Essays on Economic Modelling of Farmers' Behaviours

Special Cases of Structural Change, Technology Adoption and Policy Changes

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Abstract

Multiple socio-economic and biophysical factors affect farmers' behavioural responses to economic policy and technology adoption, but personal beliefs and expert opinions are also important for making actual choices on farm policy and agricultural innovations. Using econometric and mathematical programming models, this thesis assessed farmers' behavioural responses to farm structural changes, technology adoption and policy interventions. For structural changes, the results showed that conversion to organic farming in the European Union (EU) is a two-tier decision, with a first choice of staying conventional or moving to conversion and a second choice of mixed or organic production. This gradual conversion process encourages the presence of nested structures within the process, largely influenced by socio-economic and biophysical variables such as milk prices, policy incentives and technology factors. Following milk quota abolition under the EU Common Agricultural Policy (CAP) reform, risk of price uncertainty emerged as another key factor for the organic conversion process of Swedish dairy farms.

In econometric modelling of farmers' choices and impacts of responses to adopting agricultural technology, the parametric econometric specification is commonly applied. However, it cannot guarantee the true specification of behavioural responses to agricultural innovation. In this thesis, a recently developed nonparametric (NP) kernel density estimator was applied in impact assessment of agricultural technology adoption, using the case of zero tillage technology in the rice-wheat cropping system of the Indo-Gangetic Plains (IGP) region. This estimator can capture possible nonlinearities in the data generation process that cannot be known *a priori*. The results showed that the NP specification outperformed the parametric specification in predicting propensity scores and produced impact estimates with small standard error. For the study area, the results showed that introduction of the new technology generated the economic benefits of markedly lower tillage costs yield in zero-tilled plots.

In a study of policy interventions, the wealth effect of the CAP direct payment system on agricultural crop production decisions was analysed using Bayesian econometrics and positive mathematical programming (PMP). Under risk, lump-sum payments may influence risk-averse farmers on crop production decisions. In simulations, no direct payment in a risky environment caused a shift in land use away from risky crops towards low-risk crops, altering the crop mix. Moreover, the farm-level wealth effect varied greatly between farms, although its magnitude was influenced by regional characteristics, *e.g.* historical farm structure and region-specific conditions.

Keywords: organic dairy, nested logit, zero tillage, nonparametric specification, direct payment, positive mathematical programming, risk, Bayesian econometrics

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Dedication

To my daughter *Aaryaa* and beloved parents

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Basnet, S.K., Manevska-Tasevska, G., Surry, Y. T Karantininis, K. The end of milk quotas: Structural impacts on conventional and organic dairy farms in Sweden (Manuscript).

II Basnet, S.K., Manevska-Tasevska, G. & Surry, Y. (2018) Explaining the process for conversion to organic dairy farming in Sweden: An alternative modelling approach. *German Journal of Agricultural Economics, 1: 14-30*

III Basnet, S.K. Analysing and measuring the economic effects of zero-tillage technology: The case of the rice-wheat cropping system of the Indo-Gangetic Plains (Manuscript).

IV Basnet, S.K., Jansson, T. & Heckelei, T. A Bayesian econometrics and risk programming approach for analysing the impact of decoupled payments in the European Union (Manuscript).

V Jansson, T., Basnet, S.K. & Heckelei, T. A note regarding the estimation of covariance matrices using unbalanced panels (Manuscript).

Abbreviations

ADB	Asian Development Bank
AGLINK	The OECD partial equilibrium model
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact modelling system
CAPSIM	Common Agricultural Policy Simulation
CIMMYT	International Maize and Wheat Improvement Centre
ESIM	European simulation model for analysing the agricultural and policy environment of the EU-12
EU	European Union
FACEPA	Farm Accountancy Cost Estimation and Policy Analysis of European Agriculture
FADN	Farm Accountancy Data Network
FADNTOOL	An EU-funded project to integrate econometric and mathematical programming models into an amendable policy and market analysis tool using the FADN database
FAO	United Nations' Food and Agriculture Organization
GENEDEC	An EU-funded project to model the socio-economic and environmental impact of decoupling farm payments
GTAP	Global Trade Analysis Project
IDEMA	An EU-funded project to model the socio-economic impact of decoupling and modulation in the enlarged EU
IRRI	International Rice Research Institute
NARES	National Agricultural Research and Extension Systems
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
WTO	World Trade Organization

1 Introduction

In economic modelling, understanding farmers' behaviours is complex as they are governed by a number of socio-economic and biophysical factors. In addition, farmers' motives and their attitudes are important in determining their behavioural responses to economic policy and technology adoption. The behavioural response, which is a product of a decision-making process, is often modelled in standard economic models as being under the influence of directly measurable covariates. However, personal beliefs and expert opinions in the form of probability distributions are also important for making actual choices on farm policy and agricultural innovations. This means that research in this area faces the challenge of incorporating farmers' motives and their cognitive knowledge in analysing farmers' optimising behaviours.

The standard econometric model or traditional mathematical programming (*e.g.* linear and quadratic programming) provides limited scope for modelling the probability distribution functions of personal beliefs and expert opinions. The resulting models often display poor performance in calibration to the observed base scenario. In a risky environment, the estimates can be sensitive to extreme outputs. For instance, a risk-averse farmer can reflect 'just satisfying' behaviours with 'good enough' solutions, rather than looking for optimal solutions. Technically speaking, farmers may not know the true values of parameters with certainty, which can result in failure to determine the optimal solutions. Therefore in this thesis the presence of optimisation errors in economic models defined in the bounded rationality environment was assumed.

In order to investigate economic modelling of farmers' behaviour, five independent studies were performed within this thesis project, under three key themes:

(i) Conversion to organic farming.
(ii) Adoption of technological innovations in farming.
(iii) Policy impacts on agricultural land use.

Under the first of these theme (Papers I and II), the policy background associated with organic farming in Sweden was analysed and the conversion dynamics in the effect of key determinants were examined using a standard parametric econometric approach. In Paper III, under the second theme, attempts were made to model farmers' responses to adoption of agricultural technology by application of a recently developed nonparametric econometric estimator (hereafter referred to as NP) to the case example of adoption of zero tillage technology in India and Nepal. In the final stage of the work (Papers IV and V), a positive mathematical programming (PMP) model was used to incorporate the risk of price and yield uncertainties. This model comprised a combination of linear and quadratic programming, with an econometric constraint of model calibration. Bayesian econometrics was employed to account for *a priori* knowledge of model parameters in quantitative modelling (Paper IV). Paper V sought to provide a supplementary note to Paper IV by estimating the variance-covariance matrix terms, *i.e.* risk factor, in unbalanced panel data with individual farms growing a different individual crop over a period of years. Overall, this thesis work made use of standard econometric tools and mathematical programming approaches to model farmers' responses when assessing the impact of policy changes and technology adoption. Application of alternative estimation approaches (*e.g.* nonparametric econometrics and Bayesian-based PMP model) can improve calibration of the base year activities, which is important for impact evaluation studies and simulation-based policy scenario analysis.

1.1 Conversion to organic farming

Much of the literature on farm structural change is concerned with the increase in farm size (Chavas & Magand, 1988; Zepeda, 1995; Gillespie & Fulton, 2001; Karantininis, 2002; Zimmermann & Heckelei, 2012; Arfa *et al.*, 2015). A few studies have made an attempt at explaining the conversion process of conventional to organic production (Pietola & Lansink, 2001; Darnhofer *et al.*, 2005; Koesling *et al.*, 2008; Breustedt *et al.*, 2011; Nachtman, 2015), but none has examined the transition dynamics of the conversion process. There is a two-year mandatory conversion period under EU regulations. A few farms complete the conversion process in a one-phase process within this stipulated transition period, while others may take more than two years or remain producing conventional milk, but with organic crops or pastures (Jordbruksverket, 2010; EU Committee of the Regions, 2014). Against this background, this thesis explored the evolutionary process of organic conversion of dairy farms in Sweden.

In the European Union (EU), Sweden is in second place in terms of proportion of total agricultural area under organic farming, after Austria, with organic production currently representing 17% of the total Swedish agricultural acreage (Statistics Sweden, 2014). However, in light of the new Swedish target of 30% organic area by 2020 (Ekologiskt Forum, 2013), the uptake rate of organic farming is currently low (*e.g.* only 13% organically produced milk) (Röös, 2014). This poses a major challenge for policy makers seeking to increase the supply of organic food.

In a scenario of decreasing milk prices over the past few years[1], conversion from conventional to organic milk production can be an attractive alternative to Swedish dairy farmers, since organic producers enjoy policy incentives and a price premium (KRAV, 2016; Hertz & Åkebrand, 2017). However, the conversion process has not taken place in a linear fashion. Instead, a substantial proportion of dairy producers have undertaken organic conversion in a two-phase process whereby they first convert their land and then convert their livestock once the land receives organic status, or may remain producing conventional milk and organic crops or pastures (Jordbruksverket, 2010; EU Committee of the Regions, 2014). This mixed mode of farming[2] by producing conventional milk and organic crop or pasture land can avoid the potential risk of market shortages of organic milk with a satisfactory premium, or may offset the productivity differences between conventional and organic production.

Partial or gradual conversion in the two-phase organic conversion process can result in a growing number of farms with a mixed mode of production. Unfortunately, there is a dearth of empirical evidence on this type of organic conversion process. Paper I describes the organic conversion process as a two-tier process, and visualises the future prospects for organic conversion in Sweden. In the two-tier conversion process, conventional farms first adopt the regulations of organic farming under the status of 'in-conversion' farms. In the second stage, their production can be recorded as fully organic. However, many in-conversion farms remain in the conversion phase for more than the two years legally required, as mixed-mode farms. In Paper II, the records on mode of production of these farms over the period 2002-2012 were examined and the two-tier conversion process was conceptualised in a nested choice structure. This

[1]The EU CAP reform abolishing milk quotas further aggravated a decreasing trend in global milk prices.

[2]The mixed mode of production is different from the mixed livestock alternative in the FADN system. In this thesis, mixed farms refers to those reported in the FADN data as 'in-conversion' for more than the two years legally required. These farms remain in-conversion because of either sequential conversion of the whole farm to organic, or *e.g.* by keeping their pasture organic, but with conventionally reared dairy animals.

conceptualisation in a nested choice framework was intended to facilitate identification of the alternative-specific (*i.e.* mode of production) and farm-specific characteristics that affect the organic conversion process. The analysis was limited to the Swedish dairy sector, but the findings can be extended to other sectors in the EU.

1.2 Adoption of agricultural innovations

This thesis is mainly concerned with structural transformation towards greater sustainability of European agriculture. However, in developing countries the problems in agricultural research can be very different, because *e.g.* the adoption level of agricultural technology is poor and the issue of food and nutrition security is of prime importance. Moreover, the socio-economic and biophysical characteristics that determine the response behaviour to technology adoption are totally different. For instance, the level of household education and household access to agricultural innovations are substantially lower. This means that research findings in a European context cannot be generalised to a developing countries context.

As a case study in a developing country context, in Paper III farm-household survey data were used to analyse farmers' responses to introduction of a soil tillage technology. This was done for the specific case of zero tillage (ZT) technology adoption in the rice-wheat system of the Indo-Gangetic Plains (IGP) region (India and Nepal). Zero tillage is a recently developed resource conservation technology that requires only a single pass of a seed drill to sow seeds in unploughed soil. Using a parametric econometric technique, most previous studies have found positive impacts of the technology on agricultural production, economic viability and environmental sustainability (Mendola, 2007; Ali & Abdulai, 2010; Wu *et al.*, 2010; Ali & Erenstein, 2013; El-Shater et al., 2016). However, the true specification of an approximated parametric model cannot be known *a priori*, which can result in model misspecification bias. Therefore the NP specification was used in Paper III to capture possible nonlinearities in the data generation process and to predict the probability density of technology adoption. Using the propensity scores of both parametric and NP specifications, the economic impact of ZT technology in the rice-wheat cropping system of the IGP region was estimated. Application of the NP econometric estimator can be seen as a novel contribution of Paper III to impact assessment studies.

1.3 Policy impact on land use pattern

In the EU-funded project (FADNTOOL), a farm-level simulation model was developed to analyse the impact of the decoupled direct payment under the Common Agricultural Policy (CAP) reform at micro level. The direct payment is an important component of the CAP, as it accounts for the largest share of the CAP budget. This is a risk-free income transfer to European farmers in the form of compensation for losses caused by price volatility and yield variability. In a risky environment, the decoupled payment has important implications for the decision-making process of risk-averse farmers.

Despite differences in modelling approaches (*e.g*. CAPRI, CAPSIM, GTAP, ESIM, AGLINK, IDEMA *etc*.), previous studies have found only a small effect of area payments on output production decisions (Andersson, 2004; Britz *et al*., 2006; Goodwin & Mishra, 2006; Balkhausen *et al*., 2008; Rude, 2008; Serra *et al*., 2009; Just, 2011; Uthes *et al*., 2011; Trubins, 2013) In particular, area allocation to cereals, beef and sheep production has declined in the EU-15, but the relative incentives for crop production activities that were not entitled to direct payments before the 2003 reform (*e.g*. forage crops and pasture) have increased. Overall, the persistent inefficiency in agricultural production has been reduced with the direct payment system.

In Paper IV, the impact of the decoupled payment on farmers' decisions on crop production activities in a risky environment was assessed. Some recent studies have attempted to derive an acreage supply function for different crop production activities under price and yield uncertainties (Sckokai & Moro, 2006; Serra *et al*., 2006; Cortignani & Severini, 2012; Petsakos & Rozakis, 2015;). Matthews (2015) also projected an increased level of price volatility in the EU in future. Possibly for the same reason, the CAP has increased its role in the most recent reform (2013-2014) to assure income stability for farmers (Cortignani & Severini, 2012; Matthews, 2015). Against this background, attempts were made in Paper IV to develop a robust mathematical programming model that includes the risk of yield and price variabilities and generates output supply elasticities at the individual farm level. In an empirical investigation, a standard PMP approach was applied using the EU Farm Accountancy Data Network (FADN) data. Application of PMP in evaluating farmers' adjustment to changes in market and policy conditions has recently received attention (Heckelei *et al*., 2012).

Relating to Paper IV, a subtle difficulty in non-definiteness can arise with the covariance for the panel of entire production activities, including attributes of missing or zero observations. For example, this problem arises with datasets containing individual farm records on growing a particular crop in any given year. In the expectation variance (EV) model, the non-definite covariance is not useful for the optimal solution. By applying the Hadamard-weighted Frobenius norm estimator suggested by Higham (2002), another definite matrix ‘closest’ to the original non-definiteness covariance in the sense of Euclidean distance was constructed in Paper V.

2 Methods

2.1 Data collection

The FADN data are the only source of micro-economic data in the EU and in this thesis they were used for the analyses reported in Papers I, II and IV. In recent years, it has become standard practice to use FADN data in the construction of programming models (*e.g.* FACEPA and CAPRI). All EU member states follow the standard EU guidelines on sampling procedure. In the sample data, each farm carries a weighting factor describing how much of the population is represented. The weights are assigned based on the farm population clustered into grid cells using type of farming (ToF)[3] and economic size of holding (ESU)[4]. However, a farm can change its ToF and ESU over time, thereby resulting in an unbalanced panel.

In Paper I, the FADN data for the period 2000-2013 were used, as reporting on organic farming started from 2002. In total, 9794 observations representing 1498 professional dairy farms[5] with at least three years of observation were considered, to calculate the transition probabilities between production states at the aggregated farm level. To explain the conversion process, national-level macro-data from the Swedish Board of Agriculture covering the study period were used. Finally, the OECD-FAO projection data were employed to simulate *ex ante* scenarios for the period 2014-2020 after removal of the milk quotas.

[3]Type of farming is determined by the relative contribution of the standard output of the different characteristics of the holding to total standard output. See Annex II of Commission Regulation (EC) No 1242/2008 (2008) for details.

[4]European size unit is defined in Community typology for agricultural holdings in the FADN methodology (Commission Decision 85/377/EEC, 1985).

[5]For professional dairy farmers, farm profit is the primary source of investment in agriculture and constitutes more than two-thirds of household income (Zimmermann & Heckelei, 2012).

The analysis in Paper II utilised the same dataset as in Paper I, but adopted a micro approach to explain the conversion process to organic dairy farming. Using the individual farm (micro) level, Paper II applied a nested logit random utility model to explain farmers' behavioural choices between organic, mixed and conventional milk production in Sweden. In the FADN data, researchers can observe only the actual production choice of the farmers, but the farmers are also aware of counterfactual alternatives through a common market, advisory services and local networks. To capture this effect, information on the attributes of counterfactual alternatives were approximated by their corresponding mean at the NUTS-3 level, which enabled estimation of a nested choice model. Schmidtner *et al.* (2012) applied a similar strategy to impute missing values for the city counties in Germany.

In Paper IV, FADN data for the period 1998-2008 were used. These data covered a total of 39 farm groups based on 13 specifications and three farm sizes on the basis of ToF and ESU. Considering only farm specialisation without animal production, the data on 10 farm groups were selected for each region across the EU. The remaining farms were kept in a residual farm group.

The evaluation in Paper III of farmers' responses to the ZT technology and its impact in the rice-wheat cropping system of the IGP was based on data obtained in a household survey conducted by the International Rice Research Institute (IRRI) and International Maize and Wheat Improvement Centre (CIMMYT) in 2008-2009. That survey was performed in collaboration with National Agricultural Research and Extension Systems (NARES) partners in Bangladesh, India, Nepal and Pakistan and with the financial support of the Asian Development Bank (ADB). However, the analysis in Paper III is limited to India and Nepal, as the survey data reported from Bangladesh and Pakistan did not have a complete set of information on the questionnaires. The survey data used in Paper III were for a total of 353 farmers in the Karnal district of Haryana state, around 100 km from the capital of India (New Delhi), and in the Rupandehi district of Nepal, the nearest national border to New Delhi (around 750 km).

In Paper V, a simulated database that resembles the FADN data structure was used. Based on a numerical example, a method for finding a definite matrix 'closest' in the Euclidean sense to the original non-definite covariance matrix was developed. This newly invented matrix always makes sure of definiteness for the covariance of entire production activities, including attributes of missing or zero observations.

2.2 Modelling framework

In the EU, a recent trend in agricultural policy analysis has been to develop a modelling system comprising econometric estimation, mathematical programming and simulation approaches[6]. In this type of system, the role of the econometric technique is to provide parameters for the programming model. Once the model is calibrated, either of these two approaches (econometric and programming) or a combination is used for simulating the economic behaviour under the desired scenarios. These two approaches have a complementary relationship in modelling farmers' responses to policy changes.

In this thesis, the application of econometric approaches began with the use of fundamental Ordinary Least Squares (OLS) and Seemingly Unrelated Regression (SUR) in Paper I to explain the transition dynamics between production states of dairy farming at macro level. The parametric econometrics approach was extended with the application of nested logit models in Paper II to identify the determinants of the conversion process to organic farming at micro level.

The application of parametric econometric models is almost a default choice in impact assessment of adoption of agricultural technology or introduction of development projects. However, parametric models have been criticised, as the model estimates can be sensitive to possible nonlinearities in the functional form that cannot be known *a priori* (Bontemps *et al*., 2009; Heinrich *et al.*, 2010; Criado & Veronesi, 2013). A nonparametric kernel regression was therefore applied in Paper III to account for all possible nonlinearities of the data and estimate the conditional probability density functions (PDFs). The more accurate the estimate of the PDFs, the higher the robustness of the impact estimates. To the best of my knowledge, this is the first empirical study to employ nonparametric kernel regression to assess the impact of technology adoption. Application of the NP specification has recently received attention in modelling and in predicting the choice probability (Bontemps *et al*., 2009).

The conventional approach of using a stand-alone econometric or mathematical programming and simulation model can scarcely serve the purpose of agricultural policy analysis. Methodological synergy between econometric methods and mathematical programming techniques has now become the norm in CAP analysis in the EU (Garforth & Rehman, 2006). Recognising this fact, the PMP technique was applied in Paper IV to incorporate the risk factor and

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[6]For example, in many EU-funded research projects such as CAPRI, IDEMA, GENEDEC, FADNTOOL and FACEPA, models have been developed for analysing EU agriculture using different quantitative approaches and/or procedures. Most of these utilise micro (farm level) or macro data available in the FADN database.

analyse agricultural policy impacts at farm level. In recent years, the application of PMP has become popular among EU modellers (*e.g*. CAPRI and FADNTOOL), as this model combines the advantages of econometrics and programming techniques to calibrate parameters.

In Paper IV, the risk factor was represented by the estimated variance-covariance matrix of crop revenues. However, the estimation procedure is not trivial, especially when certain interactions between crop activities are rarely or never observed in an unbalanced panel. This can generate a non-definite or incomplete covariance matrix, which may destroy the concavity of the EV-risk model. Paper V tested application of the Hadamard-weighted Frobenius norm estimator, as suggested by Higham (2002), for enforcing the definiteness in the estimated matrix. Utilising the enforced definite matrix, Paper IV analysed the impact of decoupled payment on farmland allocation to production activities. Bayesian econometrics was used to address the ill-posed problem of model identification utilising *a priori* knowledge on parameters.

3 Results and discussion

3.1 Conversion to organic farming

In the study sample, a substantial number of dairy farms took more than two years for conversion to organic farming and some of them remained in the transition state for an even longer time. However, in the FADN dataset, this type of farm is registered as an in-conversion farm. In this thesis, this state of production was defined as 'mixed mode of production', to differentiate it from true transition to organic production.

In Paper I, the transition probabilities were computed across different modes of production (conventional, in-conversion and mixed-mode[7]) and organic states, and the key determinants were identified based on the aggregated farm-level data. As expected, an increase in the probability of switching to organic production was observed. In the event of a decrease in milk prices this tendency was even more prominent, as farmers could pursue a normal profit even after a decrease in output prices. In fact, the policy interventions in the form of the EU Health Check reform, the Rural Development Programme (RDP) and decoupling of direct payments can result in a substantial impact on farm structural change in terms of farm size or organic production. The overall supply of milk and the organic support payment can also have pronounced effects on the organic conversion process.

Paper II showed that provision of an environmental support payment would also increase the scope for organic milk production. This type of support payment would attract risk-averse farmers to full conversion to organic farming, as this could offset the cost associated with the conversion process. In general, northern Sweden is more densely populated with organic dairy producers because farms in the region have a large share of grassland and ley. Organic

[7]To recall the definition of mixed farms, see footnote 2.

farming requires good pasture space for grazing livestock, because under organic farming regulations more than 50% of dairy feed must be produced on the farm and animals must spend most of their time out on pasture during the grazing season (Ahlman, 2010; LRF, 2016). Northern Sweden is characterised by less productive farmland, but areas with high environmental support.

Interestingly, a number of dairy farms have adopted a mixed mode of production. This trend appears to be more common with medium- and large-sized farms. These farms can keep one part of the farm's land for organic pasture and produce conventional milk on the rest of the farm. In doing so, they can still receive the environmental support for organically converted pasture land and need not necessarily follow the organic farming regulations. Otherwise, some organic producers may disappear if the mixed mode of production is not allowed (EU Committee of the Regions, 2014).

The forecast estimates on transition probabilities in Paper I showed a higher probability of conventional farms entering the organic conversion process in the aftermath of the EU milk quota reform in 2015. The probability of switching to organic production was predicted to increase slightly up to 2020, because of the milk price effect. Moreover, it was predicted that an increasing number of in-conversion farms would prolong the conversion period with partial adoption of organic farming in the forecast period.

3.2 Adoption of agricultural innovations

As a case study, in Paper III an impact assessment was conducted on the introduction of ZT technology in the rice-wheat system of the IGP region, in order to uncover the impact of adoption of agricultural innovations in developing countries. The findings showed that socio-economic variables such as age of household head, farm size, farm labour wages and social networking were important factors for adoption of ZT technology.

The impact estimates in Paper III showed that the tillage costs were substantially lower in ZT plots because no tillage operations are needed for land preparation. The magnitude of the tillage cost-saving impact was highest in areas where animal-drawn ploughing was common (*e.g.* Rupandehi district). The use of chemical herbicides was found to be lower in ZT plots practising crop residue mulching (*e.g.* Rupandehi district). However, the yield of wheat grain was found to be lower in ZT plots. More importantly, the application of the NP specification in modelling produced propensity scores with higher accuracy and resulted in statistically significant impact estimates.

3.3 Policy impact on land use pattern

The CAP direct payment is a risk-free income transfer to farmers, with no effect on their production decisions on agricultural crops. However, this could cause a wealth effect by changing the decreasing absolute risk aversion (DARA) coefficient with the change in family income. Previous studies have reported only a small wealth effect on crop production decisions, revealing minimal distortion of farmland allocation to crop production activities (Andersson, 2004; Britz *et al*., 2006; Goodwin & Mishra, 2006; Balkhausen *et al*., 2008; Rude, 2008; Serra *et al*., 2009; Just, 2011; Uthes *et al*., 2011; Trubins, 2013). Paper IV confirmed previous findings, but also showed that the effect size could vary in a risky environment. The results showed that high-risk crops (*e.g.* soft wheat, rapeseed, potato and sugarbeet)[8] were more sensitive to the wealth effect because of a high risk of uncertain revenues. However, the level of impact was also influenced by the initial characteristics of the regions, such as former farm structure and region-specific conditions.

At the farm level, the size of impact varied widely, from -8.92% (5th percentiles) to +3.31% (95th percentiles), depending upon the level of risk associated with the crops grown. The riskier the crop, the larger the distortionary wealth effect. Moreover, the contribution of the decoupled direct payment to family income was important. Paper IV found that the higher the contribution of the direct payment to total farm income, the larger the change in DARA coefficient and hence the greater the wealth effect. Overall, the removal of the decoupled direct payment resulted in a decrease in acreage of the main dominating cereal crops, allowing for some substitution between high- and low-risk crops, but the changes were farm-specific.

[8]Crops with higher variance in their revenue.

4 Conclusions and future perspectives

In this thesis, the behavioural responses of farmers to policy interventions and adoption of agricultural innovations were modelled in different cases and using different approaches.

First, the standard econometric approaches were applied to evaluate adoption of organic farming practices in the Swedish dairy industry. Using a binary choice modelling approach, an attempt was made to explain the process of farm structural change from conventional to organic production. In the analysis, the effects of socio-economic and policy-related variables on structural transformation of dairy farming, in particular the propensity to adopt organic production practices, were also investigated. The results showed that the expected decrease in milk prices in the aftermath of the EU milk quota reform can persuade conventional farmers to convert to the practices of organic farming. However, with an increase in milk supply, an increasing trend for adopting a two-phase conversion process was also observed. In this process, conventional farmers first convert part of their farm land to organic farming, and then gradually keep transforming their dairy animals to organic milk production. However, this process was found to be greatly affected by socio-economic and biophysical variables such as milk prices, policy incentives and technology factors.

In Sweden, organic farming is still a niche production alternative for small and low-yielding dairy farms. Large farms could adopt an optimal mix of conventional and organic production systems. However, technological advances in organic production (*e.g.* to achieve higher milk yield) are essential for the expansion of organic farming. The recent relaxation in Swedish policy as regards parallel production of conventional and organic produce, although currently restricted to research and educational purposes, can retain organic producers in the dairy industry, which in turn can bring about a structural change in dairy farming in Sweden.

Interestingly, given a future decrease in milk prices[9], the out-sample prediction of the organic conversion process showed a tendency for farmers to prolong the conversion period as mixed-mode farms. This implies that in-conversion farms are likely to opt for gradual conversion to organic farming or to partly adopt organic farming, so that they can to some extent compensate for potential losses in farm income by accessing organic farm subsidies.

Since the FADN sample is a rotating panel and can contain sampling noise, a further improvement can be made by combining the observed transitions of sample farms (the micro data) with the population distribution of farms across production states (the macro data). The combination of different sets of data can increase the precision of model estimates and out-sample predictions of farm structural change. This could also be of interest to research analysts and policy makers for future scenario projections.

In a developing country context, agricultural systems are still concerned with increasing food production and providing livelihoods for millions of rural families. Therefore, a prime need of these countries is to increase agricultural productivity at a minimal environmental cost. This thesis considered the case of ZT technology adoption in the rice-wheat system in the IGP region. Recently reported declines in agricultural productivity in IGP are creating a challenge for the region to feed its growing population. To counteract the productivity decline, conservation agriculture and associated resource conservation technologies such as ZT are now being promoted in the region.

In this thesis, survey data on farms in the rice-wheat cropping system of India and Nepal were analysed to assess the economic impact of ZT technology on wheat production in IGP. In contrast to the common practice of utilising the parametric specification in modelling, a recently developed NP specification was applied to avoid possible misspecification in the propensity score model. The results showed that the NP specification outperformed the parametric specification (logit model) in estimating the propensity scores and produced impact estimates with small standard errors. The cost associated with tillage operations was, as expected, markedly lower in ZT plots. However, this technology resulted in a decrease in wheat production.

This novel application of the NP specification can be further extended to impact assessments of agricultural innovations, development projects and policy interventions. A well-specified econometric model is important for precise quantitative evaluation of policies and technological interventions. This could be of interest to development practitioners and policy makers in efforts to

[9]The milk price projections for the period 2015-2020 by the OECD-FAO in their most recent medium-term agricultural outlook.

understand whether a technological intervention or development project is generating the intended effects.

Returning to the EU CAP, analysis of the decoupled direct payment system under the 2003 CAP reform revealed that it caused noticeable wealth effects on crop production decisions, especially as regards high-risk crops. The level of impact was very small at aggregate level, but for individual farms the levels of wealth impact were much larger. In general, significant negative impacts were observed with high-risk crops, while the opposite was observed with low-risk crops. This allowed for some substitutions between high- and low-risk crops, but also influenced the effects at the farm and crop levels, which differed in terms of sign and magnitude. In principle, the direct payment is presumed to have no impact on crop production decisions. However, in a risky environment, this risk-free income transfer could cause a shift in land use away from risky crops towards lower-risk crops, reflecting the DARA property. This falls outside the realm of the 2003 CAP reform, and does not comply with the green-box measure of the WTO regulations.

To conclude, the novel approaches to economic modelling of farmers' behaviours used in this thesis provided important knowledge and insights not afforded by conventional methods. Future work on integrating the micro (farm-household) data with the macroeconomic information can produce a robust economic model to explain the farmers' behaviours in response to farm structural change, technology adoption and policy changes.

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