Incentive mechanisms for food safety control in pork supply chains

A study on the relationship between finishing pig producers and slaughterhouses in the Netherlands

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Abstract

Food borne illness today still results in high societal costs, even though FBOs have implemented food safety control systems. In addition, the susceptibility to food borne diseases of the human population is likely to increase in the coming decades. Thus food safety control needs to be improved. Since 2005, a new EU food safety policy aims to improve food safety through shifting primary responsibility for food safety from government to FBOs and through shifting food safety control from company level to supply chain level. This research aims to contribute to improvement of food safety by analyzing private incentive mechanisms aimed at food safety control on supply chain level. It focuses on the two stage supply chain between pig producers and slaughter company in the Netherlands.

A framework for designing and developing incentive mechanisms for food safety control is developed. An incentive mechanism aimed at food safety control is defined as the set of the performance and compliance measurement system and the compensation scheme between buyer and supplier, which aims to induce the supplier to apply measures to control food safety hazards as the buyer requests. The framework includes all important characteristics of incentive mechanisms for food safety and their relationships. In this thesis the influence on supplier behaviour of four important characteristics of incentive mechanisms for food safety control are analysed, namely 1) the type of performance compensation, 2) the causes for variability in performance between suppliers, 3) the accuracy of a test to determine supplier performance, and 4) the reliability of information provided by the supplier. It uses different food safety hazards in pork: lesioned livers, *Mycobacterium avium*, and residues of antibiotics. Results show that a penalty for each lesioned liver was more effective to induce pig producers to use control measures than a collective premium. Variability in liver lesion prevalence between pig producers with a penalty for each lesioned liver occurred because each pig producer used different control measures with different effectiveness. The accuracy of a *Mycobacterium avium* test showed to have a significant impact on pig producer behaviour to use control measures if an incentive mechanism was in place. Finally, information about the use of antibiotics provided by pig producers without an incentive system for the reliability of the information was insufficiently reliable to guarantee absence of residues in pork. It is concluded in this thesis that private incentive mechanisms can be used to reduce opportunistic behaviour of pig producers, thereby improving food safety control on supply chain level and helping to raise food safety control to the next level. For optimal inducement it is important that the performance and compliance measurement system is attuned to the compensation scheme.

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Coen van Wagenberg
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Summary

Food safety is an essential food attribute for consumers and a key policy dossier for governments, making it a critical decision item for food business operators (FBOs), such as retailers, food processors and primary producers. Notwithstanding the safety control systems which FBOs have implemented, food borne illness today still results in high societal costs. This combined with the likely increase in susceptibility to food borne diseases of the human population shows the need to improve food safety control. Two recent changes in the EU food safety policy aiming to improve food safety can be observed. The first change is the shift of primary responsibility for food safety from government to FBOs. The second change concerns the shift of controlling food safety at company level to supply chain level. FBOs are looking for strategies to induce suppliers to use inputs and production processes that improve raw material safety given the presence of information asymmetry and possible opportunistic behaviour. Supply chain management literature argues that incentive mechanisms can be used to induce trading partners to apply behaviour which improves performance. Incentive mechanisms thus might be used to improve food safety performance on supply chain level. Knowledge on how incentive mechanisms can effectively induce food safety control on supply chain level is lacking. This research aims to contribute to improvement of food safety by analyzing incentive mechanisms aimed at food safety control. It focuses on the two stage supply chain between pig producers and slaughter company in the Netherlands. To realise the aim of this research, the following five research questions were posed:

1) What are key elements of incentive mechanisms aimed at food safety control?
2) How effective are incentive mechanisms with a collective insurance premium and a price reduction per lesioned liver in reducing liver lesion prevalence in finishing pigs?
3) What causes variability in liver lesion prevalence in finishing pigs of pig producers subjected to an incentive mechanism with a price reduction per lesioned liver?
4) What is the impact of the accuracy of a *Mycobacterium avium* test on the *Mycobacterium avium* prevalence in finishing pigs of pig producers subjected to an incentive mechanism with financial compensation aimed at *Mycobacterium avium* prevalence?
5) What is the reliability of information about antibiotics usage in finishing pigs provided by pig producers used as compliance measurement in an incentive mechanism without compliance compensation?

Methods and results

To answer the research questions, 5 studies were conducted presented in chapter 2 to 6. In chapter 2 a framework for designing and analyzing incentive mechanisms aimed at food safety control is developed. The framework combines relevant aspects of food safety control on company level and on supply chain level. Key elements of incentive mechanisms aimed at food safety control were identified in a literature review on actual and theoretical incentive mechanisms aimed at food quality and food safety control. An incentive mechanism aimed at food safety control is defined as the set of performance and compliance measurement system and compensation scheme between buyer and supplier, which aims to induce the supplier to apply measures to control food safety hazards as the buyer requests. Performance relates to intrinsic product attributes in the products of a FBO, such as a contamination level. Compliance is the extent to which a FBO follows (EFSA, 2007)procedures that aim to control food safety, such as HACCP–procedures. Key elements of incentive mechanisms are the performance and compliance measurement system and the compensation scheme. The performance and compliance measurement system is characterised by the indicators to determine food safety performance and compliance, the accuracy of the measurement, and the actor who conducts and determines performance and compliance measurement. The performance and compliance compensation scheme is characterised by the type of compensation.

Chapter 3 to 6 address how specific characteristics of performance and compliance measurement system and compensation scheme influence supplier performance and compliance. Chapter 3 analyses the relationship between the type of compensation and actual performance. The effectiveness of two types of performance compensation for liver lesion prevalence in finishing pigs, a collective insurance premium per delivered finishing pig and a price reduction per delivered finishing pig with a lesioned liver, was analysed with an out–of–sample forecast test on a time series of liver lesion inspection data of Dutch finishing pigs from 2003 to 2006. After introduction of the price reduction, mean liver lesion prevalence decreased from 9 to 5%. A reduced liver lesion prevalence ranging from 0 to 46 percentage points was observed on 67% of 1069 farms that delivered both during the insurance and the price reduction period. The number of farms with a liver lesion prevalence of 5.0% or less increased from 52 to 68%. However, even with the incentive mechanism with price reduction, variability in liver lesion prevalence between pig producers was observed. Concluding, chapter 3 demonstrates that an incentive mechanism with a penalty on products off–specification was more effective in inducing pig producers to reduce liver lesion prevalence in finishing pigs than an incentive mechanism with a collective insurance fee.

Chapter 4 addresses variability in liver lesion prevalence in finishing pigs observed in chapter 3 and analyses the relationship between decision making, actions used, and actual performance. Regression and correlation analyses were applied on liver lesion inspection data of Dutch finishing pigs combined with data from a farmer survey about control measure used and factors underlying the decision to use control measures. Factors underlying the decision were based on the Theory of Planned Behaviour. Results show that of the 185 pig producers in the analysis, 96% used anthelmintics, i.e. medication to control infections with the roundworm *Ascaris suum*, the main cause of liver lesions in finishing pigs. These pig producers used a variety of combinations of active compounds, application methods, and duration of application. Application of anthelmintics by sprinkling over feed was associated with 2.4% higher liver lesion prevalence compared to other application methods. Furthermore, pig producers underestimated their liver lesion prevalence, thus reducing their need to apply effective management practices to lower liver lesion prevalence. In conclusion, chapter 4 shows that variability in liver lesion prevalence of pig producers subjected to an incentive mechanism with a price reduction per lesioned liver was caused by using different control measures with varying effectiveness and underestimation of liver lesion prevalence.

Chapter 5 focuses on the relationship between performance measurement accuracy, actions and performance. A dynamic optimization model with a grid search of deliveries of finishing pigs from pig producers to a slaughterhouse, which included a possible future control system for *Mycobacterium avium* (Ma), was developed to analyse how accuracy of a new serodiagnostic test to determine Ma seroprevalence influenced finishing pig producer incentives to control Ma seroprevalence. Model input combined data collected from literature with expert estimations. Serodiagnostic test accuracy was defined by sensitivity, i.e. the probability of correctly qualifying a product with increased risk, and specificity, i.e. the probability of correctly qualifying a product without increased risk. Results show that higher sensitivity and lower specificity resulted in usage of more intense Ma control measures applied by pig producers, higher producer costs and lower Ma prevalence. The minimal penalty value needed to comply with a threshold for average Ma seroprevalence in finishing pigs at slaughter was lower at higher sensitivity and lower specificity. With imperfect specificity a larger sample size decreased pig producer incentives to control Ma seroprevalence, because the higher number of false positives resulted in an increased probability of rejecting a batch of finishing pigs irrespective of whether the pig producer took control measures. Concluding, chapter 5 shows that higher sensitivity and lower specificity of a serodiagnostic test lowers expected average Ma seroprevalence in finishing pig deliveries of pig producers subjected to an incentive mechanism with a penalty for deliveries with increased Ma prevalence. With imperfect testing specificity and low hazard prevalence, a larger sample size can decrease pig producer incentives to improve performance.

Finally, chapter 6 investigates the relationship between reliability of compliance information provided by the supplier and monitoring of residues of antibiotics in finishing pigs. No control system to check the reliability of provided compliance information existed in

practice. A dataset of 479 deliveries with information about antibiotics usage in finishing pigs during 60 days prior to delivery to a slaughter company provided by finishing pig producers was combined with screening results for antibiotics residues in the same finishing pigs. A Pearson chi–square test was used to analyse reliability of provided information. Results show that twice as much pig producers reported using antibiotics in the group of 82 pig producers with detected antibiotics residues (11.0%) as in the group without detected antibiotics residues (5.5%). For 89% of deliveries with a finishing pig with detected antibiotics residues 'did not use antibiotics' was reported. In conclusion, chapter 6 demonstrates that without a control system to check its reliability, the information about antibiotics usage during 60 days prior to delivery reported by pig producers, did not guarantee absence of antibiotics residues in the finishing pigs. This information was, therefore, insufficiently reliable to be used in a control system for antibiotics residues in finishing pigs by a slaughterhouse.

This thesis analyses the influence of a number of important characteristics of incentive mechanisms for food safety control on supplier behaviour. It demonstrates that incentive mechanisms can be used to reduce opportunistic behaviour of suppliers, thereby helping to raise food safety control to the next level. For optimal inducement of suppliers it is important that the performance and compliance measurement system is attuned to the compensation scheme.

Theoretical contribution

This thesis contributes to food safety management, incentive and supply chain management theory. This thesis has three contributions to food safety management theory. First, private incentive mechanisms aimed at food safety control can be used to aid the shift of food safety control at company level to supply chain level. Second, the developed framework provides insight on how to combine relevant technological and managerial aspects to improve food safety control on supply chain level. Third, this thesis was the first study to analyse the impact of diagnostic testing accuracy on supplier incentives to control food safety.

This thesis has one contribution to incentive theory. The influence of the inaccuracy of a diagnostic test on supplier incentives to exert effort implies that inaccuracy in performance measurement must be considered in incentive Theory and in principal–agent models used to analyse incentive problems.

This thesis has three contributions to supply chain management theory. First, properly designed incentive mechanisms can align company interests to improve supply chain performance. Second, the performance and compliance measurement system and the compensation scheme should be set coherently to optimally induce suppliers to improve performance. Third, opportunistic behaviour cannot be neglected as reason for distortion of information exchanged in supply chains.

Managerial implications

A number of general managerial implications can be drawn from this thesis, of which the most important ones are presented here. A penalty on products off–specification is effective to induce suppliers to improve food safety performance. Parameters of the performance and compliance measurement system, such as diagnostic testing accuracy and sample strategy, and of the compensation scheme should be attuned for optimal inducement of suppliers to control food safety. Only if reliability of information about used control actions provided by a supplier can be checked easily, it can be used in incentive mechanisms aimed at food safety control as compliance measurement.

A number of specific managerial implications for pig producers and pig slaughter companies can also be drawn from this thesis. Pig producers should be induced to apply anthelmintics to finishing pigs in feed, in water or by injections instead of sprinkling over feed, because sprinkling over feed showed to be less effective to lower liver lesion prevalence than other application methods. Pig slaughter companies should increase effort to provide pig producers with information about their actual liver lesion prevalence in finishing pigs, because a more accurate estimation of liver lesion prevalence can help to increase the need to treat *Ascaris suum* infections and lower liver lesion prevalence. The Dutch pork chain can implement an incentive mechanism, similar to that of liver lesions, to lower prevalence of other lesions in finishing pigs detected at slaughter, such as lung lesions, pleurisy, skin lesions and leg lesions. Pig slaughter companies or governments in other countries can also implement an incentive mechanism similar to the Dutch mechanism to lower liver lesion prevalence in finishing pigs.

Further research

Based upon the discussion in this thesis many suggestions for further research can be made. The three most important suggestions are as follows. First, further research is needed to investigate applicability and effectiveness of alternative performance and compliance measurement indicators and alternative types of performance and compliance compensation to induce suppliers to control food safety, that are not evaluated in this research. Second, for improved design of new incentive mechanisms further analysis of the relationship between supply chain characteristics, supplier–buyer relationship characteristics and the optimal settings of incentive mechanism parameters is needed. Third, research is advised which includes public health effects into analyses of food safety control on supply chain level in order to provide policy advise for optimal setting of food safety objectives and for determining the optimal privatization level of combined public and private food safety control and verification.

Samenvatting

Incentive mechanismen voor beheersing van voedselveiligheid in varkensvleesketens: Een onderzoek naar de relatie tussen vleesvarkenshouders en slachterijen in Nederland

Voedselveiligheid is een essentieel voedsel attribuut voor consumenten en een zeer belangrijk beleidsdossier voor overheden. Hierdoor is voedselveiligheid cruciaal voor levensmiddelenbedrijven zoals retailers, verwerkers en primaire producenten. Echter, ondanks de invoering van beheerssystemen voor voedselveiligheid door levensmiddelenbedrijven blijven voedselgerelateerde infecties grote maatschappelijke gevolgen hebben. Dit, gecombineerd met de waarschijnlijke toename van bevattelijkheid voor voedselgerelateerde infecties van de humane bevolking, toont de noodzaak tot verder verbeteren van de voedselveiligheid. Twee recente veranderingen in het Europese voedselveiligheidsbeleid om de voedselveiligheid verder te verbeteren kunnen worden geobserveerd. De eerste verandering betreft de verschuiving van de primaire verantwoordelijkheid voor voedselveiligheid van overheid naar bedrijfsleven. De tweede verandering betreft de verschuiving van de beheersing van voedselveiligheid op bedrijfsniveau naar beheersing op ketenniveau. Levensmiddelenbedrijven zijn dan ook op zoek naar strategieën om hun leveranciers ertoe aan te zetten die grondstoffen en productieprocessen te gebruiken, die de veiligheid van de geleverde producten verbeteren. Hierbij dient wel rekening te worden gehouden met asymmetrische informatie en opportunistisch gedrag. In de keten management literatuur wordt beargumenteerd dat incentive mechanismen kunnen worden gebruikt om handelspartners ertoe aan te zetten gedrag te vertonen dat de prestatie verbetert. Incentive mechanismen lijken dus geschikt om de voedselveiligheid op ketenniveau te verbeteren. Echter, kennis over hoe incentive mechanismen effectief voedselveiligheid op ketenniveau kunnen verbeteren ontbreekt. Dit onderzoek heeft als doel om bij te dragen aan de verbetering van de voedselveiligheid door het analyseren van incentive mechanismen gericht op beheersing van voedselveiligheid op ketenniveau. Het richt zich op de twee schakel keten tussen vleesvarkenshouders en slachterij in Nederland. Om het doel van dit onderzoek te realiseren, zijn de volgende vijf onderzoeksvragen geformuleerd:

1) Wat zijn kernelementen van incentive mechanismen gericht op beheersing van voedselveiligheid?

2) Hoe effectief zijn incentive mechanismen met een collectieve verzekeringspremie en met een prijskorting per afgekeurde lever in het verlagen van de prevalentie afgekeurde levers in vleesvarkens?
3) Wat veroorzaakt variabiliteit in de prevalentie afgekeurde levers in vleesvarkens van vleesvarkenshouders die onderworpen zijn aan een incentive mechanisme met een prijskorting per afgekeurde lever?
4) Wat is de impact van de accuratesse van een test op *Mycobacterium avium* op de *Mycobacterium avium* prevalentie in vleesvarkens van varkenshouders die onderworpen zijn aan een incentive mechanisme met financiële compensatie gericht op *Mycobacterium avium* prevalentie?
5) Hoe betrouwbaar is door varkenshouders aangeleverde informatie over het antibioticagebruik in vleesvarkens gebruikt als maat voor naleving binnen een incentive mechanisme zonder compensatie voor naleving?

Methode en resultaten

Om de onderzoeksvragen te beantwoorden zijn 5 onderzoeken uitgevoerd, die worden gepresenteerd in hoofdstuk 2 tot en met 6. In hoofdstuk 2 wordt een raamwerk ontwikkeld voor het ontwerpen en analyseren van incentive mechanismen gericht op beheersing van voedselveiligheid. Het raamwerk combineert relevante aspecten van beheersing van voedselveiligheid op bedrijfsniveau met die op ketenniveau. Kernelementen van incentive mechanismen gericht op beheersing van voedselveiligheid zijn geïdentificeerd via een literatuuronderzoek naar bestaande en theoretische incentive mechanismen gericht op beheersing van voedselkwaliteit en voedselveiligheid. Een incentive mechanisme gericht op beheersing van voedselveiligheid is gedefinieerd als de set van het systeem om prestatie en naleving te meten en het compensatie schema tussen leverancier en koper, met als doel de leverancier ertoe aan te zetten om maatregelen te nemen die de voedselveiligheid beheersen zoals de koper wenst. Prestatie verwijst naar intrinsieke product attributen, zoals besmettingsniveau. Naleving verwijst naar de mate waarin voedingsmiddelenbedrijven procedures volgen die gericht zijn op de beheersing van voedselveiligheid, zoals HACCP–procedures. Kernelementen van incentive mechanismen zijn het systeem om prestatie en naleving te meten en het compensatie schema. Het systeem om prestatie en naleving te meten wordt gekenmerkt door de indicatoren om de prestatie en naleving vast te stellen, de accuratesse van deze meting, en de actor die de meting uitvoert en prestatie en naleving vaststelt. Het compensatie schema wordt gekenmerkt door het type compensatie.

Hoofdstuk 3 tot en met 6 behandelen hoe specifieke kenmerken van het systeem om prestatie en naleving te meten en van het compensatie schema de prestatie en naleving van leveranciers beïnvloeden. Hoofdstuk 3 analyseert de relatie tussen type compensatie en prestatie. De effectiviteit van twee typen compensatie voor prevalentie afgekeurde levers in vleesvarkens, een collectieve verzekering per afgeleverd vleesvarken en een prijskorting per afgeleverd vleesvarken met een afgekeurde lever, is geanalyseerd met een out–of–sample forecast test op een tijdreeks van 2003 tot en met 2006 van lever inspectie resultaten van vleesvarkens geleverd aan een grote Nederlandse slachterij. Na introductie van de prijskorting daalde de gemiddelde prevalentie afgekeurde levers van 9 naar 5%. Op 67% van de 1069 varkensbedrijven, die zowel in de periode met de verzekering als de met de prijskorting vleesvarkens leverden, werd een verlaagde prevalentie afgekeurde levers gevonden, variërend van 0 tot 46 procentpunten. Het aantal varkensbedrijven met 5,0% of minder afgekeurde levers nam toe van 52 tot 58%. Echter, zelfs met het incentive mechanisme met de prijskorting, bleef variabiliteit in prevalentie afgekeurde levers tussen varkenshouders bestaan. Concluderend, hoofdstuk 3 laat zien dat een incentive mechanisme met een boete op producten buiten specificatie effectiever was om varkenshouders ertoe aan te zetten om de prevalentie afgekeurde levers in vleesvarkens te verlagen dan een incentive mechanisme met een collectieve verzekeringspremie.

Hoofdstuk 4 behandelt de variabiliteit in prevalentie afgekeurde levers in vleesvarkens, zoals vastgesteld in hoofdstuk 3. Het analyseert de relatie tussen besluitvorming, gebruikte acties, en prestatie. Regressie en correlatie analyses zijn toegepast op lever inspectie resultaten van vleesvarkens geleverd aan een grote Nederlandse slachterij gecombineerd met gegevens uit een enquête onder varkenshouders over gebruikte beheersmaatregelen voor leverafwijkingen en onderliggende factoren van het besluit om beheersmaatregelen te gebruiken. De onderliggende factoren zijn gebaseerd op de Theory of Planned Behaviour. De resultaten laten zien dat van de 185 varkenshouders in de analyse er 96% antiwormmiddelen (anthelmintica) gebruikten om een infectie te beheersen met de rondworm *Ascaris suum*, de belangrijkste oorzaak van afgekeurde levers in vleesvarkens. De varkenshouders gebruikten een variatie aan combinaties van werkzame stoffen, toedieningmethoden, en duur van toedieningen. Toediening van antiwormmiddelen via strooien over voer werd geassocieerd met 2,4% hogere prevalentie afgekeurde levers in vergelijking met de andere toedieningmethoden. Verder onderschatten varkenshouders de prevalentie afgekeurde levers, wat bij hen de noodzaak verlaagt om effectieve methoden toe te passen voor het verlagen van de prevalentie afgekeurde levers. Concluderend, hoofdstuk 4 laat zien dat variabiliteit in prevalentie afgekeurde levers in vleesvarkens tussen varkenshouders onderworpen aan een incentive mechanisme met een prijskorting per afgekeurde lever werd veroorzaakt door het gebruik van verschillende beheersmaatregelen met verschillende effectiviteit en door het onderschatten van de prevalentie afgekeurde levers.

Hoofdstuk 5 richt zich op de relatie tussen de accuratesse van de prestatie meting, acties en prestatie. Een dynamisch optimalisatiemodel met een grid search van leveringen vleesvarkens van varkenshouders aan een slachthuis is ontwikkeld om te analyseren hoe de accuratesse van een nieuwe serodiagnostische test op *Mycobacterium avium* (Ma) incentives van varkenshouders beïnvloedt om Ma seroprevalentie te beheersen. Hiertoe bevat het model een mogelijk nieuw beheersingssysteem voor Ma seroprevalentie. Input voor het model is gebaseerd op literatuur en expert schatting. Serodiagnostische test accuratesse is gedefinieerd door de sensitiviteit, de kans op het correct classificeren van een product als met verhoogd risico, en de specificiteit, de kans op het correct classificeren van een product als zonder verhoogd risico. De resultaten laten zien dat een hogere sensitiviteit en een lagere specificiteit leiden tot gebruik van striktere beheersmaatregelen door varkenshouders, tot hogere kosten voor varkenshouders, en tot lagere Ma seroprevalentie. De minimale waarde van de boete om aan een grenswaarde voor gemiddelde Ma seroprevalentie te voldoen was lager bij een hogere sensitiviteit en bij een lagere specificiteit. Bij imperfecte specificiteit waren incentives van varkenshouders om Ma seroprevalentie te beheersen lager bij een grote steekproefomvang dan bij een kleine steekproefomvang, omdat het groter aantal vals positieven leidde tot een verhoogde kans van afwijzen van een levering ongeacht of een varkenshouder beheersmaatregelen nam. Concluderend, hoofdstuk 5 laat zien dat hogere sensitiviteit en lagere specificiteit van een serodiagnostische test de verwachte gemiddelde Ma seroprevalentie verlaagde in leveringen vleesvarkens van varkenshouders onderworpen aan een incentive mechanisme met een boete voor leveringen met verhoogde Ma seroprevalentie. Bij imperfecte test specificiteit verlaagde een grotere steekproefomvang incentives van varkenshouders om hun prestatie te verbeteren.

Tot slot, hoofdstuk 6 onderzoekt de relatie tussen nalevinginformatie aangeleverd door de leverancier en het monitoren van residuen van antibiotica in vleesvarkens zonder een systeem om de juistheid van geleverde nalevinginformatie te controleren. Een dataset van 479 leveringen vleesvarkens met informatie over het gebruik van antibiotica in deze vleesvarkens gedurende de 60 dagen voor levering aan een groot Nederlands slachthuis, zoals aangeleverd door varkenshouders, was gecombineerd met resultaten van een test op residuen van antibiotica in de vleesvarkens. Een Pearson chickwadraat test is gebruikt om de betrouwbaarheid van geleverde informatie te analyseren. De resultaten laten zien dat twee keer zoveel varkenshouders aangaven antibiotica te hebben gebruikt in de groep van 82 varkenshouders waarbij residuen van antibiotica werden gevonden (11,0%) als in de groep varkenshouders waarin geen residuen van antibiotica werden gevonden (5,5%). Bij 89% van de leveringen waarin minstens één vleesvarken werd gevonden met een residu van antibiotica werd 'geen antibiotica gebruikt' gemeld door de varkenshouder. Concluderend, hoofdstuk 6 laat zien dat zonder een systeem om de betrouwbaarheid te controleren van door varkenshouders aangeleverde informatie over het gebruik van antibiotica gedurende 60 dagen voor levering, deze informatie onvoldoende betrouwbaar was om de afwezigheid van residuen van antibiotica in vleesvarkens te kunnen garanderen. Deze informatie was dus onvoldoende betrouwbaar om te worden gebruikt in een beheersingssysteem voor residuen van antibiotica in vleesvarkens.

Dit proefschrift analyseert de invloed op het leveranciergedrag van een aantal belangrijke kenmerken van incentive mechanismen gericht op beheersing van voedselveiligheid. Het laat zien dat incentive mechanismen kunnen worden gebruikt om opportunistisch gedrag van leveranciers te verminderen, waarmee het helpt om de beheersing van voedselveiligheid naar een hoger niveau te tillen. Om leveranciers optimaal ertoe aan te zetten voedselveiligheid te beheersen via een incentive mechanisme, is het belangrijk dat binnen een incentive mechanisme het systeem om prestatie en naleving te meten is afgestemd op het compensatie schema.

Wetenschappelijke bijdrage

Dit proefschrift draagt bij aan voedselveiligheidsmanagement theorie, incentive theorie en supply chain management theorie. Dit proefschrift heeft drie bijdragen aan voedselveiligheidsmanagement theorie. Ten eerste, private incentive mechanismen gericht op beheersing van voedselveiligheid kunnen de verandering van de beheersing van voedselveiligheid op bedrijfsniveau naar beheersing op ketenniveau ondersteunen. Ten tweede, het ontwikkelde raamwerk biedt inzicht in hoe relevante technologische en management aspecten in de beheersing van voedselveiligheid te combineren om de beheersing van voedselveiligheid op ketenniveau te verbeteren. Ten derde, dit proefschrift was de eerste studie die de impact van de accuratesse van een diagnostische test op leverancier incentives om voedselveiligheid te beheersen heeft geanalyseerd.

Dit proefschrift draagt ook bij aan incentive theorie. De invloed van de accuratesse van een diagnostische test op leverancier incentives om acties te ondernemen, impliceert dat de accuratesse van de methode om prestatie en naleving te meten onderdeel moet uitmaken van incentive theorie en van principaal–agent modellen, gebruikt om deze problemen te analyseren.

Dit proefschrift heeft drie bijdragen aan supply chain management theorie. Als eerste, correct ontworpen incentive mechanismen kunnen belangen van meerdere bedrijven in een keten op een lijn brengen en daarmee ketenprestaties verbeteren. Als tweede, het systeem om prestatie en naleving te meten en het compensatie schema moeten in samenhang worden vastgesteld om ervoor te zorgen dat leveranciers optimaal ertoe worden aangezet prestatie en naleving te verbeteren. Als derde, opportunistisch gedrag kan niet genegeerd worden als oorzaak van het uitwisselen van onjuiste of onvolledige informatie in ketens.

Aanbevelingen voor de praktijk

Verschillende aanbevelingen voor de praktijk volgen uit dit proefschrift. De belangrijkste worden hier gepresenteerd. Een boete op producten buiten specificatie is effectief om leveranciers ertoe aan te zetten de beheersing van voedselveiligheid te verbeteren. De parameterwaarden van het systeem om prestatie en naleving te meten en van het compensatie schema moeten in samenhang worden vastgesteld om ervoor te zorgen dat leveranciers optimaal ertoe worden aangezet prestatie en naleving te verbeteren. Alleen als de betrouwbaarheid van informatie over gebruikt acties aangeleverd door een leverancier eenvoudig gecontroleerd kan worden, kan deze informatie worden gebruikt als maat voor prestatie en naleving in incentive mechanismen gericht op de beheersing van voedselveiligheid.

Uit dit proefschrift volgen verschillende aanbevelingen voor varkenshouders en varkensslachterijen. Varkenshouders moeten worden gestimuleerd om antiwormmiddelen aan vleesvarkens te geven via de toedieningmethoden door het voer, in het water of via injecties, omdat strooien over voer geassocieerd is met een hoger prevalentie afgekeurde levers dan de andere toedieningmethoden. Varkensslachterijen worden aanbevolen om varkenshouders informatie te verstrekken met hun werkelijke prevalentie afgekeurde levers in de vleesvarkens, omdat een meer accuraat beeld van de prevalentie afgekeurde levers de noodzaak bij varkenshouders kan helpen vergroten om *Ascaris suum* infecties te beheersen en daardoor de prevalentie afgekeurde levers te verlagen. De Nederlandse varkensketen kan incentive mechanismen vergelijkbaar aan dat van afgekeurde levers implementeren om de prevalentie van andere slachtafwijkingen zoals longafwijkingen, pleuritis, huid afwijkingen en pootafwijkingen, te verlagen. Varkensslachterijen en/of overheden in andere landen kunnen ook een incentive mechanisme vergelijkbaar aan het Nederlandse mechanisme implementeren om de afgekeurde lever prevalentie in vleesvarkens te verlagen.

Verder onderzoek

Gebaseerd op de discussie in dit proefschrift kunnen vele suggesties voor verder onderzoek worden gedaan. De drie belangrijkste suggesties zijn de volgende. Ten eerste, verder onderzoek is nodig naar de toepasbaarheid en effectiviteit van alternatieve indicatoren om prestatie en naleving te meten en van alternatieve typen van prestatie en naleving compensatie ingezet om leveranciers ertoe aan te zetten de voedselveiligheid te beheersen. Ten tweede, om het ontwerpen van nieuwe incentive mechanismen te verbeteren is verder onderzoek nodig naar de relatie tussen karakteristieken van de keten, karakteristieken van de leverancierkoper relatie, en de optimale setting van parameters van een incentive mechanisme. Ten derde, om beleidsadviezen te verbeteren ten aanzien van optimale publieke doelen betreffende voedselveiligheid en ten aanzien van het optimale niveau van privatisering in een system dat publiek en privaat toezicht en controle betreffende voedselveiligheid combineert, wordt aanbevolen om volksgezondheidseffecten te integreren in analyses van het beheersen van voedselveiligheid op ketenniveau.

Chapter 1

General introduction

1.1. Food safety

Food safety is an essential food attribute for consumers and a key policy dossier for governments, making it a critical decision item for food business operators (FBOs), such as retailers, food processors and primary producers. To guarantee food safety FBOs have implemented control systems such as Hazard Analysis Critical Control Points (HACCP), Good Hygienic Practices, ISO 9001, ISO 22000, British Retail Consortium, and Global–GAP (Luning *et al.*, 2006). Notwithstanding, food borne illness today still has a high societal impact (EFSA, 2010; Mead *et al.*, 1999; Scharff, 2010). Societal impact of food borne illness is not likely to decrease in the next decades, because susceptibility of the human population to food borne illness is expected to increase. Increased susceptibility arises from growing number of persons aged 65 and over (Eurostat, 2010), of people with diabetes (IDF, 2009), and of immunodeficient individuals suffering from diseases as cancer and chronic viral diseases, because improved treatments increase survival rates (La Vecchia *et al.*, 2010; Palella *et al.*, 1998). This shows the need to improve food safety control.

In the EU two changes aiming to improve food safety can be observed recently. The new EU food safety policy, implemented with the General Food Law (GFL) in 2005 puts primary food safety responsibility with FBOs and prescribes that food safety control must be based on an integrated approach throughout the supply chain. The first change is the shift from primary responsibility for food safety from government to FBOs. The second change concerns the shift of food safety control from company level to supply chain level. This thesis aims to support improvement of food safety control through the development of private initiatives for food safety control on supply chain level.

1.1.1. From public to private responsibility

The first change concerns the shift of primary responsibility for food safety from government to FBOs. The EU food safety policy at the end of the 20^{th} century was insufficiently equipped to deal with societal expectations about food safety control (EFSA, 2007). Therefore, in 2005 the EU put into force a new food safety policy with Regulation (EC) No 178/2002, the GFL.

The GFL prescribes that FBOs have primary responsibility for food safety, whereas governments keep the responsibility for supervising that marketed products are safe. In addition, the GFL states that food safety control must be based on science, risk assessment and an integrated approach throughout the supply chain.

Having primary responsibility for food safety control, the food industry is looking for private initiatives to improve food safety control. Such private initiatives can replace public food safety control if effectiveness of private initiatives equal or exceed effectiveness of public control. Shleifer (1998) argued that private ownership is the crucial source of incentives to innovate and to become efficient. Jayasinghe–Mudalige and Henson (2006) showed that private market–based incentives had a greater impact on food safety responsiveness of firms in the Canadian red meat sector than government regulatory actions. Ollinger and Moore (2008) observed that private actions accounted for about 80% and regulation about 20% of the overall reduction in the share of samples of cattle and hog carcasses, ground beef, and broilers testing positive for salmonella. This suggests that private initiatives of the food industry can indeed improve food safety control compared to public control.

1.1.2. From company level to supply chain level

The second change concerns the shift from food safety control on company level to supply chain level. Currently adopted food safety control systems focus on controlling food safety hazards on company level without considering the rest of the supply chain (Luning *et al.*, 2006). But, many food safety hazards can enter the supply chain in multiple stages (Alban and Stärk, 2005; Nauta *et al.*, 2005; Valeeva *et al.*, 2004). If food safety hazards can enter in earlier stages in the supply chain, safety of food items not only depends on control of these hazards in a FBO’s production processes, but also on safety of the raw materials as purchased from its suppliers. Hence, further improvement of food safety can be realised through improving safety of purchased raw materials. This suggests that food safety control on supply chain level can indeed improve food safety. But, how to improve food safety of purchased raw materials?

1.1.3. Incentive mechanisms

Safety of raw materials results from processes and inputs used by the supplier. Food safety attributes of raw materials are often difficult and costly to verify (Unnevehr *et al.*, 2004). In addition, it is often difficult or even impossible for a buyer to observe the production processes used by a supplier. The increasing number of suppliers and global sourcing of raw materials due to, amongst others, consolidation and product proliferation in the food industry further complicates verification of food safety attributes of all purchased raw materials. This results in information asymmetry between supplier and buyer about the safety of raw materials, creating room for opportunistic behaviour of a supplier (Hirschauer and Musshoff, 2007). So, FBOs are looking for strategies to induce suppliers to use inputs and production processes that improve raw material safety given the presence of information asymmetry and possible opportunistic behaviour.

Interactions in the presence of information asymmetry are addressed in *Incentive Theory* (Laffont and Martimort, 2002). Incentive theory considers how a buyer can optimally cope with private information of a supplier. According to incentive theory a principal, e.g. a buyer, delegates a task, e.g. producing safe raw materials, to an agent, e.g. a supplier. The supplier exerts effort to fulfil the task, if expected utility of exerting effort exceeds expected utility of not exerting effort. Suppliers can be induced to increase food safety performance, by ensuring that expected utility if the supplier exerts effort that improves food safety exceeds expected utility if he does not. Supply chain management literature argues that incentive mechanisms can be used to induce trading partners to apply behaviour which improves performance (Jeschonowski *et al.*, 2009; Otley, 1999). An incentive mechanism does so by rewarding performance and sharing risk (Boehlje, 1999). Incentive mechanisms are widely used by traders, food processors, and livestock slaughter plants to improve product quality of purchased raw materials (Boys *et al.*, 2007; Chalfant *et al.*, 1999; Hueth and Ligon, 2002; Hueth *et al.*, 2007). This suggests that incentive mechanisms might be used to improve food safety performance on supply chain level. Although incentive mechanism aimed at food safety control exist in practice (e.g. Alban *et al.*, 2002), they are scarce and knowledge on how incentive mechanisms can effectively induce food safety control on supply chain level is lacking.

1.1.4. The Dutch pork supply chain as research object

This research was initiated and partly conducted within the Dutch Transforum Agro&Groen project DRIVE ("Sustainable Reassessment and innovation in the pork supply chain"). The aim of DRIVE was to achieve a new design of the Dutch pig meat supply chain in which relevant sustainability goals could be implemented. To realize and guarantee sustainability goals in the Dutch pork supply chain, DRIVE proposed to analyse incentive mechanisms based on individual farmer interests. Specifically, DRIVE focused on food safety control to improve both public health and the international competition of the Dutch pig meat sector. Participation of a major Dutch slaughter company in DRIVE ensured that data was available and accessible.

To analyse incentive mechanisms for food safety, the pork supply chain is an interesting case, because pig meat and products thereof 1) can contain different relevant food safety hazards, such as campylobacter, salmonella and *Mycobacterium avium* (EFSA, 2010; Tirkkonen *et al.*, 2007; Van der Gaag *et al.*, 2004) and 2) are recognised as an important source for food–borne outbreaks (EFSA, 2010). Because many of the relevant hazards can enter the pork supply chain in primary production, it is an important stage in the pork supply chain to control food safety hazards. This suggests that incentive mechanisms between pig producers and slaughter companies that induce pig producers to control food safety can be important to control food safety in the pork supply chain.

Research on incentive mechanisms for food safety control between pig producers and slaughter companies in the Netherlands is especially interesting, because pig producers and slaughter companies in the Netherlands are independent organisations. The Dutch pork supply chain between pig producers and slaughter companies lacks long term contracts. Dutch slaughter companies compete actively for receiving finishing pigs. Pig producers can shift easily between slaughter companies and to exporting finishing pigs. In this setting initialization of new incentive mechanisms to improve food safety by an individual slaughter company might be a viable method to improve food safety performance of Dutch pig producers.

1.2. Research aim and research questions

This research aims to contribute to the improvement of food safety and public health by analyzing incentive mechanisms aimed at food safety control of the two stage supply chain between pig producer and slaughter company in the Netherlands. To realise the aim of this research five studies were carried out, which are subsequently presented in the next five sections.

1.2.1. Framework for incentive mechanisms aimed at food safety control

Before focussing on incentive mechanisms aimed at food safety control between pig producer and slaughter company in the Netherlands, the aim of study 1 is to develop a framework to design and analyse incentive mechanisms aimed at food safety control. First, relevant aspects of food safety control on company level are identified. Second, additional relevant aspects of food safety control on supply chain level are discussed. This includes identification of key elements of incentive mechanisms aimed at food safety control in a literature review focussing on actual and theoretical incentive mechanisms aimed at food quality and food safety control. Third, the relevant aspects and key elements are combined in a framework for designing and analysing incentive mechanisms aimed at food safety control. Study 1 aims to answer the research question:

RQ1 What are key elements of incentive mechanisms aimed at food safety control?

1.2.2. Effectiveness of incentive mechanisms

Study 1 shows performance and compliance measurement system and compensation scheme as the key elements of an incentive mechanism aimed at food safety control. A characteristic of the performance and compliance compensation scheme is the type of compensation. Study 2 analyses the impact of two types of performance compensation on supplier performance in terms of liver lesion prevalence in finishing pigs. Lesioned livers are unfit for human consumption, so each pig slaughtered in the EU must be inspected for liver lesions (Regulation (EC) No 854/2004). The main cause for liver lesions is an infection with the roundworm *Ascaris suum* (*A. suum*) on the farm (Stewart and Hale, 1988). So, liver lesions in finishing pigs should be controlled at farm level. A slaughterhouse can only market lesioned livers against lower revenue. In the Netherlands pig producers compensate slaughterhouses for these financial consequences. Compensation is arranged through an incentive mechanism, which also induces pig producers to lower liver lesion prevalence. Two incentive mechanisms with a different type of performance compensation existed successively in the last decade. In July 2004, a collective insurance premium per delivered pig was replaced by a price reduction per delivered pig with a lesioned liver. The effectiveness of these types of performance compensation is analysed with an out–of–sample forecast test on a time series of liver lesion inspection data of Dutch finishing pigs from 2003 to 2006. Study 2 aims to answer the research question:

RQ2 ***How effective are incentive mechanisms with a collective insurance premium and a price reduction per lesioned liver in reducing liver lesion prevalence in finishing pigs?***

1.2.3. Impact incentive mechanism on supplier actions and performance

Study 2 shows that average liver lesion prevalence halved after implementation of the incentive mechanism with a price reduction for each pig with a lesioned liver. However, study 2 also shows large variability in liver lesion prevalence between individual pig producers when the price reduction was in place. The price reduction could have induced only part of the pig producers to use management practices to lower liver lesion prevalence, or some pig producers might use less effective management practices. If management practices or the lack of it, that result in high liver lesion prevalence are known, a new incentive mechanism can be designed to deal with these inefficient management practices. Study 3 identifies management practices associated with high liver lesion prevalence in finishing pigs. It uses regression and correlation analysis on liver lesion inspection data of Dutch finishing pigs combined with data from a farmer survey about management practices used and factors underlying the decision to use control actions. Factors underlying the decision are based on the Theory of Planned Behaviour. Study 3 aims to answer the research question:

RQ3 ***What causes variability in liver lesion prevalence in finishing pigs of pig producers subjected to an incentive mechanism with a price reduction per lesioned liver?***

1.2.4. Impact of performance measurement accuracy in incentive mechanisms on supplier performance

Study 1 shows the performance and compliance measurement system as the other key element of an incentive mechanism next to the performance and compliance compensation scheme. A characteristic of performance and compliance measurement system is the accuracy of the performance measurement. Knowledge on how reward schemes and measurement scale must be set together for optimal incentive provision is lacking (Jeschonowski *et al.*, 2009). Literature about the impact of testing accuracy on supplier incentives to control food safety was lacking. Study 4 analyses the impact of performance measurement accuracy on supplier performance in terms of *Mycobacterium avium* (Ma) seroprevalence if a penalty on products off–specification is used. Because pigs may be a reservoir for Ma infections in humans, pig meat from Ma infected pigs needs to be excluded from the pork supply chain (Komijn *et al.*, 1999). Currently, detection of Ma infections in pigs is based on product testing in the slaughterhouse, i.e. palpation and incision of the lymph nodes, which is characterised by a relatively high number of false negatives (Komijn *et al.*, 2007; Wisselink *et al.*, 2006). This renders the current control system insufficient to guarantee public health. A new system is needed to control Ma in the pork supply chain. Control points of Ma in the pork supply chain are all located at primary production level (Pavlík *et al.*, 2005). Thus, a new control system could include an incentive mechanism to steer pig producer behaviour towards using production processes that result in a low risk of Ma infections. Study 2 shows that an incentive mechanism with a penalty on products off–specification can be used to steer finishing pig producer behaviour. For Ma, a new serodiagnostic test has been developed for which the accuracy needs further optimization (Wisselink *et al.*, 2010). Study 4 analyses how accuracy of the new Ma serodiagnostic test to determine performance influences food safety performance when an incentive mechanism with a penalty on products off–specification is used. It uses a dynamic optimization model with grid search of deliveries of finishing pigs from producers to a slaughterhouse and includes a possible future control system for Ma. Study 4 aims to answer the research question:

RQ4 What is the impact of the accuracy of a Mycobacterium avium test on the Mycobacterium avium prevalence in finishing pigs of pig producers subjected to an incentive mechanism with financial compensation aimed at Mycobacterium avium prevalence?

1.2.5. Information provided by suppliers as compliance measurement in incentive mechanisms

In study 1 the actor who conducts performance and compliance measurement and determines performance and compliance is identified as another characteristic of the measurement system. Differences in performance can originate from suppliers using different actions to control a hazard, as study 3 shows. Identification of control actions used by a supplier prior to delivery can help to distinguish suppliers with a higher risk from those with a lower risk. This provides opportunity to design a risk–based control system. In studies 2, 3 and 4 the buyer conducts performance and compliance measurement. However, it is often difficult or even impossible for a buyer to observe the control actions used by a supplier. A simple way of gathering information about the control actions used by the supplier is suppliers providing information about the control actions they used. The provided information, however, can only be used in an incentive mechanism to determine compliance if it is reliable. Opportunistic behaviour can be a reason for provision of unreliable performance information (Feldmann and Müller, 2003). Literature on reliability of compliance information was, however, not available. Study 5 analyses reliability of compliance information about antibiotics usage in finishing pigs provided by pig producers. Antibiotics residues can only be prevented if pig producers correctly use antibiotics. To analyze reliability of provided information, a Pearson chi–square test is used on a dataset with screening results for antibiotics residues in finishing pigs combined with provided information by pig producers about antibiotics used in the same finishing pigs during 60 days prior to delivery to a slaughter company. Study 5 seeks to answer the research question:

RQ5 What is the reliability of information about antibiotics usage in finishing pigs provided by pig producers used as compliance measurement in an incentive mechanism without compliance compensation?

1.3. Outline of the thesis

Figure 1.1 presents the outline of the thesis with the relationship between the chapters. Chapter two presents the key elements of incentive mechanisms aimed at food safety control (study 1). Chapter three to six each analyse a specific characteristics of the key element of an incentive mechanism aimed at food safety control. Chapter three presents the effectiveness of two types of performance compensation in an incentive mechanism to induce pig producers to control liver lesions in finishing pigs (study 2). Chapter four identifies the actions taken by pig producers to control liver lesions with a price reduction per finishing pig with a lesioned liver in place (study 3). Chapter five analyses the impact of test accuracy on supplier performance using Ma in finishing pigs if a penalty on products off–specification is used (study 4). Chapter six analyses if information provided by pig producers to a slaughter company about usage of antibiotics in delivered finishing pigs is sufficiently reliable to be used as compliance measurement in an incentive mechanism, if no performance compensation scheme is enforced (study 5). Finally, chapter seven integrates the findings in the general conclusion and discussion.

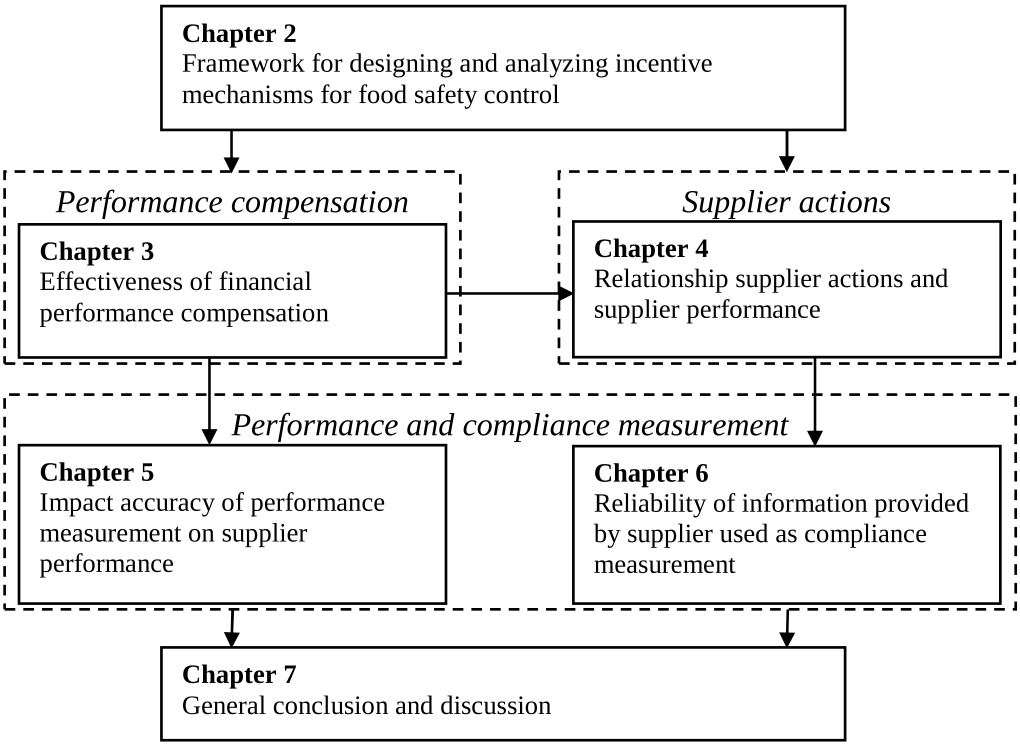

Figure 1.1: Outline of the thesis with relationship between chapters.

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Chapter 2

Framework for designing and analyzing incentive mechanisms for food safety control in EU supply chains[1]

Abstract

The EU food industry has full responsibility for food safety control since 2005. This requires new relationships within supply chains and between food business operators and governments. For optimal food safety control on supply chain level in the EU, this chapter proposes a framework for designing and analyzing incentive mechanisms for food safety control. Incentive mechanisms, which consist of a performance and compliance measurement system and a compensation scheme, induce suppliers to control food safety. Multiple incentive mechanisms together between at least two stages of a supply chain make up an incentive system. The framework can be used to design and analyze incentive mechanisms in supply chains in which food business operators must cooperate with trading partners from other supply chain stages.

2.1. Introduction

Food safety is an important food attribute for consumers, governments and food business operators (FBOs). To control food safety in recent decades FBOs in the EU adopted quality assurance systems, as Hazard Analysis Critical Control Points (HACCP), Good Hygienic Practices, ISO 9001, ISO 22000, British Retail Consortium, and Global–GAP (Luning *et al.*, 2006). However, in 2008 the EU still reported 5332 food borne outbreaks resulting in 45,622 cases of human zoonoses, 6230 hospitalizations and 32 deaths (EFSA, 2010). Reported cases are only a fraction of food borne illnesses. Societal costs of food borne illnesses are expected to be high, although reports are scarce. The EU estimated its costs of food–borne salmonella in

[1] C.P.A. van Wagenberg , G.B.C. Backus, J.G.A.J. van der Vorst and H.A.P. Urlings.
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2003 at €2.8 billion (European Commission Press Release IP/03/1306). Mangen *et al.* (2005) estimated the costs of campylobacteriosis in the Netherlands in 2000 at €21 million. Demographic and public health developments in the EU will likely increase the population's susceptibility to food borne illness. The number of people of 65 years and older in the EU–27 is expected to grow from 16% of the population in 2004 to 30% in 2050. The number of immunocompromised people with increased susceptibility to food safety hazards is also expected to grow, because more people will be cured from diseases as cancer with chemotherapy and radiation treatment (La Vecchia *et al.*, 2010), more people will longer survive chronic viral diseases as HIV (Palella *et al.*, 1998), and more people will have diabetes (IDF, 2009). So, without further improvement of food safety control, food borne illness and associated societal costs are likely to increase.

Quality assurance systems currently adopted by EU FBOs focus on food safety control within FBOs without considering the rest of the supply chain (Luning *et al.*, 2006). But, many food safety hazards must be simultaneously controlled in multiple supply chain stages (Alban and Stärk, 2005; Luning *et al.*, 2006). Current quality assurance systems are thus insufficiently equipped to control food safety on supply chain level. For further improvement of food safety control, new systems focusing on supply chain level are needed.

Food safety legislation in the EU at the end of the 20th century, being fragmented and based on prescriptive laws using governmental inspection and compliance testing (EFSA, 2007), was insufficiently equipped to improve food safety control. With Regulation (EC) No 178/2002 the EU adopted new legislation to control food safety based on integrated risk analysis throughout the supply chain. Primary legal responsibility lays with FBOs, governments have final responsibility to supervise that marketed products are safe. Regulation (EC) No 882/2004 on official controls opens possibilities to use private control systems in public food safety control, the so–called verification–of–control principle. A government verifies if FBOs' private control systems sufficiently guarantee safety of marketed products without using public control herself. In this setting FBOs can design and implement effective and efficient solutions on supply chain level to improve food safety control. But, this requires new relationships between FBOs in supply chains and between FBOs and governments.

To arrange cost–effective strategic food safety control on supply chain level that can meet future EU–targets for food safety, this chapter proposes and discusses incentive mechanisms. First, relevant aspects of food safety control at FBO level are discussed in section 2.2. Second, additional relevant aspects of food safety control at supply chain level are discussed in section 2.3. The aspects are combined in a framework of incentive mechanisms for food safety control at supply chain level in section 2.4. Finally, section 2.5 concludes.

2.2. Food safety control at food business operator level

Food safety is the "assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use" (Codex Alimentarius, 2003). A food product is safe for human consumption if it has been produced by applying all food safety requirements appropriate to its intended use, meets risk–based performance and process criteria for specified hazards, and does not contain hazards at levels that are harmful to human health (Codex Alimentarius, 2005). In their techno–managerial approach Luning and Marcelis (2006) argue that a food product's safety depends on food behaviour and human behaviour. Food behaviour relates to food safety hazards and control measures, which are discussed first in this section. Because food safety is a public good, food safety legislation is important to consider. Human behaviour relates to decision making, which according to Simon *et al.* (1987) is evaluating and choosing among alternatives to reach a goal, or a company objective for food safety. Company objectives for food safety and the legal environment are discussed next. Finally, decision making on food safety control is discussed.

2.2.1. Food safety hazards

Food safety problems are caused by insufficient control and detection of food safety hazards. The Codex Alimentarius (2003) distinguishes microbiological (e.g. bacteria, viruses, parasites, protozoa, fungi), chemical (e.g. residues of pesticides and medicines, heavy metals, xenobiotics) and physical hazards (e.g. radiation, foreign bodies as glass, metal, wood, stone). Food safety hazards can be characterized in how they enter and evolve in a product. A contaminant is "any biological or chemical agent, foreign matter, or other substance not intentionally added to food which may compromise food safety or suitability" (Codex Alimentarius, 2003). Examples are microbiological hazards. In contrast, other hazards can only enter a product if specific operating procedures are used, as residues and needles. For microbiological hazards that can multiply as salmonella, food safety risks can increase after entering a product. Conversely, chemical and physical hazards do not multiply in a product. Because hazards can differ in their characteristics, optimal control strategies can also differ between hazards.

2.2.2. Control measures

To control food safety FBOs can use control measures as heating, cooling, pasteurisation, cleaning, disinfection, logistical processing, and using hazard free raw materials. A control measure is "any action and activity that can be used to prevent or eliminate a food safety hazard or reduce it to an acceptable level" (Codex Alimentarius, 2003). Only if all FBOs in a supply chain apply adequate control measures, end product safety can be guaranteed. A control measure can reduce risks of multiple hazards or a combination of control measures can be necessary to reduce the risk of a single hazard. Preventive and corrective measures can be distinguished. Preventive measures ensure a hazard does not enter a product. Corrective measures eliminate or reduce a hazard in a product. Hazards, for which no corrective measures exist, can be controlled by preventive measures, or products contaminated with such hazards can be processed separately for markets for which these hazards pose no risk. For contaminants, a combination of preventive and corrective control measures can be necessary. Hazards which can only enter a product if specific operating procedures are used, can be precluded by abandoning these procedures. Hazard and process properties determine the set of relevant control measures.

2.2.3. Company objectives for food safety

A company objective for food safety is the food safety level of its end products a FBO aims at. Company objectives can be related to products and processes. Product related company objectives focus on intrinsic product attributes as contamination level for relevant hazards or Performance Objectives and Performance Criteria (EFSA, 2007). Process related company objectives focus on compliance with procedures that aim to control food safety, for example the level at which food safety guidelines as HACCP–procedures are followed. In recent years, with the legal prescription of HACCP, food safety control in the EU has shifted increasingly from product to process control. Company objectives can focus on effectiveness, the extent to which food safety is improved, and on efficiency, relating costs and benefits to effectiveness. Company objectives can aim at compliance with food safety legislation or with private norms. Private norms should include legal norms and can include additional norms, and can be used as a strategic marketing tool. For most hazards, a company objective of zero risk is generally unrealistic due to unintentional entrance in products. Currently, company objectives for food safety are generally set roughly through the obligatory HACCP–system. Concrete company objectives are, however, mostly still lacking.

2.2.4. Legal environment

The legal environment sets requirements to FBOs. It can prescribe usage of specific control measures or safety control systems, for example HACCP. It can also prohibit usage of specific control measures, for example in the EU, irradiation of food products. The legal environment can prescribe company objectives or be used as a guideline to set them. General food laws and product liability laws apply to all hazards. Product liability laws can induce FBOs to improve food safety, if contaminations can be traced to the source and the responsible FBO faces liability costs (Buzby *et al.*, 2001). Difficulty to identify the source limit product liability laws to improve food safety on farms and processing plants (King *et al.*, 2007). Product liability laws can differ between countries. For example, punitive damages and class action law suits are less well developed in the EU than in the USA. For specific chemical hazards, EU Regulations (EC) No 396/2005, 2377/90 and 1881/2006 establish process and product norms. For microbiological hazards, the European Food Safety Authority defined Appropriate Level of Protection, Food Safety Objective, Performance Objectives, and Performance Criteria (EFSA, 2007). Criteria for some specific microbiological hazards in specific products are set in EU Regulations (EC) No 2073/2005 and 2160/2003. But, these criteria and criteria for other hazards and products still need further development in EU food safety laws to set concrete objectives for food safety control. The legal environment provides guidelines for setting food safety objectives for FBOs and legal constraints to the set of relevant control measures.

2.2.5. FBO decision making on food safety control

If a FBO with the applied control measures does not meet company objectives, it should apply more effective control measures. The decision which control measures to apply is thus essential for food safety. Costs and turnaround time are important in FBO decision making. Control measures can increase costs through labour, investment in equipment, and redesign of production processes. Testing and sampling require investment in technologies and labour of FBO and laboratory personnel. Audits and inspections require labour of auditors, inspectors and FBO personnel. Control measures, sampling, testing, audits and inspections can be time consuming (Unnevehr *et al.*, 2004), increasing turnaround time and lowering shelf life of products. But, control measures can also have positive externalities as lower production and processing costs, higher sales prices, increased sales, and increased market access.

Control measures aim to decrease contamination levels in products and number of products with a relevant food safety risk, thereby lowering internal and external failure costs. Internal failure costs are additional processing and production costs for the FBO of products not within specification. External failure costs are financial consequences for other supply chain stages, as additional processing and production costs, and for society due to human illness and death. Financial consequences for society can be calculated with the human capital or the friction cost method (Koopmanschap and Van Ineveld, 1992) using Quality of Life, Quality Adjusted Life–Year or Disability Adjusted Life–Year (Abelson, 2003; Mangen *et al.*, 2005). A FBO that caused external failure costs, only faces these costs when traceability shows that it is involved (Van der Vorst, 2006). External failure costs are revealed through product recalls (Thomsen and McKenzie, 2001), damaged relationships with suppliers and subsequent trade implications, and liability for public health problems (Buzby *et al.*, 2001). FBOs can sometimes insure themselves against external failure costs. In a sense, control measures are an insurance against failure costs with their costs as insurance premium. How costs and turnaround time are weighted in the decision to control food safety depends on the decision making organisation. Generally, FBOs focus more on direct costs and gains and attributable external failure costs, whereas public organisations on societal costs.

Drivers of human decisions also drive FBO decisions. Rational people maximize expected utility knowing all options, probabilities and effects. However, bounded rationality makes human behaviour deviate from rational behaviour (Simon, 1955). Deviations, as systematic errors in assessing probabilities and predicting values under uncertainty (Tversky and Kahneman, 1974), comparison of gains and losses to a reference value (Kahneman and Tversky, 1979), valuing losses twice as heavy as gains (Tversky and Kahneman, 1992), contra productive financial incentives (Pokorny, 2008), fairness considerations (Rabin, 1993), reciprocity (Fehr *et al.*, 1997), and non–linear discounting (Frederick *et al.*, 2002), impact real decision making to apply control measures.

Drivers of FBO decisions to apply control measures as costs and turnaround time are key elements in food safety control and must be considered in an incentive system for food safety control. For accurate ex–ante evaluation of food safety control systems, insight into real FBO decision making is essential.

2.3. Food safety control at supply chain level

To enhance performance of a supply chain, FBOs must coordinate goals and activities (Schulze Althoff *et al.*, 2005). For improved food safety performance on supply chain level, FBOs must coordinate their decisions about food safety control. To coordinate FBO decision making, incentive systems can be used, which include incentive mechanisms as price premiums, profit and cost–sharing arrangements, qualified supplier programs, and long–term commitments (Boehlje, 1999). Valeeva (2005) argues that incentive mechanisms are promising to improve coordination of food safety activities over FBOs in a supply chain. Between each two stages of a supply chain an incentive mechanism aimed at food safety control can be implemented. An *incentive system aimed at food safety control* is defined here as the set of incentive mechanisms aimed at food safety control implemented in a supply chain, which aims to achieve the incentive system objectives for food safety. Figure 2.1 provides an example of an incentive system. The next two sections discuss incentive mechanisms for food safety control and incentive system objectives.

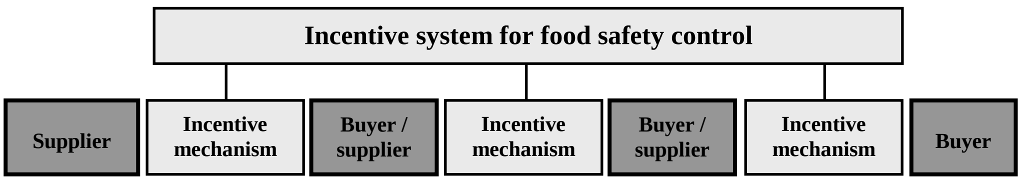

Figure 2.1: Example of an incentive system for food safety control (light gray) with three incentive mechanisms between four supply chain stages (dark gray).

2.3.1. Incentive mechanisms

To induce quality control at suppliers FBOs have implemented incentive mechanisms that measure and compensate performance (e.g. Chalfant and Sexton, 2002; Hueth and Ligon, 2002). Similarly, to induce food safety control at suppliers, buyers can use incentive mechanisms. An *incentive mechanism aimed at food safety control* is defined here as the set of performance and compliance measurement system and compensation scheme between buyer and supplier, which aims to induce the supplier to apply control measures to control food safety hazards as the buyer requests. Key elements of incentive mechanisms for food safety control were determined in a literature review on incentive mechanisms for food quality control and for food safety control, which are successively discussed.

For food quality control, the literature review revealed a number of incentive mechanisms in animal and plant production (Table 2.1). Incentive mechanisms aimed at high product quality and efficient use of inputs. Absolute and relative indicators were used to measure performance on quality attributes of raw materials and end products, and compliance with process attributes. Absolute indicators measure a supplier's performance and compliance independent of other suppliers, relative indicators benchmark with reference suppliers. The buyer or a third party conducted performance and compliance measurement. Samples and tests were used to measure product related indicators, and audits and inspections for process related indicators. Several reports mentioned sampling errors in measuring performance and compliance. Quality performance and compliance was compensated with a fixed or variable piece rate, a financial reward per produced item. Each quality attribute used its own measurement indicator and compensation.

For food safety control, the literature review revealed that actual incentive mechanisms are scarce (Table 2.2). Only Alban *et al.* (2002) describe an actual incentive mechanism that is used in practice, the others theoretical mechanisms. Measurement indicators were product and output based and included prevalence, residue level, and probability that unsafe products remained undetected within an epidemiological unit, the type–II–error. Average performance of multiple deliveries was used to average out variance in performance over deliveries. Most reports considered the measurement accuracy through sample size. Performance compensation included financial penalties for products with increased food safety risk, additional internal costs, liability costs and rendering costs.

Table 2.1: Key elements of incentive mechanisms for food quality control from literature.

Report	Incentive mechanism characteristics						Main findings
	Performance and compliance measurement					Performance and compliance compensation	
	Indicator	I / O / P[a]	A / R[b]	Who conducts	Accuracy		
Chalfant *et al*. (2002)	Prune quantity,size	O	A	Third party	Sample, testing error	Variable piece rate	Errors in grading process reduce farmer incentives to produce high quality products.
Curtis and McClusky (2003)	Potato quantity, tuber weight, tare, damages	O	A	Third party	Sample	Variable piece rate	Incentive contracts are more effective at increasing potato load quality than spot market.
Hueth *et al.* (1999)	Fruit/vegetable quality, input amount used, field management	I,O,P	-	Buyer, third party	-	Variable piece rate	Input control, monitoring, quality measurement, and residual price risk reduce information asymmetry and align incentives between growers and first handlers.
Hueth *et al.* (2002)	Tomato quantity, colour, 'limited use', soluble solids, damages	O	A	Third party	Sample	Variable piece rate	Growers facing high–powered incentives produce higher quality at higher cost. Quality measurement improves efficiency. Information constraints decrease efficiency.
Hueth and Melkonyan (2004)	Sugar beet quantity, purity	O	A, R	-	-	Variable piece rate	Regional variation in growers' ability to control measures of sugar beet quality causes variations in the set of performance indicators.
Knoeber and Thurman (1994)	Broiler meat quantity, feed conversion	I,O	R	-	-	Fixed, variable piece rate	In mixed tournaments: price changes that leave price differences unchanged don't affect performance; more able players choose less risky strategies; handicap players of unequal ability and reduce mixing prevent disincentive effects.

(Table continues on next page)

Table 2.1: Key elements of incentive mechanisms for food quality control from literature (continued).

Report	Incentive mechanism characteristics						Main findings
	Performance and compliance measurement					Performance and compliance compensation	
	Indicator	I / O / P[a]	A / R[b]	Who conducts	Accuracy		
Levy and Vukina (2004)	Broiler meat quantity, settlement costs	I,O	R	-	-	Fixed, variable piece rate	Tournaments mixing players of unequal abilities create a group composition effect. With fixed groups and a sufficiently long time horizon, piece rates improve welfare over tournaments.
Martin (1997)	Pig meat quantity, weight gain	I,O	A,R	-	-	Fixed, variable piece rate	Absolute performance measures reduce risks of income variability compared to spot market. Relative performance measures further reduce income variability.
Martinez and Zering (2004)	Pig meat quantity, leanness, PSE, safety, input amount used, feeding management	I,O,P	A	-	-	Fixed, variable piece rate	Incentive contracts induce industry to improve quality, reduce measuring costs, control quality attributes, facilitate adaptations to changing quality standards, and reduce transaction costs of relationship–specific investments.
McDonald and Schroeder (2003)	Beef quantity, yield grade, quality grade	O	A	-	All items tested	Fixed, variable piece rate	Grid base price, feeder price, and cumulative quality in a pen are main determinants of profit for cattle farmers.

[a] I/O/P = performance indicator based on Input product / Output product / Process;
[b] A/R = Absolute / Relative performance indicator

Table 2.2: Key elements of incentive mechanisms for food safety control from literature.

	Incentive mechanism characteristics							
	Performance and compliance measurement							
Report	**Indicator**	**I / O / P[a]**	**A / R[b]**	**Who conducts**	**Accuracy**	**Included deliveries**	**Performance and compliance compensation**	**Main findings**
Alban *et al.* (2002)	Salmonella prevalence	O	A	Buyer	Sample size, cut–off value	Current and past deliveries	Penalty, mandated actions	Danish program for salmonella control in pigs includes sampling procedure, exclusion of small herds, cut–off value of test, current and previous results as performance, herd assignment to performance levels.
Backus and King (2008)	Salmonella prevalence	O	A	Buyer	Sample, testing probability	Current and past deliveries	Participation premium, penalty	Incentive mechanisms allocating salmonella control effort in pork supply chain among farmers and slaughter plant result in minimum costs.
Hirschauer and Musshoff (2007)	Fungicide residue level, type–II–error	O	A	Buyer	Random control intensity	Current delivery	Bonus, penalty	High penalties can be necessary to provide sufficient incentives to farmers to keep mini–mum withdrawal periods after fungicide use.
King *et al.* (2007)	Salmonella prevalence	O	A	Buyer	Sample, testing probability	Current and past deliveries	Participation premium, penalty	Relating probability of testing to a favourable production history reduces testing costs for salmonella control in the pork supply chain.
Pouliot and Sumner (2008)	Safe product, type–II–error	O	A	Third party	-	Current delivery	Piece rate, liability costs	Traceability creates incentives for farms and marketers to supply safer food through liability. Imperfect consumer–marketer traceability dampens liability and farm incentives. Food safety declines with number of farms and marketers.
Starbird (2005)	Safe batch	O	A	Buyer	Sample size, acceptance number	Current delivery	Penalty, piece rate, internal failure costs	Regulation of sampling inspection procedures is an effective tool to improve food safety.
Starbird (2007)	Contaminated lot	O	A	Third party	Sample size	Current delivery	Revenue loss, destruction	Test accuracy and sampling error can be used to segregate safe and unsafe suppliers.

[a] I/O/P = performance indicator based on Input product / Output product / Process;
[b] A/R = Absolute / Relative performance indicator.

The literature review only showed financial compensation. However, non–financial compensation might also be used to induce suppliers in supply chains. Displaying hygiene grade cards in restaurant windows increased inspection scores (Jin and Leslie, 2003). Internal esteem and animal health equally motivated dairy farmers as monetary rewards (Valeeva *et al.*, 2007). Non–financial awards as orders, medals and decorations are used in monarchies, republics, non–profit organizations and companies to incite individuals (Frey, 2007).

Key elements of incentive mechanisms for food safety control are the performance and compliance measurement system and compensation scheme (Figure 2.2). The performance and compliance measurement system is characterised by the measurement indicators, measurement accuracy, and the actor who conducts performance and compliance measurement and determines performance and compliance. The performance and compliance compensation scheme includes the compensation types, such as financial or non–financial and bonus or penalty. Knowledge about impact of incentive mechanisms on food safety performance in practice is still limited. Insight is needed into how aspects, as self–reporting of performance, measurement accuracy, non–financial compensation, and alternative measurement indicators as type–II–error, influence effectiveness and efficiency of incentive mechanisms for food safety control.

Incentive mechanism for food safety control	
Performance and compliance measurement system • Which indicators to apply to measure product performance and process compliance? • What is the accuracy of performance and compliance measurement? • Who conducts performance and compliance measurement?	**Performance and compliance compensation scheme** • What compensation types to apply?

Figure 2.2: Key elements of an incentive mechanism for food safety control.

2.3.2. Characteristics of the supplier–buyer relationship

Because an incentive mechanism for food safety control is implemented between supplier and buyer, it must consider characteristics of their relationship. This relationship can be characterized by processes, product flow, financial aspects, information flow, incentives and governance structure (Boehlje, 1999). Financial aspects and incentives were discussed previously. Processes, product flow, information flow and governance structure are discussed subsequently.

Processes in food supply chains have specific characteristics (Van der Vorst *et al.*, 2009) to be considered in an incentive system. Biological mechanisms, weather, pests and other biological hazards result in large variation in quantity and product quality. Seasonality in production necessitates global sourcing to provide a year round supply. Quality decay, while products pass through the supply chain, limits shelf life of products. To restrict decay, conditioned processing, transportation and storage is essential. Notwithstanding, for certain products a short turnaround time from harvest to consumption is essential to prevent spoilage.

Product flow concerns supply assurance. If two FBOs have different acceptance levels for a hazard in a product due to private standards or different local legislation, and suppliers can shift deliveries from one buyer to another, the additional effort for compliance with the tighter level can result in suppliers to cease delivering to the FBO with the tightest level, endangering its supply assurance. Supply assurance interacts with the market organisation, because the risk of loosing supply assurance is smaller for a buyer who needs one out of ten available suppliers than for a buyer who needs one out of two available suppliers.

Information flow relates to the extent to which FBOs share information. Information asymmetry about food safety is present in organizational interactions due to three reasons. First, limitations to cognitive abilities of people and high transaction costs make all contracts incomplete (Williamson, 2002). Second, for other stakeholders as consumers, other FBOs or governments it is difficult or costly to observe if a FBO applies control measures (Hirschauer and Musshoff, 2007). Third, organizations refrain from information sharing fearing information misuse by trading partners (Mohtadi and Kinsey, 2005) and diminished bargaining power (Clemons and Row, 1993). Transactions in the presence of information asymmetry are addressed in *Incentive Theory* (Laffont and Martimort, 2002). A principal, e.g. a buyer, delegates a service to an agent, e.g. its supplier, shifting part of his risk of reaching the desired outcome to the supplier. The buyer compensates the supplier for the risk based on performance of the service. Two agency problems can arise. First is the adverse selection problem. Prior to contracting the buyer does not know which suppliers use what control measures. The buyer only offers low compensation to avoid paying high compensation to suppliers who don't use control measures. Low compensation is sufficient for suppliers who don't use control measures, but not for suppliers who do, due to their higher costs. So, suppliers who use control measures are not contracted and driven out of the market. Second is the moral hazard problem. After delegation of a service, the buyer cannot observe the effort of suppliers to fulfil the service. This might tempt suppliers to perform less effort, resulting in lower performance than the buyer desires. Organizational interactions with such conflicting interests are addressed in *non–cooperative Game Theory* (Kreps, 1990). A Nash equilibrium exists when neither FBO can improve performance by one–sidedly deviating from a contract.

Governance structure involves ownership structure and market organization. The ownership structure in a supply chain, as cooperative or investor owned firm, determines distribution of returns between FBOs and optimal food safety control measures for each FBO (King *et al.*, 2007). The market organisation of food supply chains has specific characteristics to be considered in an incentive system. A large number of spatially dispersed primary producers deliver products to few wholesalers or processing companies. Most primary producers are small compared to wholesalers and processing companies. In market organizations where a buyer has few suppliers, he can easier control food safety risk, than in market organizations where a buyer has numerous suppliers.

We conclude that specific processes characteristics, supply assurance, information asymmetry, ownership structure and market organization are important factors for setting incentive mechanism parameters. Exactly how these factors influence optimal incentive mechanism parameters is still unknown.

2.3.3. Incentive system and incentive mechanism objectives

Incentive system objectives are food safety levels the system aims at, comparable to company objectives, and can provide strategic guidance for setting company objectives. Incentive system objectives are set by the system's owner. Government systems aim at compliance with food safety legislation, private systems at compliance with private norms. Incentive system objectives can focus on end products and be differentiated to intermediate products and processes. If an incentive system aims to induce food safety control simultaneously in multiple supply chain stages, it encompasses a separate incentive mechanism for each stage. Each incentive mechanism has its own incentive mechanism objectives derived from the incentive system objectives. Objectives of the incentive mechanisms are coherently set to ensure the incentive system objectives can be achieved. Practical incentive system and incentive mechanism objectives should be realistic, because zero–tolerance and 100% compliance do not exist in real life. If all external failure costs are attributed to FBOs, incentive system objectives are endogenous in the system. If not, incentive system objectives must be set exogenously based on an ex–ante determined optimal food safety level. However, it is unclear what food safety level is optimal. Also, practical incentive system objectives for food safety are lacking.

2.4. Framework

The framework for designing and analysing incentive mechanisms for food safety control in EU supply chains combines the aspects elaborated upon in previous sections (Figure 2.3). The framework consists of two cycles. The first is the strategic cycle on the right side of Figure 2.3, which concerns the translation of the incentive system objectives into incentive mechanism parameters. The incentive system's owner, which can be the buyer, a third party or the government, sets incentive system objectives, for example a specific expected salmonella prevalence level in consumer products, considering relevant food safety hazards and the legal environment. Incentive system objectives are translated into incentive mechanism objectives, for example a specific maximum salmonella prevalence level in products delivered by the supplier. Measurement system parameters of the incentive mechanism, such as sample size and diagnostic test, and compensation scheme parameters, such as a penalty on products that have a salmonella level exceeding a specific threshold value, are set based on incentive mechanism objectives. The parameters are set considering the supplier–buyer relationship characteristics. The performance and compliance measurement system assesses actual product performance and process compliance of the supplier to determine measured performance and compliance. Measured performance and compliance is evaluated by the incentive system owner whether it sufficiently contributes to reaching the incentive system objectives and incentive mechanism objectives. If measured performance and compliance is insufficient to reach either incentive system or incentive mechanism objectives, incentive mechanism parameters are reset. The likely increase in susceptibility to food borne illnesses of the EU population’s could necessitate to tighten incentive system and incentive mechanism objectives, providing another reason for resetting incentive mechanism parameters.

The second cycle is operational and concerns the inducement of the supplier through the incentive mechanism. The supplier delivers products with a specific performance and compliance, which results from the specific control measures used. Measured performance and compliance is determined by the performance and compliance measurement system assessing the real product performance and process compliance of the supplier, also used in the strategic cycle. Performance and compliance compensation for the supplier is determined using the measured performance and compliance and the performance and compliance compensation scheme. The supplier considers performance and compliance compensation, effectiveness of relevant and legal control measures, and their impact on costs and turnaround time, in its selection of control measures to use. The set of relevant and legal control measures is determined by the relevant food safety hazards and legal environment.

In a supply chain, the buyer in Figure 2.3 can also be a supplier of another buyer. If the incentive system extents to the other buyer, an incentive mechanism can be implemented between the other buyer and its supplier. Both incentive mechanisms objectives are derived from the incentive system objectives. Parameters of both incentive mechanisms are coherently set given incentive mechanism objectives and supplier–buyer relationships. For each supplier–buyer relationship the system functions as described above.

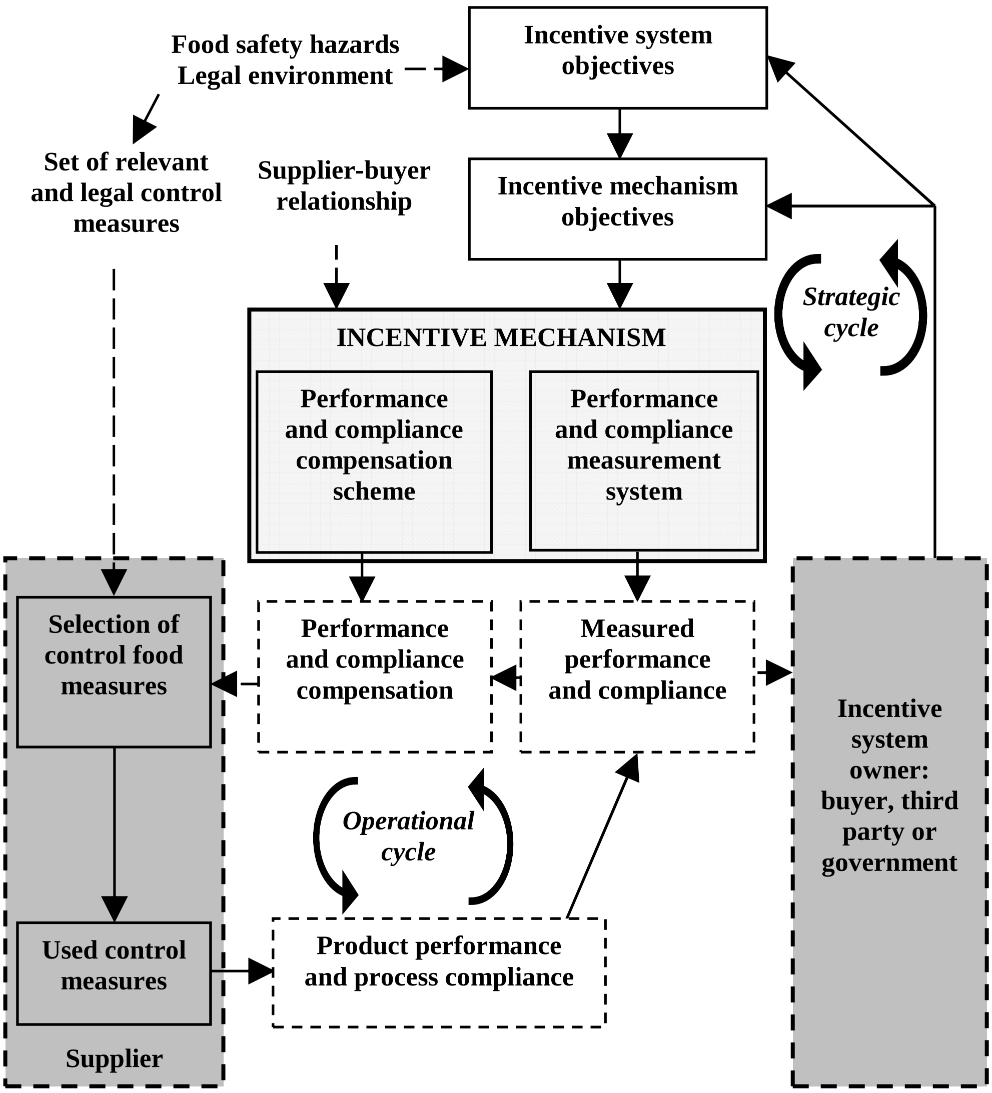

Figure 2.3: Framework for designing and analysing incentive mechanisms for food safety control in supply chains. The incentive mechanism is the light gray box. Actors are represented in dark gray boxes with dotted lines. Boxes with a thin solid line indicate key aspects for food safety control that are determined by the actors. Boxes with thin dotted lines correspond to aspects that result from control measures used by the supplier. External factors of influence on the incentive mechanism are represented without boxes. Solid arrows stand for 'A determines B', dotted arrows for 'A influences B'. The two cycles are indicated by bold italic letters and bold arrows.

In Figure 2.3 the incentive system owner can be the buyer, a third party or the government. If the buyer is the owner of the incentive system, incentive system objectives, incentive mechanism objectives and the incentive mechanism in Figure 2.3 are integrated into the buyer. Public and private organisations can also implement an incentive system together. In public–private cooperation, governments and FBOs can set incentive system and company objectives, design incentive mechanisms, set incentive mechanism parameters to improve food safety, and make agreements on who absorbs which failure costs. For example, in transition periods to tighter objectives, governments can temporarily absorb external failure costs to provide FBOs with sufficient time to develop and implement new, more effective control measures.

2.5. Conclusion and outlook

This chapter presents a framework for incentive mechanisms for food safety control in EU supply chains, which emphasizes key aspects of food safety control and provides guidelines for designing and analysing such mechanisms. Inter–company incentive mechanisms induce supplying FBOs to apply control measures. Multiple incentive mechanisms combined make up an incentive system that aims to control a hazard on supply chain level. The framework can be used to analyse and assess food safety control in EU supply chains and to set achievable public and private targets for food safety hazards.

It is important to recognize that the knowledge of how to apply incentive mechanisms for food safety control in practice is still limited. Elements of incentive mechanisms as the performance and compliance measurement system and the compensation scheme should be attuned to reach effective and efficient food safety control. Although impact on food safety performance of some elements has received attention (Backus and King, 2008; Hirschauer and Musshoff, 2007; King *et al.*, 2007; Starbird, 2005; Starbird, 2007), more insight into impact of these and other elements is needed. To improve design of new incentive mechanisms, insight into variation in efficacy of incentive mechanisms between FBOs is needed. Alternatives to reduce measurement costs, as self–reporting of performance and compliance by suppliers, have to be examined for practical applicability. Knowledge is lacking about efficacy of non–financial compensation and of alternative performance indicators as the type–II–error to induce suppliers to control food safety, and the impact of measurement accuracy on performance and compliance. Also, incentive system, incentive mechanism and company objectives for food safety are lacking in practice.

The framework was developed for the case of food safety control in EU supply chains. But it can be adapted for all settings necessitating coordinated actions of multiple FBOs, for example, to determine key elements of certification systems as used for green label producers. The framework can be a valuable tool for analysing and assessing incentive mechanisms and systems in settings where FBOs must cooperate with partners from other supply chain stages.

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Chapter 3

Incentive mechanisms for liver lesion control in finishing pigs in the Netherlands[2]

Abstract

Liver lesion prevalence in slaughtered finishing pigs in the Netherlands remained relatively high from the mid–1990s until 2004, although sufficient measures existed to control the main cause, an infection with the roundworm *Ascaris suum*. In July 2004 a new incentive mechanism was installed to induce finishing pig producers to increase control of *Ascaris suum* infections. This chapter compares the effectiveness of two Dutch incentive mechanisms: a collective insurance, in place prior to July 2004, and a reduction in producer payment for each delivered pig with a liver lesion, in place from July 2004. Liver inspection data of pigs slaughtered in 2003–2006 by a major Dutch slaughter company were analysed with an out–of–sample dynamic forecast test and non–parametric bootstrapping. Results showed that after introduction of the price reduction, mean liver lesion prevalence decreased from 9 to 5%. A reduced liver lesion prevalence ranging from 0 to 46 percentage points was observed on 67% of 1069 farms that delivered both during the insurance and the price reduction. The number of farms with a liver lesion prevalence of 5.0% or less increased from 52 to 68%. The price reduction for each pig with a liver lesion was a more effective incentive mechanism to induce finishing pig producers to control *Ascaris suum* infections than the collective insurance.

3.1. Introduction

Liver lesions are an important quality and safety attribute in pork production. In the Netherlands from the mid–1990s until 2004 mean liver lesion prevalence in slaughtered pigs fluctuated around 9%. For the 20.1 million finishing pigs reared in the Netherlands in 2003 (PVE, 2004), this amounted to around 1.8 million pigs with lesioned livers. The main cause of liver lesions was an infection with the roundworm *Ascaris suum* (*A. suum*). Pigs infected with

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[2] C.P.A. van Wagenberg, G.B.C. Backus, W.E. Kuiper, J.G.A.J. van der Vorst and H.A.P. Urlings. Published in Preventive Veterinary Medicine 93(1), pp. 19-24.

A. suum had a higher feed intake, a lower growth rate, a lower health level, and a lower lean meat percentage, leading to substantial economic losses for pig producers (Stewart and Hale, 1988; Roepstorff, 2003). In addition, the devaluation of livers with pathological lesions caused by *A. suum* resulted in economic losses of slaughterhouses. To compensate slaughterhouses in the Netherlands for these economic losses, a mandatory collective insurance with a premium per pig delivered to a slaughterhouse was in place since the 1940s. The premium was paid by the pig producers. To reduce economic losses caused by lesioned livers, in 2004 the Dutch pig industry changed this to a market–based incentive mechanism: a €1 reduction in the payment to producers for each pig with a lesioned liver. This chapter aims to analyze if the market–based price reduction provided higher incentives to finishing pig producers than the collective insurance to control *A. suum* infections as measured through liver lesion prevalence. We compared liver lesion prevalence at aggregate and individual farm level between a period in which the collective insurance was effective and a period in which the market–based price reduction was effective.

Section 3.2 provides background on liver lesions in finishing pigs in the Netherlands. Material and methods are provided in section 3.3. Section 3.4 presents the results and section 3.5 the discussion. Finally, section 3.6 concludes.

3.2. Liver lesions in finishing pigs in the Netherlands

Most lesions in the liver are caused by an infection with the roundworm *A. suum*. Adult *A. suum* worms produce eggs in the pig's intestines which are excreted with the faeces. After oral ingestion of *A. suum* eggs, larvae hatch, penetrate the pig's intestines and migrate through cecum, liver and heart to the lungs. The larvae migrate further to the trachea, are coughed up, swallowed, and end up in the small intestine where they mature into adult worms and start producing eggs. *A. suum* infections are controlled with anthelmintics during breeding and fattening. This mainly prevents new eggs being produced through termination of larvae and adult worms. Eggs remain infectious for years. The efficacy of different anthelmintics ranged from around 70 to 100% (Yazwinski *et al.*, 1997; Lacey, 1990; Stewart *et al.*, 1999; Ayoade *et al.*, 2003). Correct application of anthelmintics reduced liver lesion prevalence to 2–4% of the herd (Van Meirhaeghe and Maes, 1996).

Since the 1990s individual inspection results of all pigs delivered for slaughter are recorded in the Netherlands. Since 2006 EU legislation EG/854/2004 prescribes this as well. Pathological inspection results include lesions of livers, skin, legs, lungs and pleurisy. All slaughterhouses are legally enforced to use the Dutch inspection procedure developed by the National Inspection Service for Livestock and Meat in the early 1990s (PVV, 2006). Inspection of carcasses is conducted by official assistants, under direct supervision of veterinarians from the Dutch Food and Consumer Product Safety Authority. This guarantees independence of inspection. Inspected livers are classified on basis of the degree of pathological deformation due to an *A. suum* infection. When larvae migrate through the liver, the immune response leads to inflammatory tissue that shows as white spots. A liver has minor lesions if it has one or two white spots on the front side. These are declared unfit for human consumption, but fit for animal consumption. A liver is rejected, and consequently declared unfit for human and animal consumption, when it has three or more white spots.

To compensate Dutch slaughterhouses for the economic losses of pathological slaughter lesions including liver lesions, a mandatory collective insurance with a premium per pig delivered to a slaughterhouse was in place from the 1940s to 2004. It was based on the slaughterhouse losses and an organizational surcharge. In 2003 it was €0.31 per pig and included €0.02 for lesioned livers. The insurance provided limited incentives to an individual pig producer to control *A. suum* infections. Only if sufficient producers simultaneously lowered liver lesion prevalence, the premium would decrease. For a specific producer his premium did not decrease if he reduced liver lesion prevalence on his farm. Consequently, producers with high liver lesion prevalence received the same market price as producers with low liver lesion prevalence. The expected reduction in additional production costs due to *A. suum* infections was the only incentive for producers to control it. Persisting high liver lesion prevalence indicated that pig producers had insufficient incentives to control *A. suum* infections.

On 5 July 2004 the Dutch pig industry removed lesioned livers from the insurance and replaced it by a €1 reduction in the payment to pig producers for each pig with a lesioned liver. Other pathological lesions remained insured. All Dutch slaughterhouses implemented the reduction and it is still in place in 2009. Research indicates that incentive mechanisms that related economic consequences to output quality induced producers to improve quality control (Prendergast, 1999). Economic incentive mechanisms were used to induce farmers to produce the desired quality at the correct time (Hueth and Ligon, 2002; Martinez and Zering, 2004) and thereby contributed to higher food quality levels (Jayasinghe–Mudalige and Henson, 2007) or to the same food quality levels at lower costs (King *et al.*, 2007). Economic benefits for pig producers of controlling *A. suum* infections with the price reduction exceeded those with the insurance system. Mean liver lesion prevalence with the price reduction was therefore expected to be equal or lower than with the insurance system.

Mean liver lesion prevalence is a measure of the effectiveness of an incentive mechanism to induce pig producers to control *A. suum* infections. However, this measure does not show the heterogeneity in producer responses to an incentive mechanism. Individual producer responses are needed to gain insight into the extent to which the incentive mechanisms actually induce all producers to control *A. suum* infections. Agricultural producers are heterogeneous in many aspects. Pig producers were heterogeneous in risk attitude (Pennings and Leuthold, 2000). Broiler producers differed in abilities that affect production performance (Knoeber and Thurman, 1994). To induce agents with heterogeneous abilities to exert effort, a set of individualised contracts was optimal in a situation without transaction costs (Levy and Vukina, 2002). Reversely, under an incentive mechanism with one incentive level for all agents, or a uniform incentive mechanism, each agent exerted a different effort. Thus, only agents who experienced sufficient motivation of a uniform incentive mechanism exerted action. Both insurance and market–based price reduction are uniform incentive mechanisms. Consequently, differences are expected between pig producers in the control of *A. suum* infections and in liver lesion prevalence. The fraction of producers with a low liver lesion prevalence is a second measure of effectiveness of an incentive system. A more effective incentive system has a larger fraction. Because the economic benefits of controlling *A. suum* infections are higher with the price reduction than with the insurance, a larger fraction of producers was expected to be motivated to control *A. suum* infections by the price reduction than by the insurance.

3.3. Material and methods

3.3.1. Dataset

The dataset included liver inspection results of each delivery of finishing pigs at a Dutch slaughter company from January 2003 to December 2006. It contained 234,880 deliveries from 7829 suppliers including imports covering 3.1 million pigs in 2003, 3.5 million in 2004, 6.4 million in 2005 and 7.9 million in 2006. This represented 22% of all pigs slaughtered in the Netherlands in 2003, 24% in 2004, 44% in 2005, and 56% in 2006.

Coding of livers with minor lesions (one or two white spots) and rejected livers (more than two white spots) varied between slaughterhouse locations and in time. In some locations rejected livers and livers with minor lesions were both coded ‘rejected’, in other locations all were coded ‘livers with minor lesions’ and this changed in time for some locations. Therefore, no distinction was made between livers with minor lesions and rejected livers in this analysis, and the sum of prevalence of livers with minor lesions and rejected livers was used.

3.3.2. Statistical analysis of the aggregate impact

First, we used the Box–Jenkins method (Box and Jenkins, 1970) to derive a univariate time series model of liver lesion prevalence for the insurance period (week 1–79). Then, this model was used to forecast liver lesion prevalence in the price reduction period (week 80–209). Finally, an out–of–sample dynamic forecast test (Clements and Hendry, 1998) on the time series of weekly weighted mean liver lesion prevalence was used to determine impact of the change from the insurance period (week 1–79) to the price reduction period (week 80–209). This test assumes that the error terms ε_t in the time series are uncorrelated and have mean zero. The time series included lesion liver prevalence of each delivery of each supplier and weighting factor was delivery size. Data were analyzed with SAS 9.1 (SAS, 2002).

3.3.3. Statistical analysis at individual producer level

Effect at individual producer level of the change from insurance to price reduction was estimated by comparing mean liver lesion prevalence between the insurance period and the price reduction period. No long–term contracts existed between pig producers and slaughter companies. Dutch slaughter companies competed actively for pigs with each other and with plants in neighbouring countries. In this setting, producers could regularly shift deliveries from one slaughter company to another. A decrease in mean liver lesion prevalence could thus have originated from producers switching slaughterhouses. Suppose that producers with a high prevalence switched from slaughterhouse A in the insurance period to slaughterhouse B in the price reduction period while producers with a low prevalence switched from B to A, then a reduction in mean liver lesion prevalence in slaughterhouse A did not originate from lower prevalence at individual producer level but from switching. Therefore, only producers who delivered in both periods were used in the analysis.

It is unclear to what extent seasonal influence of *A. suum* infections on liver lesions in finishing pigs existed (Roepstorff, 1991; Elbers *et al.*, 1992). We used the same calendar periods to overcome possible seasonal influences. Period 1 with insurance was defined from 1 July 2003 to 30 June 2004 (sample S1) and period 2 with price reduction from 1 July 2005 to 30 June 2006 (sample S2). Imports were excluded from S1 and S2 because these were not traceable to individual producers. Also, deliveries from possibly non–commercial producers with less than 500 pigs delivered in period 1 or in period 2 were excluded from S1 and S2. This resulted in 1069 producers with 2.23 million pigs in 27,483 deliveries in S1 and with 2.65 million pigs in 26,934 deliveries in S2. Including all producers that delivered at least one finishing pig in period 1 and period 2 yielded similar empirical results.

The impact of the price reduction was defined as the difference between weighted mean liver lesion prevalence per producer in S1 and in S2. A positive difference indicated a higher liver lesion prevalence in S1 than in S2 and thus a decrease from period 1 to period 2. Using paired data, the null hypothesis to test was H0: $\mu(S1–S2) \leq 0$, with S1–S2 the distribution of the paired difference between S1 and S2 and $\mu(S1–S2)$ weighted mean of S1–S2. The weighting factor for a producer was the average number of delivered pigs in these two periods. Non–parametric bootstrapping (MacKinnon, 2002) was used to test H0, because a Kolmogorov–Smirnov goodness of fit test statistic for a normal distribution of 0.20 indicated that S1–S2 was not normally distributed ($p < 0.01$). To compare the fraction of producers with a low prevalence between S1 and S2, producers were categorized into two categories in both S1 and S2: ‘low’ when weighted mean liver lesion prevalence was 5.0% or less, and ‘high’ otherwise. Four possible outcomes were ‘low’ to ‘low’, ‘low’ to ‘high’, ‘high’ to ‘low’, and ‘high’ to ‘high’. Moreover, for each outcome the null hypothesis H0: $\mu(S1–S2) \leq 0$ was formally tested.

3.4. Results

3.4.1. Development of liver lesion prevalence 2003–2006

The development of weighted weekly mean liver lesion prevalence from January 2003 (week 1) to December 2006 (week 209) is presented in Figure 3.1. Weighted mean liver lesion prevalence decreased from 8–10% to 4–6%. Decline in liver lesion prevalence started 40–50 weeks after introduction of the price reduction.

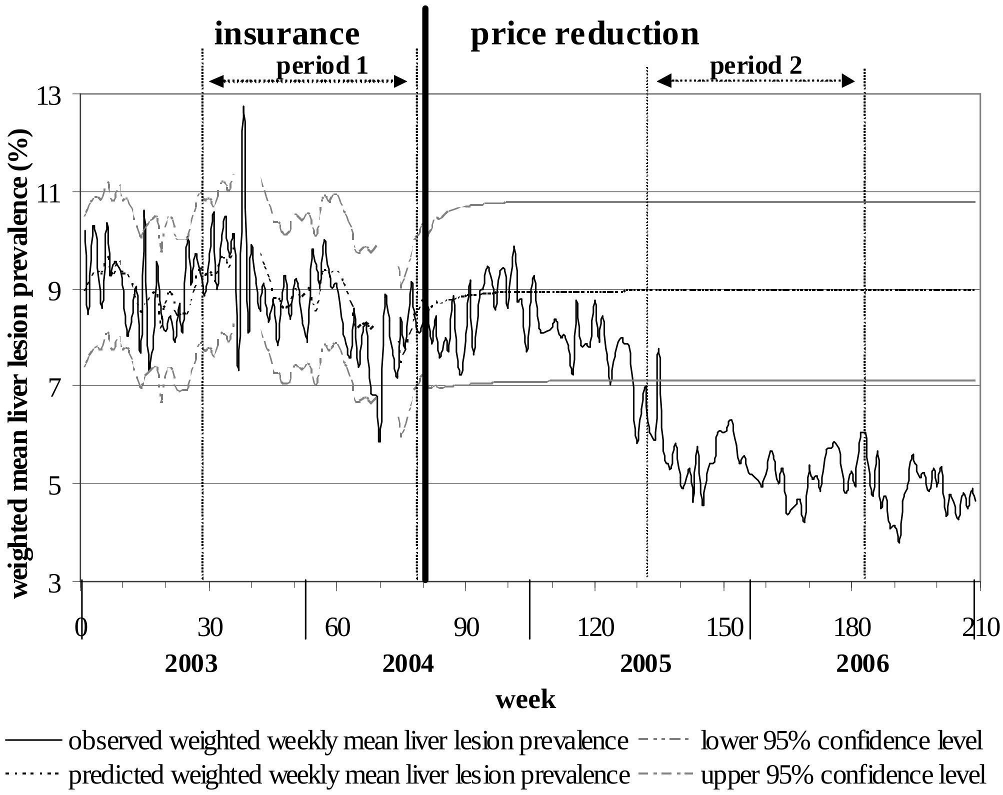

Figure 3.1: Observed weighted weekly mean liver lesion prevalence and predicted weighted weekly mean liver lesion prevalence with the lower 95% confidence level and upper 95% confidence level of finishing pigs delivered to a major Dutch slaughter company in 2003–2006 (3.1 million in 2003, 3.5 million in 2004, 6.4 million in 2005, 7.9 million in 2006). The predicted weighted weekly mean liver lesion prevalence and its confidence interval in weeks 80–209 were forecasted using data of weeks 1–79. The bold vertical line marks 5 July 2004, introduction date of the price reduction in week 80. The dashed vertical lines indicate period 1 with insurance (week 27 to week 78) and period 2 with price reduction (week 132 to week 183).

3.4.2. Aggregate impact

Box–Jenkins yielded an AR(3) model $(1 + a_1B + a_2B^2 + a_3B^3)\cdot x_t = c + \varepsilon_t$, with x_t mean liver lesion prevalence in week t, B the lag operator defined as $B^i\cdot x_t = x_{t-i}$ for all $i \in \{\ldots,-1, 0, 1,\ldots\}$, c a constant, and ε_t the error term. Removal of extreme outliers week 37, 38 and 70 as well as three following weeks 39–41 and 71–73 – to avoid outliers influencing estimates through lagged variables – resulted in a predicted $\hat{x}_t$ of

$$\hat{x}_t = \underset{(0.2748)}{0.01491} + \underset{(0.2224)}{0.14360} \cdot x_{t-1} + \underset{(0.0192)}{0.27592} \cdot x_{t-2} + \underset{(0.0012)}{0.40668} \cdot x_{t-3} \tag{1}$$

The p values in parentheses showed that coefficients of lagged terms were all significant except the one of x_{t-1}. The model had $R^2 = 0.33$. The stationary AR(3) model captured all univariate dynamics in the sample as indicated by chi–squared tests for autocorrelation between residual at week t and lags from 1 up to and including 6, 12, 18, or 24 (all $p > 0.245$). With the model as described in (1) aggregate weighted mean liver lesion prevalence values for week 80–209 were forecasted. After week 135 observed aggregate liver lesion prevalence dropped below the lower level of the 95% confidence interval of the forecasts indicating that observed prevalence was significantly ($p < 0.05$) smaller than the forecasts (Figure 3.1).

3.4.3. Impact at individual producer level

Weighted mean, median, 5% percentile, and 95% percentile of livers lesion prevalence of S1 were higher than those of S2 for the 1069 producers that delivered in both period 1 and period 2 (Table 3.1). The 1% percentile of the non–parametric bootstrap (1000 replications, seed 0) of 0.017 to test H0: $\mu(\text{S1–S2}) \leq 0$, indicated that S1–S2 was significantly different from 0 with $p < 0.001$. For producers that delivered in both periods weighted mean liver lesion prevalence on aggregate level was significantly lower in period 2 than in period 1.

Table 3.1: Liver lesion prevalence statistics of the 1069 finishing pig producers who delivered at least 500 pigs to a major Dutch slaughter company in the insurance period from 1 July 2003 to 30 June 2004 (sample S1) and in the price reduction period from 1 July 2005 to 30 June 2006 (sample S2).

Liver lesion prevalence statistic	S1	S2
Weighted mean	0.073	0.051
Standard deviation	0.085	0.054
Median	0.041	0.035
Minimum	0.003	0.004
5% percentile	0.017	0.012
95% percentile	0.268	0.152
Maximum	0.621	0.533

Of the 1069 individual producers from S1 and S2, 67% (719) showed a decrease in weighted mean liver lesion prevalence ranging from 0 to 46 percentage points (Figure 3.2). Of 350 producers with an increase 84% (294) showed an increase less than 5 percentage points.

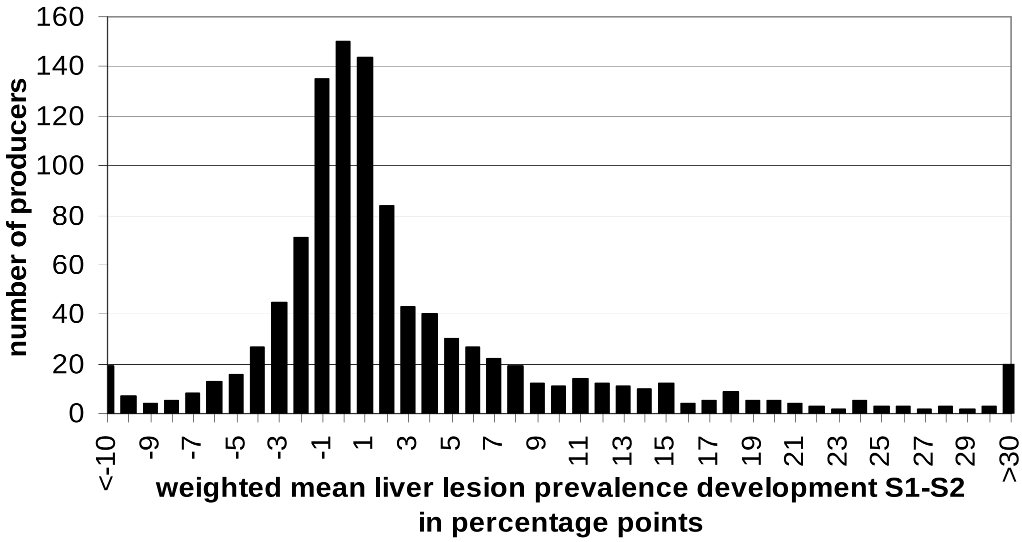

Figure 3.2: Development in weighted mean liver lesion prevalence of the 1069 finishing pig producers who delivered both in the insurance period from 1 July 2003 to 30 June 2004 (S1) and in the price reduction period from 1 July 2005 to 30 June 2006 (S2) to a major Dutch slaughter company. Developments were rounded to the nearest higher 1%–development level. A positive S1–S2 indicates a decrease in weighted mean liver lesion prevalence.

Of the 557 producers in S1 with a low mean liver lesion prevalence (≤5.0%) in the insurance period, 87% (482) retained this in S2 in the price reduction period (Table 3.2). Of the 512 producers with a high prevalence (>5.0%) in S1, 48% (246) had a low prevalence in S2. The fraction of producers with a liver lesion prevalence of 5.0% or less increased from 52% in the insurance period to 68% in the price reduction period. Additionally, producers that retained a high prevalence also significantly reduced mean prevalence.

Table 3.2: Number of finishing pig producers N_{total}, number of finishing pigs with a mean liver lesion prevalence of ≤5.0% in S2 $N_{low\ in\ S2}$, number of finishing pigs with a mean liver lesion prevalence of >5.0% in S2 $N_{high\ in\ S2}$, and weighted mean liver lesion prevalence μ in a prevalence category of S1 related to a prevalence category of S2 for the finishing pig producers who delivered at least 500 pigs to a major Dutch slaughter company in the insurance period from 1 July 2003 to 30 June 2004 (sample S1) and in the price reduction period from 1 July 2005 to 30 June 2006 (sample S2).

Prevalence category in S1	Total			Prevalence category in S2 ≤5.0%			>5.0%		
	N_{total}	μ(S1)[a]	μ(S2)[a]	$N_{low\ in\ S2}$	μ(S1)[a]	μ(S2)[a]	$N_{high\ in\ S2}$	μ(S1)[a]	μ(S2)[a]
≤5.0%	557	2.9%	3.1%	482	2.8%	2.4%	75	3.3%	7.4%
>5.0%	512	15.5%	8.5%	246	11.5%	3.1%	266	19.2%	13.4%

[a] μ(S1) and μ(S2) are weighted mean liver lesion prevalence from sample S1 and sample S2 respectively. Bootstraps (1000 replications, seed 0) showed that all differences between μ(S1) and μ(S2) within each category in S1 were significant with $p < 0.001$.

3.5. Discussion

This chapter analysed liver lesion prevalence in finishing pigs in the Netherlands in a period with a collective insurance with a premium per finishing pig and a period with a reduction in producer payment per finishing pig with a lesioned liver. The analysis demonstrated the value of the price reduction as an incentive mechanism to reduce liver lesions compared to the insurance.

Use of empirical data resulted in some limitations. Changes in external factors such as the weather, the inspection procedure, the housing systems, and the price of anthelmintics could contribute to the decrease in liver lesion prevalence. High temperature and little rain decreased the survival rate of *A. suum* eggs on pastures (Larsen and Roepstorff, 1999). The Netherlands has a temperate climate. In 2003, 2004, 2005 and 2006 the monthly mean temperature varied between 1.8–19.3 °C, 3.2–18.8 °C, 2.4–17.7 °C and 1.5–22.3 °C, respectively. The monthly mean rainfall varied between 9–96 mm, 31–127 mm, 50–159 mm and 9–181 mm, respectively. Only 2006 showed a higher maximum temperature than in the other years. However, this was in July, after the price reduction period analysed in this chapter. In addition, more than 99% of the finishing pigs in the Netherlands were kept indoors in controlled climatic conditions with only a marginal influence of the weather. Finally, Germany, eastern neighbour to the Netherlands, had a similar climate as the Netherlands and finishing pigs were kept in similar housing conditions. Available data from a slaughterhouse in North–West Germany showed that annual mean liver lesion prevalence remained around 9% from 2001 to 2006 (Personal communication H.J. Möller of VION Food Hamburg AG, 2006). This suggested that the weather did not cause the decrease in liver lesion prevalence as seen in the Dutch slaughterhouses. As the meat inspection procedures did not change since 2003, it is not to be expected that this contributed to the decrease either. It is unlikely that all 1069 finishing pig producers who delivered both in the insurance and price reduction period, renovated their housing systems simultaneously in 2004 and 2005. Housing systems are renovated around every 10 years for equipment and slatted floors to around every 40 years for the carcass (ASG, 2008). Changes to the housing systems are not expected to have caused the observed decrease in liver lesion prevalence. Finally, pig producers could have intensified *A. suum* infection control due to a structural decrease in the prices of anthelmintics. However, the prices of anthelmintics did not structurally decrease from 2003 to 2006. It is not expected that the prices of anthelmintics caused the decrease in liver lesion prevalence in the Dutch slaughterhouses. Because no change was observed in all other possible factors, that to our knowledge could have resulted in the decrease in liver lesion prevalence, the change in incentive mechanism remained as the main cause.

Increased efforts to control liver lesions required an increase in amount of purchased and used anthelmintics. The Farm Accountancy Data Network dataset of LEI Wageningen UR included medicine use of around 70 individual pig producers in the Netherlands. These data showed that amount of anthelmintics purchased in 2005 and 2006 was 16–18% higher than in 2004. This indicated that Dutch pig producers were more inclined to administer a worm treatment in 2005 and 2006 than in 2004.

Decline in liver lesion prevalence started 40 weeks after introduction of the price reduction (Figure 3.1). This can be explained by producers only starting to apply anthelmintics in new groups of finishing pigs. In normal Dutch production systems with three fattening rounds a year all groups are replaced after 4 months. Furthermore, consequent application of anthelmintics stops the production of new eggs and, in time, thus the infection pressure. Field tests also showed that after starting a treatment it took up to 18 months to reduce liver lesion prevalence (Van Meirhaege and Maes, 1996).

The mean liver lesion prevalence in S1 of the 1069 finishing pig producers who delivered both in the insurance period and in the price reduction period was 7.3%, lower than the 8–10% in Figure 3.1. So, the mean liver lesion prevalence of the deliveries excluded from S1 was higher than that of the deliveries in S1. The mean liver lesion prevalence of producers in S2 equalled the level in Figure 3.1. Thus, on average, producers that were not included in the sample had a larger decrease in liver lesion prevalence than the producers in the sample.

Valleeva *et al.* (2007) distinguished between three groups of dairy farmers that each had a different motivation to control mastitis. Common economic ground was appropriate for 37% of the sample, 35% was motivated by having an efficient (well–organized) farm that easily complied with regulatory requirements, and 28% responded to alternative designs for premium or penalty incentive programs. In this chapter we found that economic grounds provided sufficient incentives to control *A. suum* infections for 52% of the producers. The €1 price reduction increased this number by an additional 16% of the producers. A further reduction in mean prevalence must come from the 32% of producers with a high prevalence level in the price reduction period. Understanding what differentiates this group of producers from other groups can help to design more effective incentive mechanisms that provide sufficient incentives for all producers. Further research is needed to determine how all producers can be motivated to control *A. suum* infections.

3.6. Conclusion

In July 2004 the mechanism to compensate Dutch pig slaughterhouses for their costs of lesioned livers changed from an insurance with a fixed cost level per pig notwithstanding the prevalence of liver lesions on the farm, to a reduction in producer payment of €1 per pig with a lesioned liver. This introduced an additional financial incentive for finishing pig producers to control for *A. suum* infections. As a consequence, mean liver lesion prevalence dropped and the fraction of producers with a low liver lesion prevalence increased. The market–based price reduction for pigs with a lesioned liver was a more effective incentive mechanism to reduce mean liver lesion prevalence than the collective insurance.

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Chapter 4

Management practices associated with high liver lesion prevalence on Dutch finishing pig farms[3]

Abstract

This chapter analyses management practices associated with high liver lesion prevalence on Dutch finishing pig farms. Liver lesion inspection data of pigs slaughtered in 2005–2007 by a major Dutch slaughter company were combined with questionnaire results from 185 finishing pig producers about management practices used and factors underlying the decision to control *Ascaris suum* infections. Of respondents 96% applied anthelmintics using combinations of application methods, active compounds, and application durations. Sprinkling anthelmintics over feed resulted in 2.4% higher liver lesion prevalence than other application methods. Most respondents underestimated liver lesion prevalence, with larger underestimation when liver lesion prevalence was higher. This suggests that inducing finishing pig producers to apply anthelmintics through feed, through water or by injections and improving perception of liver lesion prevalence could lower mean liver lesion prevalence in the Netherlands. Adoption of these aspects in the current incentive mechanisms could improve its effectiveness.

4.1. Introduction

Liver lesions in finishing pigs are an important quality and safety attribute in the pork supply chain. Insufficient control of the main cause of liver lesions, an infection with the roundworm *Ascaris suum* (*A. suum*), leads to substantial economic losses for pig producers and slaughterhouses. Research showed that pigs infected with *A. suum* had higher feed intake,

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lower growth rate, lower health level, and lower lean meat percentage (Stewart and Hale, 1988; Roepstorff, 2003). Pathological lesions to pig livers also result in economic losses of slaughterhouses, because lesioned livers can only be marketed as raw material for animal feed or have to be disposed of. As of July 2004 the Dutch pig sector uses a reduction in producer payment of €1 per pig with a lesioned liver to induce finishing pig producers to control *A. suum* infections. As a result mean liver lesion prevalence in finishing pigs in the Netherlands decreased from 9% in 2003 to 5% in 2006, but a large spread in liver lesion prevalence between finishing pig producers remained (Van Wagenberg *et al.*, 2010). Mean liver lesion prevalence could decrease further if finishing pig producers with high liver lesion prevalence reduce it. To reduce liver lesion prevalence a finishing pig producer with high liver lesion prevalence can change management practices that impede him to reach low liver lesion prevalence. Management practices associated with high liver lesion prevalence can indicate impeding factors. This chapter aims to identify management practices associated with high liver lesion prevalence by analysing liver lesion inspection data in relation to results of a survey on management practices used and factors underlying the decision to control *A. suum* infections. Section 4.2 provides the material and methods. Section 4.3 presents the results and section 4.4 the discussion. Finally, section 4.5 concludes.

4.2. Materials and methods

To identify management practices associated with high liver lesion prevalence this chapter uses a framework to analyse the decision process to change management practices associated with liver lesion prevalence. The framework is based on organizational change processes (Zaltman *et al.*, 1973) and is given in Figure 4.1. Real liver lesion prevalence results from management practices to control *A. suum* infections used on the farm (A). A performance gap can exist between real and the lowest possible liver lesion prevalence (B). A finishing pig producer feels a need to change management practices if he perceives such a performance gap between perceived liver lesion prevalence and perceived lowest possible liver lesion prevalence (C). To close the perceived performance gap, a finishing pig producer can decide to change management practices used on the farm (D). The new management practices then result in changed liver lesion prevalence.

4.2.1. Liver lesion prevalence data

For liver lesion prevalence in finishing pigs a dataset with liver inspection results of finishing pigs delivered to a major Dutch slaughter company from January 2005 to December 2007 was used. The dataset contained 6.4 million pigs (44% of all slaughtered pigs in the Netherlands) delivered by 5359 finishing pig producers in 2005, 7.9 million pigs (56%) of 5708 producers in

2006, and 8.1 million pigs (57%) of 5117 producers in 2007. Liver lesion prevalence decreased from 2005 to 2007, but a large spread between individual finishing pig producers remained (Figure 4.2).

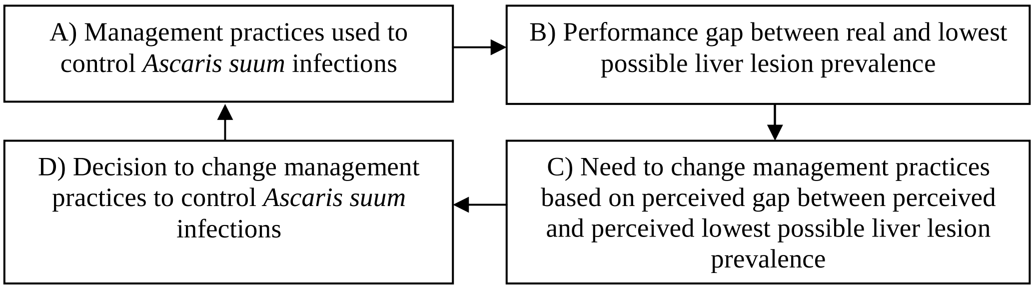

Figure 4.1: Framework to analyze finishing pig producer decision to change management practices to control *Ascaris suum* infections (based on Zaltman *et al.*, 1973).

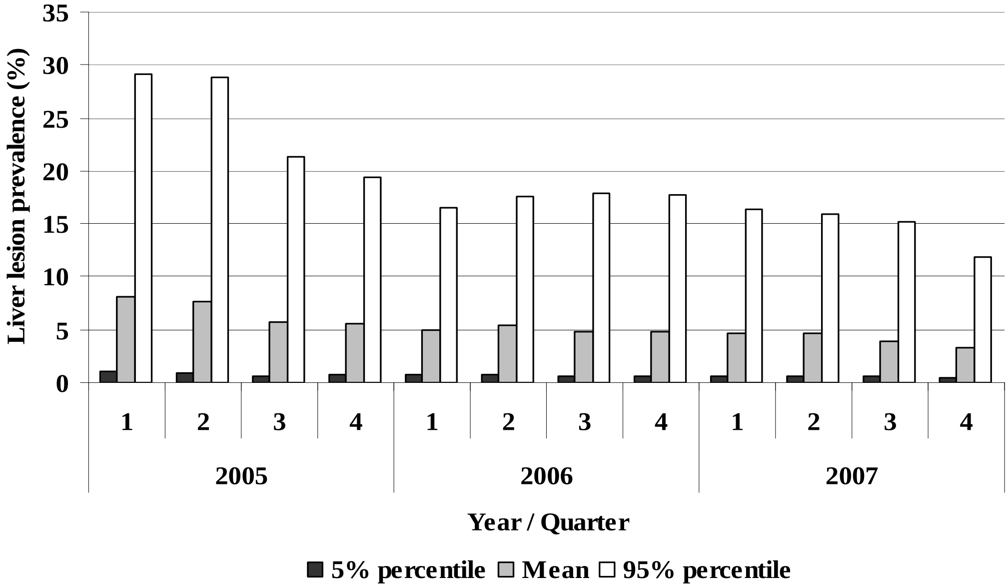

Figure 4.2: Quarterly mean, 5% and 95% percentile of liver lesion prevalence in deliveries to a major Dutch slaughter company of 5359 finishing pig producers in 2005, 5708 producers in 2006, and 5117 producers in 2007.

4.2.2. Management practices associated with liver lesion prevalence

Differences in management practices between individual finishing pig producers could explain heterogeneity in liver lesion prevalence. A preliminary list of possible management practices was identified in a literature review on management practices associated with liver lesion prevalence and *A. suum* prevalence. The list was checked for completeness by two Dutch specialist pig veterinarians. Table 4.1 provides the list of possible management practices that might be associated with liver lesion prevalence in finishing pigs in the Netherlands used in this chapter.

Table 4.1: Management practices (farm size, housing conditions, general management, anthelmintics management, hygiene management) possibly associated with liver lesion prevalence in finishing pigs in the Netherlands.

Farm size	Number of finishing pigs, number of sows
Housing conditions	foam from manure pit rising above slatted floor, slatted floor needing replacement, flies coming from manure pit
General management	Hours per week working on pigs
Anthelmintics management	Not using anthelmintics, active compound (doramectin, febantel, febendazole, flubendazole, ivermectin, levamisole), application method (through feed, over feed (topdressing), in water, injections), number of cures per production cycle, number of application days per cure, central application in water or feed, person responsible for usage
Hygiene management	Disinfecting every pen after every production cycle, using worm medicines in rest compartment, visitors strictly following hygiene guidelines, functioning of mats and trays for disinfection, perceived judgment of vet about hygiene measures

Not using anthelmintics was considered an important explanatory variable for high liver lesion prevalence and as a consequence, the process underlying the decision to treat *A. suum* infections was further specified. Several theories exist to understand and predict goal–directed behaviour as treating *A. suum* infections (Venkatesh *et al.*, 2003). We used the Theory of Planned Behaviour (TPB) (Ajzen and Madden, 1986) to analyse why a finishing pig producer decided to treat *A. suum* infections. The TPB is the most widely applied theory, applicable to a wide variety of settings (Venkatesh *et al.*, 2003), and has an easy to implement analytical framework (Leone *et al.*, 1999). In the TPB outcome beliefs refer to subjective probabilities that the behaviour of treating *A. suum* infections will produce a given outcome such as low liver lesion prevalence (Figure 4.3). Outcome beliefs are precedents of attitude, which refers to how favourable a person predicts treating infections. Referent beliefs are perceived behavioural expectations of referent groups about treatment of infections. Referent beliefs are precedents of subjective norm, which refers to the perceived social pressure to treat infections. Control beliefs refer to presence of factors that facilitate or impede treating infections. Control beliefs are precedents of perceived behavioural control, which refers to a person’s beliefs as to how easy treating infections is likely to be. Attitude, subjective norm and perceived behavioural control are precedents of intention, which indicates the readiness of a person to treat infections. The items underlying the TPB–constructs for infection control used in this chapter are presented in Figure 4.3.

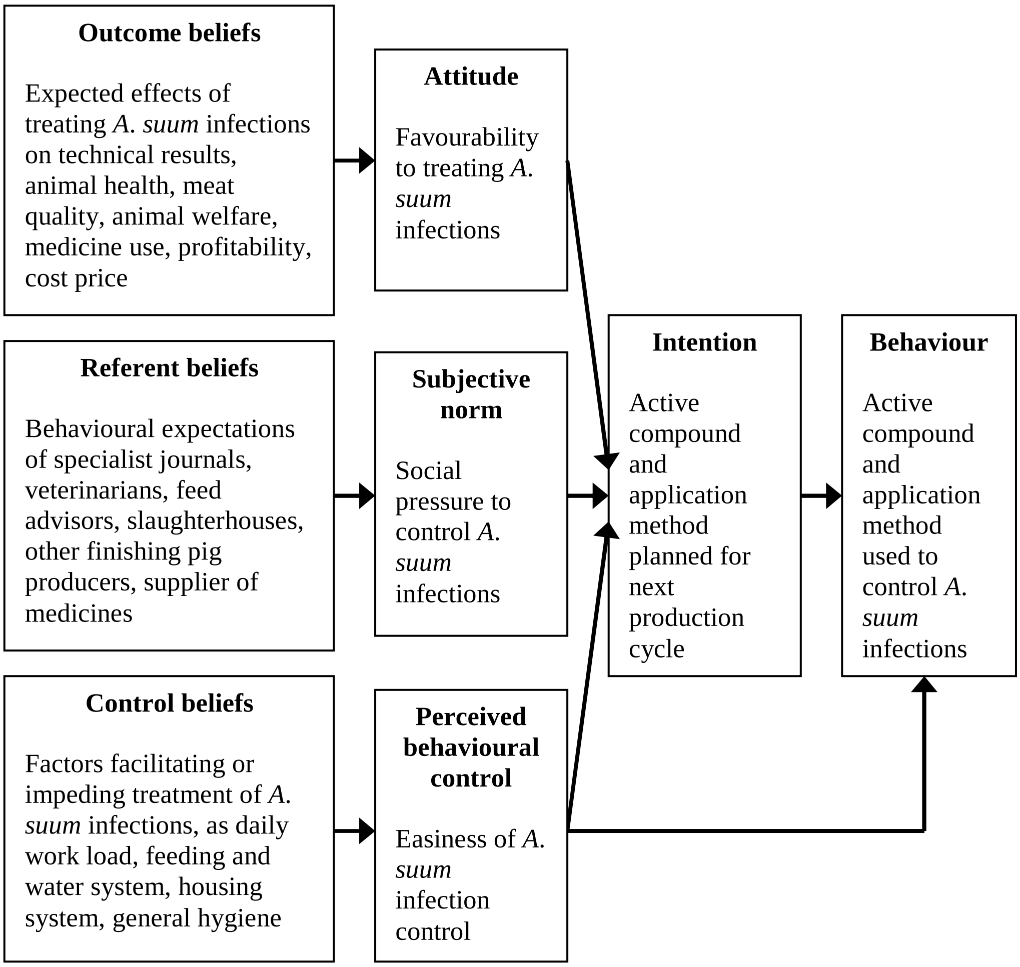

Figure 4.3: The Theory of Planned Behaviour (Ajzen and Madden, 1986) with the items underlying the TPB–constructs for *Ascaris suum* infection control in finishing pigs.

4.2.3. Questionnaire

A questionnaire was developed to measure 1) management practices associated with liver lesion prevalence on Dutch finishing pig farms, 2) perceived liver lesion prevalence, and 3) items underlying the TPB–constructs related to the decision to treat *A. suum* infections. Prior to distribution a draft version of the questionnaire was presented to two finishing pig producers to check whether the items in the questionnaire were understandable.

Farm size was measured by open questions. General management practices were measured by an interval scale. Anthelmintics management practices were measured by yes/no questions. Perceived liver lesion prevalence was measured by the item “At the moment, what is the average percentage of liver lesions on your farm?” Intention was measured with an eleven–point Juster scale from zero (almost no probability, 1% probability) to ten (certain, 99% probability) (Juster, 1966). Items related to TPB–constructs, housing conditions and hygiene management practices were measured with a seven–point Likert scale from disagree (or never) to agree (or always) (Likert, 1932).

The questionnaire was sent by mail–service on 20 December 2007. It was accompanied by an introduction letter and a postage–free return envelop. The introduction letter clarified the research aim of identifying possibilities for finishing pig producers to reduce liver lesions. Producers had the opportunity to fill in the questionnaire through Internet or to return it on paper. The finishing pig producers who responded within two weeks had a chance of receiving one of four €50 gift vouchers.

4.2.4. Construct measures

Intention to treat *A. suum* infections was measured as the sum and as the maximum of six items. Each item asked how likely it would be that the producer intended to use a specific type of active compound in the next production cycle (appendix 4.1). For the other constructs, principal component analysis was used to identify components consisting of items that capture the same underlying construct. Reliability analysis was used to determine how well the items in each component captured the underlying construct (Hair *et al.*, 2005). Components that explained more variance than the average component, i.e. components with eigenvalue 1.0 or higher, entered the analysis. Varimax rotation was used to minimize the number of variables with high loadings on more than one component. Items with a factor loading of 0.6 or higher after rotation were used in the constructs. Cronbach’s alpha was used to measure the reliability of the set of items in each construct. For sufficient reliability Cronbach’s alpha should be at least 0.6 (Field, 2005). Table 4.2 gives the measurement properties and interpretation of each TPB–construct and appendix 4.1 gives the underlying items. All constructs explain at least 60% of the variance in the items. For three out of four constructs in control beliefs the Cronbach’s alpha is below 0.6, indicating that the items only partially capture the underlying construct.

Table 4.2: Construct validity (number of items *n*, explained percentage of variance, eigenvalue of the 2nd component, Cronbach's alpha) and interpretation of the TPB–constructs from items in the questionnaire about the control of *Ascaris suum* infections in Dutch finishing pigs.

TPB–construct	*n*	Expl. % var.[a]	Ev. 2nd comp.[b]	C's alpha[c]	Interpretation: The higher the value of the TPB–construct the more a finishing pig producer …
Outcome beliefs (8 items)					
Positive outcome beliefs	6	68%	0.613	0.90	… beliefs that treating *A. suum* infections has positive effects
Negative outcome beliefs	2	73%	0.534	0.64	… beliefs that treating *A. suum* infections has negative effects
Referent beliefs (6 items)					
Opinion advisors	3	77%	0.523	0.85	… beliefs that his advisors expect that he should treat *A. suum* infections
Opinion environment	3	67%	0.612	0.75	… beliefs that people in his environment expect that he should treat *A. suum* infections
Control beliefs (18 items)					
Technical knowledge	4	63%	0.814	0.79	… beliefs that he has sufficient knowledge to treat *A. suum* infections
Labour availability	2	67%	0.664	0.50	… beliefs that he has sufficient labour available to treat *A. suum* infections
Water system suitable for	2	79%	0.410	0.37	… beliefs that his water system allows for application of anthelmintics in water
Central application in feed	1	n.a.[d]	n.a.	n.a.	… beliefs that his feeding system allows for central application of anthelmintics through feed
Perception of control	1	n.a.	n.a.	n.a.	… beliefs he can control liver lesions
Flies	1	n.a.	n.a.	n.a.	… beliefs that flies in the housing hamper treatment of *A. suum* infections
Manure	2	61%	0.786	0.35	… beliefs that problems with his manure pit hamper treatment of *A. suum* infections
Attitude (total 3 items)	3	82%	0.332	0.88	… is favourable to controlling liver lesions
Subjective norm	1	n.a.	n.a.	n.a.	… believes that people, who's opinion he values, expect him to treat *A. suum* infections
Perceived behavioural	1	n.a.	n.a.	n.a.	… believes that treating *A. suum* infections is easy for him

[a] Explained % of variance; [b] Eigenvalue of 2nd component; [c] Cronbach's alpha; [d] n.a. = not available, because the component consists of one item.

4.2.5. Finishing pig producers

Finishing pig producers were selected from the 1069 finishing pig producers participating in a previous study on liver lesion prevalence (Van Wagenberg *et al.*, 2010). No address was available for 100 producers, and 192 were related to multiple locations of a producer. Producers with multiple production locations were asked to fill out a separate questionnaire for each location. Finally, the questionnaire was sent to 777 finishing pig producers. Of these, 250 (32%) responded, of whom 9 did it through Internet and 241 through mail–service. The questionnaire results were combined with the liver lesion inspection data using the unique production location number (UBN, Uniek BedrijfsNummer). Of the 250 producers, 32 did not provide an UBN, 206 provided one UBN, and 12 producers provided more than one UBN. Results of the 32 producers who did not provide an UBN were excluded from the analysis, because no liver lesion prevalence could be linked. Results of the 12 producers who provided more than one UBN were also excluded from the analysis, because responses of the questionnaire could not be linked to one of the multiple UBN provided. In addition, 21 producers who provided one UBN could not be linked to the liver lesion inspection data, and results were also excluded from the analysis. As a consequence, results from 185 producers were analyzed.

Table 4.3 compares basic general characteristics of the respondents with the Dutch average. Respondents had a lower average number of finishing pigs and a higher average education level. They had a lower average number of sows, because breeding farms were not included in the sample. For number of hours per week spent on finishing pigs no average figures for the Netherlands are available.

Table 4.3: General characteristics of 185 Dutch finishing pig producers who responded to the questionnaire and of Dutch finishing pig producers.

Characteristic	Respondents	The Netherlands
Number of finishing pigs	1151 (st.dev. 1010)	1418 [a]
Number of sows	76 (st.dev. 177)	132 [b]
Education		
Higher agricultural education	18.9%	4.2% [c]
Secondary agricultural education	60.5%	57.1% [c]
Lower agricultural education	16.8%	} 38.7% [c]
Other education	3.8%	
Year of birth	1960 (st.dev. 9.5)	1958 [d]
Labour hours per week spend on finishing pigs		
<=20	50.8%	n.a.
20–30	29.7%	n.a.
30–40	5.4%	n.a.
>40	10.8%	n.a.

[a] Average number on farms with 500 finishing pigs or more in 2007 (CBS Statline, http://statline.cbs.nl/statweb/?LA=en).
[b] Average number of sows on farms with pigs in 2007 (LEI, 2008).
[c] In 2005 (LEI, 2008).
[d] Average age of 49 years of self–employed pig and poultry producers in 2007 (LEI, 2008).

Table 4.4 presents anthelmintics management practices of the respondents. Of the respondents 95.7% (177) did treat *A. suum* infections using combinations of application methods, active compounds and application durations. Application through feed and flubendazole were used most.

Table 4.5 shows that in each year from 2003 until 2007 respondents had a lower average liver lesion prevalence than non–respondents ($p<0.001$), indicating a possible response bias.

Table 4.4: Anthelmintics management practices of 185 Dutch finishing pig producers who responded to the questionnaire.

Anthelmintics management practices	Respondents	
	Percent	Number
Not using anthelmintics	4.3	8
Application method [a]		
Over feed (topdressing)	36.8	68
Through feed	44.9	83
Injections	20.5	38
Water	13.0	24
Used active compound [a]		
Doramectin	0.5	1
Febantel	5.9	11
Febendazole	22.2	41
Flubendazole	47.0	87
Ivermectin	17.8	33
Levamisole	18.9	35
Number of cures per production cycle [b]		
1	47.0	87
2	36.8	68
3 or more	11.4	21
Number of application days per cure [c]		
1	58.4	108
2	17.8	33
3 or more	15.7	29
Central application in water	7.6	14
Central application in feed	14.1	26
Person responsible for usage		
Farm owner	93.0	172
Farm manager	2.2	4
Employee	3.2	6
Other person	1.1	2
Nobody	0.5	1

[a] Percentages exceed 100% because some finishing pig producers used multiple application methods and multiple active compounds simultaneously.
[b] Percentages do not add to 100% because eight finishing pig producers did not apply anthelmintics and one did not provide an answer to the question.
[c] Percentages do not add to 100% because eight finishing pig producers did not apply anthelmintics, two did not provide an answer to the question, and five indicated to apply it differently than in a fixed number of days.

Table 4.5: Liver lesion prevalence statistics of 185 Dutch finishing pig producers who responded to the questionnaire and of non–respondents in the dataset.

Year	Respondent	Number of producers [a]	Liver lesion prevalence	
			Mean	Standard deviation
2003	Non–respondent	2233	11.8%	11.7%
	Respondent	185	9.4%	9.9%
2004	Non–respondent	2054	11.0%	11.0%
	Respondent	163	7.8%	7.5%
2005	Non–respondent	4651	8.7%	8.6%
	Respondent	185	6.6%	7.0%
2006	Non–respondent	4890	6.4%	6.5%
	Respondent	185	4.8%	4.6%
2007	Non–respondent	4350	5.1%	6.2%
	Respondent	185	4.0%	5.2%

[a] Number of non–respondents varied over years because the number of producers delivering to the slaughter company varied over the years. The number of respondents varied over years, because not all respondents delivered at least 500 pigs to the slaughter company each year.

4.2.6. Statistical analysis

The relationship between management practices and liver lesion prevalence were analyzed using the following linear regression model

$$\boldsymbol{llp} = \alpha + \beta_1 \cdot \boldsymbol{X}_1 + ... + \beta_{\boldsymbol{K}} \cdot \boldsymbol{X}_{\boldsymbol{K}} + \varepsilon \qquad (1)$$

where *llp* is liver lesion prevalence of a farm in 2007, α is the intercept, β_k is the regression coefficient for management practice X_k (see Table 1 for management practices), and ε the residual random error. To identify management practices that influence liver lesion prevalence a stepwise selection procedure was used.

Differences in liver lesion prevalence between finishing pig producers who did and did not use anthelmintics in 2007 were analyzed with a nonparametric exact Kolmogorov–Smirnov test with Monte Carlo simulation, because liver lesion prevalence was not normally distributed.

The eight respondents who did not use anthelmintics in 2007 were excluded from further analysis of management practices associated with high liver lesion prevalence. The relationship between measured and perceived liver lesion prevalence was analyzed using the following quadratic model

$$\boldsymbol{llp}_{\boldsymbol{perc}} = \alpha + \beta_1 \cdot \boldsymbol{llp}_{\boldsymbol{cent}} + \beta_2 \cdot \boldsymbol{llp}_{\boldsymbol{cent}}^2 + \varepsilon \qquad (2)$$

where llp_{perc} is perceived liver lesion prevalence in 2007 and llp_{cent} centralized liver lesion prevalence in 2007 around mean liver lesion prevalence of 4.1%. Using centralized liver lesion prevalence in (2) ensures that β_1 has meaning, because the intercept of llp_{cent}, i.e. mean liver lesion prevalence, lays within a range of realistic values of liver lesion prevalence (Irwin and McClelland, 2001). Without centralization a coefficient of *llp* would have low meaning, because it would be estimated at an intercept of *llp* of zero, which hardly any finishing pig producer has.

Relationships between perceived liver lesion prevalence, management practices, and factors underlying decision making behaviour represented by the TPB–constructs were analyzed with Pearson correlation analyses.

4.3. Results

4.3.1. Management practices related to high liver lesion prevalence

The result of the linear regression model of management practices on liver lesion prevalence (*llp*) is presented in (3) with p–values in parentheses. Application of anthelmintics by sprinkling over feed (*appl_over_feed*) resulted in a 2.4% higher liver lesion prevalence. Other management practices, including not using anthelmintics, were not associated with liver lesion prevalence. Although only little variance was explained by the model (model R^2 was 0.04), an analysis of variance showed that the model was significant (F–value was 5.83 and p was 0.017).

$$\boldsymbol{llp} = \underset{(0.000)}{0.032} + \underset{(0.017)}{0.024} \cdot \boldsymbol{appl\_over\_feed} \qquad (3)$$

Not using anthelmintics failed to explain variation in liver lesion prevalence. The eight finishing pig producers who did not use anthelmintics had an average liver lesion prevalence of 2.2%, about half of the average liver lesion prevalence of 4.1% of finishing pig producers who did use anthelmintics (p was 0.086). Interestingly, the finishing pig producers apparently were able to control liver lesion prevalence without anthelmintics.

4.3.2. Relationship real with perceived liver lesion prevalence

The result of the quadratic regression model of centralized real liver lesion prevalence (llp_{cent}) on perceived liver lesion prevalence (llp_{perc}) is presented in (4) with p–values in parentheses. Finishing pig producers with higher real liver lesion prevalence perceived higher prevalence (coefficient of llp_{cent} is positive), but most finishing pig producers underestimated it (constant smaller than 4.1 and coefficient of llp_{cent} smaller than 1). Underestimation of liver lesion prevalence increased as finishing pig producers had higher liver lesion prevalence (coefficient of llp_{cent} smaller than 1 and coefficient of $\boldsymbol{llp}_{cent}^{2}$ is negative). The model R^2 was 0.43.

$$\boldsymbol{llp}_{\boldsymbol{perc}} = \underset{(0.000)}{3.385} + \underset{(0.000)}{0.734} \cdot \boldsymbol{llp}_{cent} - \underset{(0.0000)}{0.014} \cdot \boldsymbol{llp}_{cent}^{2} \tag{4}$$

4.3.3. Relationship perceived liver lesion prevalence with decision factors

Table 4.6 presents Pearson correlations between perceived liver lesion prevalence and factors underlying the decision to treat *A. suum* infections. Finishing pig producers with high perceived liver lesion prevalence showed lower willingness to treat *A. suum* infections in the next production cycle (negative correlation with intention (max)), indicated to have less control over liver lesion prevalence (negative correlation with perceived behavioural control and perception of control), and perceived to lack technical knowledge about *A. suum* infections and labour availability.

Table 4.6: Pearson correlations (p–value in brackets) of perceived liver lesion prevalence and application methods with TPB construct underlying the decision to treat *Ascaris suum* infections. Pearson correlations with p–value<0.05 are bold.

	Pearson correlation (p–value)				
Factors underlying decision to treat *Ascaris suum* infections	**Perceived liver lesion prevalence**	**Application method**			
		Through feed	**Water**	**Injections**	**Over feed / topdressing**
Intention (max)	**-0.16 (0.043)**	0.07 (0.369)	0.06 (0.474)	0.06 (0.408)	0.01 (0.859)
Intention (sum)	-0.05 (0.505)	0.07 (0.376)	0.12 (0.115)	**0.24 (0.001)**	**0.18 (0.020)**
Attitude	-0.04 (0.606)	-0.05 (0.484)	-0.07 (0.352)	-0.01 (0.864)	-0.02 (0.811)
Subjective norm	0.10 (0.225)	0.05 (0.488)	0.07 (0.391)	**0.16 (0.031)**	0.05 (0.508)
Perceived behavioural control	**-0.17 (0.033)**	-0.07 (0.351)	-0.04 (0.568)	**-0.23 (0.003)**	-0.01 (0.908)
Positive outcome beliefs	-0.04 (0.611)	-0.04 (0.587)	**-0.18 (0.021)**	0.01 (0.858)	-0.02 (0.795)
Negative outcome beliefs	0.10 (0.224)	0.12 (0.130)	0.00 (0.957)	0.15 (0.056)	-0.04 (0.614)
Opinion advisors	-0.00 (0.979)	**0.17 (0.035)**	0.06 (0.443)	-0.04 (0.641)	0.12 (0.142)
Opinion environment	0.02 (0.804)	0.14 (0.079)	0.10 (0.244)	0.05 (0.571)	0.10 (0.244)
Value opinion advisors	0.12 (0.138)	0.14 (0.070)	-0.11 (0.168)	0.09 (0.225)	0.03 (0.736)
Value opinion environment	-0.02 (0.858)	0.08 (0.339)	0.00 (0.982)	0.05 (0.507)	0.13 (0.103)
Technical knowledge	**-0.30 (0.000)**	0.15 (0.058)	0.00 (0.952)	-0.11 (0.151)	0.05 (0.531)
Labour availability	**-0.16 (0.041)**	-0.08 (0.327)	-0.03 (0.653)	**-0.35 (0.000)**	0.09 (0.263)
Water system suitable for application	-0.12 (0.133)	**-0.19 (0.013)**	**0.49 (0.000)**	**-0.17 (0.029)**	0.04 (0.572)
Central application in feed	-0.14 (0.071)	**0.31 (0.000)**	0.05 (0.498)	-0.10 (0.198)	**-0.20 (0.009)**
Perception of control	**-0.38 (0.000)**	-0.04 (0.583)	0.09 (0.234)	-0.13 (0.078)	-0.09 (0.245)
Flies	-0.01 (0.904)	0.04 (0.589)	0.09 (0.251)	0.10 (0.203)	-0.06 (0.427)
Manure	0.06 (0.456)	0.04 (0.597)	-0.03 (0.672)	0.02 (0.748)	0.04 (0.561)

4.3.4. Relationship management practices with decision factors

Table 4.6 present Pearson correlations between application methods for anthelmintics and decision factors underlying the decision to treat *A. suum* infections. Finishing pig producers with intention to treat *A. suum* infections applied anthelmintics by injections and over feed (positive correlation intention (sum) with injections and over feed). The lower perceived control and higher pressure from peers, the more likely a finishing pig producer used injections (negative correlation perceived behavioural control and positive correlation subjective norm with injections). Application by injections was perceived as labour intensive (negative correlation injections with labour availability). Having a feeding or water system suitable to centrally apply anthelmintics was positively correlated with application of anthelmintics through feed or water, respectively, and negatively with other application methods.

4.3.5. Concluding statements

This section summarizes the results using the framework from Figure 4.1. Sprinkling anthelmintics over feed (A in Figure 4.4) resulted in a performance gap of 2.4% higher liver lesion prevalence (B). Finishing pig producers underestimated liver lesion prevalence, thereby decreasing the need to lower liver lesion prevalence (C). A change from sprinkling over feed to a more effective application method was hampered by finishing pig producers indicating a lack of technical knowledge and perceived control. Application by injections was hampered by its perceived labour need and central application of anthelmintics through feed or water by the need for a suitable water or feeding system (D).

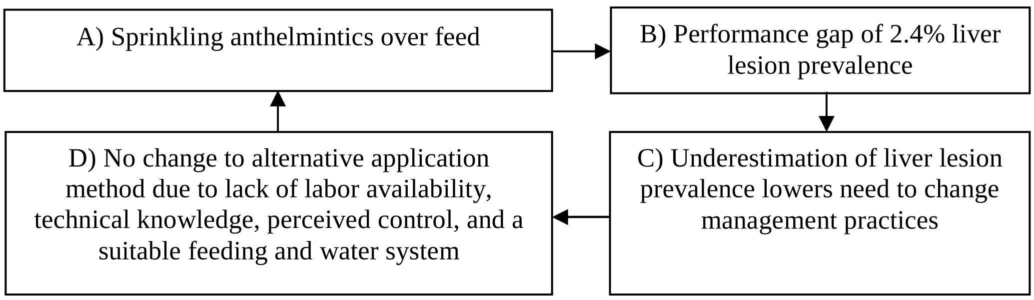

Figure 4.4: Management practices associated with high liver lesion prevalence on Dutch finishing pig farms.

4.4. Discussion

To our knowledge, no research exists that associates management practices with liver lesion prevalence in finishing pigs. Several studies, however, have been conducted to identify management practices associated with *A. suum* prevalence in pigs. Roepstorff and Jorsal

(1990) associated *A. suum* prevalence rates in finishing pigs with having a Specific Pathogen Free system, weaning age and daily cleaning. This chapter, however, did not associate cleaning with liver lesion prevalence. A cause might be that in normal management practices used on Dutch finishing pig farms cleaning after each production cycle is more common than daily cleaning. In line with this chapter Roepstorff and Jorsal (1990) did not associate active compound, application strategy, and floor type with *A. suum* prevalence. Joachim *et al.* (2001) associated number of piglet–supplying farms, number of treatments in a production cycle, and state of *A. suum* infection at the beginning of a production cycle with *A. suum* burden at slaughter. In this chapter, however, number of treatments per production cycle was not associated with liver lesion prevalence. In agreement with this chapter, Gerwert *et al.* (2004) did not associate number of treatments, active compound and cleaning method with nematode infections in sows.

Those pig producers applying anthelmintics over feed (topdressing) had 2.4% higher liver lesion prevalence than those applying it through feed, through water or by injections. This suggests that finishing pig producers who change from application over feed to another application method could lower liver lesion prevalence. However, high labour requirements restrict application by injections. Lack of a feeding or water system suitable for central application constrains using more effective application methods through feed or water. Encouraging finishing pig producers to invest in a feeding or water system that allows for central application of anthelmintics, could increase application through feed and water and lower liver lesion prevalence in the Netherlands. Roepstorff and Nansen (1994) found that Danish sow producers were not motivated to change hygiene practices to control *A. suum* infections for reasons of convenience. Further research is needed to identify how to encourage finishing pig producers to change to a more effective application method.

This chapter showed that finishing pig producers underestimated liver lesion prevalence and that underestimation was larger when liver lesion prevalence was higher. Decreasing the gap between real and perceived liver lesion prevalence could increase a finishing pig producer’s need to lower liver lesion prevalence and induce him to increase *A. suum* control. Finishing pig producers with high perceived liver lesion prevalence indicated lack of control over liver lesion prevalence and lack of intention to treat *A. suum* infections. Moreover, these finishing pig producers indicated lack of technical knowledge and lack of labour availability. Provision of technical knowledge and information about labour–extensive management practices to treat *A. suum* infections could help to increase perceived control and lower liver lesion prevalence.

Group application of anthelmintics in feed or water can result in uncontrollable variation in individual intake (Donald, 1985), possibly resulting in uneven protection amongst the pigs and a high infection pressure. This can explain the difference in liver lesion prevalence between application over feed and by injections. No difference in liver lesion prevalence was observed between application through feed and water and by injections. Whether efficacy of application over feed is lower than efficacy of application through feed or water, and whether higher liver lesion prevalence is caused by infection from finishing pigs with insufficient protection, infection pressure from the surroundings or another cause remains for further research.

Of the finishing pig producers in this chapter, 96% applied anthelmintics which is in agreement with other research (Beloeil *et al.*, 2003; Gerwert *et al.*, 2004). The 4% finishing pig producers who did not treat *A. suum* infections had lower liver lesion prevalence (2.2%) than the users of anthelmintics (4.1%). Mercy *et al.* (1989) also found that nematode prevalence was lower in pig herds not treated with anthelmintics than in herds occasionally treated. This indicates that treatment might not always be necessary to reach low liver lesion prevalence. Possibly, these finishing pig producers purchased piglets from only few breeding farms and the piglets were *A. suum* free (Joachim *et al.*, 2001), but this was not investigated in this chapter. Further research is needed to determine why finishing pig producers retained low liver lesion prevalence without treating *A. suum* infections.

The R^2 of equation (3) was 0.04. The R^2 of regression analyses of data from questionnaires are generally lower than the R^2 of regression analyses of data from controlled experiments. Uncontrolled variables in practice increase variation and lower statistical strength of relationships. An additional source of variation in this chapter is the questionnaire measuring producer's perception of reality, which could deviate from the real farm situation. Notwithstanding the low R^2, our results offer valuable insight into management practices associated with liver lesion prevalence.

This chapter aimed to identify management practices associated with high liver lesion prevalence. It used cross–sectional analysis, because this is especially suited to identify associations (Mann, 2003). A drawback of cross–sectional analysis is, however, that it cannot assess causal relationships. To determine whether application over feed indeed causes higher liver lesion prevalence compared to other application methods experimental studies or cohort studies should be performed.

The lower liver lesions prevalence of respondents compared to non–respondents indicates a possible response bias, where finishing pig producers with a better performance on *A. suum* infection control responded. In this chapter some management practices might, therefore, not have been associated with high liver lesion prevalence, while they are in real life.

4.5. Conclusion

This chapter showed that most Dutch finishing pig producers treat *Ascaris suum* infections using combinations of application methods, active compounds, and application durations. Sprinkling anthelmintics over feed (topdressing) and finishing pig producers underestimating liver lesion prevalence resulted in high liver lesion prevalence. Changing the current incentive mechanism aimed at liver lesion prevalence so it encourages finishing pig producers to apply anthelmintics through feed, through water or by injections and improves the perception of liver lesion prevalence, could lower mean liver lesion prevalence in the Netherlands.

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Appendix 4.1: Items in each component identified with principal component analysis

<u>Intention</u>

- How likely is it that the next production cycle you apply Doramectin?
- How likely is it that the next production cycle you apply Febantel?
- How likely is it that the next production cycle you apply Febendazole?
- How likely is it that the next production cycle you apply Flubendazole?
- How likely is it that the next production cycle you apply Ivermectin?
- How likely is it that the next production cycle you apply Levamisole?

Outcome beliefs

Positive outcome beliefs

- Applying worm medication improves technical results of finishing pigs (growth, feed conversion) on my farm
- Applying worm medication improves animal health of finishing pigs on my farm
- Applying worm medication improves quality of finishing pigs on my farm
- Applying worm medication improves animal welfare of finishing pigs on my farm
- Applying worm medication lowers usage of other medicines on finishing pigs on my farm
- Applying worm medication improves profitability of finishing pigs on my farm

Negative outcome beliefs

- Applying worm medication increases costs of finishing pigs on my farm
- Applying worm medication increases needed labour of finishing pigs on my farm

Referent beliefs

Opinion advisors

- My vet urges me to use worm medication
- My feed advisor urges me to use worm medication
- My slaughter plant manager urges me to use worm medication

Opinion environment

- Specialist journals urge me to use worm medication
- My colleagues urge me to use worm medication
- My supplier of medicines (he is not my vet) urge me to use worm medication

Control beliefs

Technical knowledge

- I have a lot of knowledge about applying worm medication
- I have a lot of experience with applying worm medication
- I understand exactly how worm medication works
- I know the life cycle of round worms

Labour availability

- My daily schedule provides sufficient time to apply worm medication
- I only need little labour to apply worm medication

Water system suitable for application

- My drinking water system is most suited to apply worm medication
- Can you add the worm medication centrally to the drinking water?

Central application in feed

- Can you add the worm medication centrally to the feed in the feeding kitchen?

Perception of control

- I can control liver lesions well

Flies

- Flies from the manure pit regularly cause me inconveniences

Manure

- Foam from the manure pit sometimes rises above the slatted floor
- The slatted floor in the housing needs replacement urgently

<u>Attitude</u>

- Applying worm medication to finishing pigs on my farm for me is: Unattractive–Attractive
- Applying worm medication to finishing pigs on my farm for me is: Unwise–Wise
- Applying worm medication to finishing pigs on my farm for me is: A bad idea– A good idea

<u>Subjective norm</u>

- Most people who’ s opinion I value, urge me to apply worm medication

<u>Perceived behavioural control</u>

- Applying worm medication to me is: Difficult–Easy

Chapter 5

Impact of testing accuracy on incentives for pig producers to control *Mycobacterium avium* infections in finishing pigs[4]

Abstract

This chapter analyses impact of testing accuracy on pig producer incentives to control *Mycobacterium avium* in finishing pigs. Using a dynamic optimization model and a grid search of deliveries of herds from pig producers to slaughterhouse, optimal control measures for pig producers and optimal penalty values for deliveries with increased *Mycobacterium avium* risk were identified for different sensitivity and specificity values. Results showed that higher sensitivity and lower specificity induced use of more intense control measures and resulted in higher pig producer costs and lower *Mycobacterium avium* seroprevalence. The minimal penalty value needed to comply with a threshold for *Mycobacterium avium* seroprevalence in finishing pigs at slaughter was lower at higher sensitivity and lower specificity. With imperfect specificity a larger sample size decreased pig producer incentives to control *Mycobacterium avium* seroprevalence, because the higher number of false positives resulted in an increased probability of rejecting a batch of finishing pigs irrespective of whether the pig producer applied control measures. We conclude that testing accuracy must be considered in incentive system design to induce pig producers to control *Mycobacterium avium* in finishing pigs with minimum negative effects.

5.1. Introduction

Food business operators (FBOs) can control safety of their products by using effective control measures in their production process. The behaviour of FBOs actually using control measures is thus an important factor to control food safety (Hausken, 2002). Insufficient control can lead

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[4] C.P.A. van Wagenberg, G.B.C Backus, H.J.W. Wisselink, J.G.A.J. van der Vorst and H.A.P. Urlings. Submitted to an ISI journal.

to damaged relationships between supplier and customer with subsequent trade implications, to product recalls, and to liability costs. In the EU Regulation (EC) No 178/2002 lays primary food safety responsibility with FBOs and prescribes that food safety control must be based on an integrated approach throughout the supply chain, including primary production. It also prescribes FBOs to use quality control systems based on basic hygiene measures supplemented with hazard analysis critical control points (HACCP). With HACCP, specific food safety hazards are controlled within the FBO. If control points for a hazard are located in production processes of suppliers, in addition to HACCP buyers can induce suppliers to control critical food safety attributes of the raw materials. Buyers often have imperfect information about suppliers using control measures. Furthermore, it is often costly for buyers to measure safety attributes of all raw materials. To induce suppliers to take control measures that improve quality and safety of the raw materials in settings with imperfect information, buyers can use incentive mechanisms as bonuses (Hueth and Ligon, 2002) and penalties (King *et al.*, 2007) which reward supplier performance. To determine supplier performance incentive mechanisms use results from classification systems which classify raw materials in levels of food safety risk. For microbiological and chemical hazards, classification is done with diagnostic tests. The accuracy of diagnostic tests is often imperfect (Unnevehr *et al.*, 2004). *Testing accuracy* is defined by test sensitivity and test specificity. *Test sensitivity* is the probability of correctly qualifying a product with increased risk. *Test specificity* is the probability of correctly qualifying a product without increased risk. Diagnostic testing accuracy can influence supplier incentives through the incentive mechanism. This chapter analyses how diagnostic testing accuracy influences supplier incentives to use food safety control measures in the presence of imperfect information.

Weiss (1995) identified the relationship between imperfect information amongst FBOs in a supply chain and food safety. Various studies highlighted the role of traceability and liability in inducing FBOs to control food safety (Hirschauer and Musshoff, 2007; Hobbs, 2004; Pouliot and Sumner, 2008). Incomplete tracing increases profitability of rule–breaking behaviour of farmers (Hirschauer and Musshoff, 2007). A number of studies focused on imperfect information between buyers and suppliers in the supply chain. Imperfect information can result in adverse selection and moral hazard problems (Laffont and Martimort, 2002). Adverse selection refers to the problem of how a buyer can ensure contracting only good performing suppliers. Moral hazard refers to a buyer’s inability to monitor whether a supplier exerts sufficient effort, once the supplier is contracted. Jin and Leslie (2003) showed that displaying hygiene grade cards in restaurants induced restaurants to make hygiene improvements and reduced adverse selection problem of choosing a high quality restaurant for consumers. Starbird (2007) concluded that testing accuracy can be used to segregate safe and unsafe suppliers. A number of studies addressed the issue of moral hazard and food safety. Elbasha and Riggs (2003) showed with a double moral hazard model that information provision can improve food safety. Van Wagenberg *et al.* (2010) demonstrated that a penalty on products off specification induced pig producers to improve food safety performance. King *et al.* (2007) concluded that reducing the probability of testing a pig producer in response to a favourable production history lowered system testing costs without endangering food safety. Starbird (2005) analysed the impact of the sampling inspection procedure, defined by the sample size and acceptance number, on producer incentives and concluded that regulation of sampling inspection procedures is an effective tool for policy makers to improve food safety. The importance of the inspection procedure on farmer incentives to control food safety was also highlighted by Hirschauer and Musshoff (2007). All these moral hazard studies assumed that the test used to assess supplier performance was accurate. The accuracy of diagnostic tests is, however, often imperfect (Unnevehr *et al.*, 2004). To induce suppliers to improve product quality of delivered products grading errors can be used (Chalfant and Sexton, 2002). No literature existed to our knowledge, which analysed the relationship between testing accuracy and moral hazard in food safety control. This chapter aims to fill this gap. It aims to analyze whether or not diagnostic testing accuracy has a significant impact on supplier incentives to implement food safety control measures and to characterize this impact. It uses the hazard *Mycobacterium avium* in finishing pigs.

Different species of *Mycobacterium avium* (Ma) can be found in pigs such as Ma spp. *avium* and Ma spp. *Hominisuis*. These species are a subspecies of the *Mycobacterium avium* Complex (MAC), which can cause infections in humans. Although human MAC infections are scarce, they can have serious consequences. In immunocompetent people MAC mainly caused lung infections in adults and lymph node infections in children, and worsened effects of other diseases (Falkinham 3rd, 1996). In immunocompromised people, especially AIDS patients, MAC infections are disseminated and consequences are severe. The expected survival period of AIDS patients with a MAC infection, for example, was half of those without a MAC infection (Biet *et al.*, 2005; Falkinham 3rd, 1996). Of AIDS patients up to 50% was infected with MAC depending on the country (Falkinham 3rd, 1996). The expected growth in number of immunocompromised people such as AIDS and cancer survivors and diabetes patients increases the need to control sources of human MAC infections.

Pigs may be a reservoir for MAC infections in humans and therefore Ma needs to be excluded from the pork supply chain (Komijn *et al.*, 1999). Control points of Ma in the pork supply chain can all be found at the primary producer level (Pavlík *et al.*, 2005). Detection of mycobacterial infections in pigs is laid down in EU Regulation (EC) No 854/2004 and includes palpation and incision of lymph nodes, because Ma infections can cause lymph node lesions in pigs (Thorel *et al.*, 1997). However, this method is characterized by relatively high false positive and false negative results (Komijn *et al.*, 2007; Wisselink *et al.*, 2006). In addition, it supports cross–contamination of other food safety hazards. For detection of Ma infections in pigs, a new serodiagnostic test has been developed to improve testing accuracy and to reduce cross–contamination (Wisselink *et al.*, 2010). The new test examines blood samples for Ma antibody titers. But, the new test needs further optimization of the accuracy to improve performance (Wisselink *et al.*, 2010).

Currently, two control systems for Ma in finishing pigs exist in the Netherlands. The first uses palpation and incision of lymph nodes, the second uses the new serodiagnostic test. Neither system includes financial consequences for pig producers of finishing pigs detected with Ma infection. To analyse how testing accuracy influences pig producer incentives to take Ma control measures, we modelled an alternative Ma control system which includes the new serodiagnostic test and a penalty on finishing pigs in herds detected with Ma infection. The alternative Ma control system uses an operational classification system used by a major pig slaughter company in the Netherlands. From each delivery of pigs from a pig producer to the slaughterhouse, a specific number of blood samples are examined to detect Ma infections at herd level. Test results from current and several previous deliveries determine the Ma risk level for a pig producer. The Ma risk level determines the optimal value of the selected incentive parameter, a penalty on pigs in a delivery classified with increased Ma risk, applicable to the pig producer.

The remainder of this chapter is organized as follows. Section 5.2 provides the solution procedure and model specification. Parameter settings and assumptions are presented in section 5.3. Section 5.4 elaborates on the results. Section 5.5 describes the sensitivity analysis. Section 5.6 provides the discussion and section 5.7 concludes.

5.2. Method

A dynamic optimization model with a grid search of a slaughterhouse and its supplying pig producers has been developed. The model deals with imperfect information between slaughterhouse manager and pig producers, because the manager can not observe the production process of a pig producer. This might induce pig producers to use less Ma control measures than the slaughterhouse requires.

The decision problem of the slaughterhouse manager of selecting an optimal penalty on pigs in a delivery classified as with increased Ma risk was solved using the method proposed by King *et al.* (2007). The model consists of two stages (Figure 5.1). A dynamic optimization model in stage 1, or pig producer model, determined Ma control measures that minimize pig producer costs for a given set of sensitivity, specificity and penalty values. This model is a Markov chain with discrete periods of one month and an infinite horizon with the Ma control package as the control variable and a combination of Ma risk levels in successive periods as the state variable. MATLAB routines developed by Miranda and Fackler (2002) were used to solve the pig producer model. The solution program uses policy iteration to identify an optimal Ma control package for each Ma risk level state in the steady–state. The steady–state exists because all states are recurrent, aperiodic, and communicate with each other (Winston, 1991). The solution procedure also identified the state transition matrix associated with the optimal policy, which was used to determine a long–run probability for each possible state under the optimal policy. This was used along with the optimal policy to calculate expected pig producer costs, expected slaughterhouse costs, and expected average Ma seroprevalence levels for a representative producer operating under the optimal policy. In stage 2 a grid search systematically explored the parameter space of sensitivity, specificity and penalty values to determine the optimal penalty value for the slaughterhouse to reach a threshold value for Ma seroprevalence. Input and output of the stage 1 pig producer model was used as input of the stage 2 slaughterhouse model. Output was the optimal penalty, optimal Ma control packages, Ma seroprevalence, pig producer costs, slaughterhouse costs and chain costs. Chain costs are the sum of pig producer costs and slaughterhouse costs.

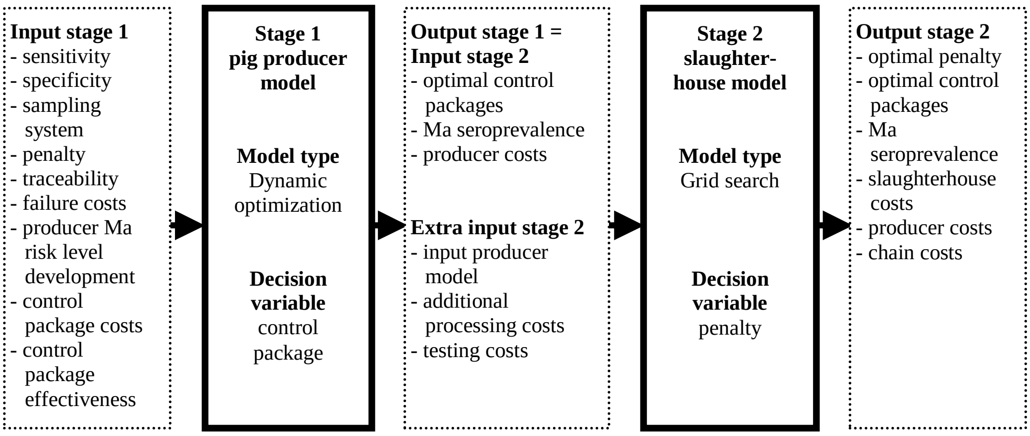

Figure 5.1: General outline of the model.

5.2.1. Model specification

The decision problem of a pig producer in (1a) is to choose a Ma control package $cp_{i,t}$, i.e. a specific combination of Ma control measures, in each period t that minimizes total discounted producer costs *tdpc*. Control packages are reversible and have a direct impact when implemented. Pig producers choose one control package $cp_{i,t}$ in each period t (1b), where $cp_{i,t}$ is an dummy variable (1c). A producer is assumed to be risk neutral. In each period t a pig producer has costs from the penalty $\boldsymbol{pen}_{\boldsymbol{RL}_t}$ on pigs in deliveries classified with increased risk and Ma control package costs cpc_i. Furthermore, it has part β_1 from additional processing costs *apc* for the slaughterhouse, because the pigs' heads and gastro–intestinal tracts are unfit for human consumption and should be disposed of safely, and part β_2 from testing costs *tc*. The penalty depends on risk level RL_t of the pig producer and on the probability that a delivery is classified without increased risk $\boldsymbol{p^s_{i,RL_t}}$.

$$\boldsymbol{tdpc} = \min_{\{cp_{1,t},\ldots,cp_{k,t}\}_{t=0}^{\infty}} \sum_{\boldsymbol{t}=0}^{\infty} \delta^{\boldsymbol{t}} \cdot \{ \sum_{\boldsymbol{i}=1}^{\boldsymbol{k}} (\boldsymbol{N} \cdot ((1-\boldsymbol{p^s_{i,RL_t}}) \cdot (\boldsymbol{pen_{RL_t}} + \beta_1 \cdot \boldsymbol{apc}) + \boldsymbol{cpc_i}) \cdot \boldsymbol{cp_{i,t}}) + \beta_2 \cdot \boldsymbol{n_{RL_t}} \cdot \boldsymbol{tc} \} \quad (1a)$$

$$\sum_{i=1}^{k} \boldsymbol{cp_{i,t}} = 1 \qquad \forall \boldsymbol{t} \quad (1b)$$

$$\boldsymbol{cp_{i,t}} \in \{0,1\} \qquad \forall \boldsymbol{i} = 1,\ldots,\boldsymbol{k}, \forall \boldsymbol{t} \quad (1c)$$

where

apc = additional processing costs for the slaughterhouse of pigs with increased risk (euro per pig in a delivery classified with increased risk);

β_1 = fraction of the additional processing costs *apc* passed on to a pig producer;

β_2 = fraction of the testing costs *tc* passed on to a pig producer;

cpc_i = costs of control package *i* (euro per pig);

$cp_{i,t}$ = dummy variable for control package *i* in period *t*;

δ = monthly discount factor;

i = index for Ma control packages;

k = number of Ma control packages;

n_{RL_t} = number of pigs in a sample at Ma risk level RL_t;

N = number of pigs in a delivery;

$\boldsymbol{p^s_{i,RL_t}}$ = probability a delivery of pig producer *i* is classified without increased risk at Ma risk level RL_t;

$\boldsymbol{pen_{RL_t}}$ = penalty (euro per pig in a delivery classified with increased risk at Ma risk level RL_t);

RL_t = pig producer Ma risk level in period *t*;

t = index for period;

tc = Ma testing costs to classify a delivery (euro per tested pig);

tdpc = total discounted producer costs.

General relationships for the evolution of the pig producer Ma risk level RL_t and related aspects are given in (2a), (2b) and (2c). Specific parameters settings used in the model calculations are given in (5a), (5b) and (5c). Evolution of the Ma risk level depends on the Ma risk levels from up to $\hat{t}$ previous periods and the test result of the current delivery TR_t (2a). The sample size (2b) and penalty level (2c) depend on RL_t.

$$\boldsymbol{RL_{t+1}} = \boldsymbol{f_1}(\boldsymbol{RL_t},...,\boldsymbol{RL_{t-\hat{t}}},\boldsymbol{TR_t}) \quad \hat{\boldsymbol{t}} \in \{0,1,2,...\} \qquad \forall \boldsymbol{t} \tag{2a}$$

$$\boldsymbol{n_{RL_t}} = \boldsymbol{f_2}(\boldsymbol{RL_t}) \qquad \forall \boldsymbol{t} \tag{2b}$$

$$\boldsymbol{pen_{RL_t}} = \boldsymbol{f_3}(\boldsymbol{RL_t}) \qquad \forall \boldsymbol{t} \tag{2c}$$

where

f_1 = function that gives pig producer Ma risk level evolution;

f_2 = function that relates sample size to pig producer Ma risk level;

f_3 = function that relates penalty to pig producer Ma risk level;

$\hat{t}$ = number of previous periods used to determine pig producer Ma risk level;

TR_t = test result in number of pigs classified with increased risk in period t.

The probability that a delivery is classified without increased risk is calculated with (3a) and (3b). The probability $\boldsymbol{p}(\boldsymbol{n_{RL_t}}, \boldsymbol{N}, \boldsymbol{d}, \boldsymbol{m}, \boldsymbol{se}, \boldsymbol{sp})$ that d or less pigs in a sample are classified without increased risk is based on a hypergeometric distribution (Cameron and Baldock, 1998) and depends on the sensitivity se and the specificity sp of the test (3a). For y pigs with Ma infection in sample $\boldsymbol{n_{RL_t}}$, the number of pigs correctly classified with increased risk has a binomial distribution with parameters y and se, and the number of pigs incorrectly classified with increased risk has a binomial distribution with parameters $\boldsymbol{n_{RL_t}} - y$ and $1 - sp$. For x pigs classified with increased risk, j are correctly classified and $x - j$ are incorrectly classified. Considering all possible prevalence levels m, $\boldsymbol{p^s_{i,RL_t}}$ is the probability that a delivery is classified without increased risk (3b).

$$\boldsymbol{p}(\boldsymbol{n_{RL_t}},\boldsymbol{N},\boldsymbol{d},\boldsymbol{m},\boldsymbol{se},\boldsymbol{sp}) = \sum_{x=0}^{\boldsymbol{d}} \left(\sum_{y=0}^{\min\{\boldsymbol{n_{RL_t}},\boldsymbol{m}\cdot\boldsymbol{N}\}} \left(\frac{\binom{\boldsymbol{m}\cdot\boldsymbol{N}}{\boldsymbol{y}}\binom{\boldsymbol{N}-\boldsymbol{m}\cdot\boldsymbol{N}}{\boldsymbol{n_{RL_t}}-\boldsymbol{y}}}{\binom{\boldsymbol{N}}{\boldsymbol{n_{RL_t}}}} \sum_{j=0}^{\min\{x,y\}} \left(\binom{\boldsymbol{y}}{\boldsymbol{j}} \boldsymbol{se}^{\boldsymbol{j}} \cdot (1-\boldsymbol{se})^{y-j} \cdot \binom{\boldsymbol{n_{RL_t}}-\boldsymbol{y}}{\boldsymbol{x}-\boldsymbol{j}} (1-\boldsymbol{sp})^{x-j} \cdot \boldsymbol{sp}^{n_{RL_t}-x-y+j} \right) \right) \right) \tag{3a}$$

$$\boldsymbol{p^s_{i,RL_t}} = \sum_{\boldsymbol{m}=0}^{1} \boldsymbol{p}(\boldsymbol{n_{RL_t}},\boldsymbol{N},\boldsymbol{d},\boldsymbol{m},\boldsymbol{se},\boldsymbol{sp}) \cdot \boldsymbol{h_i}(\boldsymbol{m}) \qquad \forall \boldsymbol{i} = 1,...,\boldsymbol{k} \tag{3b}$$

where

d = maximum number of pigs classified with increased risk in a sample to classify the delivery without increased risk;

$h_i(m)$ = probability of Ma prevalence level *m* under control package *i*;

j = number of pigs in a sample correctly classified with increased risk;

m = Ma prevalence level as percentage of pigs in a delivery with Ma infection;

$\boldsymbol{p}(\boldsymbol{n}_{\boldsymbol{RL}_t}, \boldsymbol{N}, \boldsymbol{d}, \boldsymbol{m}, \boldsymbol{se}, \boldsymbol{sp})$ = probability of *d* or less pigs classified with increased risk when a sample $\boldsymbol{n}_{\boldsymbol{RL}_t}$ from a delivery *N* contains *m·N* pigs with Ma infection using a test with sensitivity *se* and specificity *sp* at Ma risk level RL_t;

se = test sensitivity;

sp = test specificity;

x = number of pigs in a sample tested with increased risk;

y = number of pigs with Ma infection in a sample.

Slaughterhouse costs sc_t per delivery of a pig producer with Ma risk level RL_t in period *t* are calculated with (4). The slaughterhouse is assumed to be risk neutral. It absorbs part $1-\beta_1$ of additional processing cost *apc*, revenue pen_{RL_t} from the penalty to pig producers on pigs in deliveries classified with increased risk with probability $1-p^s_{i,RL_t}$, and part $1-\beta_2$ of testing costs *tc* per tested pig in sample n_{RL_t}. Expected slaughterhouse costs in the steady–state are calculated as described in section 5.2.

$$\boldsymbol{sc}_{\boldsymbol{RL}_t,\boldsymbol{t}} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{k}} (\boldsymbol{N} \cdot (1-\boldsymbol{p}^s_{\boldsymbol{i},\boldsymbol{RL}_t}) \cdot ((1-\beta_1) \cdot \boldsymbol{apc} - \boldsymbol{pen}_{\boldsymbol{RL}_t}) \cdot \boldsymbol{cp}_{\boldsymbol{i},\boldsymbol{t}}) + (1-\beta_2) \cdot \boldsymbol{n}_{\boldsymbol{RL}_t} \cdot \boldsymbol{tc} \quad (4)$$

where

$\boldsymbol{sc}_{\boldsymbol{RL}_t,\boldsymbol{t}}$ = slaughterhouse costs for a producer with Ma risk level RL_t in period *t* (euro per delivery).

5.3. Model parameters and assumptions

Optimal control packages for pig producers in the steady–state were calculated for sensitivity 0.50, 0.70 and 0.90, and for specificity 0.95, 0.97 and 0.99. Sensitivity and specificity values were set arbitrarily but reasonably to cover the range of possible values of an optimised serodiagnostic test for Ma. Sensitivity of the non–optimised serodiagnostic test was 0.14 and specificity was 0.83 (Wisselink *et al.*, 2010). The values of sensitivity and specificity were combined with penalty values €0, €2, €4, €6, €8 and €10 per pig in a delivery classified with increased risk.

In each period t a pig producer was categorized in one of six Ma risk levels $RL_t \in \{1,2,3,4,5,6\}$. We modelled the Ma prevalence measurement system used in practice by a major Dutch slaughter company. Levels 1 and 2 are levels with high risk, levels 3 and 4 with medium risk, and levels 5 and 6 with low risk. The Ma risk level RL_{t+1} depends on risk levels from 7 previous periods (5a). If a delivery has more than 1 positive pig, the producer is classified in risk level 1. If the next delivery has no positive pigs the producer moves to level 2. If a producer was in level 2 for two deliveries and the next delivery has no positives pigs, he moves to level 3, otherwise to level 1. The producer stays in level 3 the next 7 deliveries if no positive pig is found. If one positive pig is found, he moves to level 4. If two or more positive pigs are found, he moves to level 1. If a producer in level 4 has no positive pigs he moves to level 3, otherwise he moves to level 1. If a producer stayed in level 3 for 8 consecutive deliveries, he moves to level 5. The producer stays in level 5 if no positive pig is found. If one positive pig is found, he moves to level 6. If two or more positive pigs are found, he moves to level 1. If a producer in level 6 has no positive pigs he moves to level 5, otherwise to level 1. A sample size of 2 or 6, depending on the Ma risk level, was sufficient, because the system aims to identify Ma infections on herd level (5b). A sample size of 6 was used for producers with a high Ma risk level and for producers with low and medium Ma risk levels and one positive pig in the last delivery. Because this could be a false positive, the producer remained in the low or medium risk level but a sample size of 6 was used to ensure detection of a possible Ma infection in the herd. The penalty depends on the Ma risk level (5c). For this system, the decision problem of a pig producer was a Markov chain with 2,008 states.

$$\boldsymbol{RL}_{t+1} = \boldsymbol{f}_1(\boldsymbol{RL}_t,...,\boldsymbol{RL}_{t\text{-}7},\boldsymbol{TR}_t) = \begin{cases} 1 \text{ if } (\boldsymbol{RL}_t \in \{1,2,4,6\} \text{ and } \boldsymbol{TR}_t \geq 1) \text{ or } (\boldsymbol{RL}_t \in \{3,5\} \text{ and } \boldsymbol{TR}_t \geq 2) \\ 2 \text{ if } (\boldsymbol{RL}_t = 1 \text{ and } \boldsymbol{TR}_t = 0) \text{ or } (\boldsymbol{RL}_{t-1} \neq 2 \text{ and } \boldsymbol{RL}_t = 2 \text{ and } \boldsymbol{TR}_t = 0) \\ 3 \text{ if } (\boldsymbol{RL}_{t-1} = \boldsymbol{RL}_t = 2 \text{ and } \boldsymbol{TR}_t = 0) \text{ or} \\ \quad (\boldsymbol{RL}_t = 3 \text{ and } \boldsymbol{TR}_t = 0 \text{ and } \exists \hat{\boldsymbol{t}} \in \{1,...,7\} \text{ with } \boldsymbol{RL}_{t\text{-}\hat{t}} \neq 3) \text{ or} \\ \quad (\boldsymbol{RL}_t = 4 \text{ and } \boldsymbol{TR}_t = 0) \\ 4 \text{ if } \boldsymbol{RL}_t = 3 \text{ and } \boldsymbol{TR}_t = 1 \\ 5 \text{ if } (\boldsymbol{RL}_t \in \{5,6\} \text{ and } \boldsymbol{TR}_t = 0) \text{ or } (\boldsymbol{RL}_{t\text{-}7} = ... = \boldsymbol{RL}_t = 3 \text{ and } \boldsymbol{TR}_t = 0) \\ 6 \text{ if } \boldsymbol{RL}_t = 5 \text{ and } \boldsymbol{TR}_t = 1 \end{cases} \quad \forall \boldsymbol{t} \qquad (5a)$$

$$\boldsymbol{n}_{\boldsymbol{RL}_t} = \boldsymbol{f}_2(\boldsymbol{RL}_t) = \begin{cases} 2 \text{ if } \boldsymbol{RL}_t \in \{3,5\} \\ 6 \text{ if } \boldsymbol{RL}_t \in \{1,2,4,6\} \end{cases} \quad \forall \boldsymbol{t} \qquad (5b)$$

$$pen_{RL_t} = f_3(RL_t) = \begin{cases} pen & \text{if } RL_t \in \{1,2\} \\ 0.5 \cdot pen & \text{if } RL_t \in \{3,4\} \\ 0 & \text{if } RL_t \in \{5,6\} \end{cases} \qquad \forall t \tag{5c}$$

Pig producers delivered 100 pigs each month. A delivery was classified with increased risk if one or more pigs from the sample were classified with increased risk (d = 0). The monthly discount factor δ was assumed to be 0.9967, implying an annual interest rate of 4.0%. The additional processing costs *apc* of €0.92 per pig, based on lost revenue of a head of €0.06 (3 kg at €0.02 per kg), lost revenue of a gastro–intestinal tract of €0.50 per tract, and rendering costs for head and tract of €0.36 (head 3 kg and tract 6 kg at €0.04 per kg)[5], were assigned to the slaughterhouse (β_1 = 0). The testing costs *tc* of €8 per test[6] were assigned to the slaughterhouse (β_2 = 0).

Ma commonly occurs in the external environment of pig farms (Biet *et al.*, 2005). The infection route is primarily via oral ingestion (Mátlová *et al.*, 2004b). For Ma infection in pig herds, organic materials as saw dust, wood chips, and peat used as bedding material or feed supplements on pig farms are particularly hazardous. The number of Ma bacteria in these materials was higher compared to other sources in the external environment of pig farms, and the genotype of the strains found in these materials was comparable with the strains found in pig lymph nodes (Komijn *et al.*, 1999; Mátlová *et al.*, 2003; Mátlová *et al.*, 2004b). Control measures used in this research focused on the hazardous infection routes, and included avoidance of usage feed, feed supplements as kaolin and peat, and drinking water contaminated with Ma, and prevention of contact of pigs with Ma contaminated bedding material as pig–compost, birds, invertebrates and small terrestrial mammals (Mátlová *et al.*, 2003; Pavlík *et al.*, 2005; Pavlík *et al.*, 2007). Note that the control measures are reversible; they only require purchased inputs and extra labour time and do not need long term investments. Five Ma control packages were defined with increasing effectiveness that combine individual control measures (Table 5.1). Literature and expert knowledge was used to estimate Ma seroprevalence distributions for each control package. Control packages aim to prevent possible Ma contamination sources entering the farm. Not controlling a Ma contamination source increases probability of infection of pigs. Only one study about the impact of control measures on Ma seroprevalence was available. On a pig farm where preventive Ma control measures were not consistently put into effect Ma seroprevalence was 1.9%, whereas after introduction of good quality straw as bedding material, implementation of regular cleaning, and prevention of access of free living birds to the herd, Ma seroprevalence lowered to 0.0% (Pavlík *et al.*, 2007). To determine the Ma seroprevalence distribution for each control package, also literature about

[5] L. Heres, VION Fresh Meat West, personal communication, 2007.
[6] V.M.C. Rijsman, Animal Sciences Group, Wageningen UR, personal communication, 2007.

impact of control measures on lymph node lesions in pigs was used. Lymph node lesion were found in 16.1% (4.7–33.1%) of pigs fed with kaolin contaminated by Ma, whereas these lesions were found in 2.4% (0.4–6.8%) of pigs not fed with contaminated kaolin (Mátlová *et al.*, 2004a). Lesions were found in 69% of pigs (81 of 117) fed with peat contaminated by Ma (Mátlová *et al.*, 2005). Lesions were found in 7 of 8 pigs provided with pig–compost contaminated by Ma, whereas in 0 of 4 pigs not provided with pig–compost these lesions were found (Engel et al., 1978). Lesions were found in 7.2% (3.6–12.7%) of pigs kept on Ma contaminated sawdust as bedding material and only in 0.9% (0.0–2.0%) of pigs not kept on contaminated sawdust (Mátlová *et al.*, 2004b). The Ma seroprevalence probability distributions if uncontrolled contamination sources were contaminated (contamination probability of 1 in Table 5.1), were validated by two experts in Ma infections in pigs. The least intense control package 1 had the highest average Ma seroprevalence (46.0%) and the most intense control package 5 the lowest (0.1%).

Uncontrolled contamination sources are not necessarily contaminated with Ma. Table 5.2 provides the contamination probabilities that an uncontrolled Ma source was contaminated with Ma (Mátlová *et al.*, 2003). These contamination probabilities lower the probabilities of a specific seroprevalence infection level compared to contamination probabilities of 1. Table 5.1 also provides Ma seroprevalence distributions at slaughter considering the contamination probabilities of Table 5.2. The Ma seroprevalence probability distribution of control package 5 equalled the distribution with the contamination probability of 1. The Ma seroprevalence probability distributions of the other control packages were calculated with the distribution with contamination probability 1 for that control package, the Ma seroprevalence probability distribution of the next tighter control package, and the contamination probabilities from Table 5.2. For example, the probability of 0% seroprevalence in control package 4 is $0.266 \cdot 95.0 + (1–0.266) \cdot 99.0 = 97.9$ and for control package 3 is $0.042 \cdot 80.0 + (1–0.042) \cdot 97.9 = 97.2$. Control package 1 had the highest Ma seroprevalence (3.9%) and control package 5 the lowest (0.1%).

Costs for bird, small terrestrial mammal and invertebrate control were €0.07 per pig, and for water quality control €0.20 per pig (King *et al.*, 2007). Costs for feed supplements were additional costs of pigs fed supplement mix (€5.12 per pig: 2.5 kg of supplement mix at €135 per 100 kg and 2.5 kg of weaner feed at €70 per 100 kg) above costs of pigs provided with pig–compost (€3.62 per pig: 2.5 kg of pig–compost at €75 per 100 kg and 2.5 kg of weaner feed at €70 per 100 kg). Costs of uncontaminated bedding material were those of commercially available bedding material.

Table 5.1: Ma control packages with control package costs, Ma seroprevalence probability distributions and average Ma seroprevalence at contamination probabilities of Table 5.2 and of 1.

	Ma control package									
Control measure	**1**		**2**		**3**		**4**		**5**	
Bird, terrestrial mammal, and invertebrate control (€0.07/pig)			X		X		X		X	
Use of uncontaminated bedding materials (€0.15/pig)					X		X		X	
Water quality control (€0.20/pig)							X		X	
Use of uncontaminated feed and feed supplements (€1.50/pig)									X	
Control package costs (€/pig)	0.00		0.07		0.22		0.42		1.92	
Ma seroprevalence	**Cont.prob.[a]**		**Cont.prob.**		**Cont.prob.**		**Cont.prob.**		**Cont.prob.**	
probabilities at slaughter	**=T2[b]**	**=1**	**=T2**	**=1**	**=T2**	**=1**	**=T2**	**=1**	**=T2**	**=1**
0%	81.8	5.0	84.8	5.0	97.2	80.0	97.9	95.0	99.0	99.0
5%	5.6	5.0	5.6	25.0	2.6	15.0	2.1	5.0	1.0	1.0
10%	3.0	5.0	2.9	20.0	0.2	5.0	0.0	0.0	0.0	0.0
15%	2.8	5.0	2.7	20.0	0.0	0.0	0.0	0.0	0.0	0.0
20%	1.5	5.0	1.3	10.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	1.7	10.0	1.3	10.0	0.0	0.0	0.0	0.0	0.0	0.0
50%	2.4	30.0	1.3	10.0	0.0	0.0	0.0	0.0	0.0	0.0
70%	1.1	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100%	0.2	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average Ma seroprevalence (%)	3.9	46.0	2.2	15.8	0.2	1.3	0.1	0.3	0.1	0.1

[a] Contamination probability.

[b] T2 = Contamination probability in Table 5.2.

Table 5.2: Total No. of samples, No. of samples infected with Ma spp. *avium* and Ma spp. *hominisuis*, and contamination probability of sources of Ma spp. *avium* and Ma spp. *hominisuis* infections (Mátlová *et al.*, 2003).

Source of Ma infection	**Total No. of samples**	**No. of infected samples**	**Contamination probability**
Birds, flies, and invertebrates	510	19	0.037
Bedding material	231	31	0.134
Water (water and biofilm)	450	19	0.042
Feed and feed supplements (peat, kaolin, charcoal, feed concentrates)	713	190	0.266

5.4. Results

For different sensitivity and specificity values, the impact of penalty values €0 to €10 on steady–state probabilities, expected average Ma seroprevalence, expected pig producer costs, expected slaughterhouse costs, and expected chain costs were calculated. Table 5.3 provides results at sensitivity 0.50, 0.70 and 0.90, and specificity 0.95. Table 5.4 provides results at specificity 0.95, 0.97 and 0.99, and sensitivity 0.70. Expected pig producer costs consist of control package costs and penalty costs. Expected slaughterhouse costs consist of testing costs, additional processing costs and penalty revenue. Negative slaughterhouse costs indicate positive benefits.

The penalty system is implemented to reach an objective for Ma contamination of pork. Consider an objective of a threshold value for average Ma seroprevalence in finishing pigs at slaughter of 4.0%. Table 5.3 shows that irrespective of the sensitivity level a penalty is not needed to comply with the threshold, because without a penalty the expected average Ma seroprevalence was 3.9%. Pig producers did not use control packages and the slaughterhouse bared costs of Ma control of €0.43, of which €0.26 testing costs and €0.17 additional processing costs. To comply with a threshold value of 3.5%, a penalty of €4 per pig was needed at sensitivity 0.50. The penalty induced pig producers to use a combination of control packages 1 to 3, which resulted in expected Ma seroprevalence of 2.7%. Pig producer costs were €0.33, which consisted of €0.07 control package costs and €0.26 penalty costs. Penalty costs were almost four times higher than control package costs. Slaughterhouse costs were €0.13, consisting of €0.24 testing costs, €0.15 additional processing costs and a penalty revenue of €0.26. Chain costs were equal to the lowest chain costs at penalty €0. For sensitivity levels 0.70 and 0.90, a penalty value of €2 was sufficient to lower expected average Ma seroprevalence below 3.5%. At higher sensitivity more pigs were classified with increased risk, increasing the reduction in penalty costs of a lower Ma seroprevalence. Pig producers used more intense control packages at the same penalty, resulting in a lower penalty needed to reach a threshold of 3.5%. For both sensitivity values, penalty costs for the pig producer also were about four times higher than control package costs. Slaughterhouse costs were €0.33 per pig lower than without a penalty, mainly due to the penalty revenue. Chain costs were between €0.00 and €0.01 higher than in the situation without a penalty. With tighter threshold values than 3.5%, higher penalty values were needed for compliance with a threshold. Chain costs increased. Control package 4 and 5 were never optimal, because the control package costs were too high (€0.42 and €1.92) compared to a possible reduction in expected Ma seroprevalence (from 0.2% of control package 3 to 0.1% for control packages 4 and 5). At higher sensitivity pig producers used more intense control packages, which lowered the minimal penalty needed to decrease expected average Ma seroprevalence below a specific threshold value. Higher sensitivity increased pig producer and chain costs, but did not influence slaughterhouse costs.

Table 5.3: Impact of penalty (€/pig in delivery classified with increased risk) on optimal control packages, expected average Ma seroprevalence (%) and expected costs (€/pig) with sensitivity 0.5, 0.7, 0.9, and specificity 0.95.

Sensitivity	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.70**	**0.70**	**0.70**	**0.70**	**0.70**	**0.70**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**
Penalty (€/pig)	**0**	**2**	**4**	**6**	**8**	**10**	**0**	**2**	**4**	**6**	**8**	**10**	**0**	**2**	**4**	**6**	**8**	**10**
Expected Ma prevalence performance																		
Steady–state probability [a]																		
- Control package 1	1.00	0.87	0.56	0.48	0	0	1.00	0.80	0	0	0	0	1.00	0.68	0	0	0	0
- Control package 2	0	0.08	0.18	0.22	0.53	0.53	0	0	0.70	0.51	0.51	0	0	0.11	0.53	0.49	0	0
- Control package 3	0	0.05	0.25	0.30	0.47	0.47	0	0.20	0.30	0.49	0.49	1.00	0	0.21	0.47	0.51	1.00	1.00
Expected average Ma seroprevalence	3.9	3.6	2.7	2.4	1.3	1.3	3.9	3.2	1.6	1.2	1.2	0.2	3.9	3.0	1.3	1.2	0.2	0.2
Expected economic performance (€/pig)																		
Pig producer costs	0.00	0.18	0.33	0.46	0.57	0.68	0.00	0.22	0.37	0.49	0.60	0.71	0.00	0.24	0.39	0.51	0.62	0.72
- Control package costs	0.00	0.02	0.07	0.08	0.14	0.14	0.00	0.04	0.11	0.14	0.14	0.22	0.00	0.05	0.14	0.15	0.22	0.22
- Penalty costs	0.00	0.17	0.26	0.38	0.43	0.54	0.00	0.17	0.25	0.34	0.46	0.49	0.00	0.19	0.25	0.36	0.40	0.50
Slaughterhouse costs [b]	0.43	0.25	0.13	0.01	-0.06	-0.17	0.46	0.25	0.13	0.03	-0.08	-0.13	0.48	0.25	0.14	0.02	-0.05	-0.15
- Testing costs	0.26	0.25	0.24	0.24	0.23	0.23	0.27	0.25	0.24	0.24	0.24	0.23	0.28	0.26	0.24	0.24	0.23	0.23
- Add. processing cost	0.17	0.16	0.15	0.15	0.14	0.14	0.19	0.17	0.15	0.14	0.14	0.12	0.20	0.18	0.15	0.15	0.12	0.12
- Penalty revenue [b]	0.00	-0.16	-0.26	-0.38	-0.43	-0.54	0.00	-0.17	-0.25	-0.34	-0.46	-0.49	0.00	-0.19	-0.25	-0.36	-0.40	-0.50
Chain costs	0.43	0.43	0.46	0.47	0.51	0.51	0.46	0.47	0.50	0.52	0.52	0.57	0.48	0.49	0.53	0.53	0.57	0.57

[a] Control packages 4 and 5 were never optimal.
[b] Negative costs indicate positive benefits.

Irrespective of the specificity no penalty is needed to comply with a threshold value of 4.0%, because without a penalty the expected average Ma seroprevalence was 3.9% (Table 5.4). At a threshold value of 3.5%, a penalty of €2 was needed at specificity 0.95. The penalty induced pig producers to use a combination of control packages 1 to 3, which resulted in expected average Ma seroprevalence of 3.2%. Pig producer costs were €0.22, which consisted of €0.04 control package costs and €0.17 penalty costs. Penalty costs were four times higher than control package costs. Slaughterhouse costs were €0.25, consisting of €0.25 testing costs, €0.17 additional processing costs and a penalty revenue of €0.17. For specificity levels 0.97 and 0.99, a penalty value of €4 and €6 respectively was needed to lower expected average Ma seroprevalence to 3.5%. At higher specificity fewer pigs were classified with increased risk, lowering Ma seroprevalence and the possible reduction in penalty costs. At a higher specificity pig producers used less intense control packages at the same penalty value, resulting in a higher penalty value needed for reaching a threshold value of 3.5%. At specificity 0.97 penalty costs for the pig producer were double the control package costs, and at specificity 0.99 they equalled the control package costs. Higher specificity lowered the penalty for producers and thereby pig producer incentives to use intense control packages, and increased the needed penalty to comply with a Ma seroprevalence threshold. Penalty costs for the pig producer reduced if specificity increased. With tighter threshold values than 3.5%, higher penalty values were needed for compliance with the threshold and chain costs increased. At higher specificity pig producer costs were lower. Chain costs were higher with increased specificity. For penalty values lower than the additional processing costs, €0 and €2, penalty revenue was lower than savings on additional processing costs. At these penalty values higher specificity lowered slaughterhouse costs, because less pigs were classified with increased risk. For penalty values of €4 or higher, slaughterhouse costs increased with higher specificity.

5.5. Sensitivity analysis

Sensitivity analysis was conducted with 1) alternative Ma contamination probabilities, 2) alternative control package costs, 3) alternative additional processing costs, 4) attributing additional processing costs to pig producers, 5) alternative testing costs, 6) attributing testing costs to pig producers, and 7) alternative sample sizes. Higher sensitivity and lower specificity resulted in increased usage of more intense control packages irrespective of the alternative values of the first six variables, but model outcomes did change. Alternative sample sizes did, however, change impact of testing accuracy on producer usage of control packages. The results of the sensitivity analysis are provided subsequently.

Table 5.4: Impact of penalty (€/pig in delivery classified with increased risk) on optimal control packages, expected average Ma seroprevalence (%) and expected costs (€/pig) with specificity 0.95, 0.97, 0.99, and sensitivity 0.7.

Specificity	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**
Penalty (€/pig)	**0**	**2**	**4**	**6**	**8**	**10**	**0**	**2**	**4**	**6**	**8**	**10**	**0**	**2**	**4**	**6**	**8**	**10**
Expected Ma prevalence performance																		
Steady–state probability [a]																		
- Control package 1	1.00	0.80	0.56	0	0	0	1.00	0.91	0.67	0.65	0	0	1.00	1.00	0.90	0.82	0.83	0.82
- Control package 2	0	0	0.70	0.51	0.51	0	0	0	0.17	0.10	0.72	0.72	0	0	0.01	0.09	0.04	0.01
- Control package 3	0	0.20	0.30	0.49	0.49	1.00	0	0.09	0.17	0.25	0.28	1.28	0	0	0.09	0.09	0.13	0.17
Expected average Ma seroprevalence	3.9	3.2	1.6	1.2	1.2	0.2	3.9	3.6	3.0	2.8	1.7	1.7	3.9	3.9	3.6	3.5	3.4	3.3
Expected economic performance (€/pig)																		
Pig producer costs	0.00	0.22	0.37	0.49	0.60	0.71	0.00	0.09	0.15	0.20	0.24	0.28	0.00	0.03	0.05	0.06	0.07	0.08
- Control package costs	0.00	0.04	0.11	0.14	0.14	0.22	0.00	0.02	0.05	0.06	0.11	0.11	0.00	0.00	0.02	0.03	0.03	0.04
- Penalty costs	0.00	0.17	0.25	0.34	0.46	0.49	0.00	0.07	0.11	0.14	0.13	0.17	0.00	0.03	0.03	0.03	0.04	0.04
Slaughterhouse costs [b]	0.46	0.25	0.13	0.03	-0.08	-0.14	0.35	0.26	0.21	0.17	0.16	0.12	0.26	0.24	0.22	0.22	0.21	0.21
- Testing costs	0.27	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19
- Add. processing cost	0.19	0.17	0.15	0.14	0.14	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.07	0.07	0.06	0.06	0.06	0.06
- Penalty revenue [b]	0.00	-0.17	-0.25	-0.34	-0.46	-0.49	0.00	-0.07	-0.11	-0.14	-0.13	-0.17	0.00	-0.03	-0.03	-0.03	-0.04	-0.04
Chain costs	0.46	0.47	0.50	0.52	0.52	0.57	0.35	0.35	0.37	0.37	0.40	0.40	0.26	0.26	0.27	0.27	0.28	0.28

[a] Control packages 4 and 5 were never optimal.
[b] Negative costs indicate positive benefits.

Ma contamination probabilities of 1.00 for each control package resulted in higher average Ma seroprevalence of each control package (contamination probability of 1 in Table 5.1). It increased pig producer costs from €0.00 to €0.18 per pig, depending on sensitivity, specificity and penalty value. Slaughterhouse costs changed from a decrease of €0.07 to an increase of €0.93. Chain costs increased from €0.07 to €0.93. The penalty value that resulted in lowest chain costs changed from €0 per pig in the base situation to €2 or €4 with high contamination probabilities. Higher contamination probabilities increased financial gains of using a control package, because the decrease in expected average Ma seroprevalence was larger. Higher contamination probabilities also lowered the penalty value, which was sufficient to comply with a Ma seroprevalence threshold value.

If control package costs were half of the costs in Table 5.1, pig producers used more intense control packages resulting in lower expected average Ma seroprevalence. It decreased pig producer costs from €0.00 to €0.11 per pig, depending on sensitivity, specificity and penalty value. Slaughterhouse costs decreased from €0.00 to €0.04. Chain costs decreased from €0.00 to €0.11. The penalty value that resulted in lowest chain costs changed from €0 per pig in the base situation to €2 if control package costs were half. Savings on penalty costs more quickly exceeded additional costs of more intense control measures, if control measure costs were lower. Lower control package costs also lowered the penalty value, which was sufficient to comply with a Ma seroprevalence threshold value.

Pig producer and slaughterhouse manager decision remained unchanged if additional processing costs varied from €0.92 per pig to €0.46 and €1.38. If additional processing costs were assigned to the pig producer (β_1 = 1), more intense control packages were optimal. Pig producer costs were between €0.06 and €0.20 higher than if additional processing costs were assigned to the slaughterhouse, depending on sensitivity, specificity and penalty value. Additional costs consisted of additional processing costs and control package costs. Usage of more intense control packages lowered penalty costs slightly. Slaughterhouse costs were between €0.05 and €0.20 lower. Gains from lower additional processing costs outweighed lower penalty revenues. Chain costs were between €0.00 and €0.05 higher, because the increase in control package costs cancelled out the reduction in additional processing costs.

Pig producer and slaughterhouse manager decision remained unchanged if testing costs varied from €8 per test to €4 and €12. If testing costs were assigned to the pig producer (β_2 = 1), more intense control packages were optimal. Pig producer costs were between €0.19 and €0.28 per pig higher than if testing costs were assigned to the slaughterhouse, depending on sensitivity, specificity and penalty value. Additional costs consisted of testing costs and control package costs. Usage of more intense control packages lowered penalty costs slightly. Slaughterhouse costs were between €0.18 and €0.28 lower, because it faced no testing costs and the lower expected average Ma seroprevalence decreased additional processing costs.

Chain costs were between €0.00 and €0.04 higher, because the increase in control package costs cancelled out the reduction in additional processing costs and testing costs.

The impact of a doubled (from 2 and 6 to 4 and 12, respectively), tripled (6 and 18) and quadrupled (8 and 24) sample size $\boldsymbol{n_{RL}}$ on expected average Ma seroprevalence in the steady–state was analysed. Figure 5.2 presents the results for specificity *sp* 0.95, 0.97, and 0.99, sensitivity 0.70 and penalty value €2. It shows that a larger sample size not always resulted in lower expected average Ma seroprevalence. At specificity 0.95, expected average Ma seroprevalence was lower at sample size 4/12 than at sample size 2/6. However, it was higher at sample size 6/18 and 8/24 than at sample size 4/12. A larger sample size and a low specificity resulted in a higher probability of incorrectly classifying a delivery with increased risk. This lowered benefits of a lower probability of a delivery being classified with increased risk to such extent that benefits were lower than the additional costs of more intense control packages. This resulted in usage of less intense control packages and a lower expected average Ma seroprevalence at a higher sample size. Similarly, a sample size of 6/18 at specificity 0.97 and a sample size of 8/24 at specificity 0.99 minimized expected average Ma seroprevalence. The sample size minimizing expected average Ma seroprevalence increased with specificity, because at higher specificity the probability of incorrectly classifying at least one pig with increased risk was lower. Alternative penalty values and sensitivity values showed similar results.

5.6. Discussion

This paper analysed influence of sensitivity and specificity of a new serodiagnostic test for detection of Ma infections on pig producer incentives to control Ma infections in finishing pigs. Incentives were provided through a penalty on pigs in a delivery classified with increased Ma risk. A dynamic optimization model with a grid search of deliveries of pig producers to a slaughterhouse was used to provide insight into how test sensitivity, test specificity and penalty values influenced pig producer incentives to implement Ma control packages. The minimal penalty value needed to comply with a threshold value for average Ma seroprevalence in finishing pigs at slaughter depended on test sensitivity and specificity. Higher sensitivity and lower specificity induced usage of more intense control packages, resulting in lower expected average Ma seroprevalence and lower minimal penalty values, and also in higher expected pig producer costs and chain costs. Expected slaughterhouse costs were hardly influenced. Sensitivity and specificity weighed relative importance of expected producer costs to that of expected average Ma seroprevalence. A higher penalty increased usage of more intense control packages. King *et al.* (2007) similarly reported that penalties intensify control of salmonella infections in pig herds. Specificity had a larger impact than sensitivity on expected costs of pig

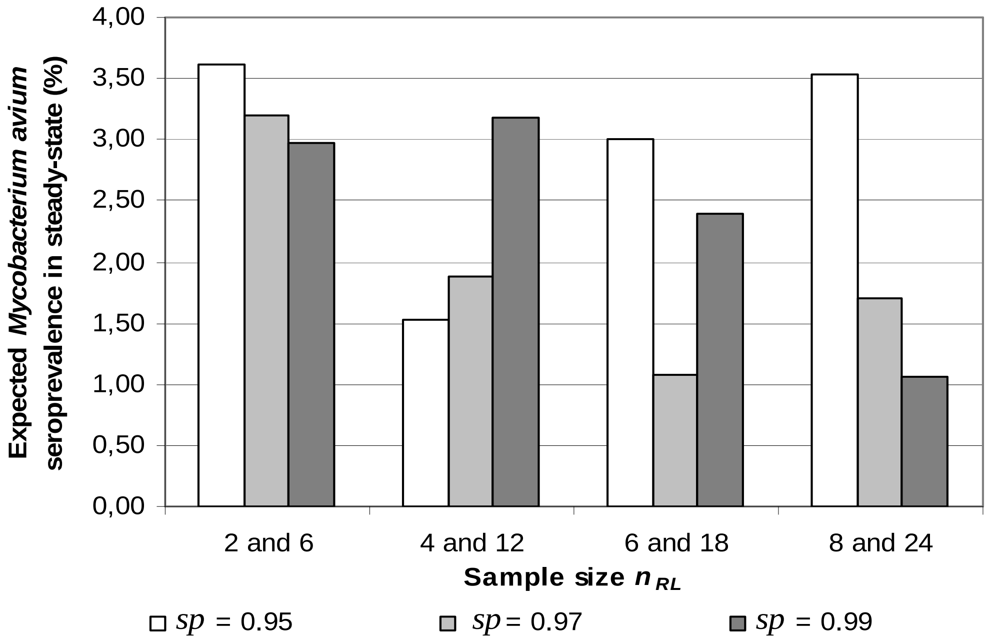

Figure 5.2: Impact of specificity *sp* and sample size n_{RL} on expected average *Mycobacterium avium* seroprevalence in the steady–state at penalty value €2 and sensitivity 0.70.

producers and slaughterhouse. This originated from a low expected average Ma seroprevalence within the herd. Jordan (1996) similarly reported that specificity has a larger impact than sensitivity on the sample size to detect *Mycobacterium paratuberculosis* infections in cattle herds. Starbird (2005) showed that larger sample size lowered the fine needed to induce suppliers to deliver safe products. Our research showed that if a test with imperfect specificity is used and hazard prevalence is low, a larger sample size can result in lower incentives to take control measures. Policy makers should thus consider the specificity of the test while setting the sample size, to prevent adverse effects on supplier incentives.

In the analysis pig producers were assumed to be risk–neutral for simplification. However, primary producers are often assumed to be risk–averse. King *et al.* (2007) showed that the level of risk aversion has no influence on the relationships among expected welfare and monetary gains and almost no effect on the quality premium for salmonella control by pig producers. Although specific parameter values might differ, we expect that impact of testing accuracy on optimal parameter values of the financial incentive system with risk–neutral producers is comparable to impact with risk–averse producers.

The research used a partial analysis on Ma. But, food safety control measures can be effective in reducing multiple pathogens and can improve production results. This research did not include such benefits, because these were outside our research scope. Improvement of farmer production results de facto lowers control package costs and increases incentives for implementation of more intense Ma control packages.

The model did not include a participation constraint of pig producers, because the research aimed to analyse how testing accuracy influences optimal parameter values of an incentive system. In countries where no long–term contracts exist between pig producers and slaughter companies, such as the Netherlands, pig producers can regularly shift deliveries from one company to another. If only part of the slaughter companies in such a country introduce a penalty, the penalty costs could induce their supplying pig producers to switch to another slaughter company. Thus, slaughter companies can only set a penalty up to a specific level, depending on the individual participation constraints of supplying pig producers. Extending the model with a participation constraint limits the optimal penalty value to a maximum. It would not change the impact of testing accuracy.

The research aim was to analyse the impact of the accuracy of a serodiagnostic test on supplier incentives to implement food safety control measures. It did not aim at analysing the feasibility of adopting the proposed incentive system in practice. Notwithstanding, some comments on the feasibility can be made based on this research. In a situation with a threshold value for Ma seroprevalence which necessitates a penalty, chain costs compared to the current situation without a penalty (results at penalty value €0) were between €0.00 and €0.12 per pig higher, depending on sensitivity, specificity and penalty value. Gains of a Ma control programme in terms of lower public health costs must outweigh these additional chain costs for it to be cost–effective for society and a sufficient part of these gains must be redistributed to the slaughter company and pig producers. Without redistribution voluntary implementation of such system is unlikely. However, if control package costs decrease, for example through technical development, or contamination probabilities of individual Ma sources are higher than the ones used in this research, a penalty system can be more cost–effective than a system without a penalty irrespective of public health gains, because minimal chain costs occurred at penalty values of €2 or €4. For implementation by an individual slaughter company in practice it also is important that gains of finishing pig producers exceed their costs, because finishing pig producers would otherwise shift deliveries to other slaughter companies (participation constraint). A slaughter company can, for example, introduce a quality premium for participation in the control programme used in King *et al.* (2007) to increase pig producer gains. Alternatively, voluntary adoption across all slaughter companies or prescription by the government could solve the problem of shifting of finishing pigs to another slaughterhouse as in the Netherlands.

Consequences for consumers originate from consumption of meat from pigs infected with Ma which remained undetected in the chain. The probability that a delivery with Ma infection is incorrectly classified without increased risk and marketed towards the consumer is the so–called type–II–error. The model does not include the type–II–error, because the reservoir for human MAC infections is unclear. Pig meat could be a source, but it is also possible that humans and pigs share common sources (Komijn *et al.*, 1999). Traceability is necessary to attribute costs originating from these infections to a food business operator (Hobbs, 2004). Currently, traceability of human MAC infections to the pork supply chain is not possible. If human MAC infections can be traced to the pork supply chain, passing on costs originating from these infections to a food business operator can be an additional incentive to induce it to control Ma infections (Pouliot and Sumner, 2008). The model can be adapted to include the type–II–error and to analyse impact of such costs. The type–II–error can be calculated using an altered version of (3b), as the sum of the probabilities a delivery which has at least one Ma infected pig, is classified without increased risk (sum m>0 to 1). Multiplication by the number of Ma infected pigs $m \cdot N$ in the delivery within the altered sum yields the expected average number of undetected Ma infected pigs. Table 5.5 provides the expected type–II–error and expected average number of undetected Ma infected pigs per delivery in the steady–state for sensitivity, specificity and penalty values of Tables 5.3 and 5.4. Table 5.5 shows that higher sensitivity, lower specificity and higher penalty values decreased the expected type–II–error and average number of undetected Ma infected pigs. The public health gains of a penalty system is the difference between the expected average number of undetected Ma infected pigs at penalty value €0 and at another penalty value. Relating the gains in expected average number of undetected Ma infected pigs to additional expected chain costs compared to the chain costs at penalty value €0 (Tables 5.3 and 5.4), yielded a cost–effectiveness between €9.47 and €19.41 per undetected Ma infected pig. Public policy makers and food business operators in the pork supply chain can use the cost–effectiveness in the decision whether an penalty on Ma infected finishing pigs to induce Ma control by pig producers is appropriate.

The model provides insight into impact of testing accuracy on incentives of pig producers to implement Ma control measures. However, the model can be adapted to analyse consequences of testing strategy for any quality attribute for which diagnostic tests are used to measure supplier performance. The model can be a valuable tool for analysing impact of diagnostic testing strategies on costs, benefits and supplier incentives to take food safety control measures in a setting of an incentive system with a penalty to induce performance.

Table 5.5: Expected type–II–error and expected average number of Ma infected pigs per delivery of 100 pigs in the steady–state for sensitivity, specificity and penalty values of Tables 5.3 and 5.4.

	Expected type–II–error					**Expected average number Ma infected pigs per delivery (100 pigs)**				
Sensitivity	**0.50**	**0.70**	**0.90**	**0.70**	**0.70**	**0.50**	**0.70**	**0.90**	**0.70**	**0.70**
Specificity	**0.95**	**0.95**	**0.95**	**0.97**	**0.99**	**0.95**	**0.95**	**0.95**	**0.97**	**0.99**
Penalty (€/pig)										
0	0.095	0.080	0.069	0.095	0.111	1.36	1.00	0.76	1.24	1.53
2	0.091	0.071	0.062	0.090	0.111	1.31	0.90	0.68	1.18	1.53
4	0.079	0.065	0.051	0.087	0.106	1.12	0.71	0.52	1.13	1.47
6	0.076	0.055	0.049	0.083	0.106	1.08	0.60	0.50	1.09	1.47
8	0.063	0.055	0.018	0.078	0.104	0.73	0.60	0.10	0.89	1.45
10	0.063	0.019	0.018	0.078	0.102	0.73	0.10	0.10	0.89	1.42

5.7. Conclusion

Higher sensitivity and lower specificity resulted in use of more intense control measures, higher producer costs and lower *Mycobacterium avium* seroprevalence. The minimal penalty values to comply with a threshold for average Ma seroprevalence in finishing pigs at slaughter was lower at higher sensitivity and lower specificity. With imperfect specificity a larger sample size decreased pig producer incentives to control *Mycobacterium avium* seroprevalence. Sensitivity, specificity, sample size and penalty value must be attuned in an incentive system to induce pig producers to implement *Mycobacterium avium* control in finishing pigs with minimum negative effects.

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Chapter 6

Reliability of food chain information about antibiotic usage in finishing pigs provided by pig producers to a Dutch slaughter company[7]

Abstract

The EU prescribes food business operators to use food chain information in order to control food safety. This research analyzes reliability of food chain information about antibiotics usage during 60 days prior to delivery to a large Dutch slaughter company. A dataset with 479 test results for antibiotics residues in tissue samples of finishing pigs was linked to information on delivery documents provided by pig producers about antibiotics usage in these pigs. A Pearson chi–square test showed that twice as much pig producers reported using antibiotics in the group of 82 pig producers with detected antibiotics residues (11.0%) as in the group without detected antibiotics residues (5.5%). For 89% of deliveries with a finishing pig with detected antibiotics residues 'did not use antibiotics' was reported. Food chain information about antibiotics usage provided by pig producers was no guarantee for absence of antibiotics residues in delivered finishing pigs. To improve reliability of this food chain information policy makers should focus on increasing control depth, the probability of detecting unreliable food chain information if a non–compliant pig producer is checked. Research is needed to determine benefits and costs of increased control depth. If costs exceed benefits food chain information about antibiotics usage is not a relevant instrument to improve food safety and pig producers should not be requested to provide it.

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[7] C.P.A. van Wagenberg , G.B.C. Backus, J.G.A.J. van der Vorst and H.A.P. Urlings. Submitted to an ISI journal.

6.1. Introduction

Food safety is an important food attribute for consumers, governments and food business operators (FBOs) that has to be further improved continuously. As food safety legislation in the EU at the end of the 20th century was insufficiently equipped to do so, the EU adopted new food safety legislation with the General Food Law (EFSA, 2007). This states that food safety must be controlled throughout the supply chain, FBOs have primary legal responsibility for food safety, and governments keep the final responsibility to supervise that marketed products are safe (Regulation (EC) No 178/2002). In this setting, for FBOs it is essential that, next to intra–company application of control measures, purchased raw materials are of sufficient safety (Van Wagenberg *et al.*, 2009). For governments it is essential that marketed products are of sufficient safety to guarantee public health. But, whether or not intermediate and consumer food products are of sufficient safety is often difficult to verify. This can result in information asymmetry about product safety between supplying and buying FBOs in food supply chains and between FBOs and governments, possibly leading to opportunistic behaviour with consequential public health risks (Hennessy *et al.*, 2003; Hirschauer and Musshoff, 2007). To reduce information asymmetry, a buyer or government can measure food safety performance with testing technologies. This can, however, be costly and time consuming (Unnevehr *et al.*, 2004). So, FBOs and governments are searching for more cost–effective strategies to reduce information asymmetry about food safety. Provision of information by supplying FBOs to a buying FBO or from FBOs to a government can be such a strategy (Van Wagenberg *et al.*, 2009). Sharing relevant information between suppliers and buyers can improve chain performance through information and relational alignment (Tan *et al.*, 2010), better coordination and planning of the supply chain (Lee and Whang, 2000) and can increase customer satisfaction (Eggert and Helm, 2003). Completeness and correctness, or reliability, of the information is essential for the user to prevent negative social and economic impacts (DeLone and McLean, 1992; Feldmann and Müller, 2003; Wang, 1996). However, fear of the information being misused (Mohtadi, 2008; Mohtadi and Kinsey, 2005) and expected negative financial consequences can result in provision of unreliable information. If a buying FBO adjusts logistical and production processes to unreliable information, it can result in lower chain performance, decreased customer satisfaction, and food safety and public health problems. If governments adjust control strategies to unreliable information, it can result in food safety and public health problems. It is, therefore, important that FBOs provide reliable information about food safety.

The public control system for food safety in the EU increasingly relies on information provided by FBOs under control. Regulation (EC) No 852/2004 prescribes FBOs in the EU to use appropriate hygiene measures and to keep records from which relevant information, on request, must be made available to receiving FBOs and the competent authority. For public health it is essential that this food chain information (FCI) FBOs provide is reliable. However, a literature review showed a lack of literature on the reliability of FCI as prescribed by EU legislation. This research aims to fill this gap by analyzing the reliability of FCI about antibiotics usage in finishing pigs in the Netherlands.

6.2. Food chain information about antibiotics usage in finishing pigs in the Netherlands

Prior to delivery to a slaughterhouse, pig producers in the EU have to provide FCI that helps slaughterhouses to control food safety such as the pigs health status, farms the pigs originate from, veterinary medicinal products administered to the pigs, occurrence of diseases affecting meat safety, results of analyses on the pigs of interest to food safety and public health, relevant reports about previous ante– and post–mortem inspections of pigs, production data which might indicate presence of diseases, and name of the attending veterinarian (Regulation (EC) No 853/2004). Pigs treated with an antibiotic slaughtered during the antibiotic's withdrawal period, the period in which pigs treated with the antibiotic are not allowed for slaughter, can result in products with a too high level of antibiotic residues and pose a risk for public health (Pikkemaat *et al.*, 2009). In Council Regulation (EEC) 2377/90 the EU establishes allowed residue levels through maximum residue limits (MRL) for veterinary medicinal products in foodstuffs of animal origin. Since 2008 pig producers in the Netherlands legally have to provide FCI to Dutch slaughter companies about antibiotics usage in delivered pigs during 60 days prior to delivery in order to improve control of antibiotics residues in pork. A major Dutch slaughter company already asked for FCI about used antibiotics during 60 days prior to slaughter since 2007. To analyse the reliability of the provided FCI this research focused on pig producers with detected antibiotics residues in finishing pigs. Under the assumption that provided FCI was reliable, i.e. correct and complete, it was expected that the percentage of pig producers who reported antibiotics usage, was higher for the group of pig producers with detected antibiotics residues than for the group of pig producers without detected antibiotics residues. Furthermore, because the withdrawal periods of detected antibiotics are less than 60 days (Table 6.1), it was expected that pig producers with detected antibiotics residues used antibiotics during 60 days prior to delivery. So, under the assumption that these pig producers provided reliable FCI, it was expected that they reported antibiotics usage in finishing pigs to the slaughter company.

Table 6.1: Withdrawal period of antibiotics found in finishing pigs delivered to a Dutch pig slaughter company in 2007 and 2008.

Antibiotic	Withdrawal period (days)[a]
Doxycycline	5 – 28
Oxytetracycline	3 – 53
Tetracycline	3 – 53
Sulfadiazine	5 – 28
Sulfamethoxazol	3 – 12
Dihydrostreptomycine	35 – 49
Penicillin G	5 – 10
Tulathromycine	33

[a] From database veterinary medicines of the Medicine Evaluation Board of the Netherlands (http://www.cbg-meb.nl/CBG/en/veterinary-medicines/database-veterinary-medicines/default.htm).

6.3. Material and method

6.3.1. Residues of antibiotics

Information about residues of antibiotics in finishing pigs was obtained from a dataset with screening results of tests for antibiotics residues in tissue samples of finishing pigs delivered to a major Dutch pig slaughter company in 2007 and 2008. This slaughter company was chosen because it had screening system for antibiotics residues and slaughtered 60% of the total number of pigs slaughter in the Netherlands (8.5 million pigs) in 2007 and 57% (8.2 million pigs) in 2008. The screened finishing pigs in the dataset were from multiple slaughter locations. For each slaughter location, screened pigs were selected randomly from deliveries of finishing pigs from farms that had double the lung lesion prevalence and pleurisy prevalence compared to the average of all farms delivering to that slaughter location. The dataset contained screening results of tests for antibiotics residues of 22,633 finishing pigs; 11,490 in 2007 and 11,143 in 2008.

Residues of antibiotics were determined with the three–step method described in Pikkemaat *et al.* (2009). First, a Nouws Antibiotics Test–screening (NAT–screening) on pre–urine kidney fluid was carried out. Second, if the NAT–screening indicated the possible presence of antibiotics, two post–screening test on meat juice (NAT–meat test) and on kidney juice (NAT–kidney test) were performed simultaneously. Third, if one or both of the post–screening tests indicated the possible presence of antibiotics, chemical confirmation based on extraction, separation and detection procedures described in Stolker and Brinkman (2005) was conducted on meat.

6.3.2. Information about antibiotics usage

For 141 finishing pigs from the dataset with screening results (93 in 2007, 48 in 2008) chemical confirmation showed residues of antibiotics. Of 45 of the finishing pigs with a chemical confirmation (31 in 2007, 14 in 2008) the laboratory only reported compliance with the MRL without reporting the measured quantitative residue level. The results from these finishing pigs were excluded from the analysis, because lack of information about the measured quantitative residue level could also mean that the level was zero, i.e. no residues. The 96 positive finishing pigs with detectable levels of antibiotics were from 74 pig producers, of whom 61 pig producers had one delivery with one positive finishing pig, 12 pig producers had two deliveries with one positive finishing pig in each delivery, and one pig producer had 11 finishing pigs in nine deliveries (two deliveries with each two positive finishing pigs). The pig producer with 11 positive finishing pigs was excluded from the analysis, because he was first subjected to intensified surveillance and finally excluded from delivery to the slaughter company. This resulted in 85 deliveries with each one positive finishing pig.

Delivery documents provided FCI about antibiotics usage in the finishing pigs during 60 days prior to delivery. For each delivery of finishing pigs arriving at a slaughterhouse the pig producer must fill out a delivery document with the FCI questions at least 24 hours prior to delivery. All pig producers declared they filled out the delivery document correctly and completely by signing the delivery document. In 2007 and 2008, different delivery documents concerning treatment statements about antibiotics usage during the 60 days prior to delivery existed. Of the 85 deliveries with a positive finishing pig, 60 delivery documents contained a statement about a group treatment, 22 about treatment of individual pigs, and three did not include a statement[8]. These last three were excluded from the analysis, resulting in 82 deliveries with a corresponding delivery document with a statement about antibiotics usage.

The deliveries without antibiotics residues were selected from the deliveries of the 22,492 screened finishing pigs without a chemical confirmation (11,397 in 2007 and 11,095 in 2008). Because the delivery documents were only available as hardcopies, a sample of 397 deliveries without antibiotics residues was randomly selected for analysis using an arcsinus–transformation (Cohen, 1977). This sample size allows for detection of statistical difference of 5% point between the percentage of pig producers who indicated antibiotics usage in the sample with a quantitative residue level on the one hand and in the sample without a quantitative residue level on the other hand, with a power of 0.95 and an alpha of 0.01 (Cohen, 1977). To exclude a possible bias in slaughter location, year and season, the numbers of deliveries from each slaughter location, year and month in the sample of deliveries without antibiotics residues were set proportional to the numbers in the sample of the deliveries with

[8] Three documents were of an older type in use prior to the time a statement about antibiotics usage was included on the document. Pig producers used this older type, probably because they had a stock of delivery documents and only asked for new documents once their stock needed replenishment.

antibiotics residues. Of the 397 delivery documents of deliveries without antibiotics residues, 299 included a statement about group treatment and 98 about treatment of individual finishing pigs.

6.3.3. Statistical analysis

A Pearson chi–square test of goodness of fit (Pearson, 1900) was used to test if the percentage of pig producers who indicated antibiotics usage was higher for the group of pig producers with detected antibiotics residues than for the group of pig producers without detected antibiotics residues for all treatment statements.

A pig producer could, however, have correctly indicated he did not use group treatment with antibiotics, even if a finishing pig in a delivery was found to have antibiotics residues, because he could have treated only this individual finishing pig. A separate analysis was, therefore, conducted for deliveries with only statements about treatment of individual finishing pigs on the delivery document. Because of the low number of deliveries, more than 25% of the expected cell counts had a value of less than five, a Pearson chi–square test of goodness of fit was not appropriate (Fingleton, 1984) and instead a Fisher's exact test (Agresti, 1992) was performed to test if the percentage of pig producers who indicated antibiotics usage in individual finishing pigs was higher for the group of pig producers with detected antibiotics residues than for the group of pig producers without detected antibiotics residues.

If antibiotics residues were detected with chemical confirmation, it can be expected that the finishing pig producer reported 'did use antibiotics' on the delivery document. So, the expected number of delivery documents with 'did not use antibiotics' would be zero. It is, however, possible that for a delivery with residues the delivery document correctly reported 'did not use antibiotics' during 60 days prior to delivery, because it can not be excluded that an individual finishing pig is found to have antibiotics residues at slaughter, even when the pig producer did comply with the withdrawal period. This is because withdrawal periods are set based on probabilistic analysis of medicine clearing times in experiments and for an individual finishing pig the medicine clearing time could exceed 60 days. In other words, it is not possible to univocally set the expected number of delivery documents reporting 'did not use antibiotics' in the deliveries with residues at zero, but it is expected to be low. The expected number of delivery documents reporting 'did not use antibiotics' was (reasonably but arbitrary) set at 10% of the 82 delivery documents found with residues of antibiotics, which is eight. A Pearson chi–square test of goodness of fit was used to compare the real number of delivery documents reporting 'did not use antibiotics' to the expected number of delivery documents reporting 'did not use antibiotics'. Setting the expected number of delivery documents reporting 'did not use antibiotics' at 20% (16) or 30% (25) yielded similar empirical results.

6.4. Results

Table 6.2 provides the number and percentage of pig producers with and without detected antibiotics residues reporting 'did use antibiotics' and 'did not use antibiotics' during 60 days prior to delivery. The percentage of pig producers who reported 'did use antibiotics' was twice as high for the group of pig producers with detected antibiotics residues by chemical confirmation in finishing pigs (11.0%) as for the group of pig producers without detected antibiotics residues in finishing pigs (5.5%) ($p=0.0686$). Using the statements about treatment of individual finishing pigs yielded comparable results ($p=0.4066$). The majority of delivery documents of the 82 deliveries with a finishing pig with detected antibiotics residues (89.0%) and of the 22 deliveries with a finishing pig with detected antibiotics residues exceeding the MRL (86.4%) did report 'did not use antibiotics' prior to delivery. The real number of delivery documents reporting 'did not use antibiotics' (73 of 82 deliveries) in deliveries with residues was higher than the expected number of eight ($p<0.001$).

Table 6.2: Number (*n*) and percentage (%) of deliveries of pig producers to a Dutch slaughter company in 2007 and 2008 with the pig producer reporting 'did use antibiotics' and 'did not use antibiotics' in the finishing pigs during 60 days prior to delivery for deliveries in which residues of antibiotics were and were not detected per type of treatment statement.

	Delivery documents reporting				
	'did use antibiotics'		**'did not use antibiotics'**		**Total**
Deliveries	***n***	**%**	***n***	**%**	***n***
Statements about group treatment and treatment of individual finishing pigs					
Without antibiotic residue	22	5.5 [c]	375	94.5	397
With antibiotic residue [a]	9	11.0 [c]	73	89.0	82
- Under MRL [b]	6	10.0	54	90.0	60
- Exceeding MRL [b]	3	13.6	19	86.4	22
Statements about treatment of individual finishing pigs					
Without antibiotic residue	6	6.1 [d]	92	93.9	98
With antibiotic residue [a]	2	10.0 [d]	18	90.0	20

[a] Based on chemical confirmation.
[b] MRL = Maximum residue limit.
[c] Statistical difference at p = 0.0686.
[d] Statistical difference at p = 0.4066.

6.5. Discussion

The analysis shows that 89% of pig producers with detected antibiotics residues reported they did not use antibiotics in the finishing pigs during the 60 days prior to delivery to a Dutch slaughter company. This shows that the provided information ‘did not use antibiotics’ was no guarantee for the absence of antibiotics residues in pork, and that the FCI was unreliable.

In 16.3% (73) of the 448 deliveries of which the delivery documents reported ‘did not use antibiotics’ a finishing pig with a quantitative level of antibiotics residue was detected. The non–compliance to provide correct FCI about antibiotics usage hampers control of antibiotics residues in pork. For the FCI to be useful, the non–compliance needs to be decreased. Non–compliance for provision of reliable information can be due to errors, because of lack of knowledge or concern, or deliberate actions (Elffers *et al.*, 2003). It was not possible to assess whether or not pig producers with detected antibiotics residues accidently or deliberately reported ‘did not use antibiotics’. But, the reasons for the presence of antibiotics residues can provide an indication for this. These reasons were identified through telephone and email contact of slaughter company personnel with the pig producers with detected antibiotics residues. Of 47 of these pig producers reasons for presence of antibiotics residues were retrieved (Table 6.3). Most reasons provided seem related to errors: cross–contamination with medicated water and feed, forgetfulness about the withdrawal period, incorrectly recording and marking of medicated finishing pigs, and the sickness of treated pigs. This is supported by the fact that 73 of the 74 pig producers, who had deliveries with a finishing pig with antibiotics residues in 2007 and 2008, had one or two deliveries with a finishing pig with residues. The

Table 6.3: Reasons provided by pig producers for presence of antibiotics residues in finishing pig deliveries to a Dutch slaughter company in 2007 and 2008.

Reason	**Number of deliveries**
Cross–contamination through water	2
Cross–contamination through feed	10
Incorrectly adjusted feeding system	2
Incorrectly adjusted medicated water system	5
Incorrectly recording antibiotics usage	4
Delivered finishing pigs were medicated, but forgot to comply with the withdrawal period	12
Delivered medicated finishing pigs due to incorrect marking of sick finishing pigs	6
Delivered finishing pigs were treated for sickness, but recovered at delivery	8
Total	49 [a]

[a] From 47 pig producers reasons were retrieved. Two pig producers provided each two reasons.

non–compliance with the presence of antibiotics residues thus seems mainly related to errors instead of deliberate actions. However, accidentally providing antibiotics in the 60 days prior to delivery by itself does not prevent deliberately reporting 'did not use antibiotics', because a pig producer could have detected the accidental provision of antibiotics prior to filling out the delivery document.

To improve compliance with the law to provide reliable FCI about antibiotics usage, factors that induce non–compliance have to be solved. To analyse compliance with regulatory laws of Dutch primary producers the Table–of–Eleven (T^{11}) can be used (Elffers *et al.*, 2003). The T^{11} includes six spontaneous compliance dimensions and five induced compliance dimensions promoting and opposing compliance with a law (Elffers *et al.*, 2003). The spontaneous compliance dimensions, which are not under direct control of a law–enforcing agency, include lack of knowledge about and clarity of rules, costs and benefits associated with compliance and non–compliance, acceptability of rules, general conformity with respect to laws and authorities, informal control by the social environment, and spontaneous detection. The induced compliance dimensions, which focus on activities of a law–enforcing agency, include the probability that an arbitrary producer will be controlled (control density), the conditional probability of detecting non–compliance given that a non–compliant producer is checked (control depth), targeting of control activities towards producers with increased risk of non–compliance, sanction certainty if non–compliance is detected, and sanction severity. Improvement of spontaneous compliance could come from increased knowledge and clarity about the rules. Specifically, some pig producers, who provided reasons for detected antibiotics residues, indicated to have interpreted the 60 day period in the question on the delivery document as the shorter withdrawal period. However, this does not solve the possible problem of deliberately providing unreliable FCI.

The induced compliance dimensions focus on control and sanctioning system. In the Netherlands slaughter companies are responsible to check the completeness and correctness of provided FCI. The Dutch Food and Consumer Product Safety Authority VWA verifies whether slaughter companies sufficiently check provided FCI. If the VWA detects a slaughter company insufficiently checking FCI, it notifies the slaughter company to improve its checks and issues the slaughter company a warning.

Concerning control and sanctioning of FCI provided by pig producers, a distinction can be made between correctness of FCI and completeness of FCI, irrespective of the reliability. First, neither the slaughter company in this research nor the official veterinarian of the VWA responsible for the ante–mortem assessment of delivered finishing pigs did structurally check correctness of provided FCI. Although all delivery documents were checked at the slaughter location, it was not possible to check correctness of FCI about antibiotics usage. So, existing sanction possibilities could not be used. Only if answers to different FCI questions were clearly inconsistent, for example a high mortality rate and no usage of antibiotics, the competent authority for the primary sector, the General Inspection Service AID, was notified, which conducted a farm visit to investigate the possible misuse of antibiotics and issued a warning or a fine depending on the severity of non–compliance. No verification on the slaughter company check of correctness of the provided FCI by the VWA existed. In conclusion, according to the induced compliance dimensions of the T[11] the control depth for the correctness of provided FCI was insufficient. Second, both the slaughter company and the official veterinarian of the VWA structurally checked whether FCI was provided. If FCI was lacking for a delivery, it was not allowed for slaughter. The pig producer was notified and provided with the opportunity to still provide FCI. After FCI was received the finishing pigs were allowed for slaughter without further consequences for the pig producer. Concluding, completeness of FCI was actively enforced.

For presence of antibiotics residues in finishing pigs two screening systems were in place. The samples from both screening systems were analysed in the state laboratory with the same methods and procedures. The first was the Dutch National Surveillance Program for detection of antibiotics residues conducted by the VWA according to Council Directive 96/23/EC. It randomly searches for antibiotics residues in a specified number of finishing pigs on slaughterhouses using prescribed sampling and analysis techniques. In the slaughter company in this research 1588 and 1516 finishing pigs were screened in 2007 and 2008, respectively. No finishing pigs had antibiotics residues exceeding the MRL in 2007, and 2 in 2008. Non–compliant cases were investigated by the AID and the pig producer was issued a warning or fined depending on severity of non–compliance. The second was the private screening system for antibiotics residues of the slaughter company in this research. The screening system was risk based using the idea that higher lung and pleurisy prevalence indicates more health problems and, therefore, a possible higher usage of antibiotics and higher risk at the presence of antibiotics residues. It did not use provided FCI to steer sampling. From each delivery of finishing pigs from farms that had double the lung lesion prevalence and pleurisy prevalence compared to the average of all farms delivering to a slaughter location one finishing pig was randomly selected for screening. This resulted in a sample size of over 11,000 finishing pigs in 2007 and in 2008. If a sample with antibiotics residues was detected, slaughter company personnel contacted the pig producer to identify the cause of the presence of residues (Table 6.3). Because the samples were analysed in the state laboratory, results of samples that exceeded the MRL were also directly from passed on to the AID for legal assessment. Such cases were equally dealt with as cases detected in the National Surveillance Program. Of the 74 pig producers, who had deliveries with a finishing pig with antibiotics residues in 2007 and 2008 detected with the private screening system, 73 pig producers had one or two deliveries with a finishing pig with residues. The slaughter company personnel pointed out to these pig producers that they incorrectly indicated no usage of antibiotics during the 60 days prior to delivery on the delivery document. The slaughter company did not apply further sanctions towards these pig producers. The single pig producer who repeatedly had antibiotics residues was first subjected to intensified surveillance and finally excluded from delivery to the slaughter company.

Currently, without a control and sanctioning system for reliability of provided FCI about antibiotics usage in finishing pigs, the provided FCI was unreliable. To improve reliability of the provided FCI, the control depth, i.e. the conditional probability of detecting incorrect FCI given that a non–compliant pig producer is checked, should be increased. Control could for example focus on a crosscheck of provided FCI with the medicine logbook of the pig producer, although this relies on the pig producer filling out the logbook correctly. For cost–effective control benefits of increased control depth in terms of public health improvement should outweigh increased control cost. Difficulty for the government or a slaughter company to verify actual antibiotics usage by pig producers and to relate this to the FCI provided on the delivery documents would probably result in high control costs. Further research is needed to determine benefits and costs of increased control depth. If costs exceed benefits, FCI is not a relevant instrument to improve food safety and pig producers should not be requested to provide this FCI.

6.6. Conclusion

This paper showed that food chain information about antibiotics usage during the 60 days prior to delivery to a Dutch slaughter company provided by pig producers was no guarantee for absence of antibiotics residues in delivered finishing pigs, and that this information was, therefore, unreliable. To improve reliability of food chain information about antibiotics usage in finishing pigs, policy makers should focus on increasing control depth, the probability of detecting unreliable food chain information if a non–compliant pig producer is checked. Further research is needed to determine benefits and costs of increased control depth. If costs exceed benefits, food chain information is not a relevant instrument to improve food safety and pig producers should not be requested to provide it.

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Chapter 7

General conclusions and discussion

7.1. Introduction

This thesis analyzed incentive mechanisms for food safety control in the Dutch pork supply chain between pig producers and slaughterhouses. Chapter 2 developed a framework for designing and analysing incentive mechanisms aimed at food safety control. It was concluded that key elements of incentive mechanisms for food safety control are the performance and compliance measurement system and the compensation scheme. Chapters 3 to 6 analysed the impact of characteristics of these key elements on supplier performance and compliance. In chapter 3 the effectiveness of two incentive mechanisms with different financial performance compensation to improve food safety performance was investigated. Chapter 4 analysed the relationship between measured performance, the decision process about the usage of control measures, and the actual control measures a pig producer used, while being subjected to an incentive mechanism with a penalty on products off–specification. Chapter 5 elaborated on the impact of performance measurement accuracy on control measures used by pig producers and on performance with a penalty on products off–specification in place. Finally, reliability of compliance information provided by pig producers about control measures used without a compensation scheme was analysed in chapter 6.

In each chapter the objectives, methods and results have been discussed. This chapter discusses general aspects and integrates all findings. Section 7.2 answers the research questions. Section 7.3 provides the general discussion. The general conclusions are presented in section 7.4. Section 7.5 elaborates on the theoretical contribution and section 7.6 on the managerial implications. Finally, section 7.7 provides an outlook for further research.

7.2. Answers to the research questions

This thesis aims to contribute to improvement of food safety by analysing incentive mechanisms aimed at food safety control between pig producers and slaughter company. To reach the aim five research questions were posed in chapter 1. This section provides answers to the research questions.

RQ1 What are key elements of incentive mechanisms aimed at food safety control?
In chapter 2 the key elements of incentive mechanisms aimed at food safety control were determined with a literature review on incentive mechanisms for food quality and food safety control. An incentive mechanism aimed at food safety control was defined as the set of performance and compliance measurement system and compensation scheme between buyer and supplier, which aims to induce the supplier to apply measures to control food safety hazards as the buyer requests. The performance and compliance measurement system is characterised by the indicator used to determine food safety performance and compliance, the accuracy of the measurement, and the actor who conducts performance and compliance measurement and determines performance and compliance. The performance and compliance compensation scheme is characterised by the type of compensation used. A combination of incentive mechanisms between multiple supply chain stages make up an incentive system for food safety control.

Chapter 2 determined the performance and compliance measurement system and the performance and compliance compensation scheme as the key elements of an incentive mechanism aimed at food safety control.

RQ2 How effective are incentive mechanisms with a collective insurance premium and a price reduction per lesioned liver in reducing liver lesion prevalence in finishing pigs?
In chapter 3 the effectiveness of two types of performance compensation in an actual incentive mechanism aimed at liver lesion control in finishing pigs was investigated: a collective insurance premium for each delivered finishing pig, in place prior to July 2004, and a reduction in pig producer payment for each delivered finishing pig with a liver lesion, in place from July 2004. Liver inspection data of finishing pigs slaughtered in 2003–2006 by a major Dutch slaughter company were analysed with an out–of–sample dynamic forecast test and non–parametric bootstrapping. Results showed that after introduction of the price reduction per finishing pig with a lesioned liver, mean liver lesion prevalence decreased from 9 to 5%. A reduced liver lesion prevalence ranging from 0 to 46 percentage points was observed on 67% of the 1069 farms that delivered both during the insurance and the price reduction period. The number of farms with a liver lesion prevalence of 5.0% or less increased from 52 to 68%.

However, even with the incentive mechanism with price reduction, variability in liver lesion prevalence between individual pig producers was observed.

Chapter 3 showed that an incentive mechanism with a penalty on products off–specification was more effective in inducing pig producers to lower liver lesion prevalence in finishing pigs than an incentive mechanism with a collective insurance premium.

RQ3 What causes variability in liver lesion prevalence in finishing pigs of finishing pig producers subjected to an incentive mechanism with a price reduction per lesioned liver?

Chapter 4 analysed causes for variability in liver lesion prevalence for the pig producers subjected to the price reduction per finishing pig with a lesioned liver as observed in chapter 3. Liver lesion inspection data was matched with results from a farmer survey. In the survey, pig producers provided data about the control measures used and factors underlying their decision making process for the treatment of *Ascaris suum* infections, the main cause for liver lesions in finishing pigs. The factors underlying the decision making process were based on the Theory of Planned Behaviour. Results showed that 96% of the 185 pig producers in the analysis used anthelmintics, i.e. medication to control *Ascaris suum* infections in finishing pigs. The pig producers used a variety of combinations of active compounds, application methods, and duration of application. Application of anthelmintics by sprinkling over feed was associated with 2.4% higher liver lesion prevalence compared to other application methods. Furthermore, pig producers underestimated their liver lesion prevalence in finishing pigs, thus reducing their need to apply effective management practices to lower liver lesion prevalence.

Chapter 4 demonstrated that variability in liver lesion prevalence in finishing pigs of pig producers subjected to an incentive mechanism with a price reduction per lesioned liver was caused by using different control measures with varying effectiveness and underestimation of liver lesion prevalence.

RQ4 What is the impact of the accuracy of a Mycobacterium avium test on the Mycobacterium avium prevalence in finishing pigs of pig producers subjected to an incentive mechanism with financial compensation aimed at Mycobacterium avium prevalence?

Chapter 5 studied the impact of accuracy of a serodiagnostic test used in the performance measurement system, defined by sensitivity and specificity, on food safety performance of pig producers using the hazard *Mycobacterium avium*. Sensitivity is the probability of correctly qualifying a product with increased risk and specificity is the probability of correctly qualifying a product without increased risk. With a dynamic optimization model with a grid search of deliveries of herds from pig producers to slaughterhouse and a theoretical incentive mechanism aimed at *Mycobacterium avium* control, optimal penalty values for deliveries with increased *Mycobacterium avium* seroprevalence were identified for different sensitivity and specificity values. Higher sensitivity and lower specificity resulted in usage of more intense control measures by pig producers, higher producer costs and lower *Mycobacterium avium* seroprevalence. The minimal penalty value needed to comply with a threshold for average Ma seroprevalence in finishing pigs at slaughter was lower at higher sensitivity and lower specificity.

Chapter 5 showed that higher sensitivity and lower specificity of a diagnostic test lowers *Mycobacterium avium* seroprevalence in finishing pig deliveries of pig producers subjected to an incentive mechanism with a penalty for deliveries with increased *Mycobacterium avium* prevalence. With imperfect testing specificity and low hazard prevalence, a larger sample size can decrease pig producer incentives to improve performance.

RQ5 What is the reliability of information about antibiotics usage in finishing pigs provided by pig producers used as compliance measurement in an incentive mechanism without compliance compensation?

Chapter 4 showed that variability in performance can also originate from suppliers choosing different combinations of control measures with varying effectiveness. To ascertain what control actions a supplier used, a buyer can ask the suppliers to provide him with information about the control measures used. This information needs to be reliable to be useful in control mechanisms on supply chain level. Chapter 6 examined the reliability of information about used antibiotics provided by pig producers in a situation without a control system to check the reliability of the provided information. A dataset with test results for antibiotics residues in tissue samples of finishing pigs was matched with information on delivery documents provided by pig producers about antibiotics usage in these finishing pigs. A Pearson chi–square test showed that twice as much pig producers reported using antibiotics in the group of pig producers with detected antibiotics residues (11.0%) as in the group without detected antibiotics residues (5.5%). For 89% of deliveries with a finishing pig with detected antibiotics residues ‘did not use antibiotics’ was reported.

Chapter 6 demonstrated that without a control system to check the reliability of the provided information, the information about antibiotics usage in finishing pigs during 60 days prior to delivery reported by a pig producer, did not guarantee absence of antibiotics residues in the finishing pigs. This information was therefore insufficiently reliable to be used in a control system for antibiotics residues in finishing pigs by a slaughterhouse.

7.3. Discussion

This thesis showed that private incentive mechanisms aimed at food safety control can improve average performance of suppliers and thereby food safety performance of a supply chain. Chapters 3 to 6 focussed on different characteristics of incentive mechanisms. Figure 7.1 combines the findings of chapters 3 to 6 in the framework of incentive mechanisms for food safety control developed in chapter 2. In this thesis, the slaughter company owned the incentive system and incentive mechanism, which were integrated in the slaughter company. The discussion in this section relates to various aspects of Figure 7.1.

7.3.1. Performance and compliance measurement system and compensation scheme

A penalty on products off–specification induced most finishing pig producers to intensify control on *Ascaris suum* infections and improved average performance compared to a collective insurance fee. This is in line with literature about food quality control, which showed that financial piece rates improve average food quality performance of primary producers (e.g. Chalfant and Sexton, 2002; Hueth and Melkonyan, 2004; Martinez and Zering, 2004; McDonald and Schroeder, 2003).

This thesis showed that settings of the accuracy of a diagnostic test and sample size in combination with a penalty on products off–specification influence supplier incentives to apply control measures. Jeschonowski *et al.* (2009) also argued that measurement scale and reward schemes should be attuned for optimal incentive provision. Higher sensitivity and lower specificity of a diagnostic test can be used to increase incentives for farmers to improve performance. Heinkel (1981) also found that the accuracy of the testing technology influenced car dealer incentives to improve car quality. Chalfant and Sexton (2002) and Hueth *et al.* (2007) showed that errors in the grading of products can be used to induce farmers to produce high quality. In normative studies on incentive mechanisms, however, generally a perfect testing accuracy is assumed (Backus and King, 2008; Hirschauer and Musshoff, 2007; King *et al.*, 2007; Resende-Filho and Buhr, 2008). But, testing accuracy in practice is often imperfect (Unnevehr *et al.*, 2004). The normative studies, therefore, could have under– or overestimated the effect of the incentive mechanisms in reality, depending on the specific values of sensitivity and specificity of the test used to determine performance.

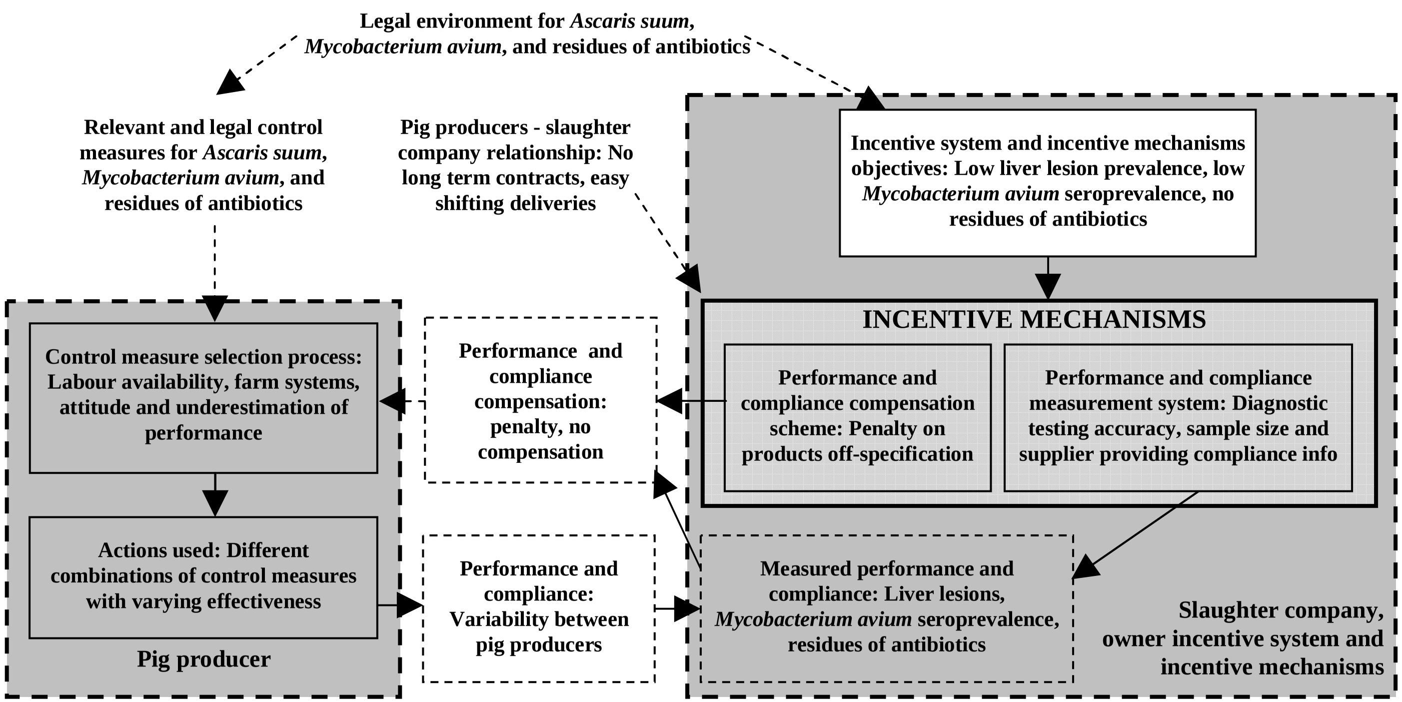

Figure 7.1: Key elements and aspects analysed within the framework for analysing incentive mechanisms for food safety control in supply chains The incentive mechanism is the light gray box. Actors are represented in dark gray boxes with dotted lines. Boxes with a thin solid line indicate key aspects for food safety control that are determined by the actors. Boxes with thin dotted lines correspond to aspects that result from control measures used by the supplier. External factors of influence on the incentive mechanism are represented without boxes. Solid arrows stand for 'A determines B', dotted arrows for 'A influences B'.

Another characteristic of the performance and compliance measurement system is the actor who carries out performance and compliance measurement and determines performance and compliance. The system owner can conduct performance and compliance measurement as in chapters 3, 4 and 5 and e.g. Hueth *et al*. (1999). Another option is a third party conducting performance and compliance measurement. Often it is assumed that a third party is independent and that, therefore, the performance and compliance measurement is reliable. Recent research raises questions on the independence of third parties (Hatanaka and Busch, 2008; Souza Monteiro and Anders, 2009). A third option mostly neglected in literature, is the supplier carrying out performance and compliance measurement. This is increasingly used in public and private food safety control, for example Food Chain Information in the EU food safety policy. If the supplier or a third party caries out performance and compliance measurement, information needs to be transferred to the system owner. In supply chain research mainly technical aspects of information flows are addressed and opportunistic behaviour as a reason for information distortion is neglected (Feldmann and Müller, 2003). Chapter 6 showed that if no compensation scheme aimed at reliability of provided compliance information existed, the provided information was not reliable and can not be used as compliance measurement in an incentive mechanism owned by the buyer. Feldmann and Müller (2003) design an incentive scheme to induce suppliers to provide reliable and truthful performance information. In this incentive scheme the reliability of provided performance information is determined through ex–post delivery determination of actual performance. It is unclear whether an adapted version of the incentive scheme of Feldmann and Müller (2003) can be used to ex–post determination of compliance with buyer requests.

7.3.2. Supplier performance

Variability in liver lesion prevalence between pig producers after implementation of the penalty was observed in chapter 3. The variability originated from heterogeneity in the use of management practices between pig producers, as shown in chapter 4. The heterogeneity could be traced to differences in labour availability, farm systems, attitude towards treating *Ascaris suum* infections, and underestimation of the liver lesion problem. Pennings and Garcia (2004) also traced heterogeneity in derivative usage of small and medium sized enterprises to differences in attitudes and perceptions. This suggests that research into performance improvement possibilities for a group of heterogeneous primary producers should not only focus on the presence or absence of specific management practices, but also on the underlying attitude towards and perception about the problem under research.

Model based research on incentive mechanisms for food safety and quality control often assumes homogeneous primary producers (e.g. Backus and King, 2008; Hirschauer and Musshoff, 2007; King *et al.*, 2007; Resende-Filho and Buhr, 2008). Policy advice based on results of such normative models can be improved by inclusion of heterogeneity between primary producers.

The variability in reaction to the change in incentive mechanism aimed at liver lesion prevalence suggests that performance can be improved by using multiple incentive mechanisms. Without transactions costs incentive mechanisms individualised to each supplier were optimal in dealing with heterogeneous suppliers (Levy and Vukina, 2002). In practice transactions costs of multiple mechanism should be balanced with the gains of performance improvement of multiple incentive mechanisms.

7.3.3. Supply chain characteristics

The objective of research in this thesis was the Dutch pork supply chain between pig producers and a slaughter company. In the Netherlands pig producers and slaughter companies are independent organisations and no long–term contracts exist between them. Pig producers can shift regularly between slaughter companies and slaughter companies compete actively for receiving finishing pigs. In this setting it is difficult for an individual slaughter company to initialize new incentive mechanisms to improve food safety, because pig producers could shift to another slaughter company. Incentive mechanisms can also be used in other stages of a food supply chain. Although the number of suppliers often is lower, the amount of food products transferred from a supplier to a buyer is often larger. The lower number of suppliers makes observance of each supplier easier, but the impact of food safety incidents can be larger due to the larger amount of food products. As has been discussed in chapter 2, the parameter settings of incentive systems for food safety control depend on the specific characteristics of the supplier–buyer relationship and the supply chain, such as supply assurance, information asymmetry, ownership structure and market organization. Caution should, therefore, be exercised when extending the results from this thesis to other stages in the pork supply chain or to other supply chains.

7.3.4. Food safety hazards

In this thesis several food safety hazards in pork relevant for public health have been used: *Ascaris suum*, *Mycobacterium avium*, and residues of antibiotics. *Ascaris suum* was chosen because it is an important quality and safety attribute in the pork supply chain, an incentive mechanism with two types of performance compensation was implemented in practice, and data was available to determine the impact of the type of performance compensation on food safety performance. *Mycobacterium avium* was chosen, while *Mycobacterium avium* infections in humans can have severe consequences, for this hazard a new serodiagnostic test is under development, and slaughterhouses in the Netherlands are considering an incentive mechanism to reduce the risk of *Mycobacterium avium*. Antibiotics residues were chosen, because the use of antibiotics is strictly regulated, under full control of the farmer, and information provided by the supplier and analytical results of antibiotics residues in the same pigs were available. As each hazard has specific characteristics, caution should be practiced in extending specific results between these hazards and to other hazards in the pork supply chain, as indicated in chapter 2.

7.3.5. Usage of field data

Field data were used in part of the studies in this thesis instead of experimental data. Usage of field data assured that the ‘participants’ showed real–life behaviour with real–life performance as a result. But, in these situations uncontrolled variables could also have caused changes in observed performance, prohibiting determination of causal relationships. However, excluding other possible causes makes it likely that the variable under research caused the observed change. In contrast, in well controlled experiments causal relationships can be proven because all variables except for the one under research, are supposed to be controlled for. But, in a purely experimental setting, pig producers could have shown a different behaviour compared to their every day behaviour, the so–called Hawthorne effect (Adair, 1984; Sonnenfeld, 1985). Different behaviour would occur, because in an experimental setting pig producers would realize they were being observed. In this research with a focus on human behaviour, the results of well controlled laboratory experiments might have been insufficiently representative for real life decision making.

In this research field data, expert data and survey data were combined. Most researches only use field, experimental, expert or survey data. To our knowledge, this research is one of the few which combines these types of data in an integrated analysis. The integration showed to be of great value to identify management practices used by suppliers, which result in lower food safety performance. Furthermore, for identification of underestimation of performance, both perceived and actual performance are needed.

7.4. General conclusions

This thesis analyzed incentive mechanisms aimed at food safety control in the two stage supply chain with pig producers and a slaughter company in the Netherlands. Based on the 5 studies described in this thesis, the following can be concluded:

- The developed framework is a valuable tool for designing and analysing incentive mechanisms aimed at food safety control to optimally induce suppliers to control food safety. An incentive mechanism is defined as the set of performance and compliance measurement system and compensation scheme between buyer and supplier, which aims to induce the supplier to apply measures as the buyer requests.

- For an incentive mechanism to optimally induce suppliers to control food safety, the performance and compliance indicator, the accuracy of the measurement (sample size, test sensitivity, test specificity), and the actor who performs the measurement and determines performance and compliance must be attuned to the settings of the performance compensation scheme.
- In a setting where suppliers are independent of buyers and no long–term contracts exist, incentive mechanisms with a penalty for products off–specification can induce suppliers to use control measures and to improve food safety performance.
- Variability in performance can be expected between suppliers subjected to an incentive mechanisms with a penalty for products off–specification due to suppliers using different combinations of control measures with varying effectiveness and suppliers underestimating performance.
- If an incentive mechanism with a penalty for products off–specification is used, the accuracy of a diagnostic test used to determine performance can also be used to induce suppliers to apply control measures through financial consequences of false positives and false negatives.
- When test specificity is imperfect, hazard prevalence is low and a penalty on products off–specification is used, a larger sample size can decrease incentives for suppliers to apply control measures, because the increased number of false positives raise the probability of classifying a product as off–specification.
- Without a check and a compensation scheme, the reliability of compliance information provided by the supplier about actions used is insufficient to be useful to control food safety hazards.

7.5. Theoretical contribution

This thesis has contributed to food safety management, incentive, and supply chain management theory.

7.5.1. Food safety management theory

This thesis has three contributions to food safety management theory. First, crrently implemented food safety control systems focus on controlling food safety hazards on company level without considering the rest of the supply chain (Luning *et al.*, 2006). Hirschauer and Musshoff (2007) suggested that identification of critical control points at suppliers and adequate monitoring procedures could reduce risks arising from malpractice of opportunistic suppliers. This thesis showed incentive mechanisms with a correct performance indicator can be used to reduce opportunistic behaviour of suppliers, thereby helping to raise food safety control to the next level.

Second, to aid improvement of food safety control, food safety and quality management research and analyses should focus on integral analysis of technological and managerial factors that contribute to food safety and quality (Luning and Marcelis, 2007). The framework presented in Figure 2.3 combines relevant technological and managerial aspects for food safety control on supply chain level and their mutual relationships. It provides guidelines for integral analysis of technological and managerial factors concerning food safety control in supply chains. Specific relationships of aspects from this framework relating to the relationship between food safety performance and human behaviour were analysed in this thesis. As such, this thesis provides valuable insights into further improvement of food safety.

Third, Starbird (2005) showed that sample size and acceptance number, i.e. the number of items in the sample to be identified as contaminated, have a significant impact on supplier incentives to control food safety. Starbird (2005), however, assumed the test used to assess each item to be perfect. In reality, diagnostics tests are often imperfect (Unnevehr *et al.*, 2004). This thesis was a first study, to our knowledge, to analyse the impact of the accuracy of a diagnostic test on supplier incentives to control food safety. Not only the sampling policy, but also the diagnostic testing accuracy should be attuned to the performance compensation scheme.

7.5.2. Incentive theory

This thesis has one contribution to incentive theory, which addresses interactions in the presence of imperfect information (Gibbons, 2005; Laffont and Martimort, 2002). Incentive theory considers how a buyer can cope optimally with private information of a supplier. In incentive theory a supplier exerts effort, if expected utility of exerting effort exceeds expected utility of not exerting effort. A buyer induces actions through rewarding performance of the buyer. Most research based on incentive theory assumes that the performance measurement system used as a basis to reward performance is perfectly accurate. This assumption is also used in literature about principal–agent models for food safety control (Backus and King, 2008; Hirschauer and Musshoff, 2007; Resende-Filho and Buhr, 2008). In practice, however, performance measurement is generally not perfectly accurate due to the use of samples and imperfect testing technologies (Hueth *et al.*, 2007; Jordan, 1996; Unnevehr *et al.*, 2004). This thesis showed that inaccuracy of a diagnostic test in relationship with the sample size does influence incentives for suppliers to exert effort. This implies that inaccuracy in performance measurement must be considered in incentive theory and in principal–agent models.

7.5.3. Supply chain management theory

This thesis has three contributions to supply chain management theory. First, Lundin and Norrman (2010) indicated that research is needed on how to deal with misalignments between companies in the supply chain which result in reduced supply chain performance. This thesis showed that properly designed incentive mechanism can align company interests and thereby improve supply chain performance.

Second, this thesis adds to knowledge about the optimum combination of reward schemes and measurement scale for incentive provision (Jeschonowski *et al.*, 2009). It demonstrated that the accuracy of a diagnostic test and sample size can be used in combination with a penalty on products off–specification to induce suppliers to use control measures. This suggests that the settings of the performance and compliance measurement system and compensation scheme should be attuned.

Third, in supply chain management opportunistic behaviour as reason for distortion of information exchanged is often neglected (Feldmann and Müller, 2003). This thesis showed that information provided by the supplier about used actions was unreliable and that opportunistic behaviour cannot be neglected as source of information distortion.

7.6. Managerial implications

This thesis showed that private incentive mechanisms implemented by buyers to induce suppliers can effectively improve food safety performance of a supply chain. The following practical guidelines for FBOs, governments or other organizations which aim to implement incentive mechanisms aimed at food safety control can be formulated:

- The performance and compliance measurement system and compensation scheme should be attuned for optimal inducement of suppliers to control food safety.
- A penalty on products off–specification is more effective to induce suppliers to improve food safety performance than a collective insurance fee.
- Expect variability between individual suppliers in terms of control actions used, food safety performance, and food safety performance change from ex–ante to ex–post a new incentive mechanism. Not all suppliers will improve performance. It is advised to analyse heterogeneity between the suppliers to determine causes of variability in performance to further optimize the incentive mechanism.
- Characteristics of a diagnostic test and sampling strategy to determine supplier performance should be attuned to prevent adverse incentives for suppliers to control food safety. Higher sensitivity and lower specificity of a diagnostic test increase incentives to control food safety hazards in combination with a penalty on products off–specification. If test specificity is imperfect, a larger sample size can result in decreased food safety

performance of suppliers, due to an increased probability of rejecting a batch of products, irrespective of whether a supplier takes control measures.

- Only if reliability of information about used control actions provided by a supplier can be checked easily, it can be used in incentive mechanisms aimed at food safety control as compliance measurement.

Additionally, a number of specific managerial implications can be made concerning the pork supply chain in the Netherlands and in other regions:

- Pig producers should be induced to apply anthelmintics to finishing pigs in feed, in water or by injections instead of sprinkling over feed, because sprinkling over feed showed to be less effective to lower liver lesion prevalence than other application methods.
- Pig slaughter companies should increase effort to provide pig producers with information about their actual liver lesion prevalence in finishing pigs. Pig producers underestimated liver lesion prevalence, resulting in lower need to treat *Ascaris suum* infections. A more accurate estimation of liver lesion prevalence can help to increase the need to treat *Ascaris suum* infections and lower liver lesion prevalence.
- Pig slaughter companies should consider to design and implement incentive mechanisms, similar to that of liver lesions, to lower prevalence of other lesions in finishing pigs in the Netherlands detected at slaughter, such as lung lesions, pleurisy, skin lesions and leg lesions. The specific settings of the incentive mechanisms should be attuned to the lesion.
- Pig slaughter companies or governments in regions outside the Netherlands should consider to introduce an incentive mechanism aimed at liver lesion prevalence in finishing pigs comparable to the Dutch mechanism. The specific settings of the incentive mechanisms should be attuned to the region.

7.7. Further research

This research resulted in many topics for further research. This section describes the most important topics.

7.7.1. Performance and compliance measurement system and compensation scheme

In this research performance and compliance measurement indicators were hazard prevalence and information provided by the supplier about actions used. The performance and compliance compensation was a penalty on products off–specification. A combination of hazard prevalence with a penalty can improve average performance of suppliers, as shown in chapters 3 and 5. However, chapter 4 showed that not all suppliers improved performance. Chapter 6 showed that provision of information by the supplier about actions used could not de used as compliance measurement in a situation without a check on reliability of provided information. Alternative performance and compliance measurement indicators and compensations might be needed to induce suppliers. Lazear and Rosen (1981) showed that in a situation with common shocks equal for all suppliers, measuring performance of an individual relative to the performance of peers, for example as the ordinal rank number, can improve incentives for individuals to exert effort over measuring absolute performance of each individual supplier. Using a financial compensation as a penalty might diminish intrinsic motivation to exert effort (Frey and Oberholzer-Gee, 1997). An alternative might be the use of non–financial awards as orders, medals and decorations, which have been widely used in monarchies, republics, non–profit organizations and companies (Frey, 2007). Further research is needed to analyse applicability and effectiveness of alternative performance and compliance measurement indicators and alternative types of performance and compliance compensation to induce suppliers to control food safety.

7.7.2. Supply chain characteristics and incentive mechanism settings

This research was conducted in the Dutch pork supply chain between pig producers and slaughter company. As has been argued in chapter 2, the parameter settings of incentive systems for food safety control depend on the specific characteristics of the hazard and of the supply chain. Further research, for example by implementing similar incentive mechanisms for other hazards in the Dutch pork supply chain, or in other regions outside the Netherlands or in other supply chains, could generalise the findings of this thesis. A comparison of optimal parameter settings of incentive mechanisms for different hazards in the same supply chain, for example the Dutch pork supply chain, can provide insight into the impact of hazard characteristics. A comparison over supply chains with different characteristics can identify constraining factors for cost–effective incentive mechanisms.

7.7.3. Food safety, public health and cost–effectiveness

Incentive mechanisms aim to internalize external failure costs of Food Business Operator (FBO) in their decision making process. For food safety, external failure costs occur in society due to illness and death. Traceability is essential for assigning external failure costs to a specific supply chain or FBO (Van der Vorst, 2006). Many food–borne illnesses and death, however, cannot be traced to a specific food product (EFSA, 2010). This research, therefore, did not include external failure costs of public health effects into FBO decision making. Inclusion of external failure costs of public health effects through incentive mechanisms in FBO decision making could improve the balance between private food safety control revenues and costs and public health revenues and costs. Quantification of public health effects into monetary value is also necessary. Direct public health costs such as hospital and medication costs can be given a monetary value relatively easy. But indirect public health costs, such as premature death or living with a disease compared to a healthy life, are more difficult to give a monetary value, although variables such as Quality Of Life, Quality Adjusted Life–Year or Disability Adjusted Life–Year can be used to do so (Abelson, 2003; Mangen *et al.*, 2005). Notwithstanding, for specific hazards data about public health costs are available (Mangen *et al.*, 2005; Mead *et al.*, 1999; Scharff, 2010), although often only at a high aggregate level. For many hazards public health cost data at a disaggregate supply chain or product level are still lacking. Endogenous inclusion of such public health costs in decision models for food safety control on supply chain level could improve these models and provide policy advice on food safety objectives that optimally balance public health revenues and costs and food safety control revenues and costs.

Food safety is controlled through a combination of private and public food safety control and verification systems. In the EU, the USA and other countries FBOs have the responsibility that their products are safe. Governments have the responsibility to supervise that marketed products are safe. To fulfil this responsibility, FBOs implement food safety control systems and governments verify the food safety control systems of the private sector. The question arises to what extent governments can outsource food safety control to the private sector for cost–effective food safety control. Private ownership is the crucial source of incentives to innovate and to become efficient (Shleifer, 1998). Using a quantitative model Hart *et al.* (1997) identified contractibility of quality reducing cost reductions, importance of quality innovations, corruption of government personnel, and patronage inside the government as important aspects which prevent outsourcing of public services to improve efficiency. Knowledge is, however, lacking about cost–effectiveness of combined public and private food safety verification and control. With a method to ex–ante determine the effectiveness of combined public and private food safety verification and control, the optimal privatization level in food safety control could be determined.

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Curriculum Vitae

Cornelis Petrus Antonius (Coen) van Wagenberg was born 1 May 1972 in Vught, the Netherlands. From 1984 to 1990 he attended the secondary school ‘Gymnasium Beekvliet’. In 1990 he enrolled in the study Econometrics at the Catholic University Brabant. He specialized in Mathematical Decision Theory and Operations Research. During his study he occupied a number of positions within the study association ‘Tilburgse Econometristen Vereniging’, including secretary of the board. In 1996 he graduated on a thesis about the impact of a new Dutch manure legislation on pig producer actions. After graduation he worked at the Research Institute for Pig Husbandry, where he conducted quantitative research on the economics of pig husbandry with a special interest in the relation between feed, manure and economics. In 2000 he took a sabbatical leave to travel through Central and South America. From 2001 to 2002 he worked for the public insurance company ANOZ in the department ‘Research and Information’ analysing the public health care consumption of Dutch people. In 2002 he moved to LEI, Wageningen UR, to conduct applied scientific research on quantitative economic aspects related to meat supply chains. In June 2005 he started his PhD and combined this with applied research at LEI, Wageningen UR. Currently, he is a senior scientist at LEI, Wageningen UR, with a specialization in quantitative analyses of food quality and safety issues in food supply chains. He has published many applied research reports and several scientific papers in peer–reviewed journals.

Training and Supervision Plan

Training and Supervision Plan of Coen P.A. van Wagenberg for Wageningen Institute of Animal Sciences and Mansholt Graduate School of social sciences

Description	Institute / department	year	ECTS*
The Basic Package			**4.0**
WIAS Introduction Course	WIAS	2006	1.5
MG3S Introduction Course	MG3S	2006	1.0
Philosophy and Ethics of Food Science & Technology	VLAG	2008	1.5
Scientific Exposure			**15.65**
International conferences			
15th IFOAM organic world congress (20–23 September)	Adelaide, Australia	2005	2.2
7th International Symposium on the epidemiology & control of foodborne pathogens in pork (9–11 May)	Verona, taly	2007	1.9
8th International Conference on Management in Agrifood chains and Networks (28–30 May)	Ede, the Netherlands	2008	1.6
21st International ICFMH Symposium “Evolving Microbial Food Quality and Safety” (1–4 September)	Aberdeen, Scotland	2008	2.2
113th EAAE Seminar on “A Resilient European Food Industry and Food Chain in a Challenging World” (3–6 September)	Chania, Greece	2009	2.2
9th Wageningen International Conference on Chain and Network Management (26–28 May)	Wageningen, the Netherlands	2010	1.9
Seminars and workshops			
HACCP training VION	VION	2005	0.15
Promstap workshop 'Science meets policy'	LEI	2007	0.6
WIAS Science Day	WIAS	2008	1.3
Mansholt PhD Day	MG3S	2008	1.3
Congres 'Voedselveiligheid’	Euroforum	2008	0.3
In–Depth Studies			**9.0**
Disciplinary and interdisciplinary courses			
Eden doctoral seminar on supply chain management research methods	EIASM	2006	3.0
Behavioral economics	NAKE	2007	6.0

(Table continues on next page)

Training and Supervision Plan of Coen P.A. van Wagenberg (continued).

Description	Institute / department	year	ECTS*
Professional Skills Support Courses			**3.8**
Techniques for Writing and Presenting a scientific paper	WGS	2007	1.2
PhD Competence assessment	WGS	2006	0.3
Mobilising your – scientific– network	WGS	2008	1.0
Science, the press and the general public: communication and interaction	WGS	2009	1.0
PhD Career assessment	WGS	2009	0.3
Research Skills Training			**6.0**
Preparing PhD research proposal	WU	2005-2006	6.0
Didactic Skills Training: ***Supervising MSc theses***			**6.5**
Minor thesis Ilze Jenniskens	WU	2005	1.5
Minor thesis Willemien van de Kandelaar	WU	2008	1.5
Minor thesis Frank Tiemessen	WU	2008	1.5
Major thesis Tsehainesh Zeweldi	WU	2010	2.0
Management Skills Training			**6.0**
Member of workers council	SSG	2005-2008	6.0
Education and Training Total			**50.95**

* one ECTS credit equals a study load of approximately 28 hours

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