no difference in the distribution of the total number of violations between farms where all pigs are inspected and farms where not all pigs are inspected.

H_1: There is a difference.

This is tested for the pooled dataset of "nulpunkt" data and welfare control data. The test yields a Z-score = 0.378, p-value = 0.707, and therefore the null hypothesis cannot be rejected. The same was tested for the indicator "most severe violation," and the result was similar with Z-score = 0.158, p-value = 0.880[8]. Therefore, the share of inspected pigs (pig units) does not affect the result of the inspection. The assumption underlying the aggregation procedure, when not all pigs are inspected, does not cause any significant bias to the data.

7.2. Comparing "Nulpunkt" Data and Welfare Control Data

7.2.1. Production Types Inspected

In order to distinguish the technological differences between the different types of pig production, we classified pig farmers into four production types: having all types of pigs, only slaughter pigs, piglets and slaughter pigs, or sows and piglets. The distribution of farms with respect to production type is shown in table 7.1.

Table 7.1: The distribution of production types in the "nulpunkt" data and the welfare control data

Production type	integrated pig producers	specialized slaughter pig producers	farms with small piglets and slaughter pigs	specialized piglet producers	Total
"nulpunkt" data	67	39	20	9	135
welfare control data	84	24	10	6	126
Total	151	66	30	15	261

If the production technology is not the same for the production types, then a difference in the distribution of production types may entail differences in animal welfare. Using Pearson's χ^2 test, it is possible to assess

[8] The same hypothesis and indicators were tested within the datasets, and it did not differ from the conclusion for the pooled dataset.

whether the distribution of production types is different between the "nulpunkt" data and the welfare control data (see section A.5 in the appendix for further information on this test).The null hypothesis is:

H_0: There is no difference in the distribution of production types between the "nulpunkt" data and the welfare control data.

H_1: There is a difference.

The test yields a χ^2 statistic = 8.147 and p-value = 0.043 at 3 degrees of freedom, and is therefore significant at the 5 % level. The null hypothesis is rejected, and there is a difference in the distribution of production types in the two datasets. In the following, the distribution of the welfare indicators is tested for the two samples. These are compared by the production type to account for the difference in the distribution of production types.

7.2.2. Animal Welfare Indicators

In the following section, we compare the distributions of the animal welfare indicators for integrated pig producers ("all") and specialized slaughter pig producers ("only slaughter"), as these two production types account for 82.8 % of the farms in the pooled dataset. There are few observations for specialized piglet producers ("sows + piglets") and farms with small piglets and slaughter pigs ("piglets + slaughter") (see table 7.2).

Table 7.2: Number of observations for production types with and without violations for the "nulpunkt" data and the welfare control data

	Violations	**No violations**	**Total**
Integrated pig producers			
"nulpunkt" data	42	25	67
welfare control data	35	49	84
Specialized slaughter pig producers			
"nulpunkt" data	15	24	39
welfare control data	14	12	26
Farms with small piglets and slaughter pigs			
"nulpunkt" data	11	9	20
welfare control data	4	6	10
Specialized piglet producers			
"nulpunkt" data	2	7	9
welfare control data	3	3	6

7.2.3. AnyViolation

AnyViolation is a categorical variable and therefore Pearson's χ^2 test can be used to test whether there is a difference between the distribution of farms with violations in the "nulpunkt" data and the welfare control data. When testing for the indicator AnyViolation, the null hypothesis is:

H_0: There is no difference in the proportion of farms with violations between the "nulpunkt" data and the welfare control data for integrated pig producers.

H_1: There is a difference.

The result of the test provides an X-squared = 6.59 with 1 degree of freedom and a p-value = 0.01. The null hypothesis is therefore rejected at the 5 % significance level, and so there is a difference in whether or not farms were in violation of the animal welfare legislation in the two datasets for integrated pig producers. The same hypotheses are tested for specialized slaughter pig producers which gives X-squared = 1.49 with 1 degree of freedom and a p-value = 0.22. The null hypothesis therefore can not be rejected and there is no difference in the distribution of farms with violations for specialized slaughter pig producers. Producers with all pig types account for 58 % of all observations, and therefore there is a difference for a substantial part of the observations in the pooled sample.

7.2.4. Total Number of Violations

Figure 7.2 provide asets.

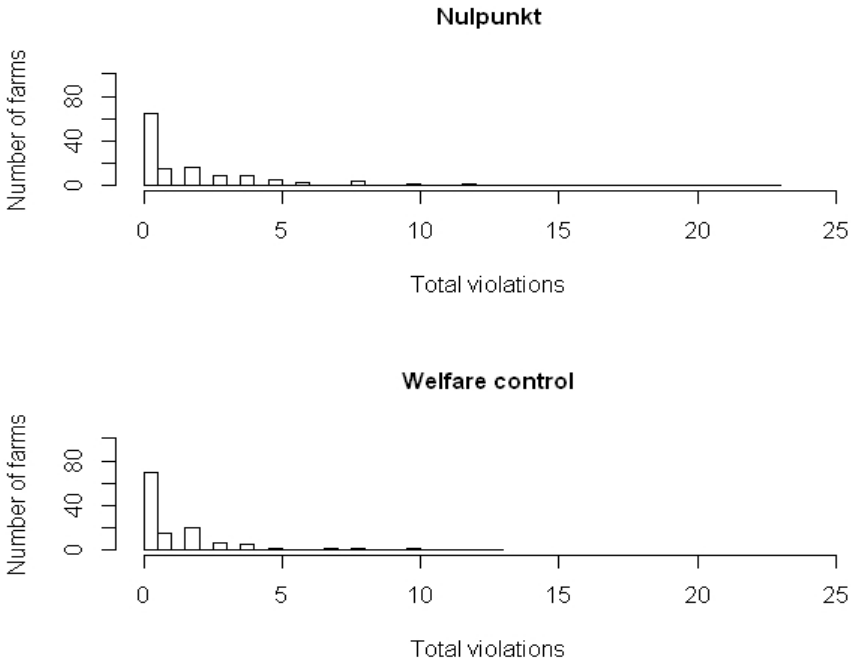


Figure 7.2: Nu control data

From figure 7.2 it can be seen that the right tail of the distribution is longer for the “nulpunkt” data than for the welfare control data. So, more farms have several violations in the “nulpunkt” data set compared to the welfare control data set. Looking at the spread of the total number of violations for integrated pig producers shows a clearer image of the differences in distributions (see figure 7.3) in that much of the difference in the total number of violations is for integrated pig producers.

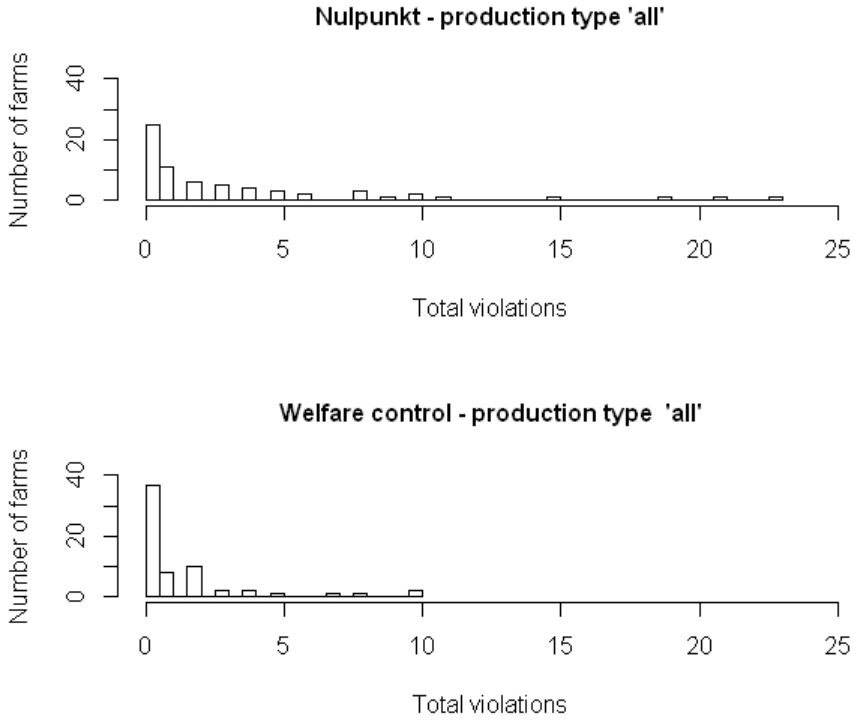


Figure 7.3: Number of integrated pig producers and total number of violations in the “nulpunkt” data set and the welfare control data set

The non-parametric Mann Whitney U test is used to test whether there is a difference in the distributions. When testing for differences in the total number of violations, the null hypothesis is:

H_0: There is no difference in the distribution of the number of violations for integrated pig producers between the “nulpunkt” data and the welfare control data.

H_1: There is a difference.

The test results in a Z-score = 2.97 and a corresponding p-value = 0.003. The null hypothesis can therefore be rejected at the 5 % significance level. There is a difference in the distributions of the total number of violations for integrated pig producers between the two data sets. From the histograms in figure 7.4, it can be seen that

there are no large differences between the two different data sets of the specialized slaughter pig producers. When testing the same hypotheses for the specialized slaughter pig producers, the non-parametric Mann Whitney U test yields a Z-score = -1.141, p-value = 0.257 and the null hypothesis can therefore not be rejected. There are no differences in the distribution of the total number of violations for specialized slaughter pig producers between the "nulpunkt" data and the welfare control data.

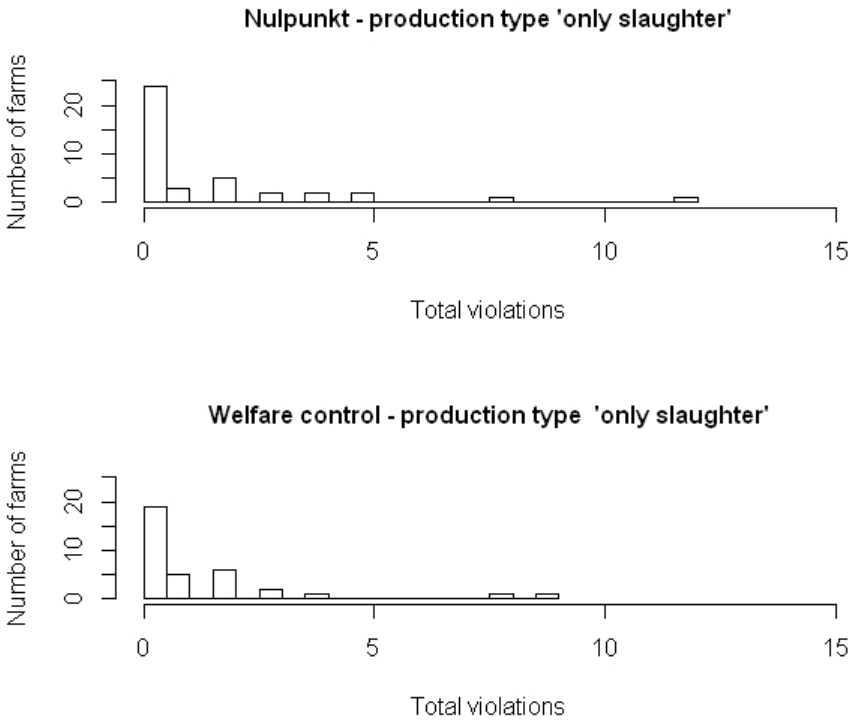


Figure 7.4: Number of specialized slaughter pig producers and the total number of violations in the "nulpunkt" data set and the welfare control data set

7.2.5. Most Severe Violation

The indicator "most severe violation" is an ordered categorical variable, and therefore the Mann-Whitney U test can be applied to test the distribution between the datasets. As before, the null hypothesis is:

H_0: There is no difference in the distribution of the most severe violations for integrated pig producers between the "nulpunkt" data and the welfare control data.

H_1: There is a difference.

The result yields a Z-score = 2.696 and a p-value = 0.007 and therefore the null hypothesis is rejected at the 5 % significance level. Testing the same hypothesis for specialized slaughter pig producers yields a Z-score =

-1.059 and p-value = 0.305 and so the null hypothesis cannot be rejected. Thus, there are no differences between the datasets. Figure 7.5 illustrates the distributions of the most severe violations for all the production types.

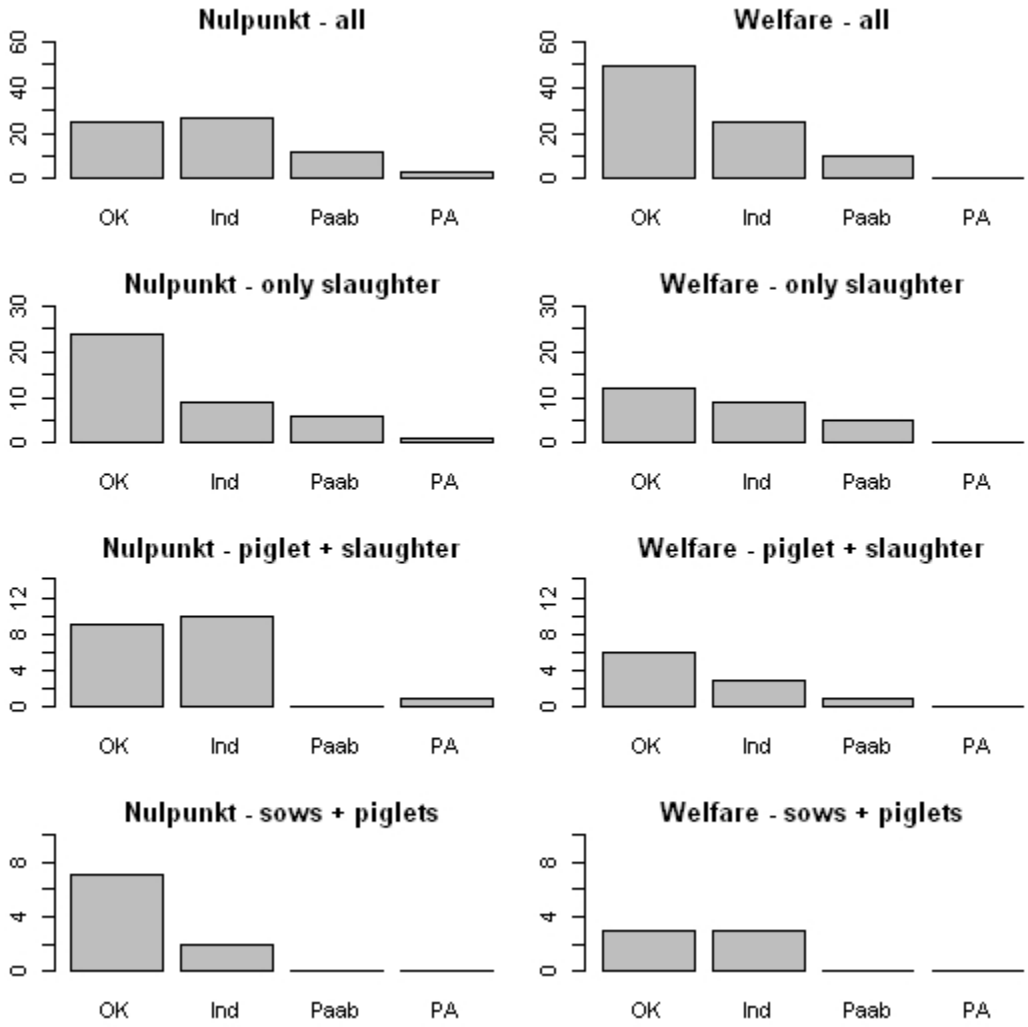


Figure 7.5: Number of farms and the most severe violations for different production types in the "nulpunkt" data and the welfare control data. The x-axis shows the most severe violations. These are "OK"→ no violation, "Ind" → admonition, "Paab" → injunction, and "PA" → police report

Besides the results from the statistical tests, the samples are also different because some police reports were excluded from the welfare control data set before we received the data from the Danish AgriFish Agency. This causes a bias in the dataset, because an unknown number of farms with the most severe violation "police report" are not included. Only police reports from the farms where the legal conviction is already finished are included in the welfare control data set. For these farms, the particular checkpoint that was violated, or the

number of violations of the farmer, are unknown. Therefore, only the indicator “most severe violation” can be used without adding further bias to the indicators of animal welfare.

7.3. Summary

This section shows that there are differences between the two datasets. First, the number of herds inspected per farm is different between the “nulpunkt” data and the welfare control data, but the number of herds inspected does not affect the indicators of welfare. So, the aggregation method is assumed not to cause any significant bias. The distribution of the production types is different between the “nulpunkt” data and the welfare control data. In the “nulpunkt” data, fewer farms are classified as integrated pig producers than in the welfare control data, but they tend to violate the animal welfare regulations more frequently and they also have more violations than the farms in the welfare control data. Furthermore, integrated pig producers have more severe violations in the “nulpunkt” data than the integrated pig producers in the welfare control data. Integrated pig producers account for 58 % of the observations in the pooled dataset[9]. The differences in the distributions of the two samples, and the number of observations involved, indicate that the “nulpunkt” data and the welfare control data should not be pooled to one dataset. As previously mentioned in section 3.3, the “nulpunkt” data set is based on a random sample, while the welfare control data set is based on a non-random sample, and some police reports are not included in the welfare control data set. Therefore, we choose to focus our further analysis solely on the “nulpunkt” data in order to avoid biased results due to non-random sampling, missing police reports and possibly less strict inspections in the welfare control data.

[9] Though not reported here there were no significant differences for the production types “piglets + slaughter” and “sows + piglets”.

8. Animal Welfare and Economics

This section presents and analyzes the relationship between economic variables and animal welfare indicators based on the "nulpunkt" dataset. As before, we focus on integrated pig producers and specialized slaughter pig producers, because they account for most observations in the dataset.

The analysis of the relationship between animal welfare and economic outcome is restricted to farms where the revenue from pig production is at least 66% of total revenue from animal production. In the following, we use several statistical tests. An overview of the main results is presented in appendix B.

8.1. Total Number of Pig Units and Animal Welfare

Winter *et al.* (1998) argue that the structural adjustment process in agriculture has contributed to declining farm animal welfare through larger farms and fewer mixed farms. It is possible to investigate the relationship between animal welfare and the number of pig units at farms, and thereby whether size is correlated with animal welfare management. This is done for integrated pig producers and specialized slaughter pig producers. In section 3.1, it was stated that the nature of the inspection can result in larger farms having more violations. In Lassen *et al.* (2012), a farmer mentions that having a large farm increases the likelihood of making minor mistakes with regards to the animal welfare legislation. On the other hand, larger farms may also be more professionally managed, and therefore have fewer violations.

Several studies within the economic literature connect herd size and animal welfare. The results in Lawson *et al.* (2004a) show that larger dairy herds are more technically efficient, although they have a higher occurrence of treated diseases. An opposite result was found in Barnes *et al.* (2011) who show that farms with lower levels of lameness tend to have lower average number of cows within the herd. Stott *et al.* (2012) find that, in extensive sheep farming, flock size is not correlated with animal welfare. The results on this matter are therefore mixed. The following section studies this in the case of pig production.

The distribution of the number of pigs for different production types in the "nulpunkt" data set is presented in figure 8.1. It shows a large spread in the distribution between farms and between production types.

Figure 8.1: Production types and the number of pig units

8.1.1. Total Number of Violations

Figure 8.2 below illustrates the relationship between the indicator for the total number of violations and the number of pigs units at the farms.

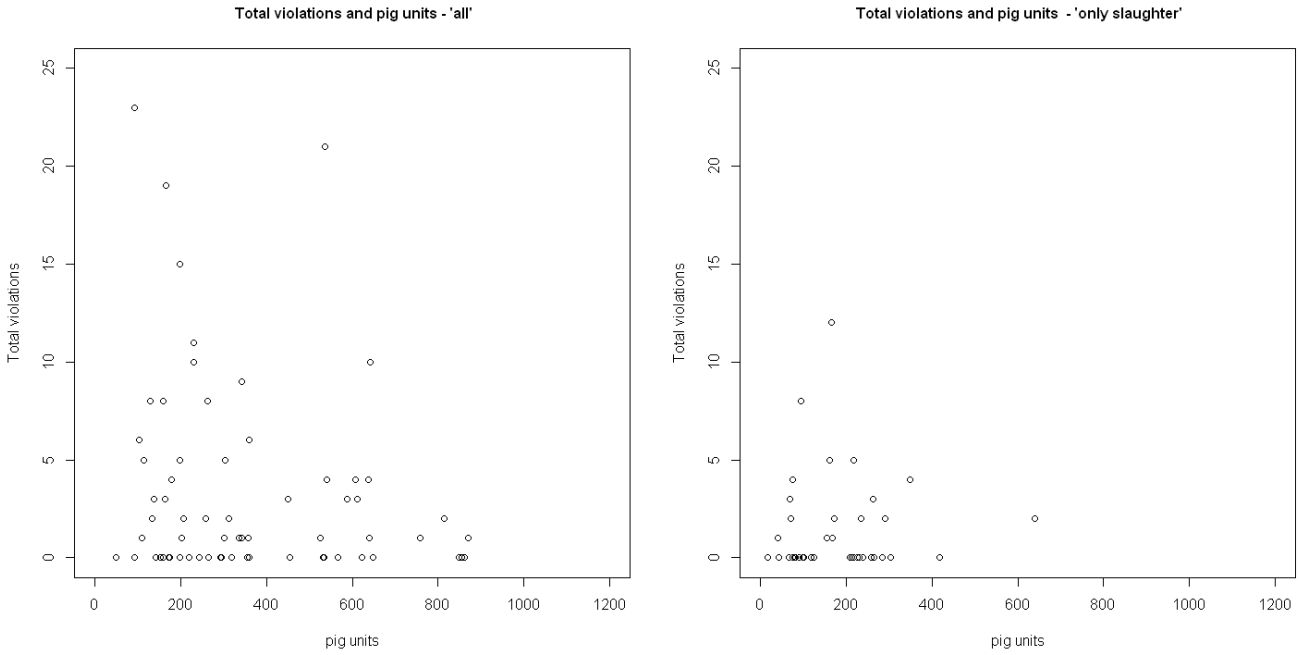


Figure 8.2: Total number of violations and the number of pig units for integrated pig producers and specialized slaughter pig producers

In figure 8.2, it is difficult to observe any relationship between the total number of violations and the number of pig units. Some small farms have no violations, while others have many, and the same is true for larger farms. A negative tendency could be depicted for integrated pig producers as larger farms have fewer violations. Pearson's correlation test can be used to test for correlation between two variables. The null hypothesis is:

H_0: The correlation between the total number of violations and the number of pig units for integrated pig producers is equal to zero.

H_1: The correlation is not equal to zero.

The correlation is -0.19 and testing this result with a t-test gives a t-value = -1.54 at 65 degrees of freedom, which has the p-value = 0.13. The null hypothesis cannot be rejected, and so there is no correlation between the total number of violations and the number of pig units for integrated pig producers. There is no significant correlation for specialized slaughter pig producers at any significance level.

8.1.2. Most Severe Violation

Figure 8.3 shows the number of pig units in the groups of the most severe violations reported for integrated pig producers and specialized slaughter pig producers. The number of pig units per farm does not seem to vary significantly with the indicator "most severe violation" for either of the production types. The median is almost the same, and so are the variances. In the case of integrated pig producers, farmers who are reported to the police for violations tend to have fewer pigs, but this is only true for 3 observations, so this could be a coincidence, which means that it is not possible to make any generalizations based on this.

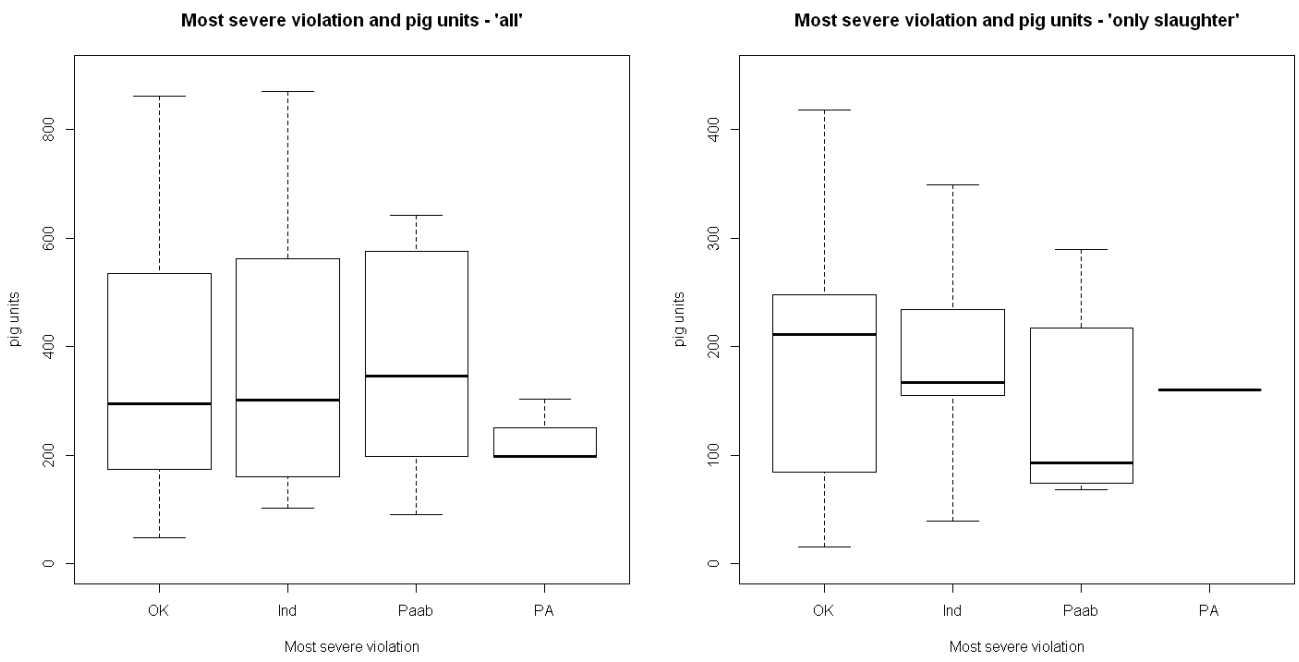


Figure 8.3: The most severe violation and the number of pig units for integrated pig producers and specialized slaughter pig producers[10]

8.1.3. AnyViolation

The difference between farms with and without violations for the two production types is tested with Welch's two-sample t-test (see section A.1 in the appendix for further information on this test). When testing with regards to the indicator AnyViolation, the hypotheses to be tested are:

H_0: There is no difference in the average number of pig units for integrated pig producers with or without violations of the animal welfare legislation.

H_1: There is a difference.

The null hypothesis cannot be rejected for integrated pig producers (t = 0.077, df = 53.57, p-value = 0.938), so there is no difference in the average number of pig units between farms with or without violations. It is also tested for specialized slaughter pig producers and this gives a t-value = 0.321 at 32.7 degrees of freedom and p-value 0.75. Therefore, for specialized slaughter pig producers, the null hypothesis also cannot be rejected.

[10]In this figure, an outlier for the production type "all" was excluded to make the boxplot easier to read.

8.2. Gross Margin per Pig Unit and Animal Welfare

Animal welfare could potentially affect gross margin in several direct and indirect ways. The central items in the calculation of the gross margin are feed costs, medicine and veterinary costs, and revenue from pig production. Section 2 discussed how animal welfare is likely to be related to input use, veterinary practice, while well-conditioned pigs are likely to earn greater revenue. The correlation between gross margins and animal welfare can go both ways. Farms with large gross margins are likely to be good managers, which could imply that they have good welfare management. The opposite could also be true. This was hypothesized in figure 3.1, which illustrated that decreasing animal welfare could increase livestock productivity and thereby gross margin.

Figure 8.4 shows the distribution of gross margins per pig unit for the different production types.

Figure 8.4: Gross margin per pig unit (DKK) and production types[11]

According to Figure 8.4, there are significant differences in gross margin between production types, but also between farms of the same production type.

A correlation test shows a significant and positive relationship between gross margin per pig unit and the total number of pig units for integrated pig producers. There is no significant correlation in the case of specialized slaughter pig producers.

[11] In this figure, an outlier for the production type "all" was excluded to make the boxplot easier to read.

8.2.1. Total Number of Violations

Figure 8.5 shows the variation between gross margin per pig unit and the total number of violations. For integrated pig producers, a correlation test shows a correlation coefficient of -0.24 with 65 degrees of freedom and p-value = 0.052. The correlation between gross margin per pig unit and the total number of violations is therefore negative and significant at the 10 % level. For specialized slaughter pig producers, the correlation coefficient is -0.20 with 37 degrees of freedom and the p-value is 0.21. Therefore, there is no significant correlation between gross margin per pig unit and the total number of violations for specialized slaughter pig producers.

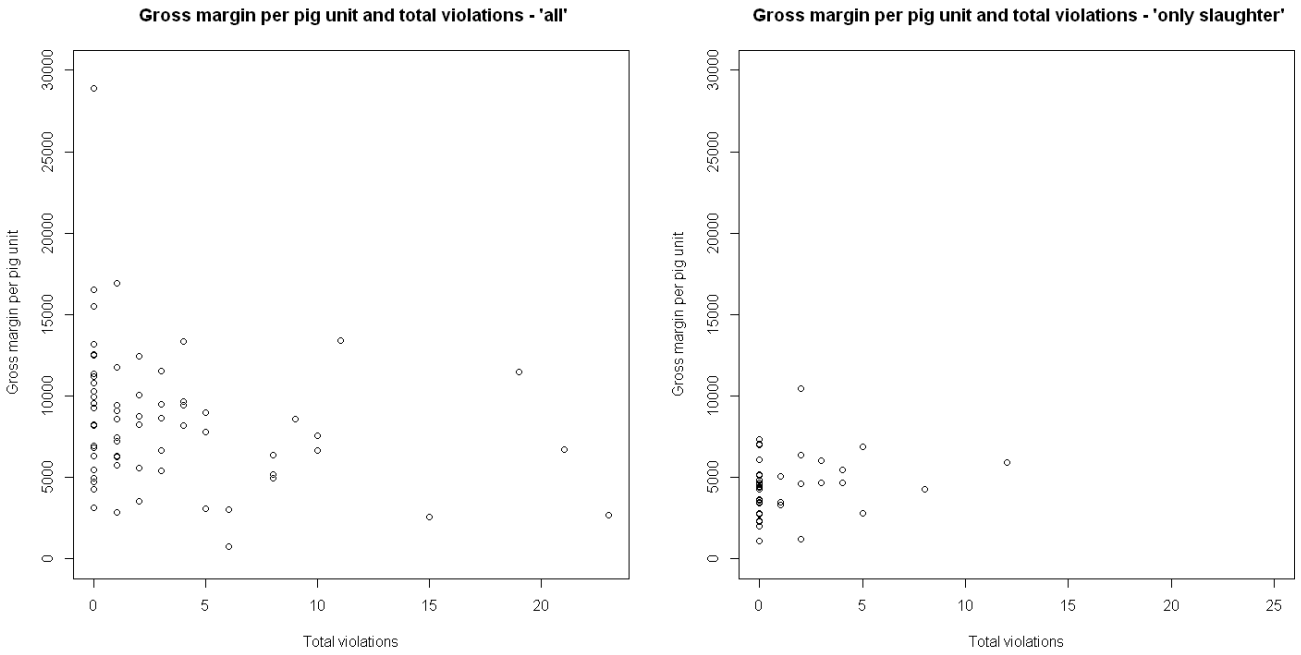


Figure 8.5: Gross margin per pig unit (DKK) and the total number of violations for integrated pig producers and specialized slaughter pig producers

8.2.2. Most Severe Violation

The indicator “most severe violation” suffers from having too few observations in the different groups of sanctions (see figure 8.6). The category “police reports” (“PA”) only has three and one observations for integrated pig producers and specialized slaughter pig producers, respectively.

There is some variation between the gross margins per pig unit between groups, but the tendencies are unclear. A one-way ANOVA can be used to test differences in means between groups (see section A.2. in the appendix for further information on this test).

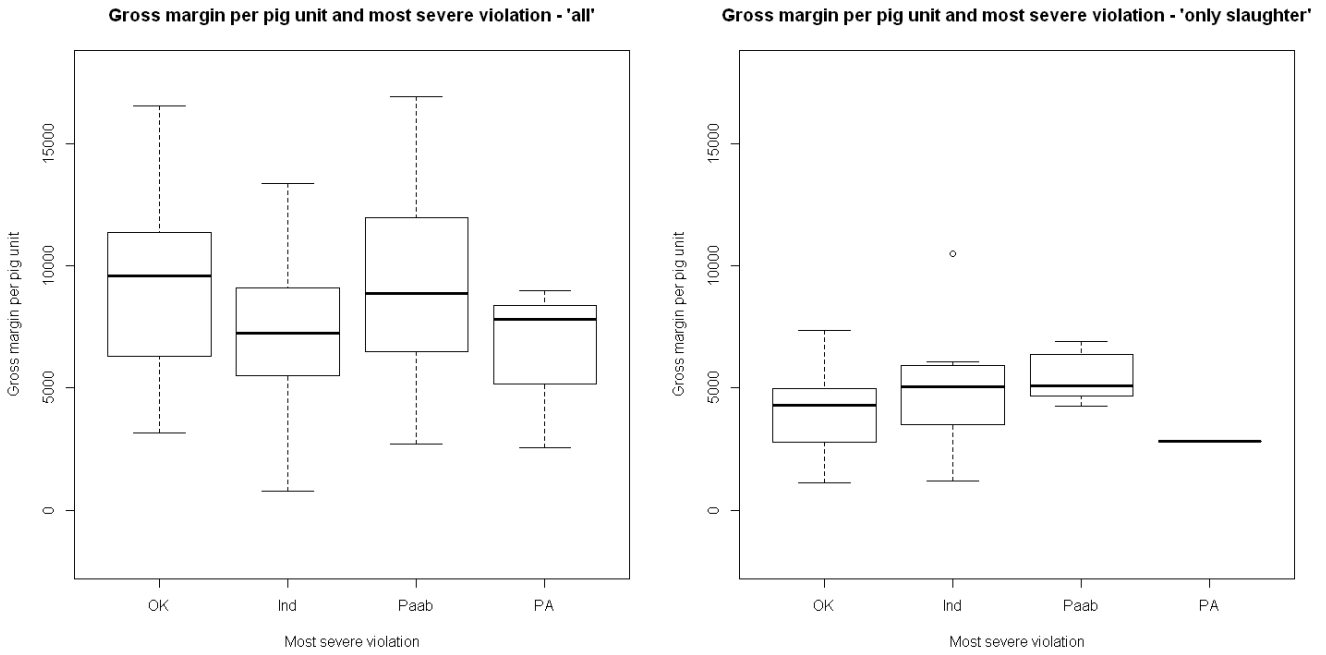


Figure 8.6: Gross margin per pig unit (DKK) and the most severe violations for integrated pig producers and specialized slaughter pig producers

We test for significant differences in the gross margin per pig unit between farms with different most severe violations for integrated pig producers and specialized slaughter pig producers:

H_0: There is no difference in the average gross margin per pig unit for farms with different most severe violations for integrated pig producers (specialized slaughter pig producers).

H_1: There is a difference.

Performing the test gives an F-value= 2.48 and a p-value = 0.07. The null hypothesis is rejected at the 10 % significance level, and therefore there is a difference in gross margins. The ANOVA does not provide information on the differences between gross margins, so a Tukey's test of multiple comparisons is used. This test compares the average gross margin per pig unit of all possible pair wise combinations of groups. The difference between farms with no violations and farms with an admonition as the most severe violation is significant at the 10 % level. On average, the gross margin per pig unit for farms with no violations was 9,925 DKK and 7,070 DKK for farms with an admonition. Notably, there is no statistical difference between farms with no violations and farms with an injunction ("Paab") as the most severe violation. The one-way ANOVA for specialized slaughter pig producers does not show any significant differences in gross margins per pig unit and the most severe violation.

8.2.3. AnyViolation

In order to see if a simpler comparison shows any differences, we compare farms with and without violations in the figures below.

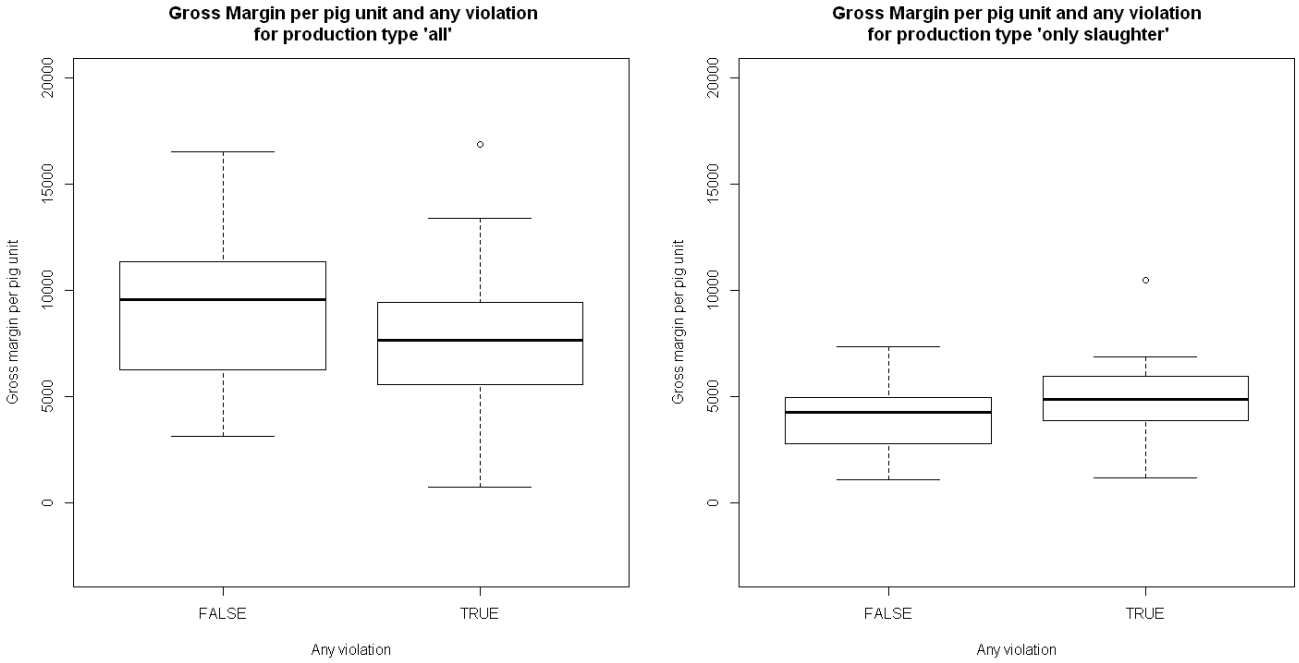


Figure 8.7: Gross margin per pig unit (DKK) and farms with and without violations for integrated pig producers and specialized slaughter pig producers

T-tests show that there is a significant difference in gross margins per pig unit at the 10 % level for integrated pig producers (t = 1.914, df = 35.85, p-value = 0.064), whereas there is no significant difference for specialized slaughter pig producers (t = -1.359, df = 24.333, p-value = 0.187).

8.2.4. Rooting Material and Sick Animals

The relationship between gross margin per pig unit for farms violating checklist criteria on rooting and playing material and sick animals is shown in figures 8.8 and 8.9. It is interesting to note that for integrated pig producers, the gross margins are larger for farms with no violations, whereas the opposite is true for specialized slaughter pig producers. For the integrated pig producers, the differences between farms with violations and farms without violations are statistically significant at the 5 % levels for rooting material (t = 2.878, df = 41.255, p-value = 0.006), but are not significant for sick animals (t = 1.322, df = 48.852, p-value = 0.192). For specialized slaughter pig producers, there were no statistically significant differences.

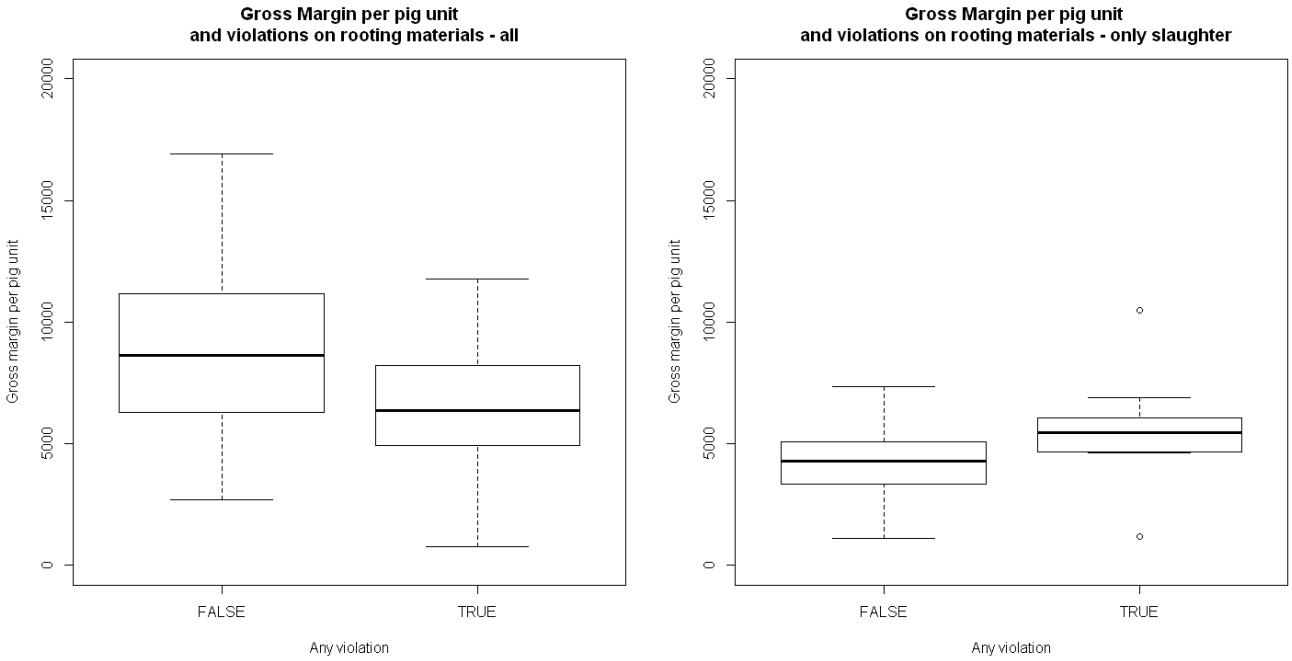


Figure 8.8: Gross margin per pig unit (DKK) and farms with and without violations concerning rooting material for integrated pig producers and specialized slaughter pig producers

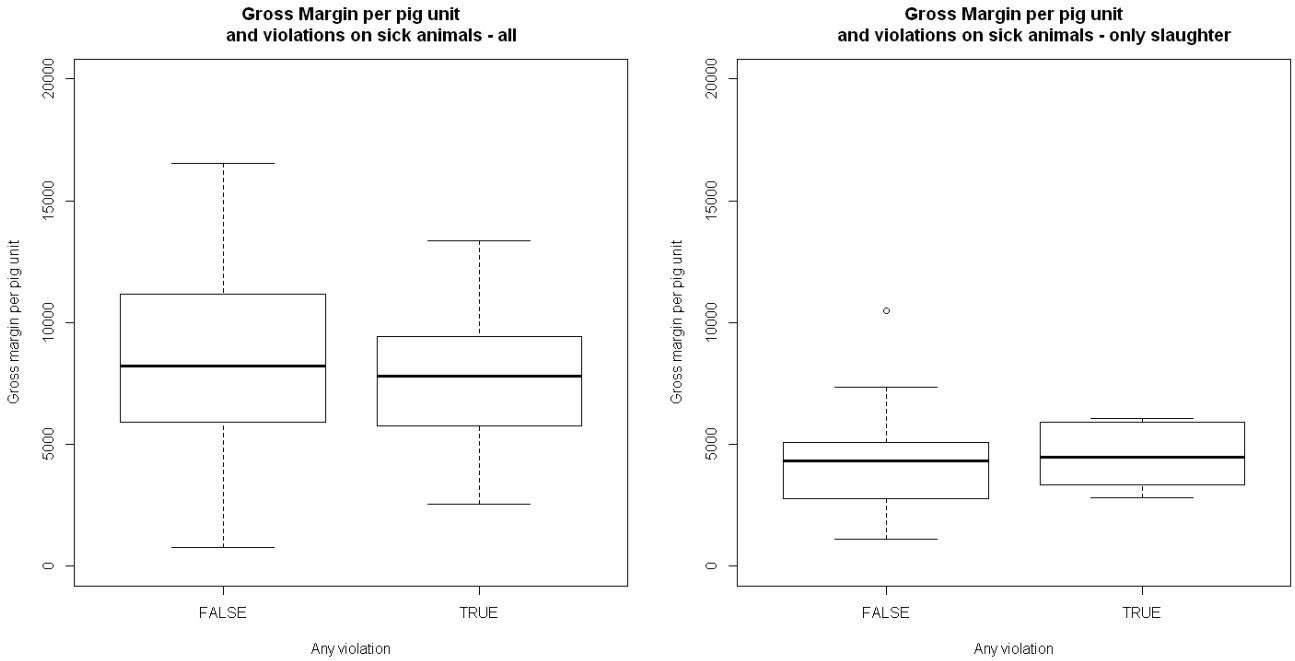


Figure 8.9: Gross margin per pig unit (DKK) and farms with and without violations concerning sick animals for integrated pig producers and specialized slaughter pig producers

8.3. Medicine and Veterinary Costs per Pig Unit and Animal Welfare

Medicine and veterinary costs are closely connected to the health management of pigs. It is therefore relevant to study the correlation with animal welfare. The measure of medicine and veterinary costs per pig unit is difficult to assess with respect to animal welfare, because high expenses could be both good and bad for welfare. Significant use of veterinarians and medicine could indicate that the farmer is bad at managing animals' health, or that the farmer is very attentive towards the animals.

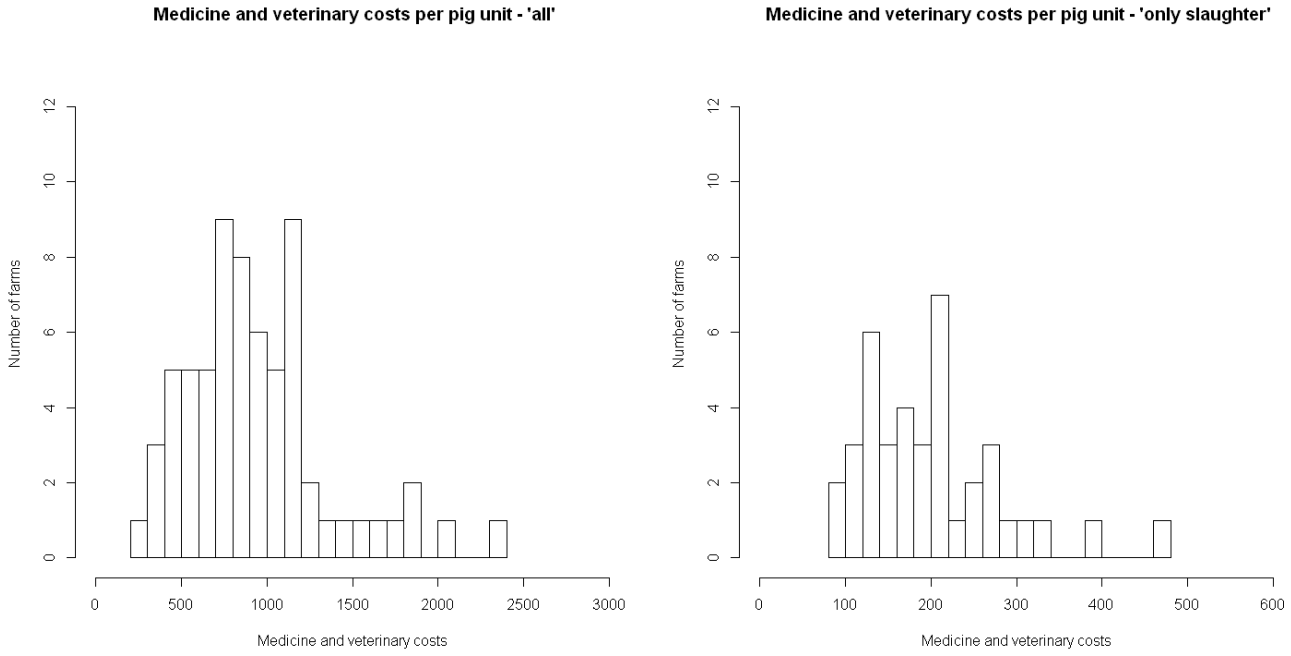


Figure 8.10: Medicine and veterinary costs per pig unit (DKK) for integrated pig producers and specialized slaughter pig producers

Figure 8.10 shows that the distribution of veterinary and medicine costs varies between production types. The study by van der Fels-Klerx *et al.* (2011) confirms a significant difference in the use of antibiotics between slaughter pig producers and farms with sow production. They also find a large between-farm variation in the use of antibiotics, and suggest that differences are due to level of hygiene, degree of preventive use, or the farmer's or veterinarian's treatment decisions. The between-farm differences are constant over time, and the variation in usage therefore doesn't change.

The variation in veterinary and medicine costs per pig unit does not seem to be affected by the number of pigs at the farm, which can be seen in figure 8.11. The fact that the costs per pig unit are not correlated with the number of pigs produced at the farm indicates that the level of hygiene and/or degree of preventive use do not depend on the size of farm either.

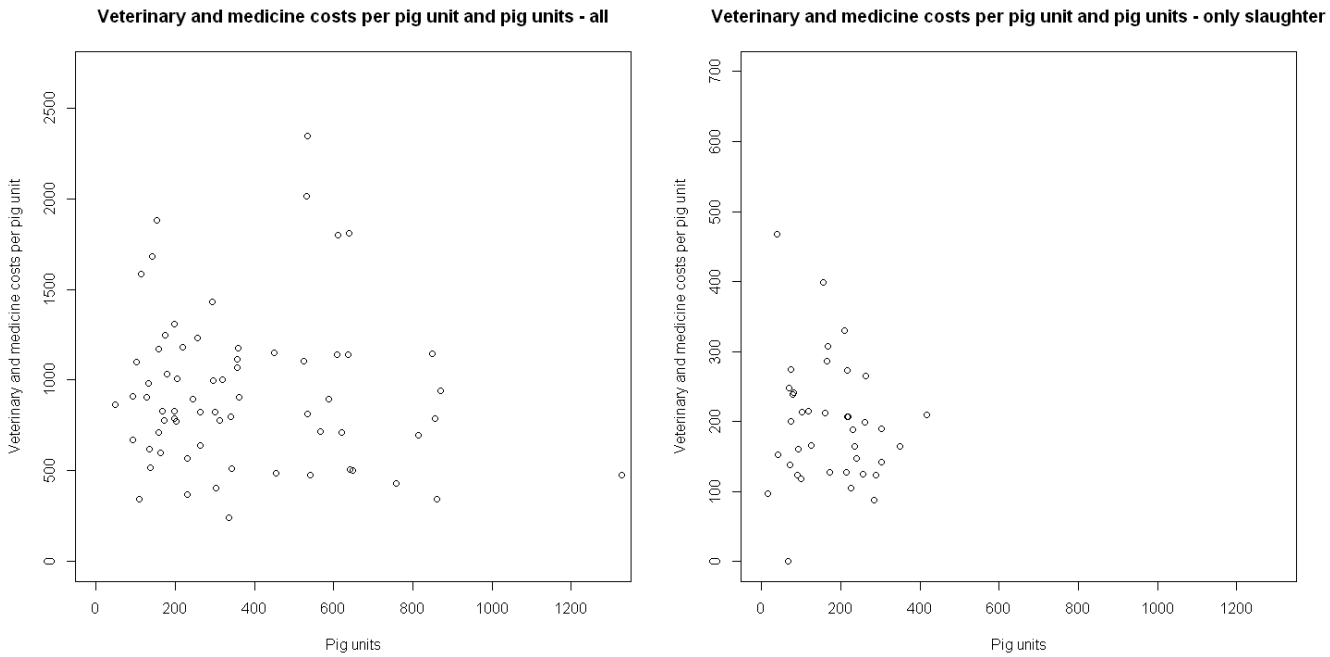


Figure 8.11: Medicine and veterinary costs per pig unit (DKK) and pig units for integrated pig producers and specialized slaughter pig producers

8.3.1. Total Number of Violations

The relationship between the total number of violations and medicine and veterinary costs per pig unit is shown in figure 8.12. It does not reveal any obvious relationships.

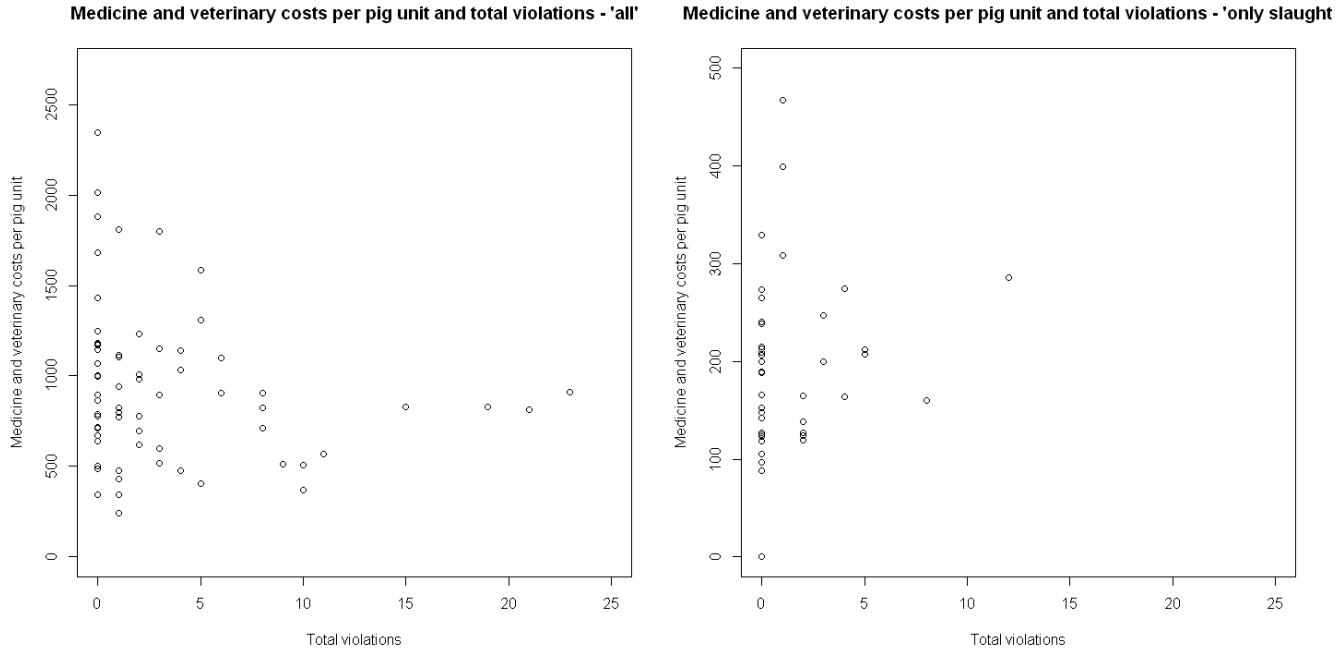


Figure 8.12: Medicine and veterinary costs per pig unit (DKK) and the total number of violations for integrated pig producers and specialized slaughter pig producers

8.3.2. Most Severe Violation

A one-way ANOVA test shows that there are no differences in veterinary and medicine costs per pig unit between the most severe violations at the 10 % level for integrated pig producers. Testing this for specialized slaughter pig producers showed that there is a difference in medicine and veterinary costs per pig unit (F-value= 2.72 with p-value = 0.06). Specialized slaughter pig producers in the group with no violations had medicine and veterinary costs per pig unit of 173 DKK on average, whereas producers with an admonition as the most severe violation had costs of 232 DKK on average. This difference in medicine and veterinary costs per pig unit is significant at the 10 % level.

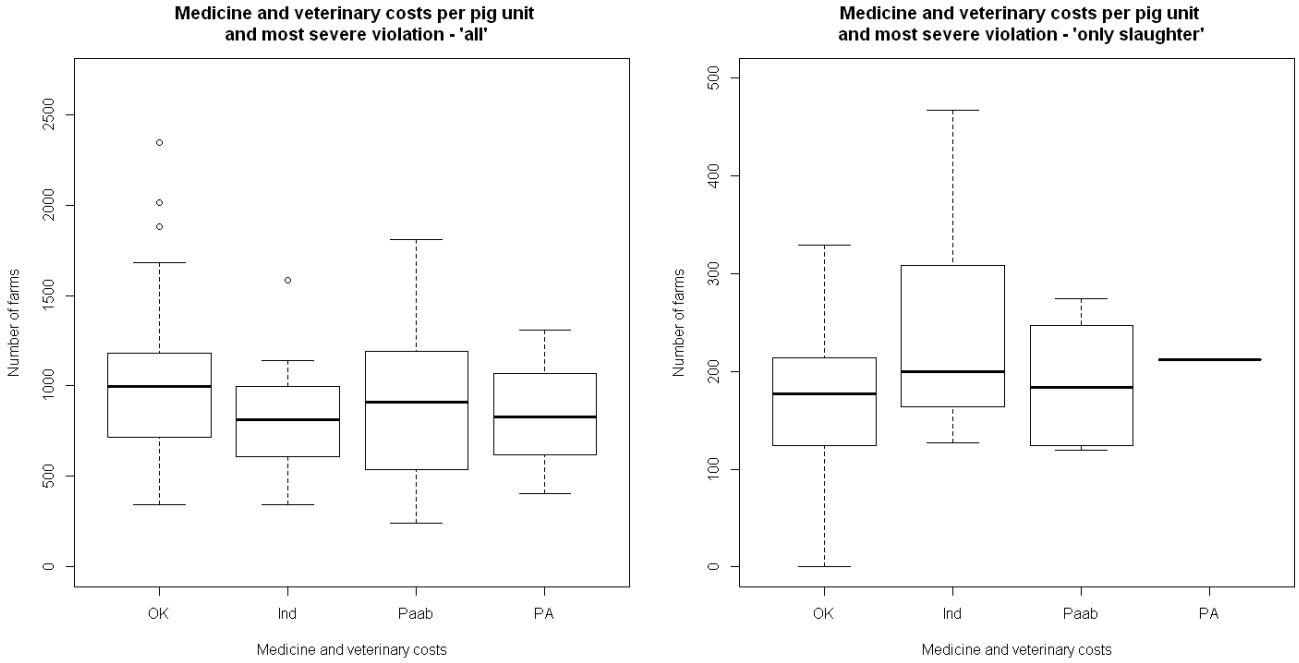


Figure 8.13: Medicine and veterinary costs per pig unit (DKK) and the most severe violations for integrated pig producers and specialized slaughter pig producers

8.3.3. AnyViolation

It can be seen from figure 8.13 above that for integrated pig producers, farmers with no violations seem to have higher medicine and veterinary costs than farmers with violations. Therefore, we separate farms with and without violations in figure 8.14.

A two-sample t-test analyzing whether there is a difference in means for farmers with and without violations shows a difference at the 10 % significance level for integrated pig producers (t = 1.796, df = 39.412, p-value = 0.080). Farmers with no violations have medicine and veterinary costs per pig unit of 1,061 DKK on average,

whereas farmers with violations have costs of 857 DKK on average. However, for specialized slaughter pig producers, the opposite tendency was significant at the 10 % level. Farms with no violations had mean medicine and veterinary costs of 173 DKK, while farmers with violations had mean costs of 232 DKK. As mentioned, causality cannot be determined based on this and the direction of the relationship between medicine and veterinary costs per pig unit and animal welfare seems to differ depending on the production type.

The relationship between the checklist measures concerning rooting material and sick animals could be argued to be the indicators most related to medicine and veterinary costs, because they indirectly concern the activity levels and health status of animals.

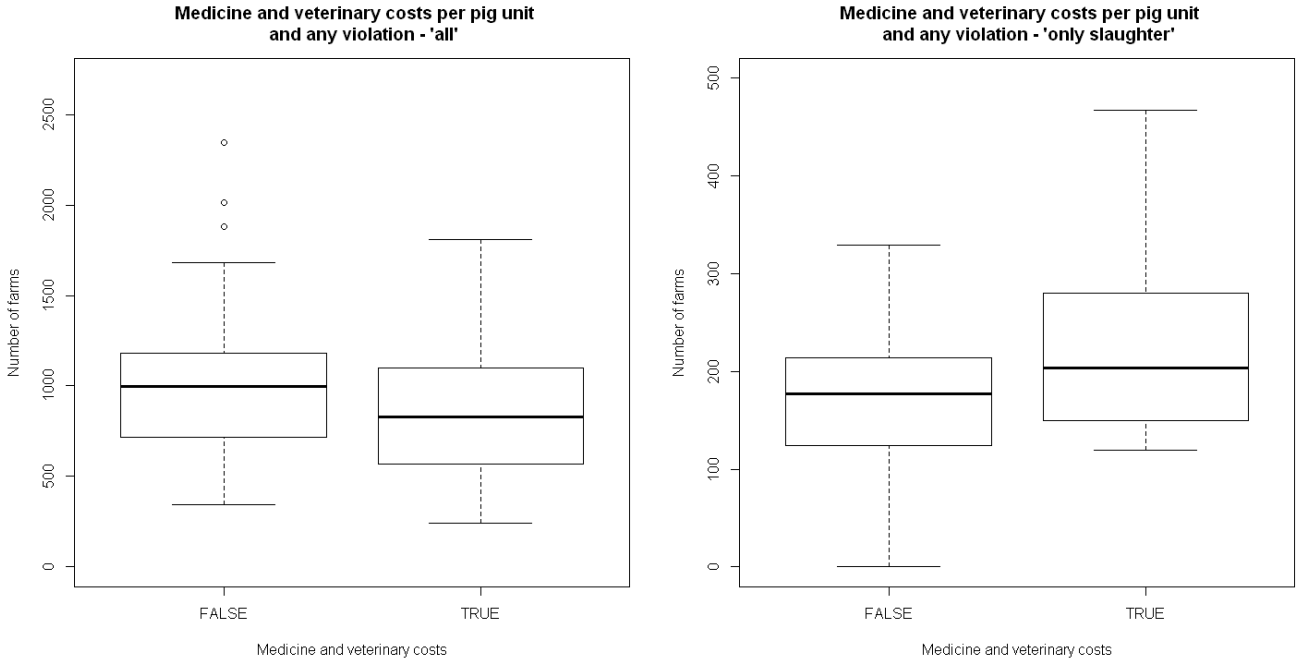


Figure 8.14: Medicine and veterinary costs per pig unit (DKK) and farms with and without violations for integrated pig producers and specialized slaughter pig producers

8.3.4. Rooting Material

The welfare indicator for rooting and playing material is tested against medicine and veterinary costs per pig unit for integrated pig producers and specialized slaughter pig producers, respectively. The effect is statistically significant at the 10 % level for integrated pig producers (t-test statistics is equal to t = 1.788 with p-value = 0.082). The average cost for farms with no violations is 980 DKK, while farms with violations have average costs

of 795 DKK. There is no statistical difference for specialized slaughter pig producers (t-test statistics is equal to t = 0.036 with p-value = 0.972).

8.3.5. Sick Animals

A t-test shows that there is no difference in medicine and veterinary cost per pig unit between farms with and without violations for integrated pig producers.

For specialized slaughter pig producers, there is also a difference in average medicine and veterinary cost per pig unit between farms with and without violations. This difference is statistically significant at the 10 % level (t-test statistics is equal to t = -2.027 with p-value = 0.083). Farms with no violations have average medicine and veterinary costs of 184 DKK, while farms with violations have average costs of 261 DKK.

In general, the association between the welfare indicators and medicine and veterinary costs per pig unit is unclear. Integrated pig producers without violations seem, however, to have higher medicine and veterinary costs than integrated pig producers with violations, whereas the opposite is true for specialized slaughter pig producers.

8.4. Revenue from pig production per pig unit and Animal Welfare

8.4.1. Total Number of Violations

The relationship between the total number of violations and revenue from pig production per pig unit is shown in the figure 8.15.

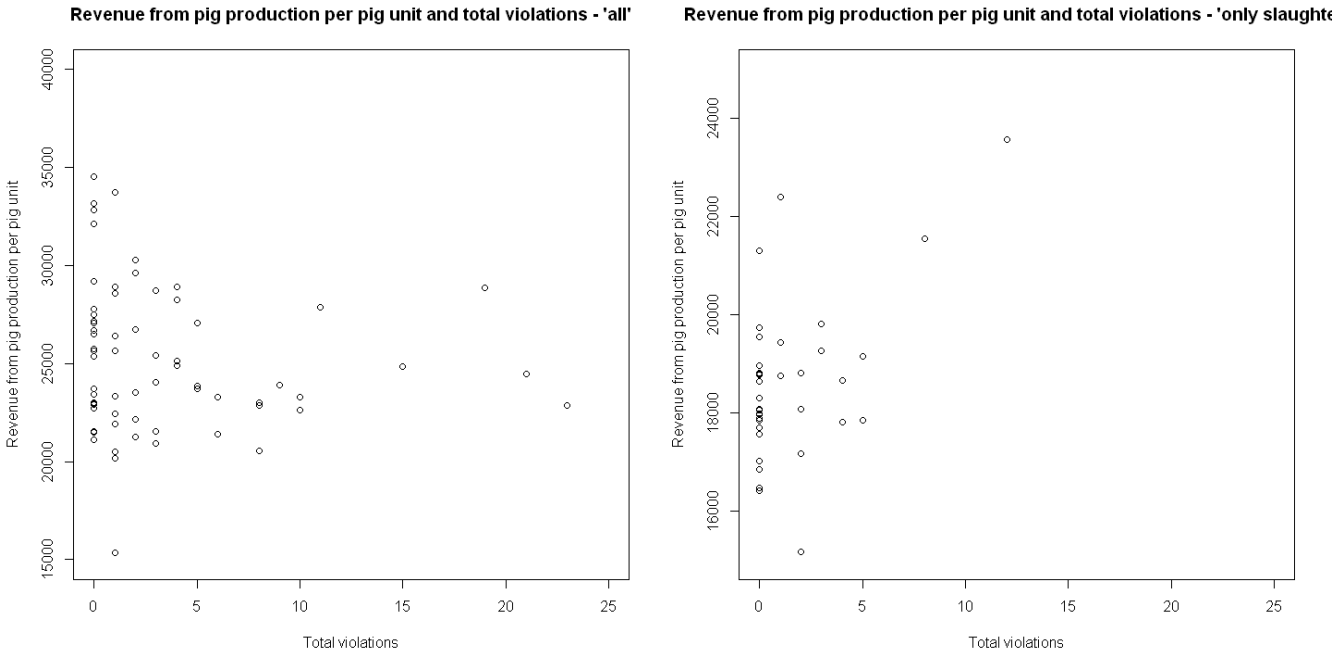


Figure 8.15: Revenue from pig production per pig unit (DKK) and the total number of violations for integrated pig producers and specialized slaughter pig producers

Pearson's correlation test shows that there is no significant correlation for integrated pig producers (t-test statistics is equal to t = -1.044 with p-value = 0.300) and positive, significant correlation for specialized slaughter pig producers (t-test statistics is equal to t = 3.778 with p-value = 0.001).

8.4.2. Most Severe Violation

The distribution of the indicator "most severe violation" is presented in the figure 8.16.

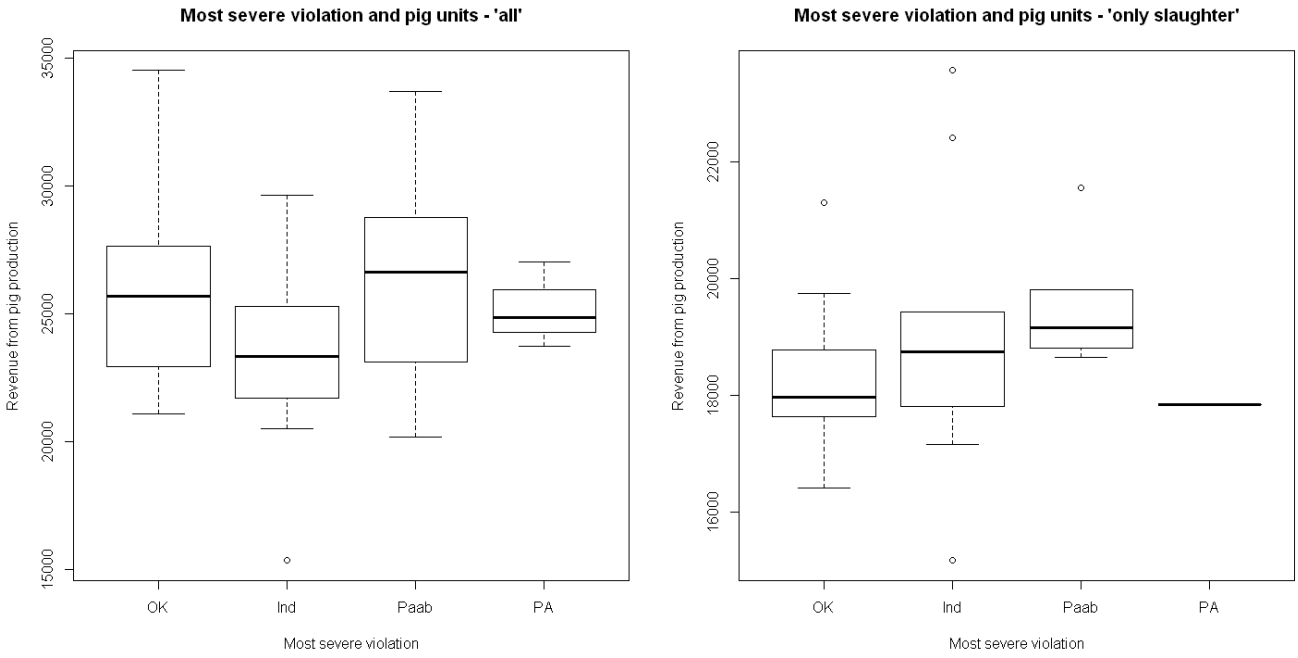


Figure 8.16: Revenue from pig production per pig unit (DKK) and most severe violation for integrated pig producers and specialized slaughter pig producers

We use one-way ANOVA to test differences in means between groups. When testing the difference for integrated pig producers and specialized slaughter pig producers:

H_0: There is no difference in the average gross margin per pig unit for farms with different most severe violations for integrated pig producers (specialized slaughter pig producers).

H_1: There is a difference.

The ANOVA only indicates a statistical difference for integrated pig producers. The F statistic has an F-value= 2.61, and a p-value = 0.06, therefore the null hypothesis is rejected at the 10 % significance level. Hence, there is a difference in revenue from pig production. To further investigate the differences, we use a Tukey's test of multiple comparisons. The difference between farms with no violations and farms with an admonition as the

most severe violation is significant at the 10 % level. On average, the revenue from pig production per pig unit for farms with no violations was 27310 DKK, and 23680 DKK for farms with an admonition. The one-way ANOVA for specialized slaughter pig producers does not show any significant differences in revenue from pig production per pig unit and the most severe violation.

8.4.3. AnyViolation

It can be seen from figure 8.17 that, for integrated pig producers, there is no difference in revenue between farmers who violate animal welfare legislation and those who do not. The difference can be observed for specialized slaughter pig producers, where farmers who violate the animal legislation have higher revenue.

In order to investigate the statistical significance of the differences, we use a two-sample t-test. The test confirms that there is no difference in average revenue between integrated pig producers, who violate animal welfare legislation, and integrated pig producers, who do not violate any of the animal welfare regulations. The observed difference for specialized slaughter pig producers is significant at the 10% significance level (t-test statistic equal to t =-1.749 with p-value = 0.096). Specialized slaughter pig producers with no violations have revenue per pig unit of 18,136 DKK on average, whereas specialized slaughter pig producers with violations have revenues of 19,160 DKK on average.

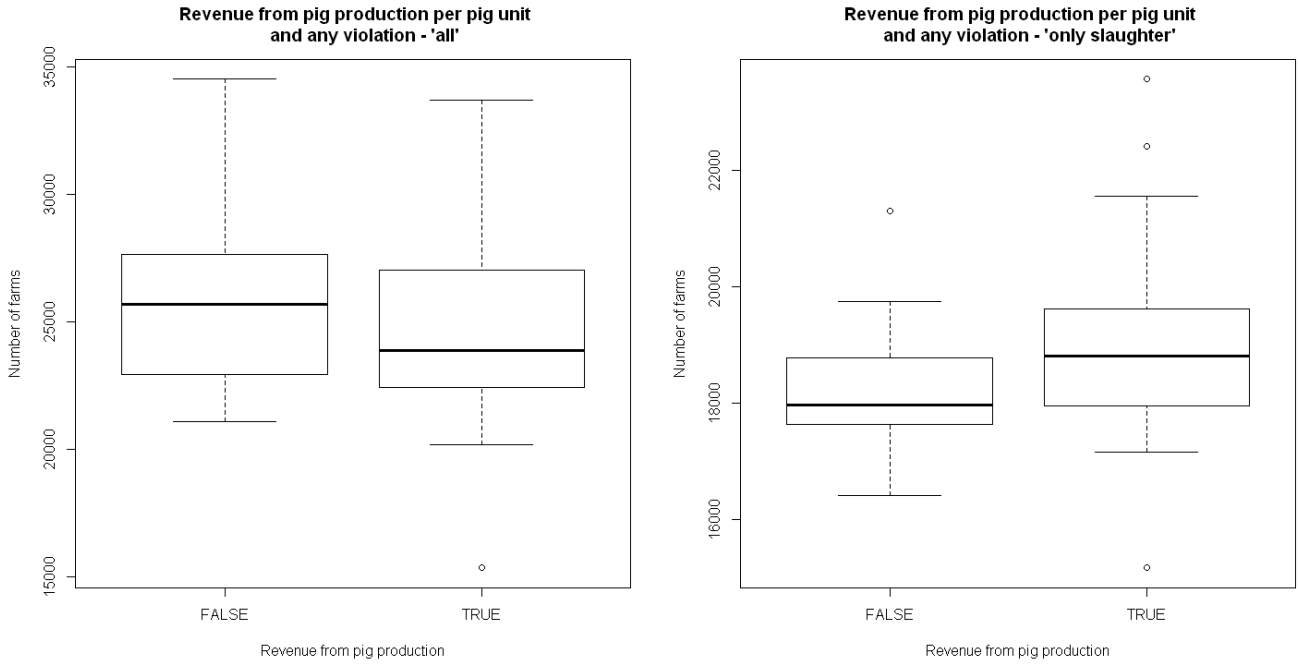


Figure 8.17: Revenue from pig production per pig unit (DKK) and AnyViolation for integrated pig producers and specialized slaughter pig producers

8.4.4. Rooting Material

The t-test revealed statistically significant difference (t-test statistic equal to t = 3.138 with p-value = 0.004) in average revenue from pig production between farms that violate the animal welfare legislation regarding provision of rooting and playing material for integrated pig producers. Farms that do not violate these requirements have on average revenue of approximately 25,858 DKK per pig unit, whereas those which violate have revenue of approximately 23,014 DKK on average. For specialized slaughter pig producers, there is no significant difference.

8.4.5. Sick Animals

According to the performed t-test, we can conclude that there is no difference in revenue from pig production per pig unit between farms with and without violations of animal welfare requirements regarding treatment of sick animals for both production types.

8.5. Feed cost per pig unit and Animal Welfare

We investigated the relationship between feed cost per pig unit and violations of animal welfare legislation. However, we did not observe any significant correlations or differences. Therefore, detailed results are omitted in order to save space.

8.6. Other costs per pig unit and Animal Welfare

8.6.1. Total Number of Violations

The relationship between the total number of violations and other costs of pig production per pig unit is shown in figure 8.18. Pearson's correlation test indicates that there is no correlation for integrated pig producers and there is a positive, significant correlation for specialized slaughter pig producers at the 10% significance level (t-test statistic equal to t = 1.799 with p-value = 0.080).

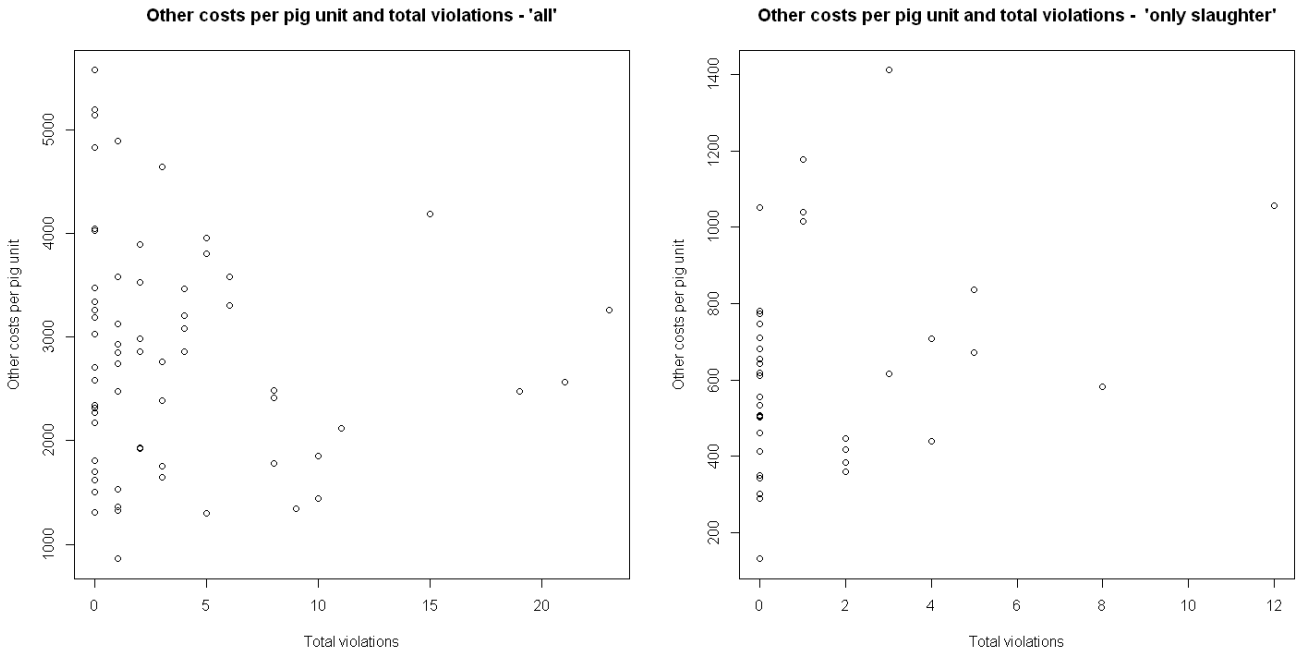


Figure 8.18: Other costs per pig unit (DKK) and total number of violations for integrated pig producers and specialized slaughter pig producers

8.6.2. Most Severe Violation

A one-way ANOVA is used to test differences in means between groups. Testing the difference for integrated pig producers and specialized slaughter pig producers is as follows:

H_0: There is no difference in the average other costs per pig unit for farms with different most severe violations for integrated pig producers (specialized slaughter pig producers).

H_1: There is a difference.

According to the results of the one-way ANOVA, there are no statistical differences for both types.

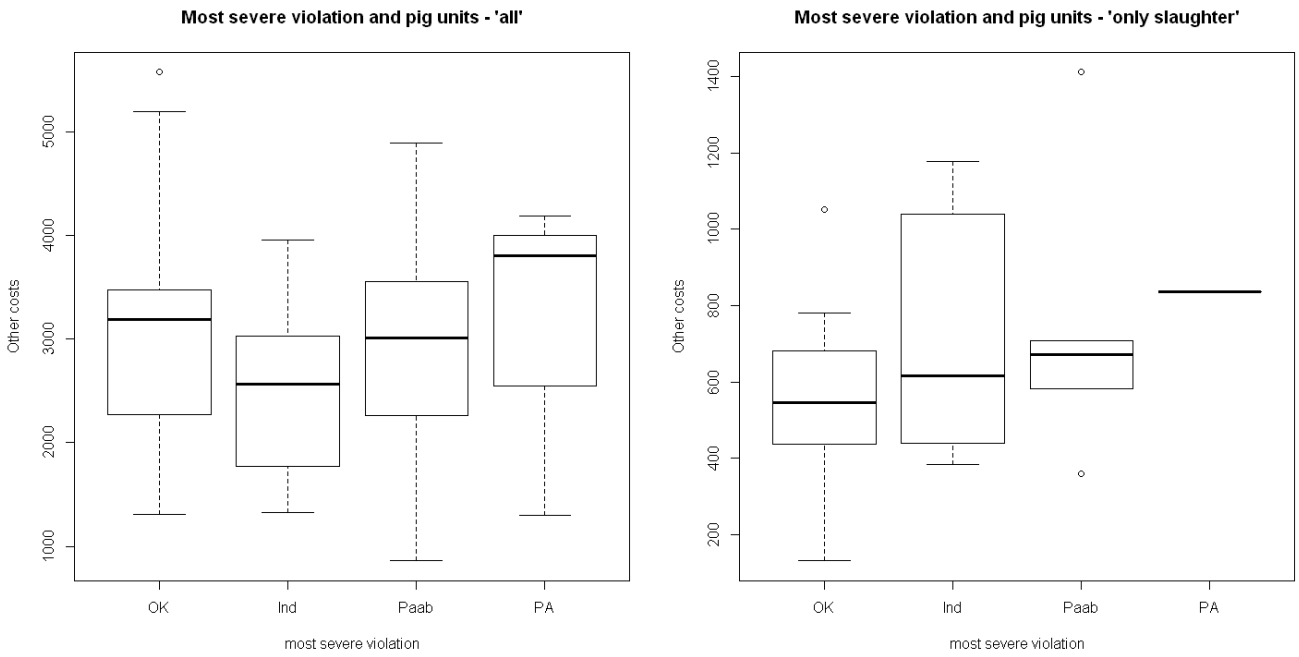


Figure 8.19: Other costs per pig unit (DKK) and most severe violation for integrated pig producers and specialized slaughter pig producers

8.6.3. AnyViolation

In order to investigate the statistical significance of the differences of the levels of the other costs between farms with and without any violations of animal welfare legislation, we use a two-sample t-test. The test confirms that there is no difference in average revenue between integrated pig producers, who violate animal welfare legislation, and integrated pig producers, who violate any of the animal welfare regulations. The observed difference for specialized slaughter pig producers is significant at the 10% significance level (t = -1.995, df = 20.439, p-value = 0.060). Farmers with no violations have other costs per pig unit of 556 DKK on average, whereas farmers with violations have costs of 744 DKK on average.

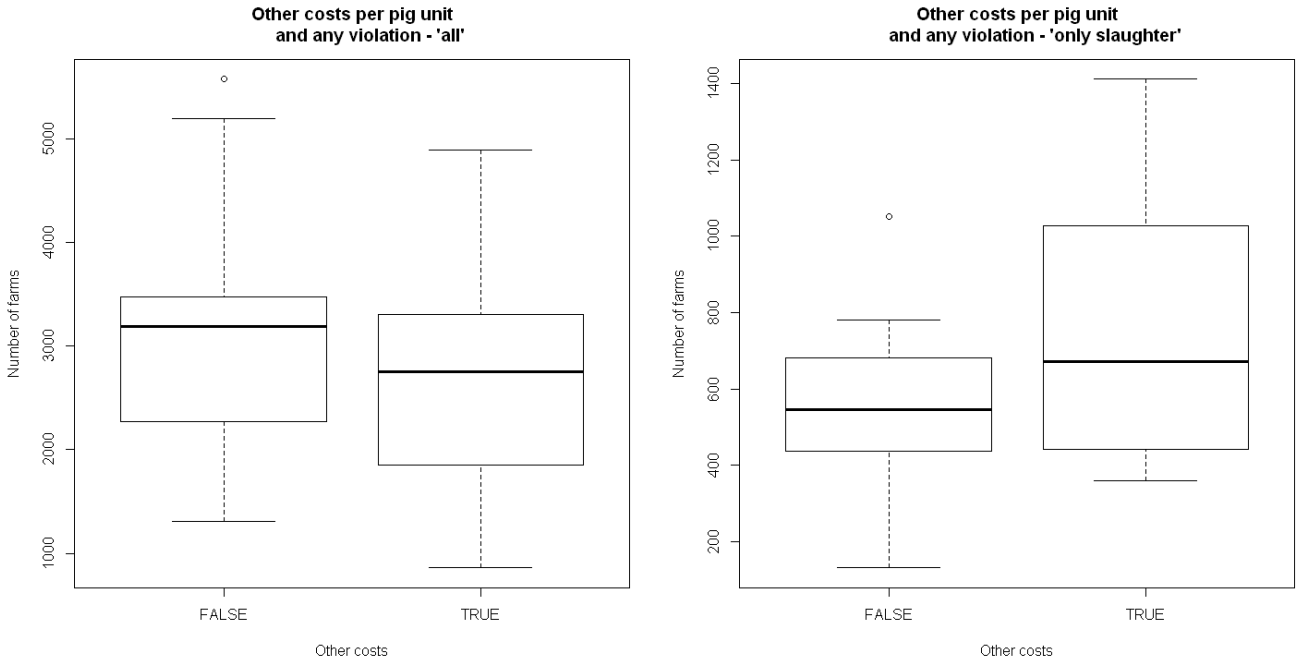


Figure 8.20: Other costs per pig unit (DKK) and AnyViolation for integrated pig producers and specialized slaughter pig producers

8.6.4. Rooting Material and Sick Animals

There is no difference between farms which meet and those which do not meet the animal welfare legislation requirements regarding the provision of rooting and playing material. Using the t-test (test statistic t=-2.138 with p-value = 0.070), we found that, for specialized slaughter pig producers, farms which violate animal welfare legislation regarding sick animals have higher other costs.

8.7. Age, Experience and Animal Welfare

Anneberg (2013) studied the risk factors related to farmers being convicted of violating the animal welfare legislation. She found that farmers who only had minor production difficulties were less likely to have been convicted of neglect of their animals than any other risk group. This group of farmers was also significantly older. Age has also been shown to be correlated with the performance of the farm in other studies, e.g. Olsen and Henningsen (2011). This section studies whether there is a significant relationship between age and animal welfare. Age is used as a proxy for experience, and one could hypothesize that young farmers have worse animal welfare than older farmers as they are more inexperienced.

8.7.1. Age

It can be seen from figure 8.21 that the age of farmers with violations versus farmers without violations does not show any clear differences[12]. The age of farmers with violations is more spread out, but there does not seem to be any significant differences.

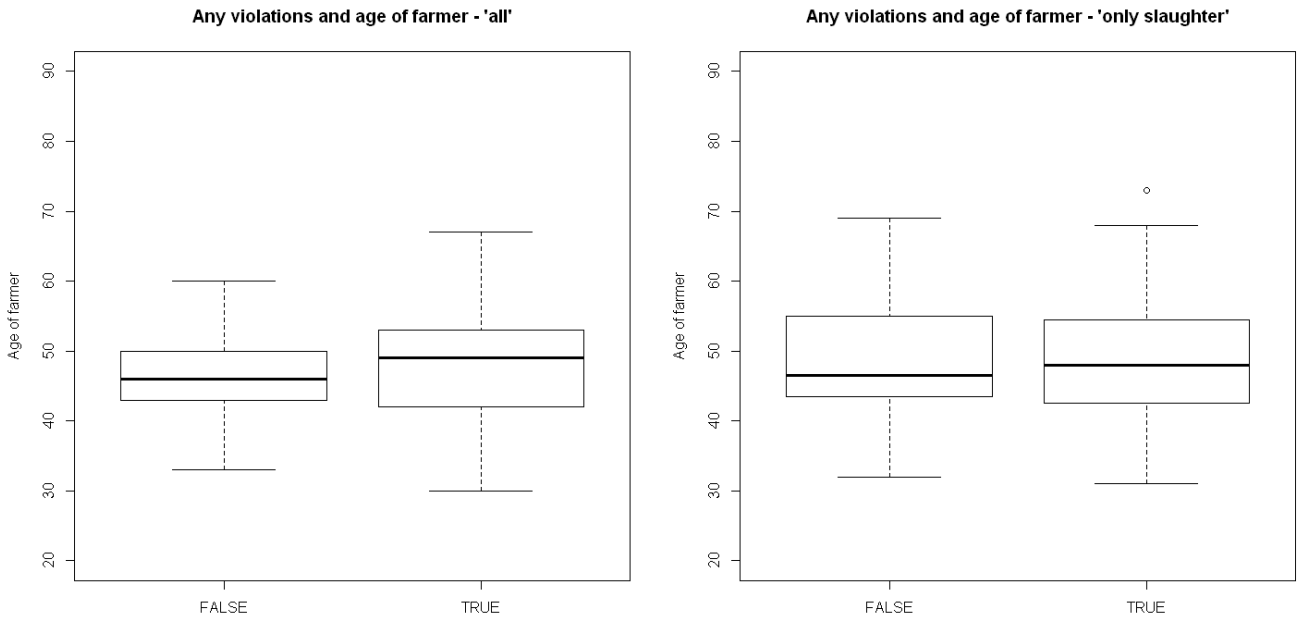


Figure 8.21: Age of the farmer and farms with and without violations for integrated pig producers and specialized slaughter pig producers

Correlation tests showed that the correlation between the total number of violations and the age of the farmer is almost zero and non-significant at the 10 % level. Neither were there any significant differences using the indicator "most severe violation."

8.7.2. Experience

Another proxy of experience is the year of establishment of the farm studied[13]. Once established, a farmer typically does not sell his farm before he stops farming entirely. Therefore, the year of establishment can be used as a proxy of the years a farmer has been managing a farm, and therefore experience in pig production. Figure 8.22 shows that there is no difference between farms with violations and farms without violations. They

[12] When analyzing "age," 7 observations were excluded, and therefore 129 observations were used. The exclusions were due to missing values for "age".
[13] The following analysis is based on 134 observations due to missing data on the year of establishment for one farm.

approximately have the same median and variation. Differences are also insignificant when using the indicators "most severe violation" and "total number of violations."

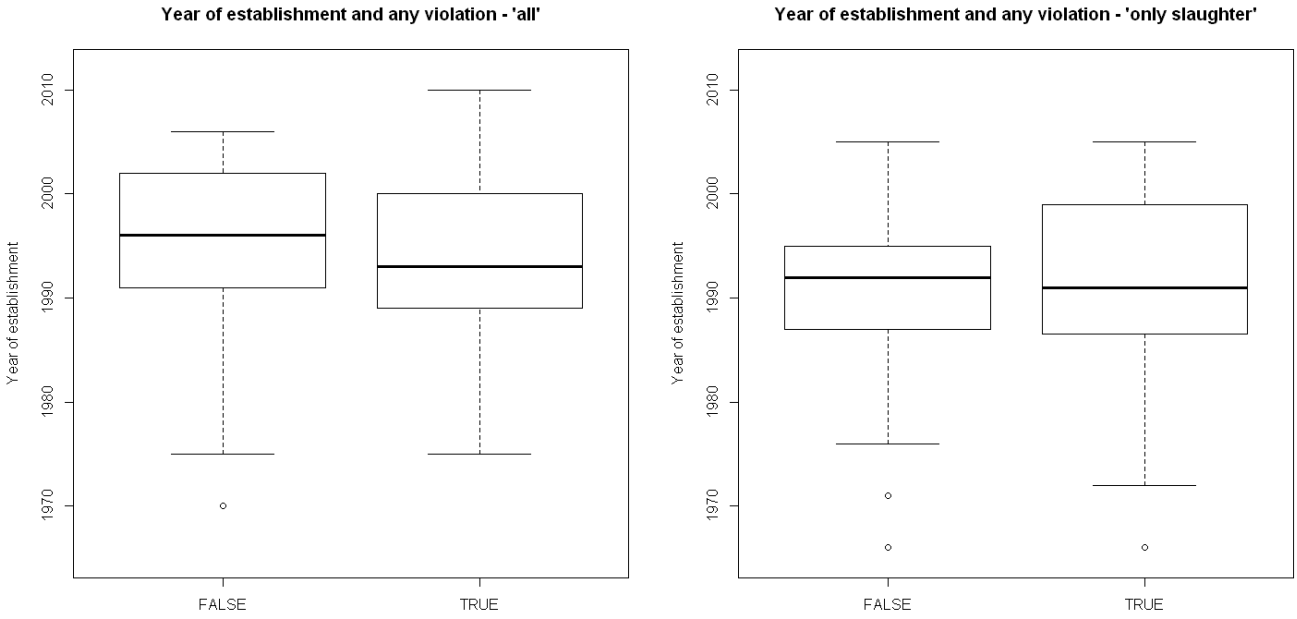


Figure 8.22: Year of establishment of the farm and farms with and without violations for integrated pig producers and specialized slaughter pig producers

8.8. Multivariate analysis of Animal Welfare and Economic outcome

The correlation analysis only allows the study of the relationship between two factors at the time. Therefore, it ignores possible correlations between the analyzed variables and other factors. This can be solved by using multivariate regression methods. In this section, we present the results of regression analyses of animal welfare indicators on socio-economic variables (e.g. proxy of farm experience, size of farm and dummy variables indicating the type of production, etc.) and the results of regression analyses of economic outcome variables (gross margin, veterinary costs) on animal welfare indicators and socio-economic variables.

8.8.1. Animal Welfare indicators versus socio-economic indicators

In this section, we present the results of the multivariate regression analyses of the relationship between animal welfare indicators and socio-economic indicators. The socio-economic indicators used in this part of the analysis consist of variables that represent the farm size, the age of the farmer, and the year of the

establishment of the farm (as proxies for experience)[14]. Additionally, we use three dummy variables that indicate whether the farm has sows, piglets, or slaughter pigs[15]as well as their interactions with farm size and animal welfare indicators (AnyRooting and AnySick). We do not use the gross margin as an explanatory variable, because we assume that animal welfare is not directly influenced by the gross margin, which is a proxy for productivity (see section 3.7). We also do not use medicine and veterinary cost as explanatory variable, because the endogeneity of this variable probably results in inconsistent estimates.

Because the indicators of animal welfare that we use in this report are not numeric variables, we cannot use basic linear regression methods (e.g. OLS) to investigate the relationship between them and the socio-economic variables. For instance, the indicator "total number of violations" is not a continuous variable, but a count variable, and hence, should be modeled using count data models. In such cases, the Poisson model is usually used. However, due to over-dispersion of zero values in the indicator "total number of violations," we use the negative binomial model. The results of the unrestricted[16] model and the restricted model are presented in table 8.1. The first two columns of the table contain the names of the variables and corresponding parameters. The next two columns present the results (estimated parameter, its standard error and corresponding p-value) of the unrestricted and restricted models. The last row of the table presents the value of the Akaike information criterion (AIC), which is used to select the most appropriate model. The best model is characterized by the lowest AIC value.

The only coefficient that is significantly different to zero in the restricted model is the coefficient of the dummy variable indicating whether or not the farm has sows. However, a likelihood ratio test indicates that the total effect of having slaughter pigs (i.e. including interaction effects) is also significantly different from zero.

According to our results, farms which have sows are more likely to violate the animal welfare legislation and violate more regulations than farms that do not have sows (e.g. integrated pig producers vs. farms that only produce slaughter pigs). However, this effect seems to diminish with farm size (pig units). The estimated effect of having slaughter pigs (e.g. integrated pig producers vs. piglet producers) on violations of the animal welfare legislation is much larger, and seems to depend even more on farm size (pig units), although the estimates of this effect are rather imprecise.

[14] We found that variables representing the age of the farmer and the year of the establishment of the farm are highly correlated. The data on the age of farmer was not available for 2 farms. Therefore, in final analysis, we use the year of the establishment of the farm as a proxy of experience.

[15] These dummy variables (and their interactions) represent the farm's type of production.

[16] The unrestricted model is the model that includes all the variables being considered as possible explanatory variables, whereas the restricted model includes only the variables selected according to the step wise model selection procedure. In this analysis, we used the step-wise model selection procedure based on the minimisation of the Akaike information criterion (AIC).

The indicators AnyRooting, AnySick, and AnyViolation are binary variables (e.g. either the farm has a violation or not). Therefore, we used the logit (binary choice) models to analyze the determinants of these animal welfare indicators.

Table 8.1: Results of negative binomial regression of the indicator "total number of violations"

		Unrestricted model			Restricted model		
Variable	**Parameter**	**Estimate**	**S.E.**	**Variable**	**Parameter**	**Estimate**	**S.E.**
Intercept	α_0	-39.680	43.370	0.360	-40.799	43.816	0.352
Size	α_1	0.161	0.173	0.353	0.163	0.175	0.351
Establishment	α_2	0.000	0.001	0.734	-	-	-
H_{Sows}	α_3	1.855	0.711	0.009	1.445	0.484	0.003
$H_{piglets}$	α_4	-0.948	0.810	0.242	-	-	-
$H_{slaughter}$	α_5	40.880	43.340	0.346	41.032	43.814	0.349
H_{Sows} * Size	α_6	-0.003	0.001	0.059	-0.002	0.001	0.111
$H_{piglets}$ * Size	α_7	0.003	0.003	0.323	-	-	-
$H_{slaughter}$ * Size	α_8	-0.162	0.173	0.348	-0.163	0.175	0.352
AIC		527.131			522.876		

The results of the logistic regression of variable AnyRooting are presented in table 8.2. In the unrestricted logit regression model of the AnyRooting indicator, t-tests and likelihood ratio tests indicate that none of the explanatory variables has a statistically significant (total) effect.

Table 8.2: Results of logistic regression of AnyRooting indicator

		Unrestricted model			Restricted model		
Variable	**Parameter**	**Estimate**	**S.E.**	**p-value**	**Estimate**	**S.E.**	**p-value**
Intercept	α_0	14.428	48.610	0.767	-2.021	0.528	0.000
Size	α_1	0.039	0.061	0.529	0.003	0.001	0.021
Establishment	α_2	-0.013	0.023	0.579	-	-	-
H_{Sows}	α_3	1.467	1.057	0.165	1.159	0.712	0.103
$H_{piglets}$	α_4	-0.058	1.243	0.963	-	-	-
$H_{slaughter}$	α_5	9.271	15.077	0.539	-	-	-
H_{Sows} * Size	α_6	-0.005	0.002	0.035	-0.004	0.002	0.027
$H_{piglets}$ * Size	α_7	0.000	0.004	0.971	-	-	-
$H_{slaughter}$ * Size	α_8	-0.035	0.061	0.563	-	-	-
AIC		157.856			150.635		

The restricted model is significant in variables representing the size of farm and its interaction with the dummy variable, which indicates whether the farm has sows or not. This means that the larger the farm, the more likely the animal welfare legislation regarding rooting and playing material is violated. However, this relationship can only be observed for farms without sows (i.e. mainly slaughter pig farms), because the sum of the coefficient of the farm size and the coefficient of the interaction effect between farm size and the dummy

variable for sows is close to zero. The effect of having sows on the likelihood of violating animal welfare legislation regarding rooting and playing material depends on the size of the farm.

The results of the logistic regression of variable AnySick are presented in table 8.3. Both the restricted model and the unrestricted model of the AnySick indicator, t-tests and likelihood ratio tests indicate that none of the explanatory variables have a statistically significant (total) effect. Therefore, we cannot draw any conclusions regarding the relationship between the explanatory variables and the dependent variable.

Table 8.3: Results of logistic regression of AnySick indicator

Variable	Parameter	Unrestricted model			Restricted model		
		Estimate	**S.E.**	**p-value**	**Estimate**	**S.E.**	**p-value**
Intercept	α_0	-128.400	112.500	0.254	-70.716	50.211	0.159
Size	α_1	0.250	0.404	0.536	-	-	-
Establishment	α_2	0.032	0.026	0.223	0.035	0.025	0.167
H_{Sows}	α_3	-0.981	0.992	0.322	-	-	-
$H_{piglets}$	α_4	1.985	1.322	0.133	-	-	-
$H_{slaughter}$	α_5	62.190	102.100	0.542	-	-	-
H_{Sows} * Size	α_6	0.002	0.002	0.383	-	-	-
$H_{piglets}$ * Size	α_7	-0.005	0.005	0.277	-	-	-
$H_{slaughter}$ * Size	α_8	-0.246	0.404	0.543	-	-	-
AIC		149.554			141.924		

The results of the logistic regression of the variable AnyViolation are presented in table 8.4. The restricted model is only significant in the parameter of the dummy variable which indicates whether sows are kept on the farm or not. This means that farms that have sows are more likely to violate animal welfare legislation than farms which do not have sows (e.g. integrated pig farms vs. slaughter pig producers). This also supports our findings presented above regarding the violations of animal welfare legislation regarding the provision of rooting and playing material.

Table 8.4: Results of logistic regression of AnyViolation indicator

Variable	Parameter	Unrestricted model			Restricted model		
		Estimate	S.E.	p-value	Estimate	S.E.	p-value
Intercept	α_0	-11.960	45.362	0.792	-16.164	21.282	0.448
Size	α_1	0.059	0.086	0.491	0.060	0.085	0.481
Establishment	α_2	-0.002	0.020	0.915			
H_{Sows}	α_3	1.330	0.910	0.144	0.671	0.373	0.072
$H_{piglets}$	α_4	-0.582	1.027	0.571			
$H_{slaughter}$	α_5	16.083	21.404	0.452	15.763	21.282	0.459
H_{Sows} * Size	α_6	-0.002	0.002	0.235			
$H_{piglets}$ * Size	α_7	0.004	0.004	0.347			
$H_{slaughter}$ * Size	α_8	-0.061	0.086	0.481	-0.060	0.085	0.486
AIC		192.01			185.55		

We used the count data and binary choice models in order to investigate the relationship between animal welfare indicators and socio-economic variables. The main conclusion is that the violation of animal welfare legislation generally does not depend on socio-economic factors such as the farm size or the farmer's experience.

8.8.2. Economic outcome versus Animal Welfare indicators

In this section, we analyze the relationship between economic outcome and animal welfare, where we treat the economic indicators (gross margin per pig unit and veterinary and medicine costs per pig unit) as dependent variables.

The explanatory variables used in both models are animal welfare indicators (total number of violations, AnyRooting, AnySick) and other farm characteristics (3 dummy variables indicating whether the farm has sows, piglets or slaughter pigs, respectively, a variable denoting size of farm (measured in pig units), and the year of establishment of the farm as a proxy of the farmer's experience).

The results of the linear regression of gross margin are presented in table 8.5. On the left-hand side of the table, the results of the general (unrestricted) regression model are presented. Most estimated parameters of the unrestricted model are insignificant at the 10% significance level. However, all estimated parameters together are significant which is indicated by the F statistic. On the right-hand side of the table, the results of the restricted model, which has been selected according to the lowest value of the AIC criterion in the step-wise model selection procedure, are presented. Based on the restricted model, we found that the only significant animal welfare indicator is the one which indicates whether the animal welfare legislation regarding

the sick animals has been violated or not. According to the estimated model, farms which violate these animal welfare requirements have on average a lower gross margin. The remaining indicators of animal welfare are insignificant. Based on the estimated parameter of the dummy variable that indicates whether the farm produces piglets, we can conclude that farms which produce piglets have on average higher gross margin per animal unit. Although the variable that denotes the size of the farm is statistically insignificant, the interaction terms of this variable with dummy variables representing different types of production are statistically significant. This means that larger farms have on average a higher gross margin per pig unit.

Table 8.5: Results of linear regression of gross margin

	Unrestricted model				Restricted model		
Variable	**Parameter**	**Estimate**	**S.E.**	**p-value**	**Estimate**	**S.E.**	**p-value**
Intercept	α_0	-31552.204	66815.613	0.638	-177.660	3997.598	0.965
Total violations	α_1	-31.116	85.455	0.716			
AnyRooting	α_2	6475.114	4108.560	0.118	1205.098	1064.871	0.260
AnySick	α_3	-616.327	4328.612	0.887	-1795.573	711.869	0.013
Establishment	α_4	15.450	33.406	0.645			
Size	α_5	27.042	21.023	0.201	28.589	18.417	0.123
H_{Sows}	α_6	636.465	1624.122	0.696	697.539	1388.550	0.616
$H_{piglets}$	α_{10}	3633.259	1755.396	0.041	2542.811	1036.303	0.016
$H_{slaughter}$	α_{11}	4912.150	4133.948	0.237	5055.129	3947.335	0.203
H_{Sows} * AnyRooting	α_7	-2569.414	2084.193	0.220	-3510.939	1397.650	0.013
$H_{piglets}$ * AnyRooting	α_8	-1736.737	2319.990	0.456			
$H_{slaughter}$ *	α_9	-4692.519	3856.868	0.226			
H_{Sows} * AnySick	α_{12}	-78.013	1937.705	0.968			
$H_{piglets}$ * AnySick	α_{13}	-1470.822	2316.777	0.526			
$H_{slaughter}$ * AnySick	α_{14}	77.776	3977.188	0.984			
H_{Sows} * Size	α_{15}	6.004	3.330	0.074	6.356	2.829	0.026
$H_{piglets}$ * Size	α_{16}	-2.888	6.328	0.649			
$H_{slaughter}$ * Size	α_{17}	-26.614	20.248	0.191	-31.173	18.281	0.091
R2 (Adjusted R2)		0.378 (0.286)			0.353 (0.306)		
F-statistics		4.138 (17, 116), p-value: 0.000			7.519 (9, 124), p-value: 0.000		
AIC		2572.688			2561.844		

Next we investigated the relationship between medicine and veterinary costs and animal welfare indicators and other farm characteristics. The estimation procedure and model selection was the same as in the case of the regression model of the gross margin. The results are presented in table 8.6.

Based on the restricted linear regression model of medicine and veterinary costs, we found that these cost generally do not depend on the animal welfare indicators. There is one small exception to this result: farms which do not have slaughter pigs and violate animal welfare regulations have on average higher costs than

corresponding farms that do not violate animal welfare regulations, but there are only a few farms of this type (7.6%) in the sample.

Table 8.6: Results of the linear regression of medicine and veterinary costs

Variable	Unrestricted model				Restricted model		
	Parameter	Estimate	S.E.	p-value	Estimate	S.E.	p-value
Intercept	α_0	-6392.000	7680.000	0.407	-337.211	444.437	0.449
Total violations	α_1	-7.120	9.644	0.462			
AnyRooting	α_2	1142.000	463.200	0.015	903.499	402.714	0.027
AnySick	α_3	358.900	488.000	0.464	117.932	165.176	0.477
Establishment	α_4	3.043	3.837	0.429			
Size	α_5	4.421	2.372	0.065	4.93	2.100	0.021
H_{Sows}	α_6	561.000	184.300	0.003	515.447	93.122	0.000
$H_{piglets}$	α_{10}	275.600	201.000	0.173	302.075	111.941	0.008
$H_{slaughter}$	α_{11}	592.300	466.000	0.206	577.649	442.375	0.194
H_{Sows} * AnyRooting	α_7	-153.700	238.400	0.520			
$H_{piglets}$ * AnyRooting	α_8	-14.810	264.800	0.956			
$H_{slaughter}$ * AnyRooting	α_9	-1150.000	434.800	0.009	-1036.895	410.295	0.013
H_{Sows} * AnySick	α_{12}	56.940	221.200	0.797			
$H_{piglets}$ * AnySick	α_{13}	-272.000	263.400	0.304	-265.568	186.955	0.158
$H_{slaughter}$ * AnySick	α_{14}	-275.800	448.400	0.540			
H_{Sows} * Size	α_{15}	0.003	0.386	0.993			
$H_{piglets}$ * Size	α_{16}	0.104	0.728	0.886			
$H_{slaughter}$ * Size	α_{17}	-4.720	2.283	0.041	-5.073	2.105	0.017
R2 (Adjusted R2)		0.602 (0.547)			0.596 (0.566)		
F-statistics		10.870 (16, 115), p-value: 0.000			19.960 (9, 122), p-value: 0.000		
AIC		1957.027			1945.147		

We can conclude that the level of medicine and veterinary costs depends on the type of production rather than on the compliance with animal welfare legislation. For instance, farms which have sows and/or piglets have on average higher medicine and veterinary cost.

8.9. Estimation of the Stochastic Output Distance Function

The stochastic output distance function estimated as an efficiency effect frontier makes it possible to study multiple inputs and multiple outputs of agricultural production in relation to animal welfare. In this specification, the stochastic frontier model consists of two parts: the stochastic frontier equation and the inefficiency equation. Contrary to the descriptive economic analysis, the stochastic output distance function

analyses the overall performance of pig producers and the relationship to animal welfare. The stochastic output distance function is estimated with 120 observations.[17]

8.9.1. Model variables

The stochastic frontier part of the efficiency effects stochastic output distance function includes 2 outputs and 6 inputs. Animal output is measured as the net value of animal production[18]. The second output variable consists of crop outputs and any revenue from the supply of services. Intermediate pig inputs include medicine and veterinary costs, and other miscellaneous pig inputs. Other intermediate inputs include crop inputs such as fertilizer, seed, pesticides, miscellaneous crop inputs and inputs not readily allocated to either crop or pig production. Capital is measured as the consumption of capital during the year. Additionally, a set of three dummy variables indicating whether the farm has sows, piglets or slaughter pigs is included in the frontier part of the model to capture possible differences in technology between the different production types of farms.

The inefficiency equation includes a set of variables indicating animal welfare (e.g. total number of violations, AnySick and AnyRooting), and the variable size (measured in number of pig units) and establishment (the year of establishing the farm as a proxy of the farmer's experience). Additionally, the dummy variables indicating the type of production and their interactions with two indicators of animal welfare (AnySick and AnyRooting) are also included in the inefficiency part of the model.

A summary of descriptive statistics of variables used in the estimation of the stochastic output distance functions is presented in table 8.7.

[17] Observations have mainly been excluded due to missing values of explanatory variables (11 farms with missing data on land input and 3 with missing data on labor input) and two outliers with implausible values of input variables were also excluded.

[18] Net production of animals is the value of the livestock at the end of the year minus the value of the livestock at the beginning of the year plus the value of all sold animals and animal products minus the value of all purchased animals.

Table 8.7: Descriptive statistics of variables used in estimation of stochastic output distance function

Variable name	Variable	Unit	Mean	Std. Dev.
Animal output	Y_1	Thousand DKK	6,777	4,960
Other outputs	Y_2	Thousand DKK	1,911	1,368
Feed	X_1	Thousand DKK	4,212	2,886
Intermediate pig input	X_2	Thousand DKK	415	444
Other intermediate inputs	X_3	Thousand DKK	1,337	819
Land	X_4	Hectares	200	129
Labor	X_5	Hours	4,903	3,884
Capital	X_6	Thousand DKK	4,474	3,541
"Has sows"	H_{Sows}	Dummy variable	56%*	
"Has piglets"	$H_{piglets}$	Dummy variable	70%*	
"Has slaughter"	$H_{slaughter}$	Dummy variable	93%*	
Total violations	Total violations	Number of violations	2.55	4.30
Rooting material - Violating regulations	AnyRooting	Dummy variable	23%*	
Sick animals - Violating regulations	AnySick	Dummy variable	22%*	
Number of pigs	Pig units	Pig units	287	209

**Frequency of 1*

8.9.2. Results of the Estimation

The results of the conducted stochastic frontier analysis are presented in table 8.8. The estimation is performed by the add-on package "frontier" (Coelli and Henningsen 2012). The upper part of the table presents the results of the output distance function model of the SFA, while the bottom part of the table provides the results of the inefficiency model of the SFA. The first two columns consist of the variable names and corresponding parameters. The next two columns present the estimation results of the unrestricted and restricted models. The difference between these two models is in the set of the variables that are used in the inefficiency model. The unrestricted model includes all variables that are described in the previous subsection. The likelihood ratio test is used to test the restricted model against the unrestricted model. Using a likelihood ratio test, we found that the model, in which inefficiency only depends on the total number of violations, AnyRooting, AnySick, and the farm size, fits the data not significantly worse than the unrestricted model[19].

We also tested the stochastic frontier model against its OLS counterpart using a likelihood ratio test. This test allows us to check whether the inefficiency term is statistically significant. The likelihood ratio test statistics is equal to 48.340 with a p-value smaller than 0.001 for the restricted model. Therefore, we conclude that the OLS model (without inefficiency) is clearly rejected. The gamma parameter (γ) indicates whether deviations from the frontier are due to noise or technical inefficiency. The estimated value of the gamma parameter is

[19] We also used the Likelihood ratio test to test the joint significance of all animal welfare indicators. Based on this test, we found that all animal welfare indicators are jointly significant.

equal to 0.450. This means that both the statistical noise and the technical inefficiency are important in explaining deviations from the frontier. The rather large share of the noise component in the composite error term supports the use of stochastic frontier analysis instead of the deterministic method.

The frontier part of the estimated model can be used to investigate the production (frontier) technology of the analyzed farms. However, in this analysis, the main focus is on the relationship between technical efficiency and animal welfare indicators. Therefore, we use the frontier estimates to check the general economic consistency of the model (e.g. we check the monotonicity conditions). The distance elasticities of the inputs in the stochastic output distance function (given by the parameters β) can be interpreted as the relative effect on the aggregate output given a 1% increase in the particular input quantity. For instance, increasing (decreasing) the feed input by 1 % would increase (decrease) the aggregate output by around 0.53%. We found that all input elasticities are negative (although the estimated parameters of variable other inputs and labor are not significantly different from zero), which means that the monotonicity conditions are globally fulfilled. This indicates that signs of the distance elasticities of the inputs are consistent with microeconomic theory, as they imply that increasing any of the input quantities can never decrease the output quantity. The elasticity of scale obtained from the output distance function is equal to the negative sum of the distance elasticities of the inputs. The calculated elasticity of scale is around 0.92, which indicates that the analyzed farms produce under decreasing returns to scale. The elasticity of scale of Danish pig producers has been estimated in other studies. Rasmussen (2010) found that the elasticity of scale of Danish pig farms declined from 1.25 in 1986 to 1.13 in 2006. The average elasticity of scale in the period was 1.19. Olsen and Henningsen (2011) found the elasticity of scale to be 1.06 on average during the years 1996-2008. Both studies find Danish pig producers to operate under increasing returns to scale. The differing results could be due to the estimation method used or due to the structure of the data. In this report, cross-sectional data was used, whereas Rasmussen (2010) and Olsen and Henningsen (2011) used panel data sets.

A positive parameter estimate of a z-variable indicates a positive relationship between the z-variable and the inefficiency term *u*. The estimated parameter of the total number of violations (δ_1) in the inefficiency model is positive and statistically significant. This means that having violations of animal welfare increases technical inefficiency (decreases technical efficiency). Similar findings regarding the relationship between the animal welfare indicator and technical efficiency are found for variable AnySick, as its estimated parameter (δ_1) is also positive and statistically significant (at the 10% significance level). This means that farms which violate regulations regarding sick animals are on average less efficient.

Table 8.8: Estimation results: the stochastic output distance function

Inefficiency effect stochastic frontier output distance function							
		Unrestricted model			**Restricted model**		
Variable	**Parameter**	**Estimate**	**S.E.**	**p-value**	**Estimate**	**S.E.**	**p-value**
Stochastic frontier output distance function:							
Intercept	α_0	7.834	75.656	0.918	-3.297	0.629	0.000
Animal output	$\alpha_1 = 1-\alpha_2$	0.750	-	-	0.793	-	-
Other outputs	α_2	0.250	0.031	0.000	0.207	0.032	0.000
Feed	β_1	-0.599	0.047	0.000	-0.534	0.053	0.000
Intermediate pig input	β_2	-0.076	0.022	0.000	-0.114	0.026	0.000
Other intermediate	β_3	-0.124	0.041	0.002	-0.069	0.042	0.102
Land	β_4	-0.109	0.032	0.001	-0.126	0.035	0.000
Labor	β_5	-0.022	0.021	0.287	-0.032	0.025	0.204
Capital	β_6	-0.079	0.020	0.000	-0.045	0.022	0.037
H_{Sows}	ρ	-9.565	75.669	0.899	0.048	0.040	0.235
$H_{piglets}$	ρ	0.024	0.027	0.366	-0.004	0.031	0.898
$H_{slaughter}$	ρ	-9.466	75.664	0.900	-0.048	0.040	0.229
Inefficiency equation:							
Intercept	δ_0	-9.001	75.920	0.906	0.375	0.081	0.000
Total violations	δ_1	0.002	0.003	0.479	0.008	0.004	0.026
AnyRooting	δ_2	-68.059	542.730	0.900	-0.052	0.045	0.249
AnySick	δ_3	0.648	0.228	0.004	0.094	0.054	0.084
Size	δ_4	-0.002	0.002	0.160	-0.002	0.001	0.000
Establishment	δ_5	0.000	0.001	0.941	-	-	-
H_{Sows}	δ_6	9.630	75.598	0.899	-	-	-
$H_{piglets}$	δ_7	-0.281	0.232	0.226	-	-	-
$H_{slaughter}$	δ_8	9.442	75.669	0.901	-	-	-
H_{Sows} * AnyRooting	δ_9	46.658	379.220	0.902	-	-	-
$H_{piglets}$ * AnyRooting	δ_{10}	-21.230	174.900	0.903	-	-	-
$H_{slaughter}$ * AnyRooting	δ_{11}	42.650	338.400	0.900	-	-	-
H_{Sows} * AnySick	δ_{12}	0.195	1.093	0.858	-	-	-
$H_{piglets}$ * AnySick	δ_{13}	-0.308	1.131	0.785	-	-	-
$H_{slaughter}$ * AnySick	δ_{14}	-0.488	0.131	0.000	-	-	-
H_{Sows} * Size	δ_{15}	0.001	0.002	0.503	-	-	-
$H_{piglets}$ * Size	δ_{16}	0.001	0.002	0.611	-	-	-
$H_{slaughter}$ * Size	δ_{17}	0.000	0.001	0.950			
	σ^2	0.010	0.002	0.000	0.011	0.003	0.001
	γ	0.562	0.126	0.000	0.450	0.246	0.068
log-likelihood value	126.926				117.945		
mean efficiency	0.492				0.918		

The estimated parameter of the remaining animal welfare indicator, AnyRooting, is negative, though it is non-significant. The negative sign of the estimated parameter of AnyRooting would indicate that violating animal

welfare regulations regarding rooting and playing material increases technical efficiency. This would not be surprising, since the provision of rooting and playing material for animals can create additional costs for the farmer (cost of material, e.g. straw, cost of additional labor to provide fresh rooting material and remove old, etc.).

However, based on the presented estimate, we can not draw such a conclusion. To further investigate the relationship between welfare legislation regarding rooting material and technical efficiency, a larger sample or preferably panel data would need to be used in the analysis.

The levels of the estimated parameter values in the inefficiency equation have no direct interpretation, while the marginal effects of the z-variables have a straight-forward interpretation. In practice, this is done by the estimation software, but the formula for this calculation is derived in Olsen and Henningsen (2011).

The marginal effects of the explanatory variables of the inefficiency equation on the efficiency estimates are presented in the histograms in figures 8.23 - 8.26.

Figure 8.23 presents a histogram of the marginal effects of the total number of violations on technical efficiency. Farms with one additional violation of the animal welfare legislation (everything else equal) have on average a 0.2 percentage points lower technical efficiency.

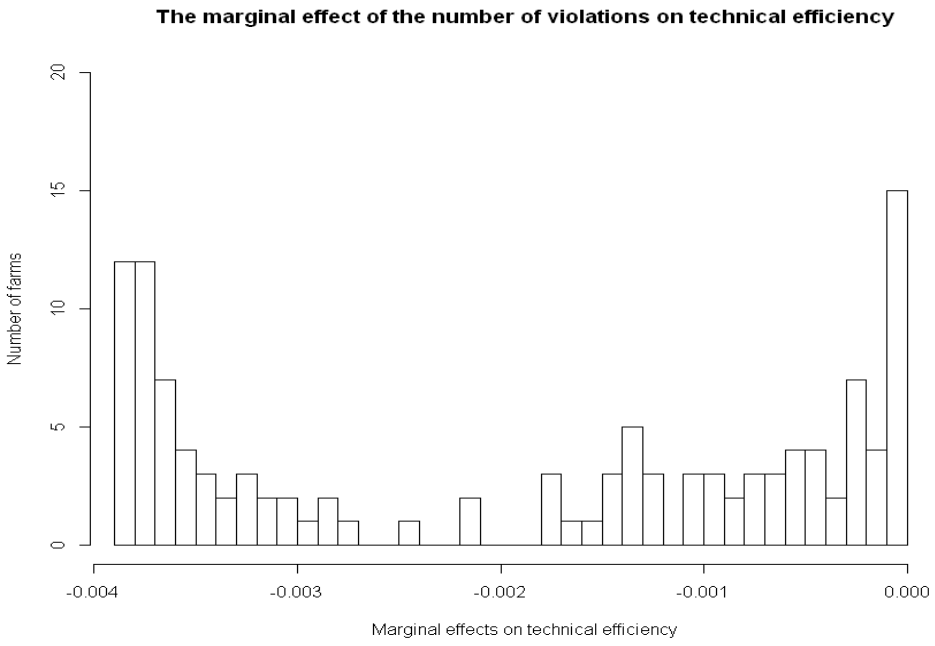


Figure 8.23: Marginal effect of the total number of violations on technical efficiency

The sign of the estimated parameter of the variable Size (measured in pig units) is negative. This means that having more pigs increases technical efficiency. On average, farms with one additional pig unit (everything else equal) have a 0.04 percentage points higher technical efficiency (see figure 8.24). This means that larger farms are more efficient.

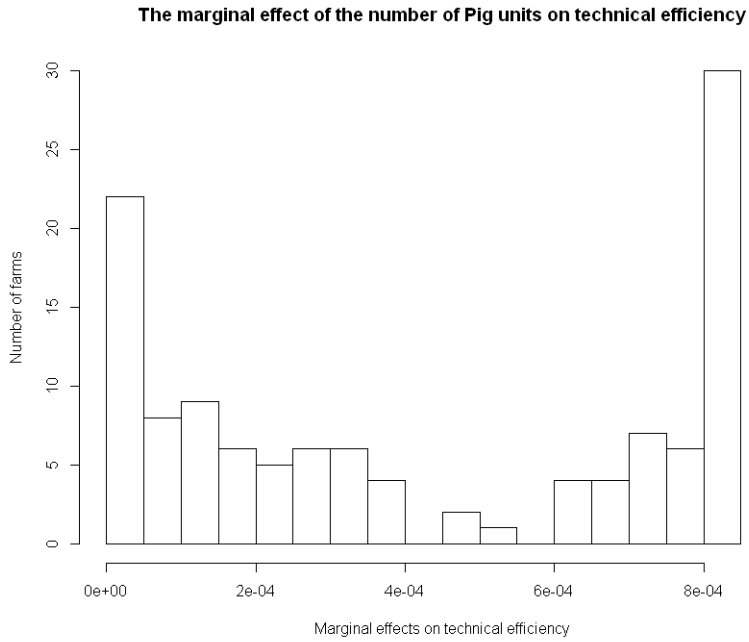


Figure 8.24: Marginal effect of the variable pig units on technical efficiency

The marginal effects of the variable AnyRooting on technical efficiency are presented in figure 8.25. Farmers who violate the regulations with regards to sick animals are on average 1.3 % less efficient than farmers who do not violate these requirements.

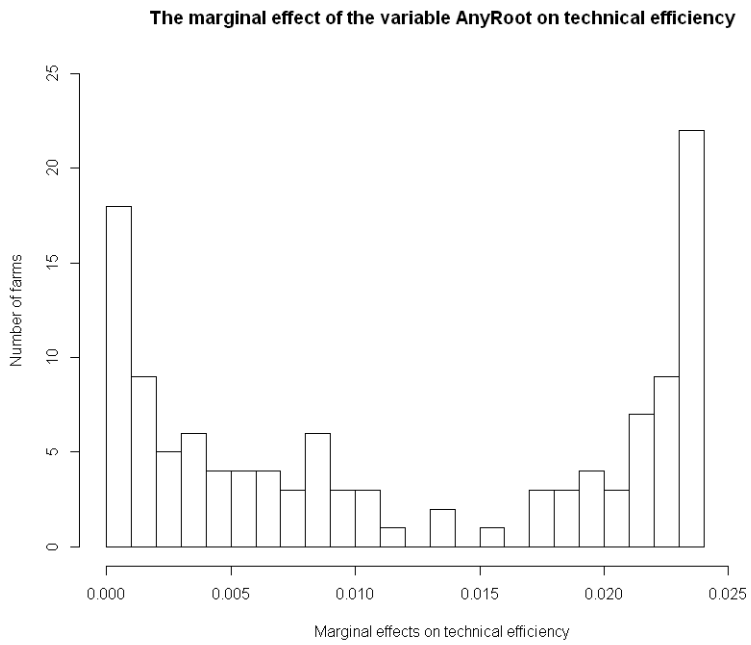


Figure 8.25: Marginal effect of the variable AnyRooting on technical efficiency

The distribution of calculated marginal effects of the AnySick variable on technical efficiency is shown in figure 8.26. Farmers who violate the regulations with regard to sick animals are on average 2.2 % less efficient than farmers who do not violate these requirements.

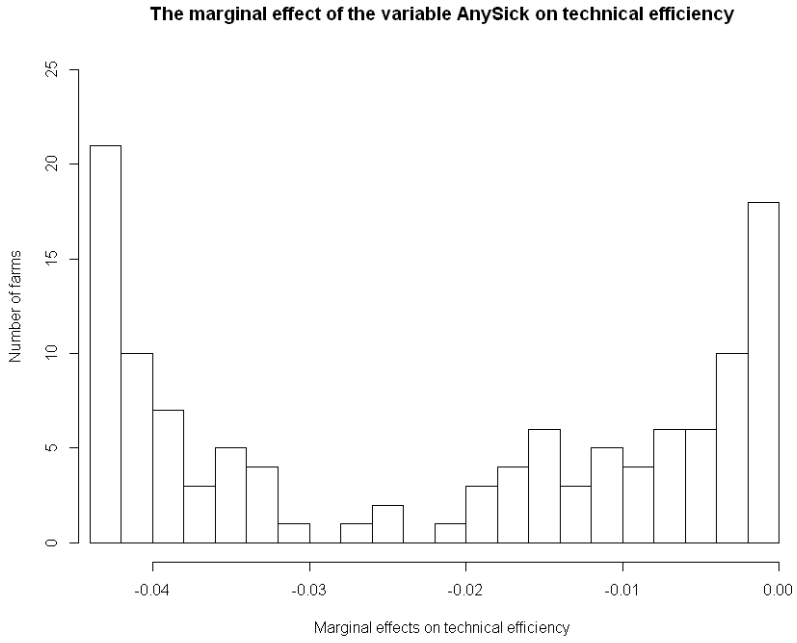


Figure 8.26: Marginal effect of the variable AnySick on technical efficiency

9. Discussion

In this section, we discuss the empirical results obtained from the descriptive analysis, multivariate regression analyses and the results from the estimation of the stochastic output distance function. Moreover, we discuss the methods that we used to answer the research questions:

- Is there a relationship between the number of pigs produced by a farmer and pig welfare?
- Is there a relationship between gross margin per pig unit and pig welfare?
- Is there a relationship between medicine and veterinary cost per pig unit and pig welfare?
- Is there a relationship between the age or experience of the farmer and pig welfare?
- Is there a relationship between the technical efficiency of a farm and pig welfare?

We used the above mentioned research questions to address the main research objective which is defined as follows:

- Is there a relationship between animal welfare and economic results at the farm level?

9.1. Pig units

The structural adjustment process in pig farming has caused farms to become increasingly larger and more specialized in order to increase profit margins and to become more competitive in the global market. Winter *et al.* (1998) argue that the structural adjustment process has caused animal welfare to decrease, e.g. due to farms becoming larger. Our descriptive analysis showed that there is no clear relationship between the farm size (number of pig units at the farm) and violations of the animal welfare regulations, i.e. larger pig producers in general neither have more nor more severe violations than smaller pig producers. These results were observed both for integrated pig producers and for specialized slaughter pig producers. The multivariate analysis generally confirmed the descriptive analysis. It revealed a positive relationship between farm size and violations of the animal welfare legislation regarding the provision of rooting and playing material for farms that do not have sows (mainly specialized slaughter pig producers), but no relationships were found for other farm types or for other indicators of animal welfare. The main conclusion from the descriptive and the multivariate analyses is that violations of animal welfare legislation do not depend on the farm size, except that large specialized slaughter pig producers have a slight tendency to violate the regulations regarding the provision of rooting and playing material more often.

In Lassen *et al.* (2012), an interviewed farmer states that given the nature of the inspection, it can be difficult to avoid having a violation when managing several thousand pigs at a farm. If this is true, our results would indicate that large farmers would be even better in following the animal welfare legislation than smaller

farmers, because larger farmers generally have the same number of violations, although the regulations apply to a larger number of pigs.

9.2. Gross Margin per Pig Unit

The results from our descriptive analysis indicate a positive relationship between animal welfare and gross margin per pig unit for integrated pig producers. For this type of pig producer, there is a negative correlation between the total number of violations and the gross margin per pig unit (statistically significant at the 10% significance level). This tendency is also present when comparing farms with and without violations, and also for farms violating regulations on rooting and playing material or sick animals, i.e. farms with no violations have larger gross margins in all cases (statistically significant at the 10% significance level). For specialized slaughter pig producers, there seems to be a slightly negative relationship between animal welfare and gross margin per pig unit, i.e. farms with no violations have lower gross margins, but this relationship is statistically insignificant. If we take other factors into account in the multivariate analysis, we only find a significant relationship between the gross margin and violations of the animal welfare regulations regarding the treatment of sick animals. Farms that violate these regulations have on average lower gross margins (everything else equal).

According to our theoretical considerations described in section 3.6, animal welfare could be either positively or negatively related to the gross margin (as a proxy for productivity). Our results indicate that the positive correlation (due general management qualities) at least outweighs the negative effect (due to higher costs of following the animal welfare regulations) for integrated pig producers, while for specialized slaughter pig producers, the positive correlation (due general management qualities) almost outweighs the negative effect (due to higher costs of following the animal welfare regulations).

9.3. Medicine and Veterinary Costs per Pig Unit

We argued that although the costs of medicine and veterinary services are related to animals' health, it is difficult to assess whether high medicine and veterinary costs indicate good or poor animal welfare. Our descriptive analysis indicates that there is a clear relationship between the animal welfare indicators and medicine and veterinary costs per pig unit, and that the direction of this relationship depends on the type of production. In contrast, our multivariate analysis does not find a notable relationship between the animal welfare indicators and medicine and veterinary costs per pig unit. These seemingly contradictory results could mean that the correlation between the animal welfare indicators and medicine and veterinary costs per pig unit that we found in the descriptive analysis, does not result from a direct relationship, but from an indirect relationship through other variables that have an effect on both animal welfare indicators and medicine and

veterinary costs per pig unit. The analysis of the complex relationship between animal welfare indicators, medicine and veterinary costs per pig unit, and other variables is an interesting field for future research.

9.4. Age and Experience

The Scientific Veterinary Committee (1997) argues that the quality of stockmanship has a large effect on the welfare of pigs. The results of Anneberg (2013) showed that older farmers were less likely to have been convicted of neglect. According to the results of our descriptive and multivariate analyses, the age of the farmer and the year of establishment of the farm (used as a proxy for the farmer's experience) do not show any correlation with the animal welfare indicators. This means that the manager's ability to comply with the animal welfare legislation is not correlated with his or her age or experience in pig production.

The reason for the difference between our findings and the results of Anneberg (2013) might be that she studied farmers with regards to the likelihood of being convicted of animal welfare neglect, whereas in our analysis, we studied violations in general.

It is worth mentioning that the use of another variable indicating a farmer's management abilities, such as years of formal education, may have yielded other results. Years of education is a proxy of the farmer's willingness to learn and improve the management of a farm. However, data on the level of the formal education was not available in our data.

9.5. Technical Efficiencies

Additionally to the descriptive analysis and multivariate regression analysis, we also used stochastic frontier analysis to investigate the relationship between the animal welfare indicators and the technical efficiency of pig producers. We found that violations of the animal welfare legislation are in general negatively correlated with the technical efficiency of pig producers. This means that farms with bad management of animal welfare are on average less efficient.

These results are similar to the results of the study by Barnes et al. (2011) who investigated the relationship between lameness and technical efficiency in dairy herds. Lameness as an indicator of animal welfare has an advantage over the animal welfare indicators that we used in this analysis, because it is an animal-based indicator. They found that herds with low prevalence of lameness had higher technical efficiencies, which shows that there is positive correlation between good welfare management and technical efficiency. On the other hand, Lawson *et al.* (2004a) showed that dairy farms with more treatments for lameness, ketosis, and digestive disorders were more technically efficient. The opposite was true for farms reporting more treatments for milk fever, which had lower technical efficiencies.

9.6. Methods

The descriptive analysis of the economic variables and welfare indicators is a simple approach to analyzing the relationship between animal welfare and economics. This is both an advantage and a drawback. The advantage of the approach is that relationships are easily visualized and it is straightforward to check obvious correlations and differences. The drawback is that it is not possible to make any conclusions on causality, and it is not possible to account for possible correlations with other factors. Therefore, we used multivariate regression analysis to facilitate a more thorough investigation of the correlations between animal welfare, socio-economic indicators and economic outcomes.

The stochastic output distance function makes it possible to analyze technical efficiency and its relationship to animal welfare. This approach accounts for more outputs and more inputs so that the estimated efficiencies are better measures of productivity than gross margins that disregard labor and capital inputs. We presented the results of a Cobb-Douglas output distance function, although researchers usually prefer to use more flexible functional forms such as the translog function. However, our data set did not include a sufficient number of observations for estimating a translog output distance function so that the estimates were too imprecise due to insufficient degrees of freedom.

9.7. Data

Only a few empirical studies that analyze the relationship between animal welfare and economic outcomes at the farm level exist. One possible reason for this is that animal welfare is a multidimensional concept, and it is difficult to obtain reliable and quantifiable data, and thus indicators which cover all aspects of animal welfare. Moreover, data and indicators need to be available for a large number of farms in order to conduct a meaningful quantitative analysis.

In this analysis, we use data from the Danish animal welfare inspection to construct indicators of animal welfare. It should be noted that the use of welfare inspection data is not comparable to an overall welfare assessment. A welfare inspection inspects the legislative requirements, whereas a welfare assessment assesses the true level of animals' welfare. However, the animal welfare inspection that is used in our analysis is a good proxy for the farmer's management of animal welfare with regards to certain issues. The aggregation of the animal welfare data could result in biased animal welfare indicators. These potential biases have been investigated. Conducted statistical tests showed that this aggregation does not induce a significant bias. The classification according to production type of farms ensures that animal welfare is compared amongst farms with similar production technologies. Farms are separated into different production types, but we only had sufficient data for two of these production types: integrated pig producers and specialized slaughter pig

producers. We limited the scope of the analysis in this report to the “nulpunkt” animal welfare inspection, because the “nulpunkt” inspection was based on randomly sampled farms. Furthermore, we found that the data from the animal welfare control were not sufficiently similar to the data from the “nulpunkt” inspection.

The registrations of the economic and animal welfare data used in this report are based on two different approaches. The economic data is accountancy data, and is therefore an aggregate of the economic transactions during the year 2011. The animal welfare data is measured at a single point in time during the fall of 2011. Therefore, it does not represent the level of animal welfare during the year. During the inspection, a farmer could be unlucky and have a violation noted despite it being a one-time event. This would not represent his general level of animal welfare, but the opposite scenario could also be the case. Furthermore, the checklist scheme is mostly constructed of environment-based indicators, which are consistent over time and easy to check. It is therefore less likely to get registered for an “undeserved” violation. Besides, it is justifiable to assume that, for the entire dataset, both lucky and unlucky events cancel out. Therefore, it is argued that the data represent a good proxy of animal welfare at the investigated farms.

10. Conclusion and Perspectives

In this report, we have studied the empirical relationships between animal welfare and the economic outcome of Danish pig producers.

We use data from the Danish animal welfare inspection to construct indicators of animal welfare. Based on a literature review, it was concluded that a multidimensional indicator is best suited to assessing animal welfare. Several indicators of animal welfare are used in the analysis, but it was found that the total number of violations of the animal welfare legislation comes closest to the ideal of a multidimensional indicator.

Two data sets on animal welfare inspection were initially taken into consideration for the economic analysis: the randomly sampled "nulpunkt" data, and the risk-based sampled welfare control data. It is not surprising that statistical tests showed that the datasets are different and should be considered separately. However, it is surprising that integrated pig producers in the "nulpunkt" data more often and more severely violate the animal welfare regulations than integrated pig producers in the welfare control data. This could indicate that the "nulpunkt" inspection was stricter than the regular welfare control inspections (see section 3.6 and Forkman 2010), and/or it could indicate that the risk-based sampled welfare control data predominantly included integrated pig producers with a lower risk of violating the animal welfare regulations than average integrated pig producers. The underlying reasons for this may be worth considering by employees who manage the animal welfare inspection in Denmark. We only used the "nulpunkt" data in the economic analysis, because it is a random sample of Danish pig producers.

The results of our analysis suggest that the size of a farm and the age and experience of the farmer are generally not correlated with animal welfare. We did not find a clear relationship between animal welfare management and medicine and veterinary costs (when taking other factors into account). Our results show that integrated pig producers with good animal welfare have higher gross margins compared to farms with bad animal welfare, but we did not find this relationship for specialized slaughter pig producers. This could indicate that farms with piglet production (mainly integrated pig producers) have larger economic incentives for providing good animal welfare than farms without piglet production (mainly specialized slaughter pig producers). In contrast, we found that good animal welfare was positively related to high technical efficiency for all production types. Anyway, based on our entire analysis, we suggest that the relationship between animal welfare and the economic outcome of pig producers should be interpreted within the context of the production type.

The results of this report show that there is in general a positive but weak relationship between animal welfare and the economic success of pig producers. This suggests that farmers who have better control of compliance

with animal welfare regulations also perform economically better and are more efficient in the production. However, based on the analyses provided in this report, we cannot conclude on the causal relationship between animal welfare and economic outcome. The investigation of the causal relationship between animal welfare, economic outcome and other relevant factors requires more detailed analyses based on additional and more detailed data.

However, although our findings about the relationship between animal welfare and the economic success of Danish pig producers are rather weak, they can still contribute to the discussion of the animal welfare legislation in Denmark. According to the results of our analyses, farmers who maintain a higher level of compliance with animal welfare regulations are not worse off than farmers who violate animal welfare regulations. This finding could be a valuable input in the political discussions on the animal welfare legislation, but the limitations of the findings should be stressed, because the causal relationship has not yet been investigated. Therefore, further studies are needed on this topic.

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Appendix

A. Statistical tests

This section provides a presentation and an overview of the statistical tests used in the report. In the description of the tests, the focus is on the intuition of using the test, and not on mathematical and statistical properties.

A.1. Welch's Two Sample T-test

Welch's two sample t-test is also known as the unequal variance t-test (Ruxton 2006). The t-test is used to compare differences in group means. The Welch's two-sample t-test is comparable to the Student's t-test. It assumes normally distributed populations, and the t-distribution is used for hypothesis testing. Contrary to the Student's t-test, Welch's two sample t-test does not assume equal sample variances of the groups being compared.

The null hypothesis: the two population means are equal.

We used Welch's t-test to test for differences in, e.g. gross margin per pig unit for farms with or without a violation.

A.2. ANOVA

Analysis of variance (ANOVA) is used to test for differences in means for 2 or more groups (Verzani 2004). The test assumes independent and normally distributed samples, and equal sample variances. The F-statistic is used to evaluate the differences between groups. The null hypothesis is that all group means are the same. The alternative hypothesis is that not all means are the same. If the null hypothesis is rejected, because there is a difference in means, then Tukey's pair-wise comparison test can be used to test for differences between groups. Tukey's test compares sample means simultaneously, unlike the ordinary t-test.

This test is used to test for differences in, e.g. gross margin per pig unit for the most severe violations.

7.2.6. A.3. χ2 Test

Pearson's χ^2 test of independence is used to test for differences between categorical variables, where the categorical variables have two or more possible values (Agresti 1990). The null hypothesis is that the relative proportions of one variable are independent of the other variable. The alternative hypothesis is that the proportions of one variable are dependent on the other variable. The distribution of the chi-square test statistic under the null hypothesis is approximately the same as the theoretical chi-square distribution.

This test is used, e.g. when testing whether there is a difference in the distribution of farms with or without violations between the “nulpunkt” data and the welfare control data.

A.4. Mann-Whitney U Test

The Mann-Whitney U test is used for ordered categorical data (Emerson and Moses 1985). It is a non-parametric test, which means that no prior assumption on distributions is made, but for sample sizes greater than 20, it follows the z-distribution. It is used to test whether two samples are drawn from the same population. The test is performed by combining the two samples into one dataset and then ranking the observations. For each sample, the number of observations ranked higher than observations from the other sample is counted. These results are compared in the test. The null hypothesis: Two samples, x and y, have identical distributions and are from the same population. The alternative hypothesis: x and y do not have identical distributions, and are not from the same population.

This test is used, e.g. to compare the distribution of the total number of violations between the “nulpunkt” data and the welfare control data.

A.5. Pearson’s Correlation Coefficient

Pearson’s product-moment correlation coefficient can be used to test the association between two numeric variables from the same sample (Wooldrige 2009). The significance of this correlation can be tested using a two-tailed t-test. The null hypothesis is that correlation equals zero. The alternative hypothesis is that correlation is different from zero.

The correlation test is used, e.g. to check for an association between gross margin per pig unit and the total number of violations.

A.6. Likelihood Ratio Test.

The likelihood ratio test compares the fit of two models by calculating The likelihood ratio (Greene 2008). The likelihood ratio expresses how many more times likely the data are under one model than the other. One model should be a special case of the other, i.e. a restricted model should be nested within an unrestricted model. The unrestricted model has more parameters, and therefore fits the data at least as well as the restricted model. If the log likelihood values are similar for the restricted and unrestricted values, then the restricted model most likely fits the data better. The likelihood ratio test statistic has asymptotically mixed χ^2 distribution (Coelli, 1995).

The likelihood ratio test is used, e.g. to compare the fit of the estimated stochastic output distance function against the nested Ordinary Least Square model, i.e. the restricted model without inefficiency.

B. Summary of the results of descriptive analysis

Table B.1 shows the results from testing the relationship between the 8 socio-economic variables and 5 indicators of animal welfare for integrated pig producers. The significance level of the test is given along with the direction of the result. If the test result is insignificant "None" is reported.

Table B.1: Test results for integrated pig producers

	Total number of violations *(correlation?)*	**Most severe violation** *(significant difference?)*	**AnyViolation** *(significant difference?)*	**AnyRooting** *(significant difference?)*	**AnySick** *(significant difference?)*
Pig units	None	None	None	None	None
Gross margin (GM)	10 %-level. Decreasing GM if violations	10 %-level. There is a difference.	10 %-level. Lower GM if violation	5 %-level. Lower GM if violation	None
Medicine and veterinary costs	None	None	10 %-level. Lower costs if violation	10 %-level. Lower costs if violation	5 %-level. Lower costs if violation
Revenue	None	10 %-level. There is a difference.	None	1 %-level. Lower revenue if violation	None
Feed costs	None	None	None	None	None
Other costs	None	None	None	None	None
Age	None	None	None	None	None
Experience	None	None	None	None	None

Table B.2 shows the results from testing the relationship between 8 socio-economic variables and 5 indicators of animal welfare for specialized slaughter pig producers. The significance level of the test is given along with the direction of the result. If the test result is insignificant "None" is reported in the cell.

Table B.2: Test results for specialized slaughter pig producers

	Total number of violations *(correlation?)*	**Most severe violation** *(significant difference?)*	**AnyViolation** *(significant difference?)*	**AnyRooting** *(significant difference?)*	**AnySick** *(significant difference?)*
Pig units	None	None	None	None	None
Gross margin	None	None	None	None	None
Medicine and veterinary costs	None	10 %-level. There is a difference	10 %-level. Higher costs if violation	None	10 %-level. Higher costs if violation
Revenue	<1 %-level. Increasing revenue if violations	None	10 %-level. Higher revenue if violation	None	None
Feed costs	None	None	None	None	None
Other costs	10 %-level. Higher other costs if violations	None	10 %-level. Higher other costs if violation	None	10 %-level. Higher other costs if violation
Age	None	None	None	None	None
Experience	None	None	None	None	10 %-level. Less experienced if violation.