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The Role of EU Agri-environmental Programmes: a Farm Level Analysis by Propensity Score Matching and by Positive Mathematical Programming Incorporating Risk

Coordinator: Ch.mo Prof. Antonio Albanese

Candidate: Linda Arata

Matriculation n. : 3911372

Tutor: Prof. Paolo Sckokai

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‘Non mi porterò ritratti di persone care, ma alle ampie pareti del mio io interiore voglio appendere le immagini dei molti visi e gesti che ho raccolto, e quelle rimarranno sempre con me.’

‘In me scorrono i larghi fiumi e s’innalzano le grandi montagne. Dietro gli arbusti della mia irrequietezza e dei miei smarrimenti si stendono le vaste pianure della mia calma e del mio abbandono. Tutti i paesaggi sono in me, ho tanto posto ora, in me c’è la terra e c’è anche il cielo.’

Etty Hillesum, Diario 1941-1943

I am grateful to everyone who has been part of my life in these years of my PhD

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Introduction

In recent years, the agricultural sector in the European Union (EU) is facing new challenges. The increasing attention to the relationship between agriculture and the environment and the rise in price volatility on agricultural markets has led to a new emphasis on agri-environmental policies as well as to a search for new risk management strategies for the farmer. These trends are strengthened by the evolution of the Common Agricultural Policy (CAP) towards an higher allocation of the EU budget to the agri-environmental schemes (AESs) over the years and towards a liberalisation of agricultural markets in the EU. Nowadays, EU farmers are required to combine the provision of environmental benefits with the production of agricultural commodities, whose market price is hardly predictable. In addition, the proposed reform of the CAP after 2013 focuses the EU agricultural policy on the environmental concern by conditioning the decoupled direct payments to the so called 'greening' and towards the search for new farm risk management tools such as the income stabilisation tool.

The research objective of this PhD thesis is in line with this challenging context, since it provides an analysis of the EU AESs from two viewpoints. First, an ex-post analysis aims at investigating the AESs for their traditional role as measures which encourage sustainable farming while compensating the farmer for the income foregone. The effects of farmers' participation in the AESs on their production plan and on the economic performances are analysed in five EU Member States. The existing literature does not comprise any study on the AESs which is focused on the impact on farm income and which makes a comparative analysis among different Member States. This comparison may have significant policy implications since it may reveal the countries where the participation in AESs requires a deeper change of the farmers' production plans and where the effects on farm income are stronger. The analysis may also identify whether the agri-environmental payment provides a fair compensation of farmers' income losses arising from program's participation. Finally, such comparison may also indicate where the AESs are effective in promoting sustainable farming practices and, by this, it may indirectly shed light on the environmental impact of such schemes. This study has been performed by applying a semi-parametric technique which combines a Difference-in-Differences estimator with a Propensity Score Matching estimator

in order to prevent the selection bias both on observed and time-invariant unobserved covariates.
The second study considers the AESs from an innovative viewpoint and it performs an ex-ante analysis investigating their role as farm income stabilizer. Although the traditional role of these schemes consists in the provision of environmental benefits and their payments wish to compensate the income forgone because of the adoption, we argue that they may play a new role in presence of increasing agricultural price volatility. Indeed, as these contracts guarantee the farmer with a fixed payment per hectare irrespectively of the crop price fluctuations, they may act as an income risk management tool available to the farmer. This study has developed a new methodological approach, which represents one of the few attempts to integrate the risk component in a Positive Mathematical Programming (PMP) framework. We think the combination of PMP with risk modelling will be one of the new research frontier in the area of mathematical programming as it allows the use of a calibrated model in analysing farm behaviour under uncertainty. The proposed method differs from the few earlier attempts as it merges the first two phases of the traditional PMP procedure using the dual relationships of a farmer's expected utility maximisation problem. Therefore, it allows the simultaneous estimation of the non linear cost function as well as of the farmer's risk aversion coefficient and of the shadow prices. The estimated model has been used to investigate the potential role of an AES as a strategy to cope with risk under different scenarios of crop price volatility.

The thesis is organized as follows. Chapter 1 provides the background for this thesis by discussing the evolution of the CAP and the increasing role of both the rural development issues and the environmental concern and by focusing on the analysis of agricultural price volatility over time. Chapter 2 presents the comparative ex-post analysis on the effects of the AESs on farm performances in five EU Member States. Chapter 3 describes the methodological proposal for integrating risk in a PMP framework and provides an empirical application where this approach is used to investigate the potential role of an AES as farmer's income stabilizer tool under scenarios of rising crop price volatility.

CHAPTER 1

Environmental concerns and price volatility: the new challenges for agriculture in the European Union

1.1 THE COMMON AGRICULTURAL POLICY AND THE ENVIRONMENTAL ISSUE

Over the last decades in developed countries there has been an increasing concern about the relationship between agriculture and the environment. In the European Union (EU), the Common Agricultural Policy (CAP) has introduced environmental measures in order to discourage negative environmental externalities and to promote positive externalities of agricultural activities. Such a concern was not included in the original framework of the CAP. When article 33 of the Treaty of Rome stated the objectives of the CAP in 1957 there were not any statements about the environment. Productivity increase, food security, support to farm income, stable market and reasonable consumer prices were the starting goals of the CAP and the instruments adopted consisted mainly of intervention buying, export subsidies and variable import levies. Although the CAP objectives were reached quickly, those market distorting mechanisms raised negative consequences soon. The price support resulted in large commodities surplus which was disposed on the world market and in large budgetary expenses for the EU. In addition the European farmers were isolated from the world market signals as they received guaranteed prices and the stress on the productivity led to an increasing use of chemical fertilizer and pesticides, which affected negatively the environment. Throughout the years the European society became aware that new instruments were needed to support farm income as well as to guarantee food security and the role of farmers as environmental and landscape service providers. Moreover, the negative environmental externalities of agriculture became increasingly important.

In the seventies and eighties the EU introduced some regulations and directives about producer groups, support to mountainous and less favoured areas, improvement of processing and marketing conditions for agricultural products and setting up for young farmers. All these measures started slightly to shift the focus of agriculture from production only to other related activities. The EU agri-environmental schemes (AESs) were introduced in the eighties as an option to be applied by Member States and they became compulsory for all Member States with the newly name of 'accompanying measures' of the CAP with the Council Regulation 2078/92 of the Mac Sharry reform. The 'accompanying measures' of the MacSharry reform included also afforestation incentives and early retirement for farmers. Since Regulation 2078/92 all Member States were obliged to offer AESs to their farmers, who could participate on a voluntary basis. These measures were cofinanced by the Guarantee Section of the European Agricultural Guidance and Guarantee Fund (EAGGF) of the EU. AESs promoted environmentally sustainable farming practices, through payments that compensated farmers for the provision of environmental goods that the market did not reward. Besides the introduction of the accompanying measures, the MacSharry reform introduced a radical change in farm income support tools: price support was reduced significantly and farmers were compensated for this cut by a coupled direct income payment per hectare and per unit of livestock. The reduction in price support, which started with the 1992 reform and was further strengthened by the following CAP reforms, made the EU farmer production decisions more respondent to market signals and avoided the negative consequences of supply surplus. Since the MacSharry reform, the CAP has developed towards a stronger market orientation and the attention on the link between agriculture and environment has increased.

The following step towards an agricultural policy considering the environmental concerns was the CAP Agenda 2000 reform (Council Regulation of the European Community, 1999), which brought together the different measures about rural development, including the AESs, into a single legal framework of support for rural development called Pillar 2, while all the measures of price support and direct farm income payments conveyed into Pillar 1. All measures of rural development converged into a single multiannual budgeting and programming approach defined every seven years. Since then, Member States have designed their Rural Development Programmes (RDPs) on a national or regional basis by choosing among a menu of rural development measures established at the EU level. The national or regional design of RDPs allows to account for the heterogeneity in the agricultural systems and in the natural resource conditions throughout the EU. All the RDPs must include the AESs and the RDPs are cofinanced by the EU and the Member States.

The 2003 CAP reform (Council Regulation of the European Community, 2003), also called the Fishler reform, enhanced the environmental concern of the CAP by introducing the cross compliance. The coupled direct payments introduced by the Mac Sharry reform has been replaced by a decoupled direct payment, based on historical farmer payments, which is subject to the compliance of minimum requirements about sustainable farming. Furthermore, the reform made modulation compulsory, meaning that a percentage of farm income support was cut and shifted to Pillar 2. In the new budget period 2007-2013 the RD measures have been reorganized and classified in four axes according to their objectives as set out in Council Regulation 1698/2005. The first three axes are thematic axes and aim at specific goals, while the fourth axis, the Leader, is a methodological axis, which promotes local bottom-up rural development strategies. Axis 1 groups the measures that aim at increasing the competitiveness of agriculture; axis 2 consists of the measures that protect the environment and maintain the rural landscape; the measures of axis 3 target towards the guarantee of the quality of life in rural areas and the diversification of rural activities. National and regional RDPs have to include all the four axes and each Member State or region decides which measures to activate in each axis from a EU list of 43 measures, as well as the EU and national budget allocation to each axis. AESs are included in axis 2 and they are compulsory for all RDPs. Each Member State must guarantee a minimum percentage of RD budget allocated to each axis: 10% for axis 1, 25% for axis 2, 10% for axis 3 and 5% for Leader. The new RD framework introduced also a single funding and programming instrument for rural development, the European Agriculture Fund for Rural Development (EAFRD). For candidate countries a specific fund has been created called IPARD, Instrument for Pre-Accession Assistance for Rural Development.

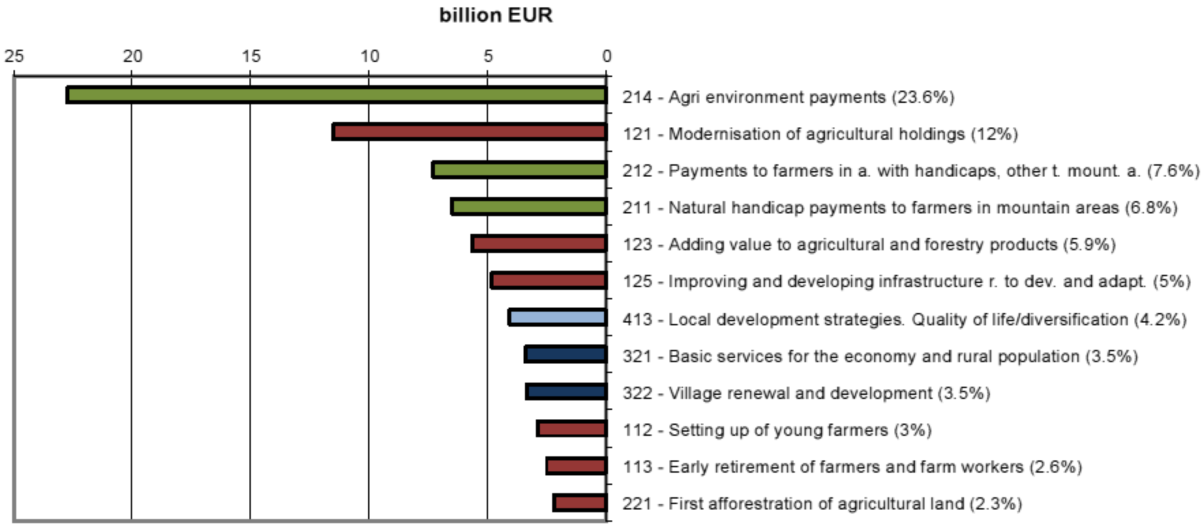
Table 1.1 lists all the RD measures proposed by the EU, grouped in the four axes, and shows the programmed allocation of EAFRD among the four axes and among measures in each axis for the budget period 2007-2013. In addition to the 43 measures proposed to all Member States there are two measures specifically devoted to Romania and Bulgaria 'Provision of farm advisory and extension services in Bulgaria and Romania' and 'Complement to direct payment' and there is an additional measure named 'Technical assistance'. The EU budget addressed to RD in the financial period 2007-2013 is 96.2 billion euro and most of the budget is assigned to axis 2 (45.1%), followed by axis 1 (33.1%) and axis 3 (13.4%). The Leader axis absorbs only 6.3% of the budget. At the EU level, the measure within axis 1 gaining the highest share of the EAFRD is "Modernization of agricultural holdings" (36.1%), while to AESs are allocated more than 50% of EAFRD money addressed to axis 2. AESs is the most significant measure in terms of EU funding for Rural Development, since it absorbs 22.7 billion (23.6% of the total EU budget for RD), followed by "Modernisation of agricultural holdings" (11.9%) and "Payments to farmers in less favoured area, other than mountain" (7.6%) (Figure 1.1). Considering the breakdown of the EU budget among the three axes in each Member States (and redistributing the Leader funds to the respective axis), significant differences arise (Figure 1.2). Eight countries, Belgium, Spain, Cyprus, Lithuania, Hungary Poland, Portugal and Romania address more than 40% of the EAFRD to axis 1, while Ireland, the UK and Austria allocate more than 70% of their funds to axis 2. None of the EU countries assign more than 35% of the EU budget to axis 3. Within axis 1 the measure 'Modernisation of agricultural holdings' represents the most relevant measure in terms of EAFRD budget in most of the countries, and the same is true for AESs within axis 2. In particular, for AESs the share equals 82.6% in Belgium, 74.2% in the UK, 74% in Sweden and 72.1% in the Netherlands. 'Basic services for the economy and rural population' and 'Village renewal and development' are the two measures of axis 3 with the highest allocation of EU funds in most Member States (Figure 1.3, Figure 1.4, Figure 1.5).

Table 1.1 Planned allocation of the EAFRD contribution over the axes and the measures, 2007-2013

Measures		Financial Plan 2007-2013	
		000 euro	**%axis**
Axis 1 - Improving the competitiveness of the agricultural and forestry sector			
111	Vocational training and information actions	953,625	2.9
112	Setting up of young farmers	2,890,772	9.1
113	Early retirement	2,502,738	7.9
114	Use of advisory services	289,286	0.9
115	Setting up of management, relief and advisory services	68,956	0.2
121	Modernisation of agricultural holdings	11,508,393	36.1
122	Improvement of the economic value of forests	536,664	1.7
123	Adding value to agricultural and forestry products	5,650,023	17.7
124	Cooperation for development of new products, processes and technologies in the agriculture and food sector and forestry sector	323,832	1.0
125	Infrastructure related to the development and adaptation of agriculture and forestry	4,822,287	15.1
126	Restoring agricultural production potential damaged by natural disasters	545,251	1.7
131	Meeting standards based on Community legislation	80,942	0.3
132	Participation of farmers in food quality schemes	17,2624	0.5
133	Information and promotion activities	174,815	0.6
141	Semi-subsistence farming	883,854	2.8
142	Producer groups	234,239	0.7
143	Provisions of farm advisory and extension services in Bulgaria and Romania	15,773	0.05
144	Holdings undergoing restructuring due to a reform of a common market organisation	194,018	0.6
Total axis 1		**31,848,092**	**33.1**
Axis 2 - Improving the environment and the countryside through land management			
211	Natural handicap payments to farmers in mountain areas	6,503,150	15.0
212	Payments to farmers in areas with handicaps, other than mountain areas	7,288,947	16.8
213	Natura 2000 payments and payments linked to Directive 2000/60/EC (WFD)	621,022	1.4
214	Agri-environment payments	22,743,913	52.4
215	Animal welfare payments	717,568	1.7
216	Non-productive investments	587,948	1.4
221	First afforestation of agricultural land	2,095,997	4.8
222	First establishment of agro-forestry systems on agricultural land	17,875	0.04
223	First afforestation of non agricultural land	283,557	0.7
224	Natura 2000 payments	71,877	0.2
225	Forest-environment payments	196,724	0.5
226	Restoring forest potential and introducing prevention actions	1,546,929	3.6
227	Non-productive investments	742,563	1.7
Total axis 2		**43,418,070**	**45.1**
Axis 3 - Improving the quality of life in rural areas and encouraging diversification of economic activity			
311	Diversification into non-agricultural activities	1,308,279	10.2
312	Business creation and development	2,097,805	16.3
313	Encouragement of tourism activities	1,244,089	9.7
321	Basic services for economy and rural population	3,400,838	26.4
322	Village renewal and development	3,332,644	25.9
323	Conservation and upgrading of the rural heritage	1,249,638	9.7
331	Training and information	114,207	0.9
341	Skills acquisition, animation and implementation of local development strategies	130,788	1.0
Total axis 3		**12,878,288**	**13.4**
Axis 4 - Leader			
411	Implementing local development strategies. Competitiveness	551,383	9.1
412	Implementing local development strategies. Environment/land management	171,106	2.8
413	Implementing local development strategies. Quality of life/diversification	4,066,244	67
421	Implementing cooperation projects	276,690	4.6
431	Running the local action group, acquiring skills and animating the territory	1,006,225	16.6
Total axis 4		**6,071,648**	**6.3**
511	Technical assistance	1,566,196	100.0
611	Complement to direct payments	459,428	100.0
	TOTAL	**96,241,722**	**100.0**

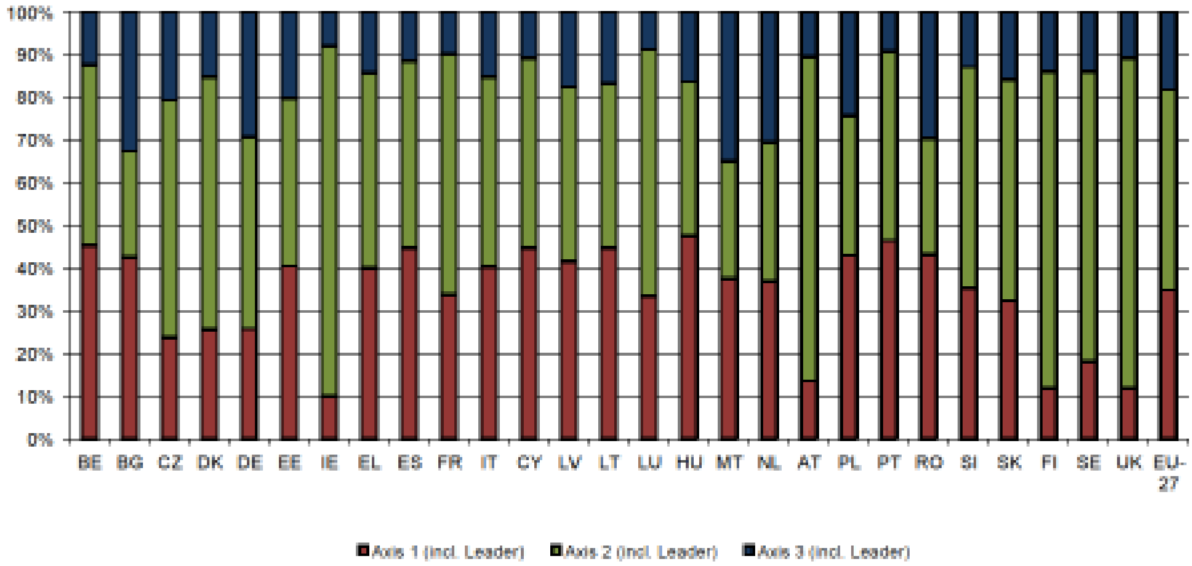
Source: European Commission, 2012: 346

Figure 1.1 Top measures of RDPs in terms of the EAFRD contribution, 2007-2013



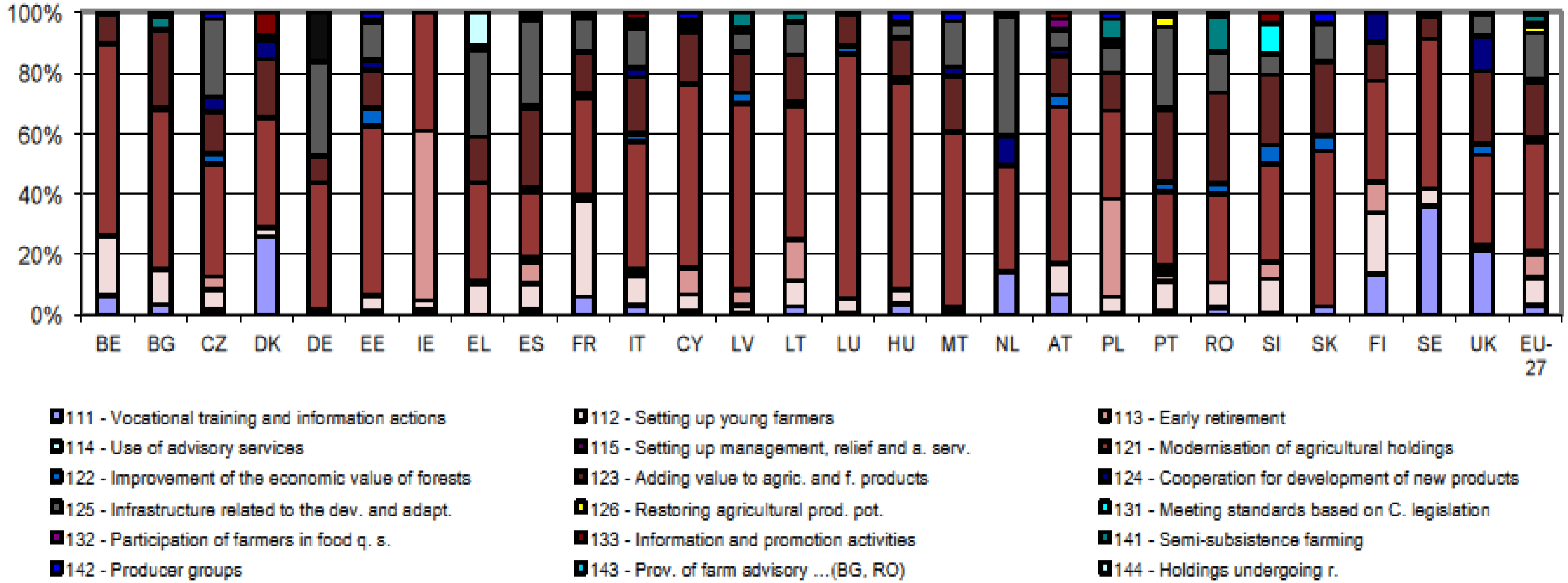
Source: European Commission, 2012: 294

Figure 1.2 Allocation of the EAFRD budget over the three RD axes in each Member State, 2007-2013



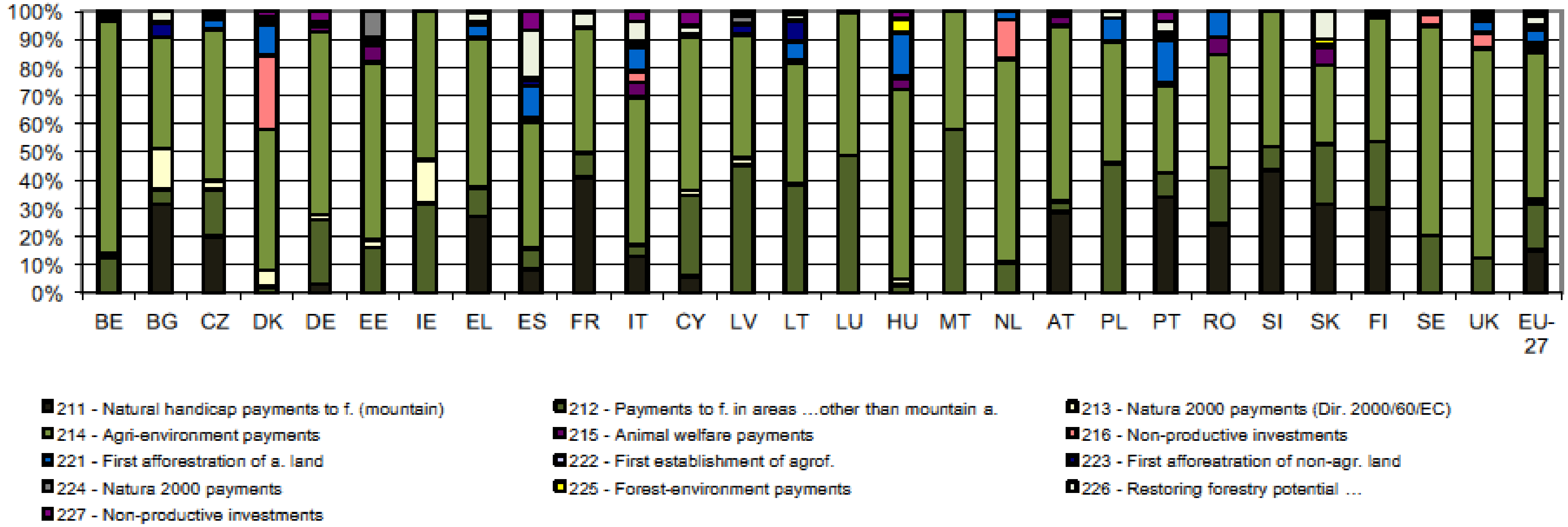
Source: European Commission, 2012: 292

Figure 1.3 Share of the EAFRD contribution allocated to each axis 1 measure in each Member States, 2007-2013



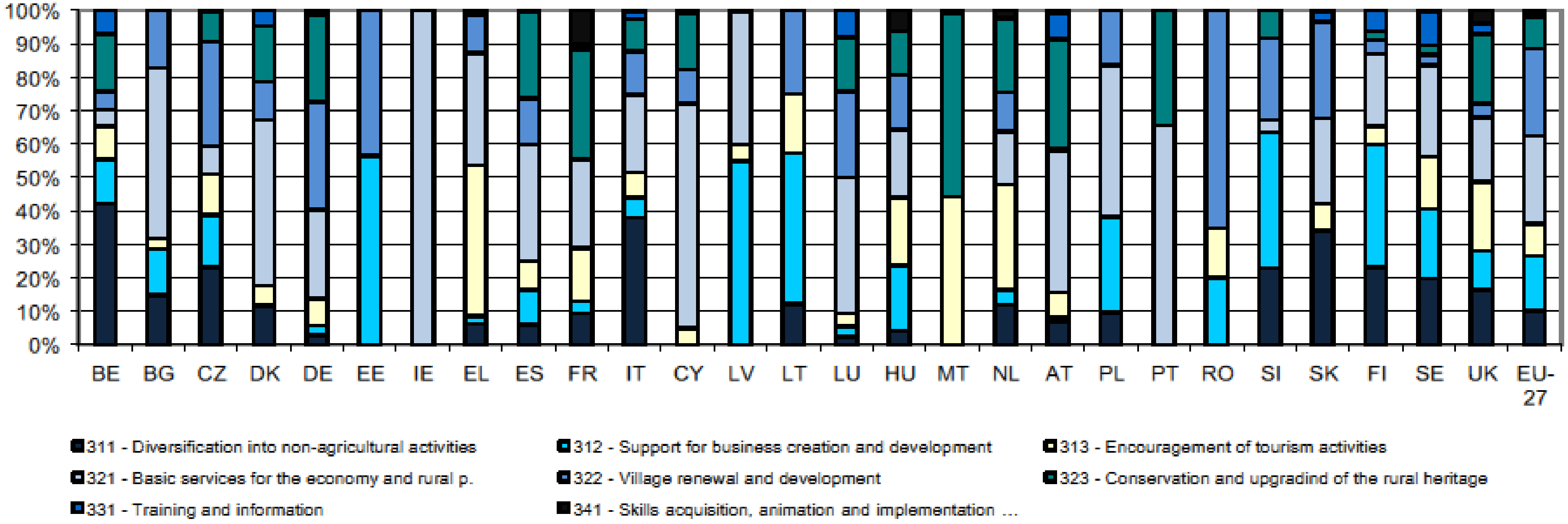
Source: European Commission, 2012: 297

Figure 1.4 Share of the EAFRD contribution allocated to each axis 2 measure in each Member States, 2007-2013



Source: European Commission, 2012: 297

Figure 1.5 Share of the EAFRD contribution allocated to each axis 3 measure in each Member States, 2007-2013



Source: European Commission, 2012: 297

1.2 THE AGRI-ENVIRONMENTAL SCHEMES IN THE EU: SOME FIGURES

The current AESs have maintained similar objectives and institutional settings of the AESs introduced in the eighties. They are voluntary contracts, of at least 5 years, stipulated between the farmer and the government. Under these contracts, the farmer provides environmental goods that go beyond the minimum requirements of the cross compliance and of the European and national compulsory environmental regulations, and they receive a fixed per hectare payment to face the additional costs and the loss of income linked to these commitments. The main objective of the AESs consists of reducing the agricultural pollution risks as well as protecting biodiversity and landscape. As part of RDPs, the AESs can be designed at national, regional or local level and this allows to take into account the heterogeneity of the natural characteristics and agricultural systems throughout the EU Member States. The agri-environmental and animal welfare programmes are the only measures that are compulsory present in all RDPs and they represent the main policy instrument to fulfil the environmental objectives of the CAP. It is possible to classify the AESs in the EU through several broad categories: organic farming, input reduction, crop rotation, reduction of irrigation, extensification of farming systems, action to conserve soil, management of landscape, pasture and high nature value farming, protection of rare varieties of plants and of animal breeds in danger of extinction, biodiversity maintenance. These broad categories are built up of different measures which may or may not be the same across Member States.

The AESs are not only the measures with the highest share of EU budget allocated to RD but their relevance is strengthened by the share of EU land subject to them and by the upward trend of the EU budget allocated to these measures. The percentage of the EU utilized agricultural area (UAA) under AESs equalled 21% in 2009 with an higher share for the EU-15 (25%) as compared to EU-12 (10%) (Table 1.2). At the Member State level, Luxembourg was the country displaying the highest share (92%), followed by Finland (91%), Sweden (82%) and Austria (70%). The EU contribution to the AESs shows an increasing trend over the period 1993-2010 (Figure 1.6). In 2010 the EU money allocated to these schemes amounted to 3.03 billion euro compared to only 76 million euro in 1993, the first year of integration of the AESs into the CAP framework. The drop of this contribution in 2007 compared to 2006 can be explained by the slow start in the implementation of AESs in the new financial period 2007-2013. If we look at the average total contribution (EU and national contribution) paid in the period 2007-2009 per hectare of UAA under AESs, this was about 163 euro at the EU level, with large differences across Member States (Figure 1.7). Malta and

Cyprus were the countries which guaranteed the largest average payment to their farmers under an AE contract, respectively 618 euro/ha and 609 euro/ha per year. The Netherlands and Greece compensated the participation to AESs with more than 400 euro/ha per year, while in Estonia, Luxemburg and Austria the contribution was larger than 300 euro/ha. The UK and Belgium corresponded to their AESs adopters less than 60 euro/ha, which was the lowest contribution among the EU Member States over the period 2007-2009.
Table 1.3 shows the breakdown of the area under AESs by type of action in each Member State in 2009, while Figure 1.8 refers to the EU level only. Only the land put under contract since 2007 has been considered. Management of landscape, pasture and high nature value actions (HNV) were the measures which covered the largest share of the UAA under AESs commitments at the EU-level (38.6%), as well as in the EU-15 (35.8%) and EU-12 (64%). The countries in which these measures were most important were Estonia (100%), Romania (99%), France (88%), Bulgaria (81%) and Sweden (71%). At the EU level these measures were followed by measures promoting extensification (14.2%) and entry level schemes (13.3%). Although organic farming covered only 8% of the EU land committed in 2009, this share was up to 78.7% in Denmark, 59.2% in Latvia and 49% in Lithuania. All the land under AESs in Luxembourg and most of the committed land in the UK and Finland was under the 'entry level scheme', which refers to a broad categories of environmental management actions aiming at providing environmental benefits just above a reference baseline, in order to receive the agri-environmental payment.

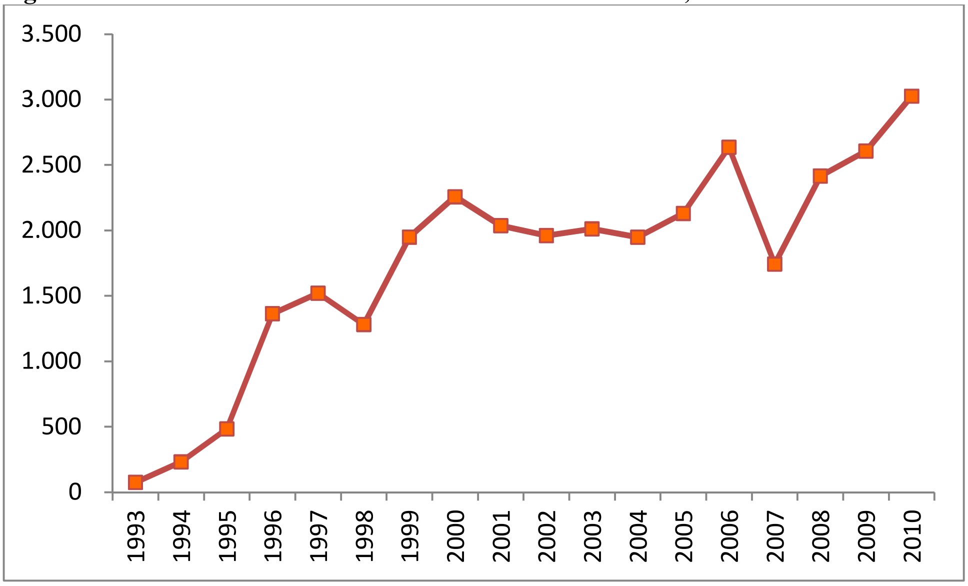
The overview presented above clarifies the main steps of the integration of the environmental concerns in the EU agricultural policy and the relevance of AESs within the CAP. The expectation is that the focus on environmentally-friendly practices of agriculture will be further strengthened in the future; the 'greening' proposed for the post-2013 CAP supports this prediction.

Table 1.2 Area under AESs in 2009

	UAA under AESs (ha)	UAA (ha)	Share of UAA under AESs (%)
EU-27	38,552,918	184,887,000	21
EU-15	33,561,363	133,208,600	25
EU-12	4,991,555	51,678,400	10
Belgium	349,465	1,365,200	26
Bulgaria	407,38	5,029,600	1
Czech Republic	624,897	3,545,800	18
Denmark	311,123	2,639,000	12
Germany	5,880,000	16,889,600	35
Estonia	423,508	931,800	45
Ireland	773,200	4,189,900	18
Greece	412,000	3,819,000	11
Spain	4,093,189	24,190,400	17
France	4,053,323	35,177,800	12
Italy	2,496,903	13,337,700	19
Cyprus	11,000	120,900	9
Latvia	375,000	1,833,000	20
Lithuania	179,935	2,689,000	7
Luxemburg	120,000	130,800	92
Hungary	1,078,000	5,783,300	19
Malta	758	10,300	7
Netherlands	93,036	1,921,400	5
Austria	2,205,771	3,168,600	70
Poland	472,262	15,624,600	3
Portugal	345,451	3,691,100	9
Romania	931,815	13,711,300	7
Slovenia	205,000	468,500	44
Slovakia	648641	1,930,300	34
Finland	2,097,864	2295900	91
Sweden	2,525,039	3,067,200	82
UK	7,805,000	17,325,000	45

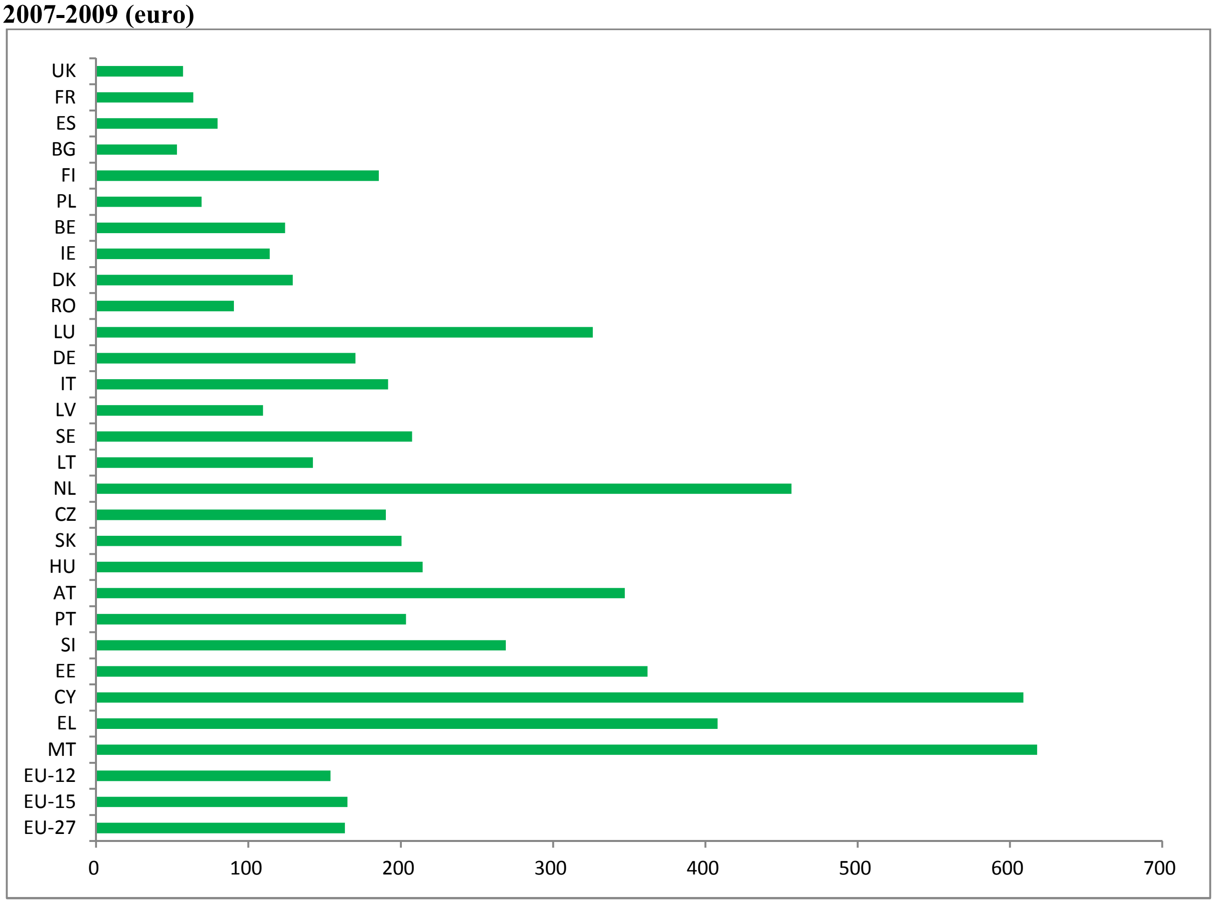
Source: Eurostat

Figure 1. 6 Trend of the EU contribution to AESs 1993-2010, million euro



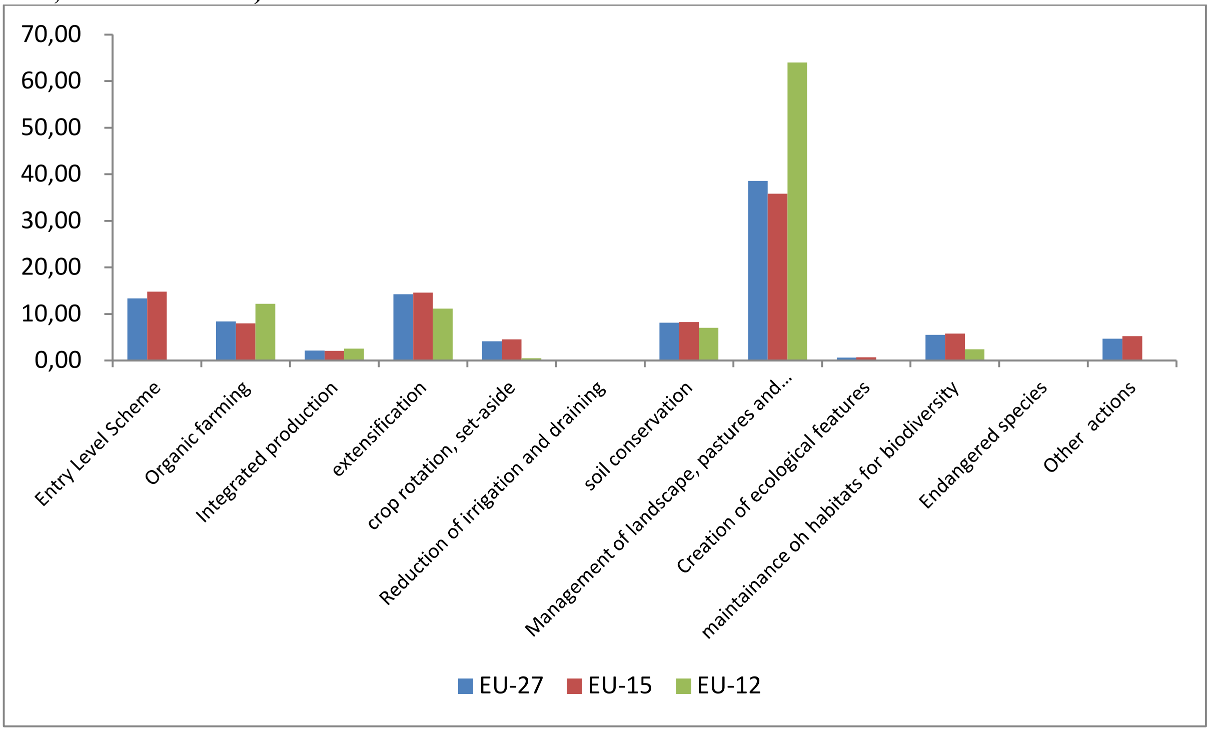
Source: own elaboration on Eurostat data

Figure 1. 7 Total public (EU +national) payment per ha of UAA under AE commitments, annual average 2007-2009 (euro)



Source: own elaboration on Eurostat data

Figure 1.8 Share of UAA under AESs by type of action, 2009 (contract signed and implemented since 2007, RDPs 2007-2013)



Source: own elaboration on Eurostat data

Table 1.3 Breakdown of the share of UAA under AESs per type of action in each EU Member State, 2009

	Entry Level Scheme	Organic farming	Integrated production	Extensification	Crop rotation, set-aside	Reduction of irrigation	Soil conservation	Management of landscape, pastures and HNV	Creation of ecological features	Maintenance of habitats for biodiversity	Endangered species	Other actions
EU-27	13.33	8.41	2.12	14.24	4.15	0.06	8.14	38.58	0.60	5.48	0.16	4.71
EU-15	14.78	8.00	2.07	14.58	4.55	0.07	8.27	35.82	0.67	5.81	0.16	5.22
EU-12	0.00	12.14	2.58	11.13	0.51	0.00	7.02	64.00	0.00	2.41	0.21	0.00
Belgium	0.00	18.81	0.00	5.31	1.83	0.00	16.60	10.66	39.72	6.85	0.21	0.00
Bulgaria	0.00	8.77	0.00	0.00	0.00	0.00	7.06	81.04	0.00	0.00	3.12	0.00
Czech Republic	0.00	28.62	4.41	15.58	0.00	0.00	1.67	48.92	0.00	0.80	0.00	0.00
Denmark	0.00	78.71	0.00	0.00	0.00	0.06	0.00	20.56	0.67	0.00	0.00	0.00
Germany	0.00	17.21	0.70	10.28	18.54	0.00	13.23	32.76	0.33	6.86	0.00	0.08
Estonia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Ireland	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.26
Greece	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Spain	0.00	12.81	4.46	5.14	1.99	0.00	1.71	7.58	0.45	45.30	0.68	19.87
France	0.24	0.93	0.00	2.11	5.13	0.27	0.22	88.40	1.33	1.33	0.04	0.01
Italy	0.00	26.06	24.82	11.38	3.83	0.00	3.48	27.18	0.37	1.43	1.43	0.02
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Latvia	0.00	59.22	0.29	0.00	0.00	0.00	0.00	22.35	0.00	18.15	0.00	0.00
Lithuania	0.00	49.07	0.00	0.00	0.00	0.00	0.00	25.31	0.00	25.61	0.00	0.00
Luxembourg	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
Malta	0.00	0.00	0.00	85.51	0.00	0.00	0.00	5.85	1.24	0.00	7.40	0.00
Netherlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.65	0.96	84.39	0.00	0.00
Austria	0.00	9.34	2.64	47.04	0.00	0.00	18.13	14.62	0.00	1.96	0.29	5.97
Poland	0.00	18.93	0.00	32.27	0.00	0.00	25.10	23.46	0.02	0.00	0.21	0.00
Portugal	0.00	18.28	48.35	10.40	0.00	0.00	3.08	19.89	0.00	0.00	0.00	0.00
Romania	0.00	0.00	0.00	0.00	0.00	0.00	0.70	98.73	0.00	0.57	0.00	0.00
Slovenia	0.00	8.58	20.52	0.23	6.38	0.00	21.51	40.75	0.00	0.32	1.72	0.00
Slovakia	0.00	5.94	3.92	65.20	0.00	0.00	11.29	0.00	0.00	13.65	0.00	0.00
Finland	40.79	2.75	0.00	28.19	3.82	0.00	23.96	0.21	0.06	0.06	0.00	0.16
Sweden	0.00	13.07	0.00	15.99	0.00	0.00	0.00	70.68	0.25	0.00	0.00	0.00
UK	93.90	4.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.77

Source: Eurostat

1.3 THE PRICE VOLATILITY ON AGRICULTURAL MARKETS: THE INCREASE OF UNCERTAINTY FOR FARMERS

Another recent challenge that EU farmers must face is the increase in agricultural price volatility that has been experienced in recent years. By price volatility we refer to price variation, which becomes a problem when it is large and unpredictable, and as such creates uncertainty which may lead to sub-optimal producer decisions. The price volatility leads to an uncertain farmer's income which may produce negative effects on investment decisions.

Looking at the long term development of agricultural commodity prices there is no evidence of a rising trend in volatility, but if we look at the medium term, since 2006 volatility has been higher compared to the previous two decades and it shows an increasing trend since 1990 (Figure 1.9). According to a study of the European Commission (2010) the price volatility of agricultural products has increased in both the EU and world markets in the period 1997-2010. The price volatility in world markets has been stronger than in the EU; however, the EU had a sharper increase in volatility than the world market in the period 2004-2010 compared to 1997-2003. Such higher price volatility increase in the EU is the consequence of the reforms of the CAP towards liberalisation. The expectation is that the recent price volatility has not been a temporary phenomenon, but it will likely persist in the future on agricultural markets, while agricultural prices are expected to increase (OECD, 2011). The reasons for this expectation are the increasing connection of the agricultural markets with financial markets, which may lead to speculative activities, the rising demand of agricultural products by the energy markets, which links agricultural markets with oil markets, and the uncertainty about the impact of climate change (DG Agricultural and Rural Development, 2011). Furthermore, world agricultural production should increase by 70% in 2050 to feed a world population which is prospected to reach 9 billion (OECD, 2011); as a consequence of the tigth balance between demand and supply the volatility will be stressed and the prices will rise. In addition, the CAP is no longer a price stabilising policy, hence European farmers are exposed directly to the world price fluctuations.

The increase in price volatility is just one of the many sources of uncertainty and risk in agriculture. Agricultural activities are exposed to different kinds of risk such as production risk, market risk, personal risk, financial risk and institutional risk (Hardaker *et al.*, 1997) and an increase in price volatility affects market risk. In a risky environment, the farmer makes his production plan based on his expectations on future and uncertain outcomes and these expectations are often based on past experiences. Most empirical studies showed that farmers are averse to risk as they are willing to sacrifice some income to ensure against the risk consequences. Given the risk averse attitude of the farmers, high commodity price volatility is negative as it makes farmer income uncertain. This may lead to non-optimal production decisions in the short run and may discourage farm investments, thus leading to a decrease in farm profitability and competitiveness in the medium-long run.

In order to reduce the negative impact of large price variations on farmer income, there has been a large debate in order to identify market stabilisation tools that may be implemented (see for example OECD, 2011, and European Commission, 2011). Some of these tools are already in place in the EU, others should be developed. Although the OECD report has a broad focus on both developing and developed countries, we will focus only on the potential market stabilization instruments in the EU.

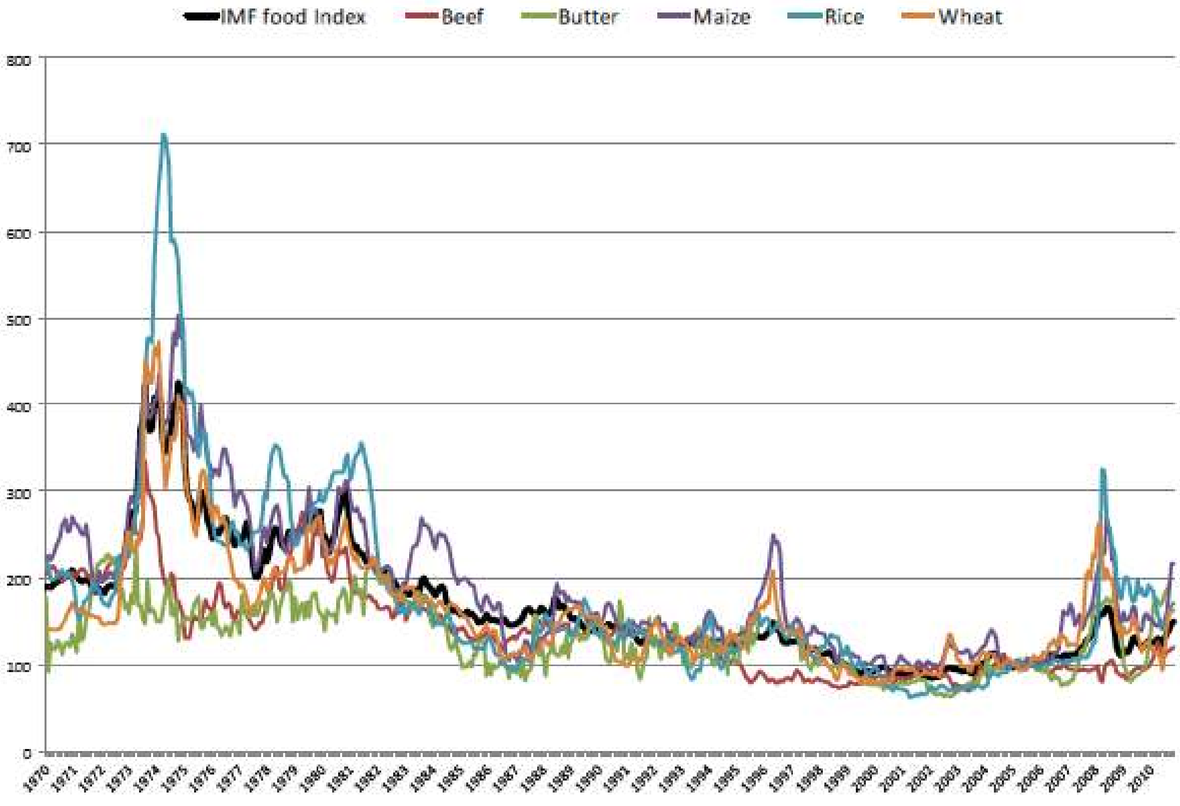
The agricultural derivatives (futures and options) have progressively been evaluated in recent years as risk management tool in agricultural markets and we expect they will become an important instruments in the future in the EU. However, in order for this tool to be effective, some effort is required to assist farmers in its implementation.

One of the most important income stabilizer currently in place in the EU is the direct income payment; although the payment is intended to support farmer income, it also acts as a risk management tool by guarantying a certain level of income which is independent of the price fluctuations. The EU intervention prices of agricultural commodities have been largely reduced by the CAP reforms; nowadays, they are set at rather low level and they work as a safety net in times of severe crisis. Other tools such as private storage aids and state aids may be useful to contrast the price fluctuations.

The European Commission in its legal proposal on the support for Rural Development after 2013 (2011) has proposed the introduction of an income stabilization tool financed by mutual funds supported by the EU budget. The income stabilization tool would compensate farmer for an income drop of at least 30% compared to the farmer average income in the previous three years and the compensation could not exceed 70% of the income loss. Although this tool would even out the extreme downward peak of income, its implementation does not seem straightforward. First, a farm’s accountancy is required in order to monitor the current farmer’s income and the income of the previous three years; second, it is not clear how such an instrument may be financed since in years of crisis we may expect that most of the EU farmers may be eligible for compensation leading to a large expense.

The OECD report stresses the importance of creating a network of up-to-date and transparent information about the fundamentals of agricultural markets as a way to improve market efficiency and to reduce price fluctuations.

Figure 1. 9 Agricultural commodity prices in real terms (2005=100)



Source: OECD, 2011: 7

1.4 RESEARCH QUESTIONS

This thesis develops from the challenging context discussed above. The rising attention of the CAP to the environmental concern, the price volatility increase on the world and on the EU agricultural markets and the search for new farmer income stabilization tools represent the background motivation of this thesis, which aims at analysing the AESs from two viewpoints.

Chapter 2 performs an ex-post comparative analysis wishing to investigate the effects of AESs adoption on farmer's practises and economic performances across five EU Member States. The existing literature does not comprise any study on the AESs which is focused on the impact on farm income and which compares the effects in different countries. Since the implementation of the AESs differs across countries as well as the agricultural systems, we expect heterogeneous effects. This comparison may have significant policy implications since it may reveal the countries where the participation in AESs requires a deeper change of the farmers' production plans and where the effects on farm income are stronger. The analysis may also indicate whether the amount of the AE payment provides a fair compensation to participants. In addition, the study may also evaluate the ability of the AESs to promote sustainable practices and, by this, it may indirectly shed light on the environmental impact of such schemes.

The ex-post analysis on AESs has been carried out by the application of a semi parametric Difference-in-Differences Propensity Score Matching estimator. Propensity Score Matching (PSM) is a methodology applied to evaluate the impact of a treatment in a non-experimental setting. Recently it has been applied to the analysis of some Rural Development measures (Pufahl and Weiss, 2009; Chabé-Ferret and Subervie, 2013). The most recent applications integrates PSM with a Difference-in-Differences (DID) estimator when panel data are available in order to control for selection bias on both observed and time-invariant unobserved covariates. The combination of PSM and DID estimators is suitable for our goal as our research consists in a program evaluation in a non-experimental setting. Moreover, the availability of farmers' panel data coming from the FADN dataset allows to control for the bias on time-invariant unobserved variables.

Chapter 3 studies the AESs from an innovative viewpoint as it performs an ex-ante analysis investigating their role as farm income stabilizer. Although the traditional role of these schemes consists in the provision of environmental benefits and their payments wish to compensate the income forgone because of the adoption, we argue that they may play a new role in presence of increasing agricultural price volatility. Indeed, the farmers participating in AESs receive a fixed payment per hectare which represents a stable share of their income independent of crop price fluctuations.

This study has developed a new methodological approach, which represents one of the few attempts to integrate the risk component in a Positive Mathematical Programming (PMP) framework. Given the importance of accounting for risk in agricultural production and the powerful calibration ability of PMP, we think that the introduction of risk in PMP modelling will be one of the new research frontier in the area of mathematical programming. The combination of PMP with risk modelling allows the use of a calibrated model in analysing farm behaviour under uncertainty. Our approach differs from the few earlier attempts since it merges the first linear phase with the second non-linear phase of a PMP farmer expected utility maximisation problem. This allows to use all the information available in the dataset to estimate simultaneously the farmer's risk aversion coefficient, the farm non-linear cost function as well as the shadow prices of resources and activities. In addition, a set of Karush-Kuhn-Tucker conditions provides the economic foundation of the model. The proposed model has been tested on three farm samples and it has been applied to investigate the potential role of an AES, the option to convert a share of farmland to grassland, as a farmer strategy to cope with income risk under different scenarios of crop price volatility.

CHAPTER 2

Impact of agri-environmental schemes on farm performances in five EU Member States: a difference-in-differences approach

2.1 INTRODUCTION AND BACKGROUND

In recent years in developed countries there has been an increasing concern about the relationship between agriculture and the environment. In the European Union (EU), the Common Agricultural Policy (CAP) has introduced environmental measures in order to discourage negative environmental externalities and to promote positive externalities of agricultural activities. For example, negative externalities are sanctioned by a reduction in direct income payments if cross-compliance is not respected, while some ad hoc directives have been implemented for addressing some specific problems (i.e. the nitrates directive). Positive externalities are encouraged by some Rural Development measures which promote environmentally sustainable farming practices, through payments that compensate farmers for the provision of environmental goods that the market does not reward. One of these measures are the agri-environmental schemes (AESs) introduced in the late 1980s as an option to be applied by Member States. Since 1992, with the Mac Sharry reform, the development of AE programs has become compulsory for all Member States with the Regulation 2078/92, while their application by farmers is still voluntary. Since 1999, with the Agenda 2000 CAP reform (EEC n. 1257/99) the AESs have become a section of the Rural Development Programs (RDPs) which represents Pillar II of the CAP.

Agri-environmental contracts are voluntary contracts, of at least 5 years, stipulated between the farmer and the government; under these contracts, the farmer provides environmental goods that go beyond the minimum requirements of the cross compliance and of the European and national compulsory environmental regulations and they receive a fixed per hectare payment to face the additional costs and the loss of income linked to these commitments. The main objective of the AESs consists of reducing the agricultural pollution risks as well as protecting biodiversity and landscape. AESs payments are co-financed by Member States and they represent a large share of the public budget for Rural Development. They can be designed at national, regional or local level and this allows to take into account the heterogeneity of the natural characteristics and agricultural systems throughout the EU Member States. The agri-environmental and animal welfare programmes are the only measures that are compulsory in all RDPs and the AESs are the most significant measure in term of EU funding for Rural Development, 23.6%, followed by 'Modernisation of agricultural holdings', 12%, and 'Payments to farmers in areas with handicaps, other than mountain areas', 7.6%. In some EU countries the AESs are mainly defined at national level with little decision power at regional level (e.g. France and the Netherlands), while in other countries they are defined and implemented at regional or subregional level (e.g. Italy, Germany, Spain).

There is quite a lot of literature about AESs; most of it tries to analyze the factors affecting farmer's participation to agri-environmental contracts (Vanslembrouck *et al.*, 2002; Defrancesco *et al*., 2007). Another widely studied topic concerns the analysis of the environmental effectiveness of farmers' environmental practices; most of these studies outline the importance of accounting for farm heterogeneity, by applying more farm-specific measures (Aakkula *et al.*, 2011). A few studies analyse the effects of AESs on farms' practices and economic results. Sauer *et al.* (2012: 6) argued that "only a few studies so far have attempted to empirically measure the actual impact of being subject to AESs on producer behaviour at individual farm level using statistical or econometric tools". The expectation is that farmers are heavily affected by participation to AESs, which may lead to a deep reorganisation of the farm and to a change in the sources of income.

An ex-post analysis tool recently applied to analyse the effects of agricultural policy measures on farm's performances is the Propensity Score Matching (PSM). Propensity score analysis has been widely developed in the last thirty years as a program evaluation method based on observational data in a broad range of disciplines, such as medicine, epidemiology, psychology, social sciences, education. More recently it has been applied also to environmental economics and to the analysis of some measures of RDPs. The most recent applications integrates PSM with a Difference-in-Differences (DID) estimator.

Pufahl and Weiss (2009) and Chabé-Ferret and Subervie (2011) applied a DID PSM estimator in order to evaluate the effect of AESs on farm choices. Pufahl and Weiss analysed the impact of AESs adoption on input use and output produced of a large sample of German farms observed over the period 2000-2005. Their work showed that farmers participating in AESs experience higher positive growth rates in sales, on-farm labour, area under cultivation, grassland and rented land compared to the ones non participating; by contrast, they have higher negative growth rates in livestock density, fertilizer and pesticide expenditure. Chabé-Ferret and Subervie (2011) investigated the land allocation changes linked to AESs participation on a sample of French farms as well as they analysed the different sources of bias and the windfall effect. The PSM estimator has also been applied to compare voluntary and compulsory environmental measures in terms of their impact on farm production choices. Sauer *et al*. (2012) found that voluntary AESs affect farmers' decisions heavier than non voluntary measures. Their analysis on a sample of the UK cereal farms showed that farmers participating into AESs do not reduce their efficiency as they efficiently adjust their production plan to the new constraints, especially by becoming less specialized and more diversified. The use of fertilizers and chemicals decreases, as well as the land and capital productivity, while labour productivity increases. Jaraitė and Kažukauskas (2012), applying a backward DID, showed that EU-15 farmers participating into voluntary AESs reduce chemical pollution more as compared to farmers not subject to voluntary AE program, indicating a cross positive effect between compulsory and voluntary measures, while the level of farm subsidy does not affect the degree of compliance with compulsory measures. PSM estimator has been also applied to the analysis of some Rural Development measures in North America.

The work of Liu and Linch (2011) studied the impact of development right programs on preventing farmland loss in six Mid-Atlantic US states. Tamini (2011) analysed the effect of extension advisory activities on farmer's adoption of best management practices in Quebec. His results showed that environmental advisory activities increase the environmental performance of farmers by increasing the rate of adoption of best management practices and this increase is larger in the case of practices related to compulsory regulations.

Despite the increasing use of PSM methods to study the effects of some Rural Development measures on farm decisions, to the best of our knowledge there are no studies that compare the effects of agri-environmental contracts on farmer's choices and economic performances in different EU countries. In addition none of the studies found in the literature focus on the impact of AESs on the farm economic variables, such as farm income. AESs are expected to differently affect farmers in different EU Member States given the different climatic conditions, the different characteristics of agriculture as well as the different national implementations of AESs. The comparison among EU countries may indicate the countries where the AESs adoption requires a deeper change of farmer's production plans and where the effects on farm income are stronger. This may also indicate how the AESs perform in different Member States and the reasons of different participation rates. This paper aims at filling this gap by applying a DID PSM estimator in order to perform comparative analysis on the effects of AESs on farmer's practises and economic performances across five EU Member States: France, Germany, Spain, the UK and Italy.

2.2 METHODOLOGY

In applied research, matching analysis is generally applied to evaluate the impact of a treatment in a non-experimental setting. The main advantage of matching compared to the standard regression models is that matching does not require any functional form specification, avoiding potential bias due to misspecification. In addition, it allows for heterogeneous effects of the treatment among individuals (Pufahl and Weiss, 2009).

The core problem of a treatment analysis is the evaluation problem. Evaluating the effect of a treatment requires being able to observe at the same time the outcome of the same individual in both states, subject and not subject to the treatment (Smith and Todd, 2005). If we indicate with Y^1 the outcome of an individual subject to the treatment and with Y^0 the outcome of the same individual in the case he had not been subject to the treatment, the effect of the treatment can be measured as: $Y^1 - Y^0$. Obviously, for each individual only one state can be observed, Y^1 or Y^0, hence there is a missing data problem that is the core of the evaluation problem. The use of all non treated individuals as counterfactual for the treated group causes a selection bias problem, since in a non-experimental setting it is likely that the treatment is not randomly assigned and the treated and control groups differ with respect to the treatment status but also with respect to other characteristics.

Matching estimators aim at overcoming the selection bias on observables by matching each treated individual with one or more non treated individuals that have similar observed characteristics, the covariates X, and interprets the difference in their outcomes as the effect of the treatment (Smith and Todd, 2005). In order for the matching estimator to be unbiased, some assumptions must be satisfied. The central assumption is the conditional independence assumption (CIA) or strong ignorability: after conditioning on a set of covariates, X, the potential outcomes are independent of treatment assignment (Rosembaum and Rubin, 1983):

$$(Y^1, Y^0) \perp D \mid X \tag{2.1}$$

where D is a dummy variable that takes value of 1 for treated individuals and 0 for non-treated individuals and $\perp$ indicates independence[1].

Another important assumption is the common support condition, which guarantees that individuals with the same X values have a positive probability of being both treated and not treated:

$$0 < P(D = 1 | X) < 1 \tag{2.2}$$

This assumption guarantees that a match can be found for each treated and untreated individual.

If the two assumptions are satisfied the matched control group can be used as counterfactual to know how the treated group would have performed in the absence of treatment. Since conditioning on a large set of covariates X may be cumbersome, Rosembaum and Rubin (1983) proposed the idea of conditioning on a function of X, the so-called "balancing score" $P(X)$, such that the conditional distribution of X given $P(X)$ is independent of the assignment into treatment. This condition is called balancing condition:

$$D \perp X | P(X) \tag{2.3}$$

The balancing score measures the probability of treatment participation given the covariates:

$$P(X) = \Pr(D = 1 | X) \tag{2.4}$$

Rosembaum and Rubin (1983) showed that if the potential outcomes are independent of the treatment conditional on X, they are also independent of the treatment conditional on the balancing score $P(X)$. Hence, assumption (2.1) becomes:

$$(Y^1, Y^0) \perp D | P(X) \tag{2.5}$$

If conditioning is based on the balancing score, matching is called PSM.

After matching has been performed, the most common parameter used to evaluate the effect of an intervention is the 'average treatment effect on the treated' (ATT), defined as the difference in the mean outcomes of the treated and the matched control group:

[1] If the interest is the average effect of the treatment on the treated, it is sufficient that $(Y^0) \perp D/X$. $(Y^1) \perp D/X$ is a necessary condition when we want to calculate the mean impact of the treatment on the untreated, while $(Y^0, Y^1) \perp D/X$ is required as a necessary condition when we calculate the average effect of the treatment on a randomly assigned individual (Heckman et al., 1997).

$$ATT = E(Y^1 \mid D = 1, P(X)) - E(Y^0 \mid D = 0, P(X)) \qquad (2.6)$$

Heckman *et al*. (1997) demonstrated that if the interest is in the estimation of the ATT, then assumptions (2.1) and (2.2) are too strong; in such a case they proposed two weaker assumptions. The first is the conditional mean independence assumption, stating that the mean outcome is independent of the treatment assignment conditional on the propensity score $P(X)$:

$$E(Y^0 \mid P(X), D = 1) = E(Y^0 \mid P(X), D = 0) \qquad (2.7)$$

The second restricts the probability of the treatment to be lower than one:

$$P(D = 1 \mid X) < 1 \qquad (2.8)$$

The replacement of assumption (2.2) by assumption (2.8) relies on the construction of ATT which requires to find for each participant an analogue non participant but it is not interested in the opposite (Smith and Todd, 2005).

Matching can be performed applying different matching algorithms: nearest neighbour, caliper and radius matching, stratification and interval matching, kernel and local linear matching (see Caliendo and Kopeinig, 2008, for a review of all these matching procedures). The algorithms differ for the weights given to each non treated unit and the choice of the algorithm depends on the specific situation and it always presents a trade off between variance and bias. The choice of the matching estimator becomes more important when there is a minimum overlap between the treated and the control group (Dehejia and Wahba, 2002). The general notation of a matching estimator that estimates the ATT is as follows:

$$\alpha = \frac{1}{N} \sum_{i=1}^{I \cap S} \left[Y_i^1 - \sum_{j=1}^{J \cap S} W_{ij} Y_j^0 \right] \qquad (2.9)$$

where i identifies the treated individuals, j identifies the non treated individuals, α is the matching estimator for the ATT, N is the number of units of the treated group falling in the region of common support, W_{ij}, $0 < W_{ij} < 1$, indicates the weights which depends on the distance between P_i and P_j and S indicates the region of common support. The common support is the region where the propensity scores of treated and non treated individual have both positive density:

$$\hat{S} = P : \hat{f}(P \mid D = 1) > 0 \ \ and \ \ f(P \mid D = 0) > 0 \qquad (2.10)$$

Matching is usually performed over the region of common support. Although restricting matching to the common support region prevents bad matching, it may also discharge from the analysis a large number of units, which fall out of the region of common support. Sometimes a 'trimming level' is specified such that the common support is the region where the density function of the probability of treated and non treated individuals are both larger than the declared level.

Cross-section matching methods correct for the selection bias on observables, which occurs when there are variables that affect simultaneously treatment assignment and outcomes. However, Heckman *et al*. (1997) pointed out that there may be variables apart from X that are unobserved and that affect both treatment status and outcomes. These variables may lead to the selection bias on unobservables. In order to partially overcome this problem, Heckman *et al*. (1997) proposed to combine the PSM estimator with a DID estimator. The conditional DID matching estimator differs from the conventional DID estimator as it compares outcomes conditional to X and calculates the treatment effect in a semi-parametric way. The conditional DID estimator compares the conditional before-after outcome of the treated individuals with that of the matched counterparts:

$$DID = \frac{1}{N}\sum_{i=1}^{I \cap S}\left[\left(Y_{it}^{1} - Y_{it'}^{0} \mid D = 1\right) - \sum_{j=1}^{J \cap S} W_{ij}\left(Y_{jt}^{0} - Y_{jt'}^{0} \mid D = 0\right)\right] \qquad (2.11)$$

where t' is the pre-treatment period and t is the post-treatment period. The DID matching estimator allows for time invariant differences in outcome levels between the treated and the control group; however, it requires that, conditional on the propensity score, in absence of treatment the average outcomes of the treated and control group would have followed parallel paths over time. Therefore, the conditional mean independence assumption (2.7) is replaced by a weaker assumption, the DID mean independence (equation 2.12), while the support condition must still be satisfied.

$$E(Y_t^0 - Y_{t'}^0 \mid P(X), D = 1) = E(Y_t^0 - Y_{t'}^0 \mid P(X), D = 0) \qquad (2.12)$$

The double difference of the DID estimator removes the bias due to time-invariant unobserved characteristics and the bias due to common time trends unrelated to the treatment. Another advantage of this technique is the possibility to use pre-programme outcomes. When the DID estimator is applied, the ATT measures the difference in the average growth of the outcome between the treated and the control group:

$$ATT = E(Y_t^1 - Y_{t'}^0 \mid P(X), D = 1) - E(Y_t^0 - Y_{t'}^0 \mid P(X), D = 0) \qquad (2.13)$$

In order to analyse and compare the effects of the adoption of agri-environmental contracts on farm practises and economic results in different EU countries we have applied the DID PSM, since this estimator is suitable for our goal. First, our research problem is a program evaluation problem where the treatment is the participation in AESs. Second, the non-experimental setting of the analysis likely leads to selection bias, as it is reasonable to think that farms that decide to participate in AESs have different characteristics compared to farms that do not and these characteristics may also affect the outcomes. Third, the use of a non parametric analysis allows to consider individual-specific effects as well as avoiding functional form misspecification. Fourth, the availability of farm-level panel data allows the application of the DID estimator, which removes the bias due to time-invariant unobserved characteristics and allows the use of pre-treatment outcomes in the matching procedure.

The adoption of the DID PSM estimator is further motivated by the studies conducted by Smith and Todd (2005) and by Heckman *et al*. (1997), which showed that DID matching estimators perform better compared to cross-sectional estimators. Finally, Heckman *et al*. (1997: 612) stated: " ... placing comparison group members in the same economic environment and administering them the same questionnaire as participants substantially improves the performance of non-experimental estimators". The characteristics of the FADN database used in this study guarantee the homogeneity of the data collection between participants and non participants and the analysis conducted separately by each Member State ensures a homogenous economic environment.

2.3 EMPIRICAL MODEL AND DATA

We have conducted the analysis of the effects of AESs participation on farmer choices and performances separately for each country. This allows heterogeneous effects in different countries and account for country specific characteristics and country specific AESs. We started from a balanced panel of farms of each country observed over the period 2003-2006 and we applied DID matching estimator (Heckman *et al*., 1997). The pre-treatment period considered is 2003, while the post-treatment period is 2006. 2006 is the last year of the 2000-2006 EU budget period and corresponds also to the last year of the 2000-2006 RDPs.

Farms of the country panel have been assigned to the treated group if they did not participate in AESs in 2003 but they did participate in 2006, and they enter the control group if they did not participate for the whole period 2003-2006. Each country treated group has been split into two subsamples according to the share of the agri-environmental payments on farm income and the analysis of the effect of AESs adoption has been carried out for each subsample; if the share is lower than the median of the full country treated sample the farm belongs to subsample 1, while if the share is larger than the median the farm belongs to subsample 2. The reason behind this splitting is that the effects of AE adoption on farmers' behaviour may differ according to the share of income dependent on AE payments. Number of farms in each sample are reported in Table 2.1.

Table 2.1 Number of farms in each country group before and after the matching

	Before the matching				After the matching			
	Treated sub sample 1	Control group	Treated sub sample 2	Control group	Treated sub sample 1	Control group	Treated sub sample 2	Control group
France	202	2101	205	2101	200	1082	202	983
Germany	129	915	129	915	129	524	128	563
Spain	48	1619	47	1619	45	216	45	143
UK	264	523	261	523	253	462	260	433
Italy	161	5239	162	5239	160	1119	162	1007

The farm level data used come from the Farm Accountancy Data Network (FADN), the EU database that collects yearly data of technical characteristics and economic results of a large sample of farms from each Member State. The data on macroeconomics indicators come from official national statistics and Eurostat. The five countries considered in our study are France, Spain, Germany, the UK and Italy, for which a balanced panel of farms observed over the period 2003-2006 has been analysed. France is the only country among the five considered where the AESs are mainly defined at national level; French regions can only partially determined the amount of payments of each measures. In the other four countries the AESs are mostly determined at regional level and in some cases they can be detailed further at local level. In Spain the regions can choose which AESs to implement from a national list. In Germany the AESs are decided by each state although there are some 'horizontal measures', which equally applied across all the states. In the UK each state, England, Scotland, Wales and Northern Ireland, defines the framework of AESs, which are detailed further at local level. Finally, in Italy the regions define the AESs to be implemented.

If we consider the share of utilised agricultural area (UAA) under AE contracts in 2006, we notice differences across Member States. While the EU-25 average share was 15.7%, Germany was the country with the highest share of UAA covered by AESs (42.1%). The percentage of the three Mediterranean countries, Italy, Spain and France, was 12.3%, 13.8% and 11.5%, respectively.

2.3.1 Propensity Score Matching

The first step of the matching procedure is to estimate a binary model of the participation in AESs selecting the variables that affect simultaneously farmers' participation and outcomes (Liu and Lynch, 2011). We estimated a country-specific logit model for the pre-treatment period 2003.

The decision of how many variables to include in a propensity score binary model is a widely discussed issue in the literature. Bryson *et al*. (2002) outlined that including too many variables in the binary model is not worth because it may exacerbate the common support problem and it may increase the variance of the estimator. By contrast, according to Rubin and Thomas (1996), one should include all variables even if they are not statistically significant with the exception of a few cases: if there is consensus that a variable does not affect the outcome, if the treated and full control mean values of a variable are 'very close', or if a variable is highly correlated with variables that are already in the model. We started from a large set of variables derived from economic theory and results of applied research and we performed likelihood ratio tests on groups of variables in order to select the best specification of each country-specific logit model. A given group of variables was kept in the model if not rejected by the test and variables of that group were included in the model even though they were not statistically significant.

The groups of variables considered in our model to explain the AESs participation and the corresponding variables in each group concern both farm technical and economic characteristics as well as macroeconomic environment and farm regional location and altitude. The groups of variables identified are: age of the farmer, altitude of the farm location (dummy variables for hill and mountain), farm size (farm UAA and rented land), farm production intensity (total farm output value per hectare, share of grassland on farm land and value of fixed assets per farm working units), use of chemical products (per hectare expenditure on fertilisers and crop protection products), farm labour (number of family working hours and hired labour working hours), farm profitability (farm income per hectare), level of farm dependence on subsidies (farm direct income payment per hectare). In order to take into account the differences in the economic environment throughout the regions of a country we included also a group for two macroeconomic indicators at the regional level: the gross domestic product per capita and the share of the agricultural value added over the total value added of the region. Finally, dummy variables have been used to indicate farm type (livestock or arable crops) and geographical location[2]. The results of each country logit model are the farm's propensity scores that are used in the matching procedure (Table A2.1 and Table A2.2).

Different matching algorithms have been implemented and the one that performs better has been selected. Since we did not condition directly on the covariates but on the propensity scores, we checked the ability of the matching procedure to balance the covariates between the treated and the matched control group. The matching quality of each algorithm has been tested by three different procedures. The first procedure consists in a t-test on the differences of the covariates means of the two groups and the null hypothesis of no differences should not be rejected after the matching. The second consists in the calculation of the standardised bias before and after the matching. The standardised bias measures the distance of the marginal distribution of the covariates and it is calculated for each covariate as the difference of the sample mean between treated and matched control group over the square root of the average of the samples variances:

$$SB_{before} = 100 * \frac{\overline{X}_1 - \overline{X}_0}{\sqrt{0.5 * (V_1(X) + V_0(X))}} \tag{2.14}$$

$$SB_{after} = 100 * \frac{\overline{X}_{1M} - \overline{X}_{0M}}{\sqrt{0.5 * (V_{1M}(X) + V_{0M}(X))}} \tag{2.15}$$

[2] The macroeconomic indicators are specified for each NUTS2 region in France, Spain and Italy and for each NUTS1 region in Germany and United Kingdom. The country geographical dummy are specified for NUTS1 regions or aggregation of them.

where SB_{before} and SB_{after} are the standardised bias before and after the matching respectively, $\bar{X}_1$ and $\bar{X}_{1M}$ are the covariates means of the treated before and after the matching respectively, while $\bar{X}_0$ and $\bar{X}_{0M}$ have the same meaning for the control group. $V_1(X)$ and $V_{1M}(X)$ are variances of the covariates before and after the matching for the treated group while $V_0(X)$ and $V_{0M}(X)$ have the same meaning for the control group. It is interesting to compare the standardised bias before and after the matching to detect the ability of the matching in reducing the bias. Although a significance level on the standardised bias does not exist, in empirical works a standardised bias below 5% is considered good (Caliendo and Kopeinig, 2008). Finally, the third procedure consists in re-estimating the logit model after the matching when the pseudo R-square should appear very small (Sianesi, 2004). When the tests on the matching quality resulted in a poor balancing of the covariates between the two groups we have better specified the model until all the three tests showed good quality of the matching. We have checked the robustness of our results by comparing the results of our 10 nearest neighbours estimator with other PSM estimators that satisfy the balancing property for the covariates. Since results are similar, this supports the robustness of our findings[3].

After testing different matching algorithms and checking the covariates balancing property, we chose to implement the nearest neighbour matching with ten neighbours, with replacement and with a caliper of 0.1. The caliper indicates the maximum distance between the propensity scores of the treated and the matched control individuals. The ten nearest neighbour matching estimator has been applied for both subsamples in each country, in order to make the results comparable. Ten nearest neighbours estimator with caliper and with replacement resulted in good matching quality in all samples analysed; it satisfied always the covariates balancing property, it reduced the standardised bias of most of the covariates and it showed a small pseudo R-square of the logit model after the matching (see Tables A2.3 and A2.4 in the Appendix A2.A). The use of ten nearest neighbours compared to the single nearest neighbour matching decreases the variance, because more individuals are used to construct the counterfactual of each treated individual, but it also increases the bias, because the additional individuals used are poorer matches. In order to avoid high increase in the bias, we have restricted the matching within a caliper of 0.1 and we have allowed for replacement. In the

[3] These results are available from the authors upon request.

ten nearest neighbour algorithm we have also imposed the common support condition in order to avoid bias due to the failure of common support (Heckman *et al*., 1997). Once the matching has been performed on 2003 data and the matching quality has been checked, the ATT on the treated is calculated using the DID estimators for different outcomes (equation 2.11) . In the DID framework, the before-after outcome differences for each participating farmer has been compared to those of the matched non participants. The outcomes analysed as potentially affected by AESs adoption concern the farmer production choices and the farm economic performances. Among production choices, we have considered the per hectare expenditure on fertilisers and crop protection, the farm total UAA, the rented land, the farm share of grassland, the number of crops grown on the farm, the family and hired labour working hours. The economic outcomes investigated are the farm output value per hectare and the variable costs per hectare, the total farm income and the farm income per hectare, computed both including and not including AE payments. The results indicate for each outcome the mean difference in the 2003-2006 growth between farmers who adopted AESs after 2003 and farmers who did never adopt AESs over the period 2003-2006. The DID estimator has been applied on each country treated subsample and on the corresponding control group. Thus, in total ten estimators have been calculated. Finally we have implemented a placebo test (Chabé-Ferret and Subervie, 2013) to test whether our data verify the DID mean independence assumption (equation 2.12), meaning that in the absence of treatment the outcomes of the treated and matched control groups would have followed parallel path conditional on the observed variables. We applied the placebo test on the period 2002-2003 in order to avoid large loss of farms in the balanced panels.

2.3.2 Variance estimation

It is worthy to briefly present the different approaches proposed in the literature to estimate the variance of the ATT estimator. The most applied and cited are mainly three.

The first one is the bootstrapping method, which is widely used in the applied works with PSM. The bootstrapping procedure consists of estimating the variance by randomly drawn samples with replacement and repeating the estimation procedure on each drawn sample. The collection of the ATT drawn from the bootstrap approximates a distribution that is used to estimate the variance. The bootstrapping procedure is computationally easy as most PSM packages perform it automatically and it allows to take into account the uncertainty which derives from the first phase of the matching procedure, the estimation of the propensity score.

Although the widespread use of the bootstrap procedure as a way to estimate the variance of ATT, Abadie and Imbens (2008) showed that bootstrap standard errors are not valid in the case of nearest neighbour matching with replacement and with a fixed number of neighbours. In such a case they proposed an analytical formula for a consistent estimator of the variance of the ATT in the case of homoscedasticity and in the case of heteroscedasticity (Abadie and Imbens, 2006).
A third approach to ATT variance estimator has been offered by Lechner (1999):

$$\operatorname{var}(ATT) = \frac{1}{N_1} * \operatorname{var}(Y \mid D = 1) + \frac{\sum_{j=1}^{J \cap S} \left(w_j\right)^2}{\left(N_1\right)^2} * \operatorname{var}(Y \mid D = 0) \qquad (2.16)$$

where $\operatorname{var}(ATT)$ is the variance of the ATT, N_1 is the number of treated units and w_j is the weight associated to each unit of the control group and $\operatorname{var}(Y)$ is the outcome variance. This formula of the variance assumes fixed weight, independent observations, homoscedasticity of the variances of the outcomes within the treated and the control group.
We have used the variance approximation approach by Lechner to calculate the variance of ATT, and consequently the significance of the ATT, in our study. The bootstrapping was not suitable as our matching algorithm is the nearest neighbour with replacement, for which bootstrap standard errors are not valid. The analytical formula proposed by Abadie and Imbens in the case of homoscedastic outcomes variance is very similar to the variance approximation by Lechner, who in addition extended the variance approximation to the case of DID matching (Eichler and Lechner , 2002). In such a case the outcomes variance is replaced with the variance of the before-after outcome differences such that:

$$\operatorname{var}(ATT) = \frac{1}{N_1} * \operatorname{var}((Y_t - Y_{t'} \mid D = 1) + \frac{\sum_{j=1}^{J \cap S} \left(w_j\right)^2}{\left(N_1\right)^2} * \operatorname{var}((Y_t - Y_{t'}) \mid D = 0) \qquad (2.17)$$

where $\operatorname{var}(Y_t - Y_{t'})$ is the variance of the difference of the outcomes before and after the treatment.

2.4 RESULTS

In order to discuss the effects of AESs adoption on farm performances, we will focus our attention on the ATT estimator, which indicates the difference in the average growth of the outcomes between the treated and the matched control group. The significance of the ATT has been calculated according to the variance equation 2.17. The results are shown from Table 2.2 to Table 2.4. In Table 2.2 the ATT for each outcome in each country subsample are reported, while Table 2.3 and Table 2.4 indicate the average positive or negative growth of the outcomes over the period 2003-2006 for both the treated and the matched control groups, from which the ATT have been calculated. A positive ATT indicates that the increase in the outcome of the treated group (adopters) is larger than the increase of the control group (non adopters); a positive ATT may also indicate that the decrease in the outcome of the treated is smaller than the decrease of the controls. On the other hand, a negative ATT indicates that the decrease in the outcome of the treated is larger than the decrease in the outcome of the controls as well as an increase in the treated outcome is smaller than the increase in the controls. We will present the results by distinguishing the effects of the participation in AESs on farmer technical production decisions and on farm economic results. Similarities and differences of these effects among the five Member States will be discussed. Finally the results of the placebo test on each country subsample will be presented in Appendix A2.B.

2.4.1 Results on farm production choices

The adoption of AESs is expected to affect farm technical decision variables as they introduce new requirements/constraints in the farm management. The effects differ across country samples as a consequence of differences in agricultural characteristics and heterogeneous adoption of different AESs. As expected, the AESs affect more heavily the production choices of the treated subsamples 2, the subsamples for which the share of agri-environmental payments on farm income is larger than the median of the full treated sample, while in subsamples 1 the impact is lower.

We will consider the effects of AESs on the country treated subsamples 2 first, then we will draw some considerations on the subsamples 1.

In the country subsamples 2 the AESs participation leads to an increase in farm size in four out of five countries: Germany, the UK, France and Italy; in the last two countries this is the consequence of the rise in farm rented land. The increase in the farm size because of AESs adoption is in line with the results obtained by Pufahl and Weiss (2009) in a large sample of German farms.

Farm crop diversification, fertilizer and crop protection expenditure per hectare and share of grassland on the farm may be considered as indicators of the effectiveness of the AESs in terms of addressing farms towards more environmentally-friendly practices. Our study shows differences in the evolution of these variables across countries. The expansion of farm size promotes farm crop diversification in Italy and France and avoids loss of crop diversification in the UK. The growth in fertilizer expenditure of participants is lower than the one of non participants in France and the UK, and such difference is statistically significant, while in Italy participating farmers experience on average a decrease in fertilizer expenditure compared to the increase of the control group. Spanish adopters surprisingly rise their fertilizer expenditure in contrast to a fall of the Spanish non adopters. Germany is the only country where the AESs adoption has a statistically significant effect on crop protection; however, the effect is opposite to what we may expect, since this expenditure per hectare increases more for the treated group than for the control group. This may be explained by the higher prices of environmentally friendly products. This differs from the findings of Pufahl and Weiss (2009). The share of grassland is affected positively by the adoption of AESs in France, Germany and Italy, even though the percentage increase is small. The differences in the effects of the AESs adoption on farm practices may be explained by the heterogeneity of the measures adopted in each country. In Italy and France the most widespread measures are the ones concerning the management of landscape, maintenance of pasture and high nature value (Eurostat, 2013); such measures represent 88% and 27% of the UAA under commitments in France and Italy, respectively[4]. This may explain the similar reaction of French and Italian participants in terms of farm size, fertiliser expenditure and crop diversification. Actions to maintain habitats favourable to biodiversity is the most widespread measure in Spain; this may explain the different evolution of farm practices among Spanish participants.

In our study the AESs participation does not seem to affect family labour as the dynamics of family labour follows the same negative growth in both the treated and the control groups. Hired labour is affected by participation only in Germany and Spain, where in the treated group it shows a negative growth statistically different from the path of the matched control group.

[4] This data refers to 2009 when the new RDPs were already in place. Data on the breakdown of UAA under different agri-environmental commitments are not available for 2006.

If we consider the treated subsamples 1 and their matched counterfactuals we see a few technical outcomes affected by agri-environmental contract participation. AESs adoption increases farm size in Germany, Spain and Italy and reduces the use of fertiliser products among Italian adopters. If we consider a significance level of 10%, we see that the AESs adoption increases crop protection expenditure in Spain, while this is reduced in Italy and it restrains the family labour drop in the UK. Rented land, share of grassland, number of crops and hired labour force are not affected in any of the five countries. Hence, if the payment represents a small share of farm income, the production choices and assets of the farm are only slightly affected.

2.4.2 Results on farm economic performances

AESs adoption does not affect only the farmer production choices but also the economic results of the farm. As for the technical impact, the effect of AESs participation on farm economic performances, the role of AE payments and the differences among countries are more evident in the country subsamples 2. Thus, as in the previous section, we will start discussing the results of subsamples 2 and then we will draw some considerations on subsamples 1.

If we consider the value of total farm output per hectare as a measure of the degree of production intensity, we would expect a negative ATT as a consequence of extensification of farms that participate in AESs. The corresponding ATT for subsamples 2 is indeed negative and statistically different from zero in France, Italy, Germany and Spain. In the first two countries both the output value per hectare and the variable costs per hectare decrease compared to an increase in the matched control groups. In Germany the negative ATT comes from the smaller growth of the two variables compared to the growth in the matched control group. The negative effect on farm output value may be explained by the potential introduction of low yield crops, by the increase in the share of grassland and by a reduction in fertilizer expenditure per hectare. The Spanish treated subsample shows a negative ATT for the output value per hectare, while the variables costs per hectare of adopters increase compared to a fall of the non adopters.

Another key economic variable that we expect being affected by AESs adoption is farm income. We may consider the farm income per hectare without AE payments as an indicator of the effect of AESs adoption on the farm economic performances, while comparing the evolution of this variable with the path of the farm income per hectare including the AE

Table 2.2 Average treatment effect on the treated (ATT) of AESs participation in the five countries over the period 2003-2006

	Subsamples 1					Subsamples 2				
Farm outcomes	**France**	**Germany**	**Spain**	**UK**	**Italy**	**France**	**Germany**	**Spain**	**UK**	**Italy**
UAA (ha)	0.317	5.544**	5.148***	1.209	5.009*	1.645 *	4.379*	0.190	4.815**	5.577**
Rented land (ha)	-0.243	3.839	1.294	2.107	3.444	2.289 **	1.397	2.567	1.925	5.050**
Number of crops grown on farm	-0.011	0.167	-0.076	0.014	0.015	0.155 **	0.043	-0.039	0.157**	0.288***
Fertiliser expenditure per ha	-2.428	0.424	9.040	0.803	-24.06**	-4.405 **	-1.217	42.607**	-6.624***	-19.168***
Crop protection expenditure per ha	1.630	-2.778	36.325*	1.369	-18.544*	-1.474	6.966*	34.298	-0.236	-11.336
Share of grassland(%)	0.271	-0.666	0.324	0.765	0.055	0.783**	1.891 ***	0.063	-0.160	3.175*
Family working hours	38.913	40.295	-183.468	121.844*	77.604	-26.800	-39.438	-128.837	59.005	39.184
Hired labour working hours	-19.514	188.622	145.052	34.267	21.508	34.939	-504.7 **	-307.013**	-159.946	322.764
Output value per ha(000 euro)	0.040	-0.057	-0.726***	-0.035	-0.244	-0.074*	-0.14 ***	-1.179***	-0.049	-0.599***
Variable costs per ha (000 euro)	0.062 *	-0.10**	0.245***	-0.049	-0.157	-0.041*	-0.072 **	0.335***	-0.062	-0.068**
Farm income (000 euro)	6.621**	11.444*	-10.460**	7.495**	14.689*	-4.225**	22.72 ***	-12.623***	6.529**	0.420
Farm income without AE payments (000 euro)	3.504	8.799	-14.665***	4.248	9.827	-10.38***	13.973 *	-19.445***	-0.619	-15.190***
Farm income per ha (000 euro)	0.031	0.080 *	-0.516***	0.076**	0.199	-0.050 **	-0.025	-0.866***	0.059	-0.245**
Farm income without AE payments per ha (000 euro)	0.006	0.065	-0.647***	0.052	-0.061	-0.104***	-0.080 **	-1.094***	0.014	-0.542***

Source: estimation results

Table 2.3 Outcome mean difference of the treated subsample 1 and of the matched control group over the period 2003-2006 for each country

	France		Germany		Spain		UK		Italy	
Farm outcomes	Treated group	Control group	Treated group	Control group	Treated group	Control group	Treated group	Control group	Treated group	Control group
UAA (ha)	3.875	3.557	6.178	0.634	3.394	-1.754	1.769	0.560	5.214	0.205
Rented land (ha)	2.373	2.616	-0.066	-3.905	-0.978	-2.271	0.671	-1.436	4.430	0.986
Number of crops grown on farm	-0.08	-0.069	0.124	-0.043	-0.133	-0.058	-0.071	-0.085	-0.006	-0.021
Fertiliser expenditure per ha	10.692	13.120	17.839	17.415	-3.083	-12.122	8.924	8.121	-6.502	17.558
Crop protection expenditure per ha	6.298	4.668	5.936	8.714	-21.828	-58.153	3.487	2.117	6.350	24.894
Share of grassland(%)	0.063	-0.208	-1.208	-0.542	0.467	0.143	0.889	0.124	3.538	3.483
Family working hours	-41.18	-80.093	-11.961	-52.256	-398.733	-215.265	-149.530	-271.374	46.094	-31.511
Hired labour working hours	-66.185	-46.671	117.310	-71.312	278.311	133.260	14.403	-19.864	272.213	250.704
Output value per ha(000 euro)	0.090	0.050	0.173	0.230	-0.873	-0.148	-0.044	-0.009	0.075	0.320
Variable costs per ha (000 euro)	0.057	-0.005	0.040	0.143	0.071	-0.174	0.077	0.126	-0.065	0.091
Farm income (000 euro)	12.807	6.186	25.251	13.806	-6.942	3.518	-1.870	-9.365	24.516	9.827
Farm income without AE payments (000 euro)	9.689	6.186	22.606	13.806	-11.146	3.518	-5.117	-9.365	15.321	9.827
Farm income per ha (000 euro)	0.109	0.078	0.244	0.164	-0.179	0.336	0.004	-0.072	0.535	0.335
Farm income without AE payments per ha (000 euro)	0.084	0.078	0.229	0.164	-0.311	0.336	-0.020	-0.072	0.274	0.335

Source: estimation results

Table 2.4 Outcome mean difference of the treated subsample 2 and of the matched control group over the period 2003-2006 for each country

	France		Germany		Spain		UK		Italy	
Farm outcomes	Treated group	Control group	Treated group	Control group	Treated group	Control group	Treated group	Control group	Treated group	Control group
UAA (ha)	5.560	3.915	6.598	2.218	-0.233	-0.423	5.011	0.196	3.619	-1.958
Rented land (ha)	5.263	2.974	-0.222	-1.619	-0.199	-2.766	0.757	-1.168	2.217	-2.833
Number of crops grown on farm	0.019	-0.135	0.063	0.019	-0.089	-0.050	-0.035	-0.191	0.352	0.064
Fertiliser expenditure per ha	5.961	10.366	17.469	18.687	16.333	-26.274	6.923	13.546	-18.340	0.828
Crop protection expenditure per ha	1.767	3.240	12.206	5.240	-47.674	-81.972	2.101	2.337	-7.714	3.622
Share of grassland(%)	0.7	-0.082	0.687	-1.203	0.212	0.149	0.605	0.766	6.675	3.500
Family working hours	-114.842	-88.041	-12.820	26.618	-180.000	-51.163	-164.138	-223.144	-69.216	-108.400
Hired labour working hours	33.267	-1.672	-550.516	-45.847	-80.289	226.724	-185.992	-26.047	182.117	-140.647
Output value per ha(000 euro)	-0.022	0.052	0.121	0.259	-1.503	-0.324	-0.033	0.016	-0.328	0.271
Variable costs per ha (000 euro)	-0.020	0.021	0.072	0.144	0.033	-0.302	0.024	0.086	-0.024	0.044
Farm income (000 euro)	0.442	4.666	33.264	10.542	-10.622	2.001	-0.878	-7.407	6.722	6.301
Farm income without AE payments (000 euro)	-5.717	4.667	24.515	10.542	-17.443	2.001	-8.026	-7.407	-8.889	6.301
Farm income per ha (000 euro)	-0.014	0.036	0.166	0.191	-0.472	0.394	-0.022	-0.081	-0.046	0.199
Farm income without AE payments per ha (000 euro)	-0.067	0.036	0.112	0.191	-0.700	0.394	-0.067	-0.081	-0.344	0.199

Source: estimation results

payment we have an indication of the ability of the AE payment to compensate the income foregone as a result of adoption. Finally the effect on the total farm income is a combination of the result concerning income per hectare and farm size. Spanish farmers are strongly negatively affected by AESs adoption as their income per hectare without AE payment falls on average by 700 euro compared to a rise of non adopters of 394 euro over the period 2003-2006 (Table 2.4). The AE payment is not sufficient to compensate the income foregone of Spanish adopters, since in this case their income per hectare still drops on average by 472 euro. A statistically significant drop in income per hectare as a consequence of participation appears also in France and Italy, where the AE payment is again not sufficient to compensate this drop. However, in these two countries the income foregone experienced by participant farmers is much lower than the one of Spanish farmers (Tables 2.2, 2.3 and 2.4). In the Italian subsample, however, the increase in farm size due to participation avoids a negative ATT for total farm income, as it happens in France. In Germany the smaller rise of per hectare income of participants compared to non-participants is compensated by the AE payments. Finally, the UK farmers of the treated subsample 2 shows the same negative growth of income per hectare of the corresponding matched control group with and without the payments. Thus, the participation in AESs seems to have no effect on the economic performance of this group of the UK farmers and the positive ATT of the total farm income derives from a larger rise in farm size of the participants. This last result complies with the finding of a research commissioned by the European Commission to Kantor Management Consultants and Institute for Rural Development Research (2012) which outlined that in the countries where the AESs absorb a large part of public budget for rural development, as it is the case for the UK, farmers declare that the main benefit of the adoption is the increase in their income. As it has been the case for the farm practices, the different impact of AESs adoption on farm economic performances may be partially explained by the heterogeneity of the measures across countries. The actions to maintain habitats favourable to biodiversity, which is the most widespread measure in Spain, seems to threat heavily the farm profitability (at least in Spain), while the Entry Level Schemes of the UK, which concern almost 94% of the UAA under environmental commitments in the UK, do not seem to damage farm income. The fair compensation of German and English adopters is confirmed by the higher uptake rate of AESs in these two countries compared to the other three countries considered, 42% and 37% of the UAA in 2006 respectively.

If we consider the treated subsamples 1 we get some different results. The farm income and the farm income per hectare of Spanish subsample 1 are strongly negatively affected by AESs participation as in the case of subsample 2. In the French subsample 1 the positive growth in the income per hectare of the treated group is not significantly different from the growth of the matched control group; however, these slight differences are summed up if we consider total farm income, which presents a positive ATT. In UK subsample 1 we see a kind of over-compensation of the agri-environmental participation. Indeed, while the income per hectare without considering the payment drops equally in both groups, the income per hectare including the AE payment increases for the treated group. In Germany and Italy the income path differs between the two groups at the 10% significance level. In Germany the AE payment leads to an overcompensation, as it increases the income per hectare of participating farmers more than that of non-participants. In Italy the positive ATT of total farm income is linked to a rise in farm size. The potential overcompensation for the UK and German farms of subsamples 1 actually derives from an absence of income foregone due to participation, given the small contribution of AE payments to farm income. The results of subsamples 1 show some similarities with subsamples 2 as German and the UK adopters are not negatively affected by AESs participation, while Spanish participants are.

2.5 Discussion and Conclusions

Compared to the simple PSM estimator, the combination of PSM with DID estimator allows to remove the bias due to time-invariant unobserved variables when panel data are available. We have checked the robustness of our results by comparing the results of our 10 nearest neighbours estimator with other PSM estimators that satisfy the balancing property for the covariates. Since results are similar, this supports the robustness of our findings.

Pufahl and Weiss (2009) remarked the importance of accounting for the heterogeneous response of treated individuals to the treatment. The different effects of AE participation in the two treated subsamples supports the need to account for heterogeneity even at a more detailed level. However, we could not split the samples further, in order to have a sufficient number of observations. In addition, the FADN data do not provide the disaggregation of payments by different AESs, which would allow to draw more specific conclusions related to each specific measure, with more clear policy implications. Finally, the FADN data on fertilisers indicates only the farm fertiliser expenditure, no data on fertiliser quantity applied

on the farm are provided which may be useful to judge the effect of AESs on the fertiliser units employed.
Despite the above limitations, our study shows some interesting findings. First, the effects of the AESs on farm production choices and economic performances are stronger on farms whit a larger share of AE payments on farm income. In all countries considered, except Spain, the farm size increases after the AESs uptake, likely as a consequence of extensification. The adoption of AESs does not seem to prevent the drop of farm family labour in any countries, while hired labour is negatively affected in Spain and Germany.
The results of our analysis seem to indicate that in Spain the AESs adoption negatively affects farmers, as the AE payment is not sufficient to compensate them for the income foregone. In addition, in Spain the AESs adoption does not seem to produce environmental benefits in terms of increasing the share of grassland or favouring crop diversification, but conversely it increases fertiliser expenditure.
The AESs uptake leads to an increase in the share of grassland in France, Germany and Italy, and this extensification may partially explain the income foregone after adoption. The decrease in fertiliser expenditure and the rise in the average number of crops by Italian and French adopters may also contribute to the income foregone. In these two countries the AE payment is not sufficient to compensate the income drop per hectare, even though the drop in these countries is much smaller compared to Spain. German adopters are compensated for the income foregone, while in the UK the adoption of AESs does not show any effects on farm income even without the payment, it produces a reduction in the expenditure in fertilisers and it favours crop diversification.
One may argue that a farmer is willing to participate in AESs only if he expects to increase his income by participation. However, the time lag between expectation and realisation may explain the actual negative impact on income of AESs adoption in some countries. Another reason of the negative effect on farm income in some countries may be the fact that 2000-2006 is the first budget period of a systematic introduction of the AESs in the RDPs; as such it may be a period where the compensation to the participant farmers has to be tested in order to find an adequate compensation for the income foregone.

In conclusion, our study suggests a potential revision of the AESs in Spain in order to produce environmental benefits and to fairly compensate participating farmers. In Italy and France, while farm practices seem to become more environmentally friendly after the AESs adoption, it would be interesting to evaluate the amount of AE payments in order to avoid undercompensation and to increase participation. Germany and the UK show positive environmental benefits after the adoption and a fair compensation for the potential income foregone. Finally, our study suggests that some measures on rural employment safeguard may be introduced as employment in rural areas may imply better preservation of landscape and natural resources.

APPENDIX A2.A

Table A2.1 Parameter estimates of logit models of farmers participation in AESs for the farm subsamples 1 and the control groups

	France	Germany	Spain	UK	Italy
Farm characteristics					
year of birth of farmer	0.017*			0.024***	0.025***
	(0.009)			(0.008)	(0.006)
dummy mountain	0.306		-0.494		1.296***
	(0.428)		(0.507)		(0.255)
dummy hill	-0.574*	0.841**	-1.299**		0.409**
	(0.296)	(0.348)	(0.554)		(0.194)
farm UAA (ha)	0.005***	0.002***			0.001*
	(0.001)	(0.001)			(0.001)
farm rented land (ha)					0.002*
					(0.001)
revenue per ha (000 euro)		-0.149**		-0.089*	
		(0.069)		(0.048)	
farm capital per working units (000 euro)		0.000	0.000	0.000	
		(0.000)	(0.001)	(0.000)	
share of grassland on the farm (%)		-0.014***	-0.093		
		(0.004)	(0.097)		
fertilizer expenditure per ha (000 euro)	-6.211***		4.221*	4.033**	-0.603
	(2.004)		(2.245)	(1.875)	(0.661)
crop protection expenditure per ha (000 euro)			-3.286**	2.848	-1.297**
			(1.481)	(2.855)	(0.597)
number of family working hours		0.000**	0.000**	0.000***	0.000***
		(0.000)	(0.000)	(0.000)	(0.000)
number of hired labor working hours		0.000	0.000	0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)
farm income per ha (000 euro)		0.743***	-0.947***		
		(0.217)	(0.252)		
farm decoupled subsidies per ha (000 euro)	-1.411		-8.868***		
	(0.895)		(2.063)		
dummy livestock farm	0.356*	1.001***		-0.529*	-0.016
	(0.202)	(0.292)		(0.309)	(0.234)
dummy permanent crop farm					0.571***
					(0.216)
*Macroeconomic indicators of the region^*					
Gross Domestic Product per capita (000 euro)	0.146***		-0.657***		
	(0.022)		(0.243)		
value added of agricultural over total value added (%)	0.337***	-0.889**	0.182		0.723***
	(0.047)	(0.379)	(0.263)		(0.149)
*Geographical location^*					
dummy north (dummy Scotland for the UK)	-0.675	0.894*		1.447***	
	(0.529)	(0.509)		(0.237)	
dummy east (dummy north-east for Italy)	0.203	-0.002	2.858*		1.150**
	(0.502)	(0.508)	(1.502)		(0.459)
dummy west (dummy northern Ireland for the UK; dummy north-west for Italy)	-0.811	-0.544		-0.120	3.324***
	(0.516)	(0.408)		(0.261)	(0.518)
dummy south (dummy Wales for the UK)				-0.783***	
				(0.300)	
dummy centre			-4.788***		3.145***
			(0.918)		(0.510)
constant	-7.254***	-2.477***	8.074**	-2.403***	-9.421***
	(0.981)	(0.717)	(3.518)	(0.541)	(0.849)
Pseudo R^2	0.093	0.071	0.346	0.134	0.120

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of the coefficient estimates.
^The macroeconomic indicators are specified for each NUTS2 region in France, Spain and Italy and for each NUTS1 region in Germany and United Kingdom. The country geographical dummies are specified for NUTS1 regions or aggregations of them.
Source: estimation results

Table A2.2 Parameter estimates of logit models of farmers participation in AESs for the farm subsamples 2 and the control groups

	France	Germany	Spain	UK	Italy
Farm characteristics					
year of birth of farmer	0.023**			0.019***	
	(0.009)			(0.007)	
dummy mountain					0732**
					(0.304)
dummy hill				0.642**	0.558***
				(0.268)	(0.191)
farm UAA (ha)	0.003***		-0.009		0.001**
	(0.001)		(0.006)		(0.001)
farm rented land (ha)			0.012*		0.002*
			(0.006)		(0.001)
revenue per ha (000 euro)	-0.259**	-0.495***		-0.21***	-0.326***
	(0.117)	(0.106)		(0.070)	(0.062)
farm capital per working units (000 euro)	0.001	-0.001*	0.001	0.000	0.000
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)
share of grassland on the farm (%)	0.019***	-0.001	-0.163		-0.000
	(0.004)	(0.004)	(0.194)		(0.004)
fertilizer expenditure per ha (000 euro)	-7.576***	-8.511***	1.421	-6.367***	
	(2.330)	(2.893)	(2.588)	(2.231)	
crop protection expenditure per ha (000 euro)		5.384**	-3.397**	5.471*	
		(2.465)	(1.383)	(3.272)	
number of family working hours					
number of hired labor working hours					
farm income per ha (000 euro)	-0.567*		-1.119***		
	(0.324)		(0.275)		
farm decoupled subsidies per ha (000 euro)			-14.454***	1.738***	
			(2.717)	(0.644)	
dummy livestock farm	0.253	-0.156		-0.071	-0.070
	(0.285)	(0.295)		(0.307)	(0.328)
dummy permanent crop farm					0.321
					(0.217)
*Macroeconomic indicators of the region^*					
Gross Domestic Product per capita (000 euro)	0.139***		-0.664*		
	(0.024)		(0.344)		
value added of agricultural over total value added (%)	0.204***		0.217		1.280***
	(0.058)		(0.367)		(0.150)
*Geographical location^*					
dummy north (dummy Scotland for the UK)	0.072	-1.529***		0.597**	
	(0.504)	(0.274)		(0.255)	
dummy east (dummy north-east for Italy)	0.871*	-2.166***	1.425		1.576***
	(0.449)	(0.421)	(2.122)		(0.586)
dummy west (dummy northern Ireland for the UK; dummy north-west for Italy)	-0.210	-1.283***		-0.344	3.543***
	(0.480)	(0.308)		(0.264)	(0.587)
dummy south (dummy Wales for the UK)				-0.392	
				(0.271)	
dummy centre			-5.711***		3.851***
			(1.234)		(0.518)
constant	-7.897***	1.100**	9.88**	-1.399***	-9.415***
	(1.021)	(0.471)	(4.744)	(0.543)	(0.815)
Pseudo R^2	0.154	0.096	0.477	0.105	0.184

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of the coefficient estimates.
^The macroeconomic indicators are specified for each NUTS2 region in France, Spain and Italy and for each NUTS1 region in Germany and United Kingdom. The country geographical dummies are specified for NUTS1 regions or aggregation of them.
Source: estimation results

Table A2.3 Covariates mean and standardized bias before and after the matching (subsamples 1 vs. control group in 2003)

	France			**Germany**			**Spain**			**UK**			**Italy**		
	treated	control	% st bias	treated	control	% st bias	treated	control	% st bias	treated	control	% st bias	treated	control	%st bias
year of birth of farmer ^	58.0	57.0*	12.7							50.0	48.0**	15.6	54.0	49.0***	39.6
	58.0	58.0	4.4							50.0	50.0	-1.8	54.0	55.0	-3.1
dummy mountain	0.044	0.024*	11.1				0.167	0.46***	-65.9				0.199	0.07***	37.6
	0.045	0.048	-1.6				0.178	0.209	-7.0				0.194	0.189	1.3
dummy hill	0.084	0.108	-7.9	0.233	0.147**	21.4	0.146	0.34***	-45.4				0.373	0.26***	24.8
	0.075	0.073	0.8	0.233	0.217	4.0	0.156	0.142	3.2				0.375	0.396	-4.5
farm UAA (ha)	140.46	10***	39.4	193.87	125.2**	20.6							58.967	32.7***	28.2
	133.99	136.23	-2.5	193.87	143.81	15							58.058	58.317	-0.3
farm rented land (ha)													28.397	12.4***	25.5
													27.312	24.998	3.7
revenue per ha (000 euro)				2.699	2.719	-0.7				1.499	3.959**	-21.5			
				2.699	2.652	1.7				1.468	1.522	-0.5			
farm capital per working units (000 euro)				431.000	416.13	3.5	174.72	152.21	14.2	374.94	385.26	-1.5			
				431.000	462.50	-7.5	182.58	186.18	-2.3	374.22	359.13	2.2			
share of grassland on the farm (%)				23.707	28.741*	-17.5	0.149	1.313	-19.7						
				23.707	22.942	2.7	0.159	0.039	2.0						
fertilizer expenditure per ha (000 euro)	0.01	0.125	-11.5				0.158	0.09***	53.4	0.086	0.08***	20.6	0.099	0.180	-7.9
	0.01	0.099	0.2				0.132	0.131	0.9	0.083	0.087	-8.3	0.1000	0.098	0.1
crop protection expenditure per ha (000 euro)							0.154	0.07***	67.7	0.040	0.02***	30.7	0.096	0.17***	-27.0
							0.136	0.134	2.2	0.037	0.034	4.8	0.096	0.096	-0.1
number of family working hours				3288	3132	12.0	2231	2302	-7.0	4056	3690***	20.0	3591	3002***	25.0
				3288	3333	-4.0	2190	2199	-1.0	3986	4080	-5.0	3571	3433	6.0
number of hired labor working hours				4912	2454.2*	16.7	469	427	3.0	1470	1359	4.0	2073	1442	10.0
				4912	2792	14.4	486	408	5.6	1404	1565	-5.8	2086	2099	-0.2
farm income per ha (000 euro)				0.518	0.353**	22.9	0.804	0.762	4.3						
				0.518	0.502	2.1	0.829	0.785	4.5						

Continued

Table A2.3 Continued

	France			Germany			Spain			UK			Italy		
	treated	control	% st bias	treated	control	% st bias	treated	control	% st bias	treated	control	% st bias	treated	control	% st bias
farm decoupled subsidies per ha (000 euro)	0.287	0.305**	-17.6				0.082	0.15***	-69.8						
	0.287	0.289	-1.9				0.087	0.089	-1.4						
value added of agricultural over total value added (%)	4.477	3.83***	28.7	1.437	1.491	-9.2	4.438	5.15***	-52.5				3.179	3.357	-11.5
	4.435	4.376	2.6	1.437	1.431	1.0	4.418	4.387	2.3				3.186	3.243	-3.7
Gross Domestic Product per capita (000 euro)	23.933	23.1***	18.4				16.357	17.157	-25.6						
	23.944	23.9	1.0				16.501	16.600	-3.2						
dummy livestock farm	0.569	0.505*	12.8	0.798	0.728*	16.6				0.693	0.841***	-35.5	0.342	0.24***	23.3
	0.570	0.568	0.5	0.798	0.818	-4.6				0.707	0.718	-2.5	0.337	0.336	0.3
dummy permanent crop farm													0.348	0.373	-5.3
													0.350	0.349	0.1
dummy north (dummy Scotland for the UK)	0.495	0.442	10.7	0.558	0.557	0.2				0.352	0.10***	62.1			
	0.490	0.473	3.5	0.558	0.579	-4.2				0.328	0.314	3.5			
dummy west (dummy northern Ireland for the UK; dummy north-west for Italy)	0.292	0.361*	-14.7	0.186	0.245	-14.3				0.148	0.208**	-15.9	0.292	0.13***	40.8
	0.295	0.295	0.0	0.186	0.173	3.1				0.154	0.156	-0.5	0.287	0.265	5.6
dummy east (dummy north-east for Italy)	0.183	0.167	4.1	0.101	0.105	-1.4	0.375	0.268*	23.1				0.093	0.25***	-42.2
	0.185	0.206	-5.5	0.101	0.089	3.8	0.400	0.405	-1.0				0.094	0.098	-1.0
dummy south (dummy Wales for the UK)										0.076	0.22***	-41.4			
										0.079	0.095	-4.5			
dummy centre							0.042	0.63***	-157.0				0.267	0.16***	27.0
							0.044	0.049	-1.2				0.269	0.278	-2.3

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of a t test on the equality of covariates mean between the treated and the control group

^ for all covariates the first line refers to the unmatched samples, the second line refers to the matched samples.

Source: estimation results

Table A2.4 Covariates mean and standardized bias before and after the matching (subsamples 2 vs. control group in 2003)

	France			**Germany**			**Spain**			**UK**			**Italy**		
	treated	control	%st bias	treated	control	%st bias	treated	control	%st bias	treated	control	%st bias	treated	control	%st bias
year of birth of farmer^	59.0	57.0***	20.5							50.0	49.0**	15.6			
	59.0	59.0	1.8							50.0	50.0	6.2			
dummy mountain													0.1420	0.072***	22.7
													0.1420	0.18	-12.3
dummy hill										0.157	0.107**	14.8	0.5	0.258***	51.4
										0.158	0.159	-0.2	0.5	0.4796	4.3
farm UAA (ha)	121.92	105.8***	23.5				46.095	64.633*	-28.6				65.966	32.68***	38.8
	120.76	120.8	-0.1				47.588	65.432	-27.6				65.966	55.719	11.9
farm rented land (ha)							24.977	20.181	9.7				25.188	12.365	23.9
							25.854	40.147	-29.0				25.188	23.34***	3.4
revenue per ha (000 euro)	1.117	2.412*	-16.5	1.859	2.719***	-32.1				0.996	3.959***	-25.8	1.6284	5.975***	-31.2
	1.123	1.121	0.0	1.873	1.884	-0.4				0.999	1.117	-1	1.6284	1.5609	0.5
farm capital per working units (000 euro)	140.74	123.6***	20.5	364.47	416.13	-14.8	176.33	152.210	14.5	582.89	385.26	10.4	321.23	285.610	8.0
	136.04	137.53	-1.8	366.76	352.12	4.2	178.36	174.150	2.5	431.32	434.32	-0.2	321.23	381.590	-13.6
share of grassland on the farm (%)	48.458	26.53***	68.6	24.395	28.741	-13.7	0.050	1.310	-21.4				24.3660	20.339	11.8
	47.822	47.404	1.3	23.804	25.187	-4.4	0.060	0.090	-0.7				24.3660	26.833	-7.2
fertilizer expenditure per ha (000 euro)	0.083	0.125**	-19.2	0.087	0.096	-16.7	0.154	0.093***	64.1000	0.063	0.075***	-27.4			
	0.084	0.084	-0.1	0.088	0.086	2.7	0.157	0.152	5.3000	0.063	0.059	10.6			
crop protection expenditure per ha (000 euro)				0.084	0.079	5.9	0.168	0.065***	72.5	0.036	0.025***	26.9			
				0.084	0.081	4.4	0.174	0.156	12.6	0.036	0.038	-5.5			
farm income per ha (000 euro)	0.246	0.425**	-22.1				0.863	0.762	10.0						
	0.248	0.241	0.9				0.891	0.870	2.1						

Continued

Table A2.4 Continued

	France			Germany			Spain			UK			Italy		
	treated	control	% bias	treated	control	% bias	treated	control	% bias	treated	control	% bias	treated	control	% bias
farm decoupled subsidies per ha (000 euro)							0.041	0.146***	-128.1	0.206	0.152***	40.3			
							0.043	0.046	-4.6	0.206	0.201	3.9			
value added of agricultural over total value added (%)	3.781	3.832	-2.7				4.583	5.151**	-42.8				4.326	3.357***	62.5
	3.762	3.854	-4.8				4.576	4.523	4.0				4.326	4.459	-8.6
Gross Domestic Product per capita (000 euro)	23.807	23.1**	15.9				15.305	17.16***	-63.7						
	23.830	23.785	1.0				15.354	15.536	-6.3						
dummy livestock farm	0.727	0.505***	46.7	0.612	0.728***	-24.7				0.709	0.841***	-32.1	0.21	0.236	-6.3
	0.723	0.715	1.7	0.609	0.616	-1.3				0.712	0.695	4.0	0.21	0.229	-4.5
dummy permanent crop farm													0.290	0.373**	-17.7
													0.290	0.252	8.1
dummy north (dummy Scotland for the UK)	0.381	0.442*	-12.4	0.449	0.557**	-21.6				0.192	0.103***	25.1			
	0.381	0.404	-4.6	0.453	0.469	-3.3				0.192	0.175	4.9			
dummy west (dummy northern Ireland for the UK; dummy north-west for Italy)	0.268	0.361***	-20.0	0.209	0.245	-8.5				0.126	0.208***	-22.1	0.080	0.129*	-15.9
	0.272	0.267	1.2	0.211	0.203	1.9				0.127	0.109	5.0	0.080	0.071	3.0
dummy east (dummy north-east for Italy)	0.307	0.167***	33.2	0.101	0.105	-1.4	0.192	0.268	-18.0				0.037	0.249***	-63.5
	0.302	0.286	3.9	0.102	0.094	2.6	0.200	0.239	-9.3				0.037	0.046	-2.8
dummy south (dummy Wales for the UK)										0.157	0.22**	-16.1			
										0.158	0.162	-1.0			
dummy centre							0.021	0.625***	-168.6				0.222	0.157**	16.6
							0.022	0.018	1.2				0.222	0.180	10.8

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of a t test on the equality of covariates mean between the treated and the control group

^ for all covariates the first line refers to the unmatched samples, the second line refers to the matched samples.

Source: estimation results

APPENDIX A2.B

In this Appendix the results of the placebo tests on each country subsample will be discussed. The placebo test (Chabé-Ferret and Subervie, 2013) aims at testing the DID mean independence assumption (equation 2.12), which indicates that in the absence of treatment the outcomes of the treated and the matched control group would have followed parallel paths conditional on observed covariates. This guarantees the ATT be an unbiased measure of the treatment effect. In order to test the assumption we have calculated the ATT for each country treated subsample and the matched control group between 2002-2003; in none of the two years the treated and the control farmers have adopted AESs. If the data verify the assumption no significant ATT should be found in that period. Tables from A2.5 to A2.8 shows the results of the placebo tests. We could not implement such a test on Italian subsamples as in 2003 a large number of Italian farmers were replaced by farmers newly monitored in the FADN database and thus the panel 2002-2006 would have been too small.

Results of the placebo tests show that in most of the countries the ATT over the period 2002-2003 is significant for a few outcomes only and this significance is at 10% significance level in most cases. The only exception is represented by the UK treated and control farmers from subsample 1 which show different pattern before the treatment for the farm UAA, rented land and output value and variable costs per hectare. The presence of some significant ATT before the treatment starts may be explained by anticipation effects, due to the time lag between the implementation of the agri-environmental practices and the administrative application. However, we may conclude that the parallel trend assumption holds in our data in most of the countries subsamples, while the results of the treatment effect on some outcomes of the UK subsample 1 should be interpret cautiously. .

Table A2.5 Results of the placebo test on France subsamples over the period 2002-2003

Farm outcomes	**France subsample 1**			**France subsample 2**		
	Mean difference of the treated group	Mean difference of the matched control group	ATT	Mean difference of the treated group	Mean difference of the matched control group	ATT
UAA (ha)	2.765	1.282	1.484	1.612	1.718	-0.106
Rented land (ha)	2.969	1.190	1.779*	1.280	1.570	-0.291
Number of crops grown on farm	0.032	0.014	0.019	-0.016	-0.002	-0.014
Fertiliser expenditure per ha	-6.116	-7.407	1.290	-0.432	-6.485	6.053***
Crop protection expenditure per ha	-9.353	-5.544	-3.809*	-3.660	-4.898	1.239
Share of grassland(%)	0.154	0.231	-0.077	-0.571	0.199	-0.770**
Family working hours	106.773	113.441	-6.668	160.492	81.523	78.969
Hired labour working hours	12.924	6.030	6.895	-75.956	-17.789	-58.167
Output value per ha(000 euro)	-0.009	-0.031	0.022	-0.043	-0.066	0.023
Variable costs per ha (000 euro)	-0.030	-0.032	0.003	0.013	-0.012	0.025
Farm income (000 euro)	5.836	1.245	4.590	-1.899	-1.635	-0.265
Farm income without AE payments (000 euro)	6.219	1.400	4.819	-0.369	-1.325	0.957
Farm income per ha (000 euro)	0.042	0.020	0.021	-0.032	-0.034	0.002
Farm income without AE payments per ha (000 euro)	0.047	0.022	0.025	-0.019	-0.031	0.011

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of a t test on the equality of mean differences in the treated and control group.
Source: estimation results

Table A2.6 Results of the placebo test on Germany subsamples over the period 2002-2003

	Germany subsample 1			**Germany subsample 2**		
Farm outcomes	Mean difference of the treated group	Mean difference of the matched control group	ATT	Mean difference of the treated group	Mean difference of the matched control group	ATT
UAA (ha)	2.465	1.073	1.392	-0.563	1.842	-2.405
Rented land (ha)	-0.258	-1.242	0.984	-7.333	2.172	-9.506*
Number of crops grown on farm	-0.171	-0.046	-0.125	-0.078	-0.070	-0.009
Fertiliser expenditure per ha	3.538	4.711	-1.173	2.909	2.505	0.404
Crop protection expenditure per ha	0.037	1.270	-1.234	1.494	3.052	-1.559
Share of grassland(%)	-0.199	0.050	-0.248	-0.100	0.861	-0.961*
Family working hours	5.764	-18.005	23.770	-28.870	-26.585	-2.284
Hired labour working hours	-849.114	52.113	-901.2*	-32.426	27.981	-60.407
Output value per ha(000 euro)	-0.018	0.052	-0.071	0.018	-0.018	0.035
Variable costs per ha (000 euro)	-0.009	0.067	-0.076*	0.004	0.019	-0.015
Farm income (000 euro)	8.771	4.380	4.391	3.480	6.346	-2.866
Farm income without AE payments (000 euro)	9.126	4.669	4.457	5.241	6.577	-1.336
Farm income per ha (000 euro)	0.005	0.000	0.005	0.027	-0.030	0.058
Farm income without AE payments per ha (000 euro)	0.008	0.003	0.006	0.037	-0.027	0.064

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of a t test on the equality of mean differences in the treated and control group.
Source: estimation results

Table A2.7 Results of the placebo test on Spain subsamples over the period 2002-2003

	Spain subsample 1			**Spain subsample 2**		
Farm outcomes	Mean difference of the treated group	Mean difference of the matched control group	ATT	Mean difference of the treated group	Mean difference of the matched control group	ATT
UAA (ha)	1.391	2.194	-0.802	2.845	3.649	-0.804
Rented land (ha)	1.142	2.297	-1.155	1.268	3.354	-2.086
Number of crops grown on farm	-0.023	0.007	-0.030	0.044	-0.016	0.060
Fertiliser expenditure per ha	17.338	3.767	13.572	-78.942	2.542	-81.484*
Crop protection expenditure per ha	-0.291	1.669	-1.960	13.739	21.824	-8.086
Share of grassland(%)	-0.103	-0.166	0.063	0.055	-0.096	0.151
Family working hours	99.116	55.711	43.406	40.467	24.253	16.214
Hired labour working hours	32.628	57.082	-24.454	71.089	60.693	10.396
Output value per ha(000 euro)	0.097	0.036	0.060	0.259	0.220	0.039
Variable costs per ha (000 euro)	-2.420	0.034	-2.453	-0.138	0.164	-0.30***
Farm income (000 euro)	47.886	1.249	46.637	3.042	4.116	-1.074
Farm income without AE payments (000 euro)	49.292	1.283	48.009	4.058	4.132	-0.073
Farm income per ha (000 euro)	2.426	-0.025	2.451	0.374	0.069	0.304
Farm income without AE payments per ha (000 euro)	2.440	-0.025	2.464	0.382	0.069	0.312

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of a t test on the equality of mean differences in the treated and control group.
Source: estimation results

Table A2.8 Results of the placebo test on UK subsamples over the period 2002-2003

	UK subsample 1			**UK subsample 2**		
Farm outcomes	Mean difference of the treated group	Mean difference of the matched control group	ATT	Mean difference of the treated group	Mean difference of the matched control group	ATT
UAA (ha)	-0.446	-6.002	5.556***	2.179	-0.754	2.933*
Rented land (ha)	0.324	-7.105	7.429***	1.574	-1.154	2.728
Number of crops grown on farm	-0.010	-0.008	-0.003	-0.010	0.059	-0.069
Fertiliser expenditure per ha	1.586	6.238	-4.652	2.745	-1.340	4.085
Crop protection expenditure per ha	-0.204	0.772	-0.977	1.313	0.936	0.376
Share of grassland(%)	-0.036	0.612	-0.648	0.050	0.188	-0.138
Family working hours	-35.465	-38.200	2.735	-16.863	-17.534	0.672
Hired labour working hours	-62.320	-60.031	-2.289	20.887	-91.035	111.923
Output value per ha(000 euro)	0.145	0.237	-0.092**	0.087	0.100	-0.013
Variable costs per ha (000 euro)	0.044	0.121	-0.08***	0.048	0.057	-0.009
Farm income (000 euro)	12.399	10.103	2.296	7.047	5.208	1.839
Farm income without AE payments (000 euro)	12.437	10.109	2.328	7.251	5.228	2.023
Farm income per ha (000 euro)	0.111	0.094	0.017	0.038	0.037	0.000
Farm income without AE payments per ha (000 euro)	0.111	0.094	0.018	0.039	0.037	0.001

***, **, * indicate statistical significance at 1%, 5% and 10% respectively of a t test on the equality of mean differences in the treated and control group.
Source: estimation results

CHAPTER 3

Incorporating Risk in a Positive Mathematical Programming Framework: the Role of agri-environmental Schemes as Income Stabilisers[5]

3.1 Introduction

Risk is an important component of agricultural production and it affects farmers' production choices. Although the distinction between risk and uncertainty is commonly based on the knowledge of the probability of the outcomes, Hardaker *et al*. (1997) do not make such distinction. They define uncertainty as imperfect knowledge and risk as uncertain consequences of the imperfect knowledge. Agriculture by its nature is exposed to weather variability, plant and pest diseases and farmer faces different kinds of risk. Hardaker *et al*. (1997) classified the farmer's risk in production risk, market risk, institutional risk, personal risk and financial risk and in recent years the increase in price volatility on agricultural markets have increased market risk. Under a risky environment, the decision-maker makes the choices based on his expectation of uncertain outcomes and these expectations are often based on past experiences. Most empirical studies showed that farmer is a risk averse agent as he is willing to sacrifice some income to ensure against the risky consequences (Feder, 1980). Since risk is a structural component of agriculture and the farmer is not a risk neutral agent, ignoring risk in modelling farm behaviour is likely to lead to biased results.

There are several tools the farmer may adopt to mitigate the consequences of market risk and these options have been discussed in Chapter 1 of this thesis. In this chapter we will consider the agri-environmental schemes (AESs) from a different viewpoint, since we aim to analyse the potential role of a specific AES (the option to convert a share of farmland to grassland) as a farm strategy to cope with risk. The analysis has been performed by developing a new methodological approach which incorporates farm risk in a farm level Positive Mathematical Programming (PMP) model.

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[5] I would like to make special thanks to Michele Donati (University of Parma) for his fundamental help in the development of the theoretical model of this chapter and in its implementation in the GAMS software.

Although PMP is a powerful and widely used technique to calibrate mathematical programming models to the base year observed outcome levels, there are a few attempts in the literature to introduce risk modelling in a PMP framework (Paris and Arfini, 2000; Severini and Cortignani, 2011; Petsakos and Rozakis, 2011). This may be explained by the difficulty in estimating two different non-linear terms in the objective function, the cost function and the risk component. The idea of combining risk modelling with PMP relies on the information contained in the farm non-linear cost function estimated in the PMP procedure. As this cost function incorporates any type of model misspecification, data errors, aggregate bias, price expectation and risk behaviour (de Frahan *et al.*, 2007), it should be possible to isolate the risk component such that the impact of risk on farmer's choices may be studied. We think that the introduction of risk in PMP modelling will be one of the new research frontier in the area of mathematical programming. Our proposal presents some innovation compared to the previous literature, since it merges the first linear phase with the second non-linear phase of the PMP farmer expected utility maximisation problem. This allows to estimate simultaneously the farmer's risk aversion coefficient, the farm non-linear cost function as well as the shadow prices of resources and activities.
The proposed model has been tested on three farm samples and the ensuing calibrated model has been used to perform simulations to check the potential role of the grassland program as farm income stabiliser under different scenarios of crop price volatility. The idea is that, since the adoption of AESs guarantees a fixed payment to the farmer independent of market conditions and crop yields, these measures may act as an insurance against risk. The mathematical programming framework is suitable for our purpose as it allows to model easily the grassland program which competes with the other crops for farmland.

The chapter is organized as follows: section 3.2 introduces the expected utility theory as the framework for risk modelling and section 3.3 compares the different types of mathematical programming models specifying how the risk may be included. Section 3.4 provides a literature review on the standard PMP approach and its extensions while section 3.5 describes the new methodological approach developed to incorporate risk in a PMP framework. Section 3.6 presents an empirical application of the methodological approach and the simulated scenarios, whose results are discussed in section 3.7. Finally, section 3.8 draws some conclusions.

3.2 RISK MODELLING: THE EXPECTED UTILITY THEORY

The most widely used framework for the analysis of decision making under uncertainty is the expected utility theory proposed by Bernoulli in 1738 and later developed by Von Neumann and Morgenstern in 1944 (Kaiser and Messer, 2011). According to such theory, the individual preferences can be represented by an individual utility function $U(W)$ of a monetary outcome, W. The individual utility function $U(W)$ associates to each outcome of an action a scalar number indicating the level of satisfaction of the individual. In order for a well-defined single-dimensional individual utility function to exist the agent preferences must comply with three axioms: ordering and transitivity, independence and continuity. The agent chooses the action which maximizes his expected utility, $EU(W)$, which is the sum of the utility associated to each potential outcome weighted by the probability of each outcome to occur.

Letting W_1, W_2 be two uncertain monetary outcome levels and $U(W_1)$, $U(W_2)$ the corresponding utility values, we have:

$EU(W_1,W_2) < U\left[E(W_1,W_2)\right]$	if the agent is risk averse, meaning that he prefers a certain outcome compared to an uncertain outcome with the same expected value;
$EU(W_1,W_2) = U\left[E(W_1,W_2)\right]$	if the agent is risk neutral, meaning that he is indifferent between a certain outcome and an uncertain outcome with the same expected value;
$EU(W_1,W_2) > U\left[E(W_1,W_2)\right]$	if the agent is risk lover, meaning that he prefers an uncertain outcome to a certain outcome with the same expected value.

The comparison presented above suggests that the shape of the individual utility function indicates the risk attitude of the agent, specifically:

$U'(W) > 0, U''(W) < 0$	for a risk averse agent,
$U'(W) > 0, U''(W) = 0$	for a risk neutral agent,
$U'(W) > 0, U''(W) > 0$	for a risk lover agent,

where U' and U'' are respectively the first order and the second order derivatives of the individual utility function.

Arrow (1974) and Pratt (1964) defined the absolute risk aversion coefficient and the relative risk aversion coefficient as two measures of the risk attitude of an agent. The two coefficients are defined as:

$$\alpha = -\frac{U''(W)}{U'(W)} \qquad (3.1) \qquad\qquad \alpha_r = -\frac{U''(W)}{U'(W)} \cdot W \qquad (3.2)$$

where α is the absolute risk aversion coefficient and α_r is the relative risk aversion coefficient. While α indicates the attitude to face a bet of fixed size, α_r indicates the attitude towards a bet equal to a given share of the agent's income. α takes positive, negative or zero values whether the agent is risk averse, risk lover and risk neutral respectively. The larger is the absolute value of α the stronger is the risk aversion or risk loving of the agent. α and α_r may vary depending on the level of wealth. It is reasonable to assume that if the level of wealth increases the willingness to face a bet of fixed size increases or at least it remains the same; in this case we have a decreasing absolute risk aversion coefficient (DARA) if such willingness increases or a constant absolute risk aversion (CARA) if it does not change. Similarly, we may expect that the willingness to face a bet of a fixed share of wealth decreases when the wealth increases or at least it remains the same. In this case the coefficient of relative risk aversion increases (IRRA) or remains the same (CRRA).

3.3 MATHEMATICAL PROGRAMMING MODELS AND THE INTEGRATION OF RISK

In a mathematical programming model, risk faced by farmers can be introduced either by randomising the behaviour of input and output prices or by introducing uncertainty in the supply of limiting inputs as well as in the technical coefficients specification. There are different techniques to accommodate risk in a mathematical programming framework, such as mean-variance approach, MOTAD, target MOTAD, chance constrained programming, discrete stochastic sequential programming. These techniques are exhaustively presented in most textbooks on mathematical programming (e.g. Kaiser and Messer, 2011).

In this section we will present one of the first methodologies developed, which is still one of the most frequently applied, the mean-variance approach (E-V). This technique will be applied in section 3.5 in order to introduce price risk in a farm-level PMP model.

The E-V model was proposed by Freund in 1956 and it relies on the pioneering work of Markowitz (1952). This approach integrates risk into programming models by means of expected utility theory. Freund showed that under a given set of assumptions (normal distribution of unitary gross margin; negative exponential individual utility function, $U(W) = 1 - e^{-\alpha W}$; CARA preferences; expected utility hypothesis) the agent decision problem under uncertain input and output prices can be formulated as:

$$\max EU(\tilde{\pi}) = E(\tilde{\mathbf{g}})'\mathbf{x} - \frac{1}{2}\alpha \mathbf{x}'\mathbf{V}\mathbf{x} \qquad (3.3)$$

$$\text{subject to} \qquad \mathbf{Ax} \leq \mathbf{b} \qquad (3.4)$$

$$\mathbf{x} \geq 0 \qquad (3.5)$$

where $EU(\tilde{\pi})$ is the expected utility with respect to random income, $\tilde{\pi}$, $E(\tilde{\mathbf{g}})'$ is the expected unit gross margin vector and $\mathbf{V}$ is the variance-covariance matrix of the unit gross margin vector; $\mathbf{x}$ is the vector of unknown activity levels, $\mathbf{b}$ is the vector of the supply of fixed input, while $\mathbf{A}$ is the matrix of the technical coefficients which indicates the fixed input requirements per unit of activity. The quantity $\frac{1}{2}\alpha \mathbf{x}'\mathbf{V}\mathbf{x}$ is the risk premium, which indicates the amount the agent is willing to pay to avoid the risky consequences of uncertain outcomes. The risk premium may be interpreted as an insurance against risk and therefore it is the cost for the uncertainty that the economic agent faces.

The inclusion of the risk component in a mathematical programming model may improve the validation and the calibration of the model. Before proceeding further in the presentation of the different types of mathematical programming models and to show the integration of risk in each model, we need to define precisely the difference between the concept of validation and calibration in mathematical programming, which are sometimes wrongly used interchangeable

3.3.1 Validation and calibration of mathematical programming models

Validation of a mathematical programming model is an important step to check the model performances when the model is intended either for predictive or for prescriptive use. The meaning of validation is controversial: McCarl and Spreen (2004: 18-1) refers to validation as

'exercises determining whether the model user and or modelling team feels the model behaviour is close enough to real world behaviour'. There are two kinds of validation categories: validation by construct and validation by results. Validation by construct does not test the model but assumes the model was built properly and therefore it is valid; validation by results compares the model outcomes with the real world outcomes. An exhaustive overview of the different tests of validation by results are presented in McCarl and Spreen (2004).
The calibration of a mathematical programming model is the process of adjusting the model in order to reproduce the variable levels or the exogenous elasticities observed in the reference year. The calibration may consist in adding additional constraints or adjusting model parameters. PMP is a common calibration method in mathematical programming introduced in the eighties.

3.3.2 Normative, Positive and Econometric Programming Models

In this section a brief overview of the different categories of mathematical programming models is carried out, with a special attention to the possible ways of modelling risk. Mathematical programming models can be classified in three classes: normative, positive and econometric (Buysse *et al.*, 2007b).
Normative mathematical programming models (NMP) have mainly a prescriptive character indicating how the decision maker ought to behave. This kind of model is not calibrated to the base year observed data and they reproduce an outcome that may be largely different compared to the observed outcome. However, a wide divergence between the modelled outcome and the observed outcome may be unacceptable in policy analysis. Besides the lack of calibration, another disadvantage of NMP is the jumpy behaviour from one corner solutions to another when some parameters change. Linear models are the most common NMP models and the linearity is represented in both objective function and constraints. Often these models suffer of over-specialisation as the number of empirically justified constraints is usually lower than the number of observed activities. As in a linear formulation the number of constraints is the upper bound of the number of non-zero activities in the model, over-specialisation occurs by construction. In order to overcome the overspecialization problem and to maintain the linear character of the model, the inclusion of additional binding constraints is required. However, although tightly constrained models may reproduce the observed situation, they are likely to be inappropriate to represent the reaction to policy changes. Another way to get results closer to the ones observed consists in the introduction of

non-linear terms in the objective function, such as a risk term. However, although the inclusion of non-linear components in the model may overcome the overspecialisation problem, these models often deviate from reproducing the observed situation. Despite these disadvantages, the NMP models have dominated the modelling efforts in agricultural economics for more than fifty years and nowadays they are still applied. The reasons for their success are the requirements of a minimum dataset and their ability to model new policies or practices for which data are not yet available.

PMP models have been developed since the eighties with the aim of overcoming the drawbacks of NMP. PMP models assume that the observed activity levels correspond to the optimum choice which maximizes the objective function of the decision maker subject to some constraints. If the starting model with a set of linear constraints is not able to reproduce the observed activity levels it means that there is a non-linear term in the objective function and the optimal observed activity set is a combination of binding constraints and first order conditions (Howitt, 1995). Howitt (1995:330) stated that 'The LP solution is an extreme point of the binding constraints. In contrast, the PMP approach views the optimal farm production as a boundary point, which is a combination of binding constraints and first order conditions'.

PMP models allow to overcome two disadvantages of the NMP models: they reproduce exactly the base year observed situation and they react smoothly to parameter changes.

A recent frontier of mathematical programming is what Buysse *et al*. (2007b) called econometric mathematical programming (EMP). When data are available, the EMP approach joins the econometric and mathematical programming techniques by estimating some parameters of the programming model by econometric techniques and later using the resulting estimated model to simulate new practices or policy changes. EMP combines the positive aspects of econometrics, i.e. the use of observed data to estimate some economic relationships, with that of mathematical programming, the possibility to model new activities, new constraints and policy changes. Examples of this integration can be found in Paris and Arfini (2000) and in Heckelei and Wolff (2003).

3.4 POSITIVE MATHEMATICAL PROGRAMMING

Since our study represents an attempt to incorporate risk modelling into a PMP framework, we will proceed by providing a literature review on the standard PMP approach and its developments (section 3.4.1 and 3.4.2). Later we will focus on the existing proposals of combining risk modelling with PMP (section 3.4.3).

3.4.1 The standard PMP approach

PMP is a methodology to calibrate mathematical programming models to the base year observed outcomes by using the dual information provided by the calibration constraints. Besides the perfect calibration to the base year level of the endogenous variables, PMP avoids the introduction of artificial constraints and it guarantees smooth reactions to changes in parameter values. Although the PMP methodology was already applied in the eighties in agricultural economics research, it was formalised and published for the first time by Howitt in 1995. The basic assumption of PMP is that the observed choices of the decision maker are the optimum choices, which maximise the decision maker's objective function. Howitt (1995:332) stated that 'if the model does not calibrate to observed production activities with the full set of general linear constraints that are empirically justified by the model, a necessary condition for profit maximization is that the objective function be nonlinear in at least some of the activities'. The information contained in the dual values of the calibration constraints are used to infer the marginal cost of each activity level and by that to recover a farm non-linear cost function such that the endogenous variables replicate exactly their level in the base year.

The standard PMP approach is a three step procedure (Paris and Howitt, 1998). In the first step a linear or non-linear programming model is specified adding to the set of resource constraints (equation 3.7) a set of calibration constraints (equation 3.8) that bind the activities to the observed levels:

$$\max \pi = \mathbf{p}'\mathbf{x} - \mathbf{c}'\mathbf{x} \qquad (3.6)$$

$$\text{subject to} \quad \mathbf{Ax} \leq \mathbf{b} \quad (\mathbf{y}) \qquad (3.7)$$

$$\mathbf{x} \leq \overline{\mathbf{x}} + \boldsymbol{\varepsilon} \quad (\boldsymbol{\lambda}) \qquad (3.8)$$

$$\mathbf{x} \geq \mathbf{0} \qquad (3.9)$$

where π is the profit to be maximised, $\mathbf{p}$ and $\mathbf{c}$ are the $n \times 1$ vectors of output prices per unit of activity and accounting variable costs per unit of activity respectively and $\mathbf{x}$ is the $n \times 1$ vector of endogenous activity levels. In the standard PMP approach, the $\mathbf{x}$ vector can be partitioned into a $(n-m)\times 1$ vector of preferable activities bounded by the calibration constraints and into a $m \times 1$ vector of marginal activities, or less profitable activities, bounded by the resource constraints. $\mathbf{A}$ is the $m \times n$ matrix of technical coefficients which indicates the amount of each resource used per unit of each activity, $\mathbf{b}$ is the $m \times 1$ vector of resource availability, $\overline{\mathbf{x}}$ is the $n \times 1$ vector of observed activity levels in the reference year and $\boldsymbol{\varepsilon}$ is a small positive number vector (perturbance term vector) which prevents the linear dependency between the calibration and the resource constraints. The first step results in the dual value vectors $\mathbf{y}$ and $\boldsymbol{\lambda}$ associated to the resource constraints and to the calibration constraints respectively. The dual values vector of the calibration constraints $\boldsymbol{\lambda}$ represents the differential marginal costs vector, which added to the activity observed accounting costs vector provides the total marginal costs to produce observed activity levels. The value of λ is equal to zero for the marginal activities, as these activities are bounded by the resource constraints. $\boldsymbol{\lambda}$ is not present in the accounting book of the farmer but it is implicitly included in the observed output level and it captures any type of model misspecification, data errors, aggregate bias, risk behaviour and price expectations (De Frahan *et al*., 2007).

The second step of PMP uses the dual values of the calibration constraints to recover a non-linear cost function. As stated by Heckelei and Britz (2005) "Any type of non-linear function with the required properties qualifies for phase 2. For reasons of computational simplicity and lacking strong arguments for other type of functions, a quadratic cost function is often employed." The quadratic cost function usually applied is a multi-output quadratic functional form without input prices, which are assumed to be fixed at the market level:

$$C(\mathbf{x}) = \mathbf{d}'\mathbf{x} + \frac{1}{2}\mathbf{x}'\mathbf{Q}\mathbf{x} \tag{3.10}$$

where $\mathbf{d}$ is the $n \times 1$ linear term vector of the cost function and $\mathbf{Q}$ is the quadratic $n \times n$ matrix which is symmetric and positive semi-definite to guarantee the convexity property of the cost function.

The parameters of the cost function are recovered by using the information contained in the dual values of the calibration constraints by using the equation:

$$\mathbf{MC}(\mathbf{x}) = \mathbf{c} + \boldsymbol{\lambda} = \mathbf{d} + \mathbf{Q}\mathbf{x} \tag{3.11}$$

where $\mathbf{MC}$ is the farm marginal cost function vector. This marginal cost function does not include the opportunity cost of fixed inputs, which are implicitly accounted in the dual value of the resource constraints of the final model.

The estimation of $\mathbf{d}$ and $\mathbf{Q}$ implies the estimation of (n+n*(n+1)/2) parameters where n indicates the number of activity in the base year farm production plan. Originally PMP was proposed to calibrate mathematical programming models with a minimum dataset. The PMP pioneering works provided examples of recovering the farm cost function when only data on a single farm in one year was available. Besides the extreme case of just one observation available, most PMP problems are ill-posed, meaning that the number of parameters to be estimated is larger than the number of observations. To overcome the under-determination problem, PMP modellers adopted some ad hoc restrictions on the parameters (see de Frahan *et al.*, 2007 and Heckelei and Britz, 2005 for an overview). The most common assumption of the first implementations of PMP was setting the off diagonal elements of the $\mathbf{Q}$ matrix equal to zero, implying that the marginal cost of activity i is not affected by the level of activity j. Under this assumption, the substitution and complementarity relationships between activities are not considered.

Together with this common hypothesis, some additional restrictions were imposed. The most common ones consisted in setting the linear term $\mathbf{d}$ of the marginal cost function equal to zero or equal to the accounting costs vector $\mathbf{c}$; one may also equates the accounting costs vector $\mathbf{c}$ to the average costs vector of the quadratic cost function. In all these cases the marginal costs of the less profitable activities, which are bounded by the resource constraints, are constant as their activity shadow values, λ, derived from the first phase of PMP, are equal to zero. An ad hoc solution to get an increasing marginal costs for the marginal activities consisted in retrieving some share of the dual values of the resource constraint and transfer it to the dual values of the calibration constraints. Helming (2005) used the exogenous supply elasticity to recover all the on-diagonal elements of the $\mathbf{Q}$ matrix.

Paris and Howitt (1998) proposed the application of the Generalized Maximum Entropy (GME) technique in the second step of PMP in order to recover all the (n+n*(n+1)/2) parameters of the farm total cost function in the case of both ill-posed and well-posed problems. GME also allows the integration of exogenous information, such as supply elasticity, in the estimation phase and it accommodates multiple observations. By the introduction of GME in the mathematical programming framework, the authors started to cross the bridge between econometrics and mathematical programming. However, their work still used only one observation. Heckelei and Britz (2005) argued that the use of a single observation does not provide any information on the curvature of the cost function and hence the farm response to economic changes is largely dependent on the ad hoc restrictions or on the support values applied in the GME estimation. One way to deal with inappropriate modelling of farm reaction to changes, when the problem is ill-posed, consists in the use of exogenous information, such as supply elasticities. Heckelei and Britz (2000) extended the use of GME in a PMP framework when multiple observations are available. Multiple observations give information on the second order derivatives of the cost function and if the problem is well-posed arbitrary curvature of the cost function is avoided. When multiple observations are available and the problem is well-posed either GME or Least Squares (LS) can be implemented in a PMP framework to estimate the non-linear cost function (Paris and Arfini, 2000).

When all the parameters of the quadratic matrix are estimated either by GME or by LS, the Cholesky factorisation is applied in order to guarantee the symmetry and positive semi-definiteness of the $\mathbf{Q}$ matrix. The Cholesky factorisation decomposes the quadratic matrix into a lower triangular matrix and a diagonal matrix such that:

$$\mathbf{Q} = \mathbf{LDL}' \tag{3.12}$$

where $\mathbf{L}$ is a unit lower triangular matrix and $\mathbf{D}$ is a diagonal matrix whose elements are restricted to be non-negative. The estimation of the parameters of a mathematical programming model by the traditional econometrics techniques such as LS and GME on multiple observations are still a few (Heckelei *et al.*, 2012).

Once the non-linear cost function has been estimated, the third step of the standard PMP uses this function to recover a calibrated non-linear programming model (equations 3.13-3.15) which reproduces exactly the base period level of primal and dual solutions without the calibration constraints.

$$\max \pi = \mathbf{p}'\mathbf{x} - \mathbf{d}'\mathbf{x} - \frac{1}{2}\mathbf{x}'\mathbf{Q}\mathbf{x} \tag{3.13}$$

$$\text{subject to} \quad \mathbf{Ax} \leq \mathbf{b} \qquad (\mathbf{y}) \tag{3.14}$$

$$\mathbf{x} \geq \mathbf{0} \tag{3.15}$$

3.4.2 Developments of PMP

Following the seminal papers by Howitt (1995) and Paris and Howitt (1998), there have been many methodological developments in the area of PMP, aiming to improve the standard approach. Paris and Arfini work (2000) dealt with the problem of zero activity levels in some farms of an homogenous sample. They solved the self-selection problem by adding to the n farm LP models of the first step an additional model for an artificial farm and through this they calibrated a frontier cost function. The artificial farm resulted by summing the resources and the crop activity levels of all farms in the sample.

Paris (2001) proposed the Symmetric Positive Equilibrium Problem (SPEP) as a way to avoid the linear technology of the fixed input and to make the demand and supply of fixed input responsive to output levels and input price changes. The SPEP model contains symmetric primal and dual constraints in the first step, it recovers a total cost function which includes the cost of quasi-fixed inputs in the second step, and in the third step it results in a set of input demand, output supply, marginal cost and marginal revenue equations.

One of the most important modifications to the original PMP approach was proposed by Heckelei and Wolff (2003). The authors argued that the standard PMP approach leads to inconsistent parameters estimates of the calibrated cost function when multiple observations are used. They showed that, when multiple observations are available, the dual values of the resource constraints of the first step of PMP are different from the values of the third step non-linear model, which is assumed to be the 'true' model. As the dual values of the first step are used to recover the non-linear cost function and these values are shown to be distorted, they concluded that the estimates of the cost function parameters are biased. Howitt (2005) showed that for a single observation the dual values are the same in the first phase model and in the third phase model; when multiple observations are available, he proposed a two-step LP calibration in order to avoid the inconsistency. The alternative calibration procedure proposed by Heckelei and Wolff consists of skipping the first step of PMP and employing directly the first order conditions of the desired programming model to estimate simultaneously the non-linear cost function and the dual values. Let's consider the desired programming model taking this form:

$$\max \pi = \mathbf{g}'\mathbf{x} - \mathbf{d}'\mathbf{x} - \frac{1}{2}\mathbf{x}'\mathbf{Q}\mathbf{x} \quad (3.16)$$

subject to $\mathbf{A}\mathbf{x} \leq \mathbf{b} \;\; (\mathbf{y})$ (3.17)

$$\mathbf{x} \geq 0 \quad (3.18)$$

where $\mathbf{d}$ and $\mathbf{Q}$ need to be estimated and $\mathbf{g}$ is the per unit of activity gross margin vector.

Assuming that the observed activity levels deviate from the optimum choices by a small stochastic error $\mathbf{e}$, with mean zero and standard deviation σ, and that all the resource constraints are binding, the optimality first order conditions are:

$$\mathbf{g} - \mathbf{d} - \mathbf{Q}(\overline{\mathbf{x}} - \mathbf{e}) - \mathbf{y}'\mathbf{A} = 0 \qquad (3.19)$$

$$\mathbf{A}(\mathbf{x} - \mathbf{e}) = \mathbf{b} \qquad (3.20)$$

The two optimality conditions (3.19) and (3.20) are used to estimate the parameters of non-linear cost function by either GME or LS techniques.

The work of Heckelei and Wolff represents a remarkable attempt to join mathematical programming model with econometric techniques within the new framework of EMP. De Frahan *et al*. (2007) showed the implementation of the direct estimation of the optimality conditions of the desired model to calibrate an agricultural model, SEPALE, composed by a collection of farm-level mathematical programming models. The authors did not include any resource constraints in the model, but the resources are considered tradable, thus entering the cost function as variable inputs. Another empirical application of the approach proposed by Heckelei and Wolff is represented by the work of Buysse *et al.* (2007a), which analysed the impact of the 2003 sugar reform in the EU by applying a PMP model to a sample of Belgian farmers. The authors applied directly GME estimation to the first order conditions of a farm level model with a quadratic cost function, assuming the tradability of land among farmers.

A further extension to the standard PMP approach is represented by the model proposed by Arfini and Donati (2008). Paris in his book 'Economic Foundations of Symmetric Programming' (2011: 397-404) refers to this model as an ingenious answer to two problems arising from the standard PMP. The first problem is the tautology problem raised by the presence of calibration constraints in the first phase of PMP, while the second issue concerns the non- obvious connection between the n- LP independent problems of the first phase and the recovery of a quadratic matrix of the cost function common to all farms in the second phase. The idea of Arfini and Donati is to merge the first linear phase with the second non-linear phase of the PMP and to estimate simultaneously the parameters of the non-linear cost function, the shadow price of resources and the differential marginal costs. The theoretical representation of the model for the n^{th} farm is:

$$\min\left\{\sum_{n=1}^{N}\frac{1}{2}\mathbf{u}'_n\,\mathbf{u}_n+\sum_{n=1}^{N}\left(b_n y_n+\mathbf{r}'_n\,\overline{\mathbf{x}}_n-\mathbf{p}'_n\,\overline{\mathbf{x}}_n\right)\right\} \tag{3.21}$$

subject to

$$A'_n\,y_n+\mathbf{r}_n\geq\mathbf{p}_n \tag{3.22}$$

$$\mathbf{r}_n=\mathbf{Q}\overline{\mathbf{x}}_n+\mathbf{u}_n \tag{3.23}$$

$$y_n,\mathbf{r}_n\geq 0 \tag{3.24}$$

where $\overline{\mathbf{x}}_n$ is the vector of observed activity levels, b_n is the land available on the farm, A'_n is the matrix of technical coefficients, $\mathbf{p}_n$ is the vector of output prices, y_n is the shadow price of land, $\mathbf{r}_n$ is the activity marginal cost vector, $\mathbf{Q}$ is the quadratic term of the non linear cost function, which is common to all farms, while $\mathbf{u}_n$ is the vector of farm deviations from the cost function . The model merges the first linear phase with the second non-linear phase by minimising an objective function subject to a set of constraints. The objective function has two components: the square of the farm deviations from the average cost function and the differences between the primal and dual objective function of an LP problem which should be equal to zero. The constraint (3.22) is the dual constraint of the LP problem and it indicates the traditional economic equilibrium stating that marginal cost must be larger or equal to marginal revenue while the constraint (3.23) represents the link between the LP problem and the quadratic problem. Paris provided the Karush-Kunh-Tucker (KKT) conditions for the resolution of this model and he showed the ability of the model to reproduce the base year activity levels without explicit calibration constraints, which are nevertheless implicit in the setup of the problem.

Arfini and Donati (2011) provided an empirical application of a similar model to analyse the effects of some Health Check CAP reform proposals on farm samples in three different European regions. The main contribution of this model compared to the 2008 version consists in the estimation of the specific variable accounting costs, $\mathbf{c}$, together with the estimation of the non linear cost function, while the shadow value of land is approximated by some exogenous rental prices. In order to estimate $\mathbf{c}$ correctly an additional constraint is added to the model which bounds the total estimated accounting cost to be lower or equal to the total variable costs included in the FADN database. Another constraint bounds the total estimated non-linear cost function to be larger or equal to the total variable costs included in the FADN database.

3.4.3 Positive Mathematical Programming and Risk Modelling

The above literature review on PMP and its extensions has showed that PMP is a powerful and 'alive' technique to calibrate mathematical programming models. It is powerful in the way it allows for an exact reproduction of the base year activity levels and it is 'alive' as it is subject to modifications and improvements over time. A relatively new research frontier in the area of mathematical programming concerns the integration of risk modelling in a PMP framework. So far there have been a few studies in this direction. The idea is that if the dual values of the calibration constraints of PMP capture also the risk behaviour, it should be possible to make explicit the risk component separately from the other non-linear cost components. Modelling the risk component explicitly allows to identify the farmer attitude towards risk and the role of risk in farmer's choices, as well as to perform simulation under different risk scenarios. Below we present three attempts of integrating risk into the PMP modelling recently proposed in the literature.

The first attempt in this direction was made by Paris and Arfini (2000), who introduced the risk in a PMP model relying upon the E-V approach proposed by Freund (1956). The first step of their work consisted in calculating exogenously the farm absolute risk aversion coefficient, α, by the application of a chance-constrained interpretation of the dual relation: $\mathbf{A'y} + \alpha\mathbf{Vx} \geq E(\tilde{\mathbf{p}})$. From the chance-constrained approach, they obtained an estimate for α equals to $\frac{-\tau}{\sqrt{\bar{\mathbf{x}}\mathbf{V}\bar{\mathbf{x}}}}$ where τ is the standardized normal random variable and $\mathbf{V}$ is the exogenous variance-covariance matrix of output prices. After the exogenous calculation of α, they introduced α in the first phase of a PMP model which includes the price risk according to the mean-variance approach. The first step model is expressed by:

$$\max EU(\tilde{\pi}) = E(\tilde{\mathbf{p}})'\mathbf{x} - \mathbf{c}'\mathbf{x} - \frac{1}{2}\alpha\mathbf{x}'\mathbf{Vx} \qquad (3.25)$$

$$\text{subject to} \qquad \mathbf{Ax} \leq \mathbf{b} \qquad (\mathbf{y}) \qquad (3.26)$$

$$\mathbf{x} \leq \bar{\mathbf{x}} + \boldsymbol{\varepsilon} \qquad (\boldsymbol{\lambda}) \qquad (3.27)$$

The only endogenous variables in this first phase model is the vector of activity levels $\mathbf{x}$. The recovery of the marginal cost equation follows the second phase of the standard PMP approach without risk and the final calibrated model results in:

$$\max EU(\tilde{\pi}) = E(\tilde{\mathbf{p}})'\mathbf{x} - \frac{1}{2}\mathbf{x}'\mathbf{Q}\mathbf{x} - \frac{1}{2}\alpha\mathbf{x}'\mathbf{V}\mathbf{x} \quad (3.28)$$

subject to $\mathbf{A}\mathbf{x} \leq \mathbf{b}$ (3.29)

Given the lack of data, the two authors could not apply their proposed methodology to a farm sample. The Paris and Arfini (2000) study drove the attention of agricultural economists on the new challenging problem of incorporating risk into PMP and they made the first methodological proposal in this area; however, their model does not estimate directly the absolute risk aversion coefficient, which is calculated exogenously.

A more recent attempt to introduce risk into a PMP framework has been carried out by Severini and Cortignani (2011). Their work extended the work of Heckelei and Wolff (2003) by the inclusion of a "gross margin risk" modelled by the mean-variance approach. In their work the gross margin risk is related to the random behaviour of prices and yields; however, it is not possible to isolate the price risk from the yield risk. They estimated endogenously the absolute risk aversion coefficient by skipping the first phase of PMP and applying directly the GME on the first order conditions of the desired model:

$$\max_{\mathbf{w}_t,\mathbf{d},\boldsymbol{\alpha},\mathbf{Q},\mathbf{L},\mathbf{y}_t} H(\mathbf{w}_t) = -\sum_{t=1}^{T}\mathbf{w}'_t \ln \mathbf{w}_t - \mathbf{w}^{\varepsilon}{}'\ln \mathbf{w}^{\varepsilon} \quad (3.30)$$

$$E(\tilde{\mathbf{g}}_t) - \mathbf{y}_t'\mathbf{A} - \mathbf{d}_t - \mathbf{Q}(\bar{\mathbf{x}}_t - \mathbf{S}\mathbf{w}_t) - \boldsymbol{\alpha}\mathbf{V}(\bar{\mathbf{x}}_t - \mathbf{S}\mathbf{w}_t) = 0 \quad (3.31)$$

$$E(\tilde{\mathbf{g}}_t) - \mathbf{y}_t'\mathbf{A} - \mathbf{d}_t - \mathbf{Q}(\bar{\mathbf{x}}_t - \mathbf{S}\mathbf{w}_t) - \boldsymbol{\alpha}\mathbf{V}(\bar{\mathbf{x}}_t - \mathbf{S}\mathbf{w}_t) < 0 \quad (3.32)$$

$$\mathbf{A}'(\bar{\mathbf{x}}_t - \mathbf{S}\mathbf{w}_t) = \mathbf{b}_t \quad (3.33)$$

$$\mathbf{Q} = \mathbf{L}'\mathbf{L} \quad (3.34)$$

$$\mathbf{S}^{\varepsilon}\mathbf{w}^{\varepsilon} = \left[\left(\mathbf{Q}^{-1} - \mathbf{Q}^{-1}\mathbf{A}(\mathbf{A}'\mathbf{Q}^{-1}\mathbf{A})^{-1}\mathbf{A}'\mathbf{Q}^{-1}\right) \odot \left(\frac{\mathbf{g}}{\bar{\mathbf{x}}}\right)\right] \quad (3.35)$$

$$\sum_{s=1}^{S}\mathbf{w}_{\mathbf{j,t,s}} = 1 \quad (3.36)$$

$$\sum_{s=1}^{S}\mathbf{w}^{\varepsilon}{}_{\mathbf{j,t,s}} = 1 \quad (3.37)$$

where $H(\mathbf{w}_t)$ is the measure of entropy to be maximised, $\mathbf{S}$ is the matrix of the support values of the error terms, $\mathbf{w}_t$ is the vector of the weights associate to each support value, $\mathbf{S}^{\varepsilon}$ is the support matrix for the elasticities and $\mathbf{w}^{\varepsilon}$ is the corresponding vector of the weights.; $\overline{\mathbf{g}}$ is the sample mean of gross margin per unit of activity; the other symbols have the same meaning as defined previously. This model maximises the uncertainty (entropy) associated to each activity level (equation 3.30) conditional on the equilibrium constraint, which sets the marginal cost equal to marginal revenue for activities that are actually observed in the farm production plan (equation 3.31) and marginal cost larger than marginal revenue for activities not currently produced by the farm (equation 3.32). The other constraints are the structural constraint (3.33), the Cholesky decomposition of the quadratic matrix $\boldsymbol{Q}$ which guarantees the convexity of the estimated cost function (3.34), the elasticity reparameterization (3.35) and the probability constraints (3.36) and (3.37). The model estimates simultaneously the non-linear cost function, the absolute risk aversion coefficient and the shadow price of land. The paper presents an illustrative empirical application to a small sample of farms located in the centre of Italy with the aim of evaluating the effect of a revenue insurance schemes on farm production choices and on farm gross margins. In their work, Severini and Cortignani (2011) did not consider any structural foundation behind the model.

Petsakos and Rozakis (2011) proposed an innovative framework for integrating risk into PMP. They applied a second order Taylor expansion to a logarithmic utility function and they obtained an expected utility function. Although the risk aversion coefficient is not explicit in the model, it can be derived applying the Arrow-Pratt rule (equation 3.2) and it exhibits DARA preferences. They used the expected utility function in a three step procedure to estimate the true variance-covariance matrix of the gross margin per unit of activity. The first step consists in a farmer maximisation problem under the expected utility theory:

$$\max EU(\mathbf{x}) = \ln(W_0 + E(\tilde{\mathbf{g}})'\mathbf{x}) - \frac{1}{2}\left(\frac{\left\|E(\tilde{\mathbf{g}})'\right\|}{W_0 + E(\tilde{\mathbf{g}})'\mathbf{x}}\right)^2 \mathbf{x}'\mathbf{V}_1\mathbf{x} \qquad (3.38)$$

$$\text{subject to} \qquad \mathbf{Ax} \le \mathbf{b} \qquad (\mathbf{y}) \qquad (3.39)$$

$$\mathbf{x} \ge \overline{\mathbf{x}} - \boldsymbol{\varepsilon} \qquad (\boldsymbol{\lambda}) \qquad (3.40)$$

$$\mathbf{x} \ge 0 \qquad (3.41)$$

where W_0 is the initial wealth, $\mathbf{V_1}$ is the variance-covariance matrix of the gross margin per unit of activity of the first phase and the other variables have the same meaning as previously declared. The idea is that $\mathbf{V_1}$ is a national or regional matrix, while the farm makes his choice based on an individual variance-covariance matrix which is not known. Petsakos and Rozakis proposed to use the dual information of the first phase to adjust the matrix $\mathbf{V_1}$ and get an individual farm matrix $\mathbf{V}_2$ which calibrates the model according to equation (3.42).

$$\left\|E(\tilde{\mathbf{g}})'\right\|^2\left[\frac{\mathbf{V}_2\bar{\mathbf{x}}}{(W_0+E(\tilde{\mathbf{g}})'\bar{\mathbf{x}})^2}-\frac{E(\tilde{\mathbf{g}})'\bar{\mathbf{x}}'\mathbf{V}_2\bar{\mathbf{x}}}{(W_0+E(\tilde{\mathbf{g}})'\bar{\mathbf{x}})^3}\right]=\left\|E(\tilde{\mathbf{g}})'\right\|^2\left[\frac{\mathbf{V}_1\bar{\mathbf{x}}}{(W_0+E(\tilde{\mathbf{g}})'\bar{\mathbf{x}})^2}-\frac{E(\tilde{\mathbf{g}})'\bar{\mathbf{x}}'\mathbf{V}_1\bar{\mathbf{x}}}{(W_0+E(\tilde{\mathbf{g}})'\bar{\mathbf{x}})^3}\right]+\boldsymbol{\lambda} \tag{3.42}$$

where $\mathbf{V}_2$ is the only unknown variables.

The third step consists in a calibrated model which perfectly reproduces the base year observations without the calibration constraints

$$\max EU(\mathbf{x})=\ln(W_0+E(\tilde{\mathbf{g}})'\mathbf{x})-\frac{1}{2}\left(\frac{\left\|E(\tilde{\mathbf{g}})'\right\|}{W_0+E(\tilde{\mathbf{g}})'\mathbf{x}}\right)^2\mathbf{x}'\mathbf{V}_2\mathbf{x} \tag{3.43}$$

subject to

$$\mathbf{Ax}\leq\mathbf{b} \tag{3.44}$$

$$\mathbf{x}\geq 0 \tag{3.45}$$

The work of Petsakos and Rozakis represents a remarkable proposal to include risk into a PMP framework, without applying the E-V approach. Their proposal avoids the direct estimation of the absolute risk aversion coefficient which can be calculated by applying the Arrow-Pratt rule. In addition their model is based on DARA preferences. The weaknesses of their study concerns what they assume that the misspecification of the initial variance-covariance matrix of the unitary gross margin is the only reason why the starting model does not reproduce the observed activity level. Besides the risk, the cost function is still linear.

3.5 INTEGRATING RISK INTO A PMP MODEL: A NEW METHODOLOGICAL PROPOSAL

Given the few attempts found in the literature to integrate risk into a PMP framework, and lacking an established consensus on the most suitable one, we have elaborated a new proposal for the integration of agricultural risk in a farm level PMP model. The proposal has a mathematical and economic justification and takes advantage of the recent developments in both PMP and risk modelling literature.

We have explored this research area since we think the combination of PMP with risk modelling will be a new research frontier in the analysis of farmers' behaviour. Given the importance of accounting for risk in agricultural production and the powerful calibration ability of PMP, the integration of the two elements represents a relevant development in farm modelling. The proposed model estimates both the farm non-linear cost function and the farmer's absolute risk aversion coefficient.

This new methodological proposal relies upon the model of Arfini and Donati (2008, 2011), that merges the first linear phase of PMP with the second non-linear phase by using the dual relationships of a farmer's expected utility maximisation problem. The model estimates simultaneously the differential marginal cost and the shadow price of resources which usually belong to the first PMP phase, as well as the farm non-linear cost function and the farmer's coefficient of absolute risk aversion. The model specification is the following:

$$\min_{\mathbf{u},\mathbf{y},\boldsymbol{\lambda},\alpha} \frac{1}{2}\mathbf{u}'\mathbf{u} + \mathbf{y}'\mathbf{b} + \mathbf{c}'\bar{\mathbf{x}} + \boldsymbol{\lambda}'(\bar{\mathbf{x}} + \boldsymbol{\varepsilon}) + \alpha\bar{\mathbf{x}}'\mathbf{V}\bar{\mathbf{x}} - E(\tilde{\mathbf{p}})'\bar{\mathbf{x}} \qquad (3.46)$$

subject to

$$\mathbf{c} + \alpha\mathbf{V}\bar{\mathbf{x}} + \mathbf{A}'\mathbf{y} + \boldsymbol{\lambda} \geq E(\tilde{\mathbf{p}}) \qquad (3.47)$$

$$\mathbf{c} + \boldsymbol{\lambda} = \mathbf{Q}\bar{\mathbf{x}} + \mathbf{u} \qquad (3.48)$$

$$\mathbf{y} \geq 0, \boldsymbol{\lambda} \geq 0, \alpha \geq 0 \qquad (3.49)$$

The meaning of the symbols is the same as before. The objective function minimises the square of the individual farm deviations, $\frac{1}{2}\mathbf{u}'\mathbf{u}$, from the common cost function and the difference between the primal and the dual objective function of a farmer's expected utility maximisation problem. This difference at the optimum should be equal to zero. The constraint (3.47) represents the dual constraint which indicates the economic equilibrium condition stating that the marginal cost must be larger or equal to the marginal revenue. The constraint (3.48) indicates the relationship between the marginal cost of the first phase of the standard PMP and the marginal cost of the farm non linear cost function. It is worth to notice that the observed activity levels are directly introduced in the model without defining any calibration constraints, which raised several critiques to the standard three-phase PMP approach. Solving the model either by GME or by LS leads to the simultaneous estimation of the shadow prices of resources, $\mathbf{y}$, the shadow prices of activities, $\boldsymbol{\lambda}$, the quadratic matrix of the cost function, $\mathbf{Q}$, the individual farm deviations from the cost function, $\mathbf{u}$, and the farmer's absolute risk aversion coefficient α. Since the model (3.46) - (3.49) is based on a farmer's expected utility maximisation problem following the E-V approach, the coefficient of farmer's absolute risk aversion, α, is farm specific and it is independent of the level of wealth (thus, it corresponds to CARA risk preferences).

Since the model (3.46) - (3.49) is a mathematical programming model with inequality constraints and sign restricted variables, a set of KKT conditions provides the solution of the model. In order to derive the KKT conditions, we write the Lagrange function of the model:

$$L = \frac{1}{2}\mathbf{u}'\mathbf{u} + \alpha\bar{\mathbf{x}}'\mathbf{V}\bar{\mathbf{x}} + \mathbf{y}'\mathbf{b} + \boldsymbol{\lambda}'(\bar{\mathbf{x}} + \boldsymbol{\varepsilon}) + \mathbf{c}'\bar{\mathbf{x}} - E(\tilde{\mathbf{p}})'\bar{\mathbf{x}} + \mathbf{w}'(E(\tilde{\mathbf{p}}) - \mathbf{c} - \alpha\mathbf{V}\bar{\mathbf{x}} - \mathbf{A}'\mathbf{y} - \boldsymbol{\lambda}) + \mathbf{v}'(\mathbf{c} + \boldsymbol{\lambda} - \mathbf{Q}\bar{\mathbf{x}} - \mathbf{u}) \tag{3.50}$$

where $\mathbf{w}'$ and $\mathbf{v}'$ represent the Lagrange multipliers associated to each constraint. From the Lagrange function we can derive the KKT conditions, where the sign is dictated by the direction of the optimisation and by the sign of the variables, and their associated complementary slackness conditions:

$$\frac{dL}{d\mathbf{u}} = \mathbf{u} - \mathbf{v} = 0 \quad (3.51a) \qquad \mathbf{u}'\frac{dL}{d\mathbf{u}} = \mathbf{u}'(\mathbf{u} - \mathbf{v}) = 0 \quad (3.51b)$$

$$\frac{dL}{d\mathbf{y}} = \mathbf{b} - \mathbf{A}\mathbf{w} \geq 0 \quad (3.52a) \qquad \mathbf{y}'\frac{dL}{d\mathbf{y}} = \mathbf{y}'(\mathbf{b} - \mathbf{A}\mathbf{w}) = 0 \quad (3.52b)$$

$$\frac{dL}{d\boldsymbol{\lambda}} = \bar{\mathbf{x}} + \boldsymbol{\varepsilon} - \mathbf{w} + \mathbf{v} \geq 0 \quad (3.53a) \qquad \boldsymbol{\lambda}'\frac{dL}{d\boldsymbol{\lambda}} = \boldsymbol{\lambda}'(\bar{\mathbf{x}} + \boldsymbol{\varepsilon} - \mathbf{w} + \mathbf{v}) = 0 \quad (3.53b)$$

$$\frac{dL}{d\alpha} = \bar{\mathbf{x}}'\mathbf{V}\bar{\mathbf{x}} - \mathbf{w}'\mathbf{V}\bar{\mathbf{x}} \geq 0 \quad (3.54a) \qquad \alpha\frac{dL}{d\alpha} = \alpha(\bar{\mathbf{x}}'\mathbf{V}\bar{\mathbf{x}} - \mathbf{w}'\mathbf{V}\bar{\mathbf{x}}) = 0 \quad (3.54b)$$

$$\frac{dL}{d\mathbf{w}} = E(\tilde{\mathbf{p}}) - \mathbf{c} - \alpha\mathbf{V}\bar{\mathbf{x}} - \mathbf{A}'\mathbf{y} - \boldsymbol{\lambda} \leq 0 \tag{3.55a}$$

$$\mathbf{w}'\frac{dL}{d\mathbf{w}} = \mathbf{w}'(E(\tilde{\mathbf{p}}) - \mathbf{c} - \alpha\mathbf{V}\bar{\mathbf{x}} - \mathbf{A}'\mathbf{y} - \boldsymbol{\lambda}) = 0 \tag{3.55b}$$

$$\frac{dL}{d\mathbf{v}} = \mathbf{c} + \boldsymbol{\lambda} - \mathbf{Q}\bar{\mathbf{x}} - \mathbf{u} = 0 \qquad (3.56a) \qquad \mathbf{v}'\frac{dL}{d\mathbf{v}} = \mathbf{v}'(\mathbf{c} + \boldsymbol{\lambda} - \mathbf{Q}\bar{\mathbf{x}} - \mathbf{u}) = 0 \qquad (3.56b)$$

KKT condition (3.51a) indicates that the dual value, $\mathbf{v}$, associated to the marginal cost function equation is equal to the farm deviation from the cost function, $\mathbf{u}$; since the model tries to keep $\mathbf{u}$ as small as possible, $\mathbf{v}$ should result in a small positive or negative number too. $\mathbf{w}$ is the dual value of the economic equilibrium constraint (3.47) and it can be interpreted as the shadow output quantity, thus $\mathbf{w} = \mathbf{x}$. Substituting $\mathbf{v} = \mathbf{u}$ and $\mathbf{w} = \mathbf{x}$ in (3.52a) and (3.53a), we can recognize in these two conditions the resource constraints and the calibration constraints respectively. Hence, the model (3.46)-(3.49) implicitly represents the constraints of a first phase model of the standard PMP and as a consequence the model calibrates to the base year activity level without making the first phase explicit. This prevents from the critiques raised against the standard PMP approach. The other KKT conditions represent a tautology (condition 3.54a) and the constraints of the model (conditions 3.55a and 3.56a).

The estimated variables of the model (3.46) - (3.49) are then used to construct a non-linear model which includes both the estimated farm quadratic cost function and the estimated risk term (equations 3.57 -3.59). The model calibrates the endogenous variable levels to the base year without the calibration constraints and it can been used in simulation analysis:

$$\max EU(\tilde{\pi}) = E(\tilde{\mathbf{p}})'\mathbf{x} - \frac{1}{2}\mathbf{x}'\mathbf{Q}\mathbf{x} - \mathbf{u}'\mathbf{x} - \frac{1}{2}\alpha\mathbf{x}'\mathbf{V}\mathbf{x} \qquad (3.57)$$

subject to

$$\mathbf{A}\mathbf{x} \le \mathbf{b} \qquad (3.58)$$

$$\mathbf{x} \ge 0 \qquad (3.59)$$

where $\mathbf{x}$ is the vector of endogenous activity levels, $\mathbf{Q}$, $\mathbf{u}$ and α have been estimated previously by equations (3.46)-(3.49) and $E(\mathbf{p})'$, $\mathbf{V}$, $\mathbf{A}$ and $\mathbf{b}$ are exogenous parameters. Equation (3.57) is the farmer expected utility to be maximised which is equal to the expected revenue minus the estimated farm non linear cost function and the risk premium. Equation (3.58) is the usual resource constraint.

The new methodological proposal for the incorporation of risk in a PMP framework represents an innovative approach compared to the previous studies in this challenging research area. Our model differs from the work of Paris and Arfini (2000) as we estimate endogenously the farmer's coefficient of absolute risk aversion and we do not rely upon the standard three-step PMP. Although the endogenous variables in our model are the same variables estimated in the model of Severini and Cortignani (2011), our proposal differs from their model in the viewpoint adopted to solve the problem. While Severini and Cortignani skipped the first phase of the PMP and they estimated directly the optimality conditions of the desired model, we merged the first linear phase with the second non-linear phase by using the dual relationships of an expected utility maximisation problem. Finally, our approach differs from the proposal of Petsakos and Rozakis (2011) as it applies the E-V approach and it estimates both the non-linear cost function and the non-linear risk term.

The advantages of our proposed estimation approach compared to the direct estimation of the optimality conditions of the desired model (Heckelei and Wolff, 2003; Severini and Cortignani, 2011) consists in the possibility of using additional information such as the variable accounting cost per unit of activity available in our dataset and the difference between the primal and the dual objective function of a farmer expected utility maximisation problem. In addition, our model specifies only the dual constraint on marginal costs while the estimation of the optimality conditions involves the specification of both the dual constraint and the resource constraint. However, one of the two constraints is redundant in an optimisation model and it may affect the parameters' estimation. Finally, the estimation carried out by Severini and Cortignani, according to the procedure proposed by Heckelei and Wolff (2003) introduces the deviations in the output level, while our deviations concern the individual departure from the common cost function.

3.6 EMPIRICAL MODEL AND DATA

In this section an empirical application of the theoretical model presented in section 3.5 will be provided considering crop price risk only. First the model (3.46) –(3.49) has been estimated and the ability of the model to calibrate to the base year activity levels has been checked. This first step has estimated the farm non-linear cost function as well as the endogenous farmer's absolute risk aversion coefficient and the shadow prices. Then, the calibrated model (3.57) – (3.59) has been applied to analyse the farmer's reactions to the introduction of an agri-environmental program under different crop price volatility scenarios. The ability of the model to represent the farmer's response to these scenarios has been investigated, as well as the potential role of a grassland program as a strategy to cope with price risk. The model has been applied to three farm samples, differentiated by size (small, medium and large). Each sample is composed by fourteen farms and the small sample size is justified by the illustrative role of the empirical application. The estimation of the model and the simulations have been applied to each farm sample.

3.6.1 Empirical model

Four crops are included in the empirical model (sugar beet, common wheat, corn and barley), and it is assumed that these crops are grown in all farms in the base year. The base year (or baseline situation) is the year observed when no simulations are made. These crops are the most widely grown crops in the area under study. This simplification is justified by the interest in modelling risk in a PMP framework rather than modelling the activities not observed, which can be added following the proposal of Paris and Arfini (2000). According to most PMP theoretical papers, we have introduced the land constraint as the only resource constraint. We adopt a non-linear quadratic cost function, the most frequently used functional form in PMP works, while we assume that the absolute risk aversion coefficient is farm specific.

The empirical model (3.46) – (3.49) for the n^{th} farm is the following:

$$\min \frac{1}{2}\begin{bmatrix} u_{sb} & u_w & u_c & u_b \end{bmatrix}\begin{bmatrix} u_{sb} \\ u_w \\ u_c \\ u_b \end{bmatrix} + y*b + \begin{bmatrix} c_{sb} & c_w & c_c & c_b \end{bmatrix}\begin{bmatrix} \bar{x}_{sb} \\ \bar{x}_w \\ \bar{x}_c \\ \bar{x}_b \end{bmatrix} + \begin{bmatrix} \lambda_{sb} & \lambda_w & \lambda_c & \lambda_b \end{bmatrix}\begin{bmatrix} \bar{x}_{sb}+\varepsilon \\ \bar{x}_w+\varepsilon \\ \bar{x}_c+\varepsilon \\ \bar{x}_b+\varepsilon \end{bmatrix} +$$

$$+\alpha*\begin{bmatrix} \bar{x}_{sb} & \bar{x}_w & \bar{x}_c & \bar{x}_b \end{bmatrix}\begin{bmatrix} v_{sbsb} & v_{sbw} & v_{sbc} & v_{sbb} \\ v_{wsb} & v_{ww} & v_{wc} & v_{wb} \\ v_{csb} & v_{cw} & v_{cc} & v_{cb} \\ v_{bsb} & v_{bw} & v_{bc} & v_{bb} \end{bmatrix}\begin{bmatrix} \bar{x}_{sb} \\ \bar{x}_w \\ \bar{x}_c \\ \bar{x}_b \end{bmatrix} - \begin{bmatrix} E(\tilde{p}_{sb}) & E(\tilde{p}_w) & E(\tilde{p}_c) & E(\tilde{p}_b) \end{bmatrix}\begin{bmatrix} \bar{x}_{sb} \\ \bar{x}_w \\ \bar{x}_c \\ \bar{x}_b \end{bmatrix}$$

Subject to

$$\begin{bmatrix} c_{sb} \\ c_w \\ c_c \\ c_b \end{bmatrix} + \alpha*\begin{bmatrix} v_{sbsb} & v_{sbw} & v_{sbc} & v_{sbb} \\ v_{wsb} & v_{ww} & v_{wc} & v_{wb} \\ v_{csb} & v_{cw} & v_{cc} & v_{cb} \\ v_{bsb} & v_{bw} & v_{bc} & v_{bb} \end{bmatrix}\begin{bmatrix} \bar{x}_{sb} \\ \bar{x}_w \\ \bar{x}_c \\ \bar{x}_b \end{bmatrix} + \begin{bmatrix} a_{sb} \\ a_w \\ a_c \\ a_b \end{bmatrix} y + \begin{bmatrix} \lambda_{sb} \\ \lambda_w \\ \lambda_c \\ \lambda_b \end{bmatrix} \geq \begin{bmatrix} E(\tilde{p}_{sb}) \\ E(\tilde{p}_w) \\ E(\tilde{p}_c) \\ E(\tilde{p}_b) \end{bmatrix}$$

$$\begin{bmatrix} c_{sb} \\ c_w \\ c_c \\ c_b \end{bmatrix} + \begin{bmatrix} \lambda_{sb} \\ \lambda_w \\ \lambda_c \\ \lambda_b \end{bmatrix} = \begin{bmatrix} q_{sbsb} & q_{sbw} & q_{sbc} & q_{sbb} \\ q_{wsb} & q_{ww} & q_{wc} & q_{wb} \\ q_{csb} & q_{cw} & q_{cc} & q_{cb} \\ q_{bsb} & q_{bw} & q_{bc} & q_{bb} \end{bmatrix} \begin{bmatrix} \bar{x}_{sb} \\ \bar{x}_w \\ \bar{x}_c \\ \bar{x}_b \end{bmatrix} + \begin{bmatrix} u_{sb} \\ u_w \\ u_c \\ u_b \end{bmatrix}$$

$$\begin{bmatrix} y_{sb} \\ y_w \\ y_c \\ y_b \end{bmatrix} \geq 0, \begin{bmatrix} \lambda_{sb} \\ \lambda_w \\ \lambda_c \\ \lambda_b \end{bmatrix} \geq 0 \;, \; \alpha \geq 0$$

where the subscripts sb, w, c, b indicate sugar beet, wheat, corn and barley respectively, y and b are the shadow prices of land and land availability respectively and $\bar{x}$ is the observed crop production in the base year. $\mathbf{V}$ is the variance-covariance matrix of output prices[6] and it is assumed to be equal for all farms. The other symbols are the same as previously defined.

At this point, it is worth to remark which variables in the models are exogenous and which are endogenously estimated, as well as the farm specific variables and the variables common to all farms in the same sample. The observed crop production, $\bar{\mathbf{x}}$, the vector of the accounting variable costs per unit of production, $\mathbf{c}$, the expected prices vector, $E(\tilde{\mathbf{p}})$, the available farm land, b, and the matrix of technical coefficients, $\mathbf{A}$, are all farm-specific exogenous variables; the variance-covariance matrix, $\mathbf{V}$, is exogenous and common to all farms, implying that all farmers face the same volatility of the crop market prices. The solution of the model results in the simultaneous estimation of the endogenous variables: the quadratic matrix of the cost function, which is common to all farms of the same sample, and the farm specific variables, which are the shadow values of the calibration constraints and of land, the farmer's absolute risk aversion coefficient, and the farm deviation from the common cost function. The model has been estimated both by LS and by GME. The estimation of the endogenous variables of the baseline model has been carried out separately for each farm sample, such that the quadratic matrix $\mathbf{Q}$ of the cost function is common to all farms of the same sample. The consideration of three farm samples is justified by the purpose of analysing samples of homogenous farms in order to get better estimates of the common quadratic matrix of the cost function.

The estimated and calibrated model is:

[6] In this methodological proposal we have considered market risk as the only source of farm income variability, while yields are considered fixed from one year to another.

$$\max \pi = E(\tilde{\mathbf{p}})'\mathbf{x} - \frac{1}{2}\mathbf{x}'\mathbf{Q}\mathbf{x} - \mathbf{u}'\mathbf{x} - \frac{1}{2}\alpha\mathbf{x}'\mathbf{V}\mathbf{x} \tag{3.60}$$

$$\mathbf{A}\mathbf{x} \leq \mathbf{b} \qquad (\mathbf{y}) \tag{3.61}$$

$$\mathbf{x} \geq 0 \tag{3.62}$$

where $\mathbf{x}$ is the vector of the unknown output quantities, the other variables have been already defined and the equations logic is the same as that of equations (3.57)-(3.59). The calibrated model has been used in simulation scenarios.

3.6.2 Simulation scenarios

The calibrated model has been applied to investigate the potential role of an AES as farm income stabiliser tool, by detecting the amount of land the farmer is willing to place under environmental commitments in presence of different levels of crop price volatility. The simulation scenarios have been applied separately to each farm sample. The AES considered in our simulations is the option to convert a share of farmland to grassland or pasture. This type of AES aims at reducing soil erosion and nitrates leaching as well as improving water quality and protecting biodiversity. This kind of program has been introduced as a new activity in the model, which competes for land with the other crops. It is assumed that the variable cost of grassland under agri-environmental commitments is equal to the revenue from its sale; hence, this activity is a no-risk activity, since it affects farm income just by its fixed agri-environmental payment. The introduction of grassland under environmental program in the model does modify neither the cost function nor the risk term.

While introducing the new activity we have simulated different levels of crop price volatility, in order to detect the amount of committed grassland and the changes in land allocation among crops at different price risk levels. The price risk (or price volatility) is represented by the variation in the price of a crop from time t_0 to time t_1. In order to simulate the crop price volatility we have used monthly times series data from the official statistics and thus we have assumed that all farms face the same price risk. The time series have been manipulated by changing the variations of each monthly crop price on a year base in order to simulate different levels of volatility. From each time series we have constructed a variance-covariance matrix which correspond to a different level of price volatility.

In scenario 1 the crop price volatility is set equal to the baseline situation. Scenario 2 is the zero price volatility scenario, while in scenario 3 the simulated volatility is half of the baseline. Volatility in scenarios 4 and 5 is larger than the baseline by 50% and 100% respectively. Each simulated scenario has been applied to each farm sample separately.

3.6.3 Data

The three farm samples employed in the empirical model have been constructed from the 2009 data on territorial aggregates of AGREA, the regional agency for the delivery of agriculture support in Emilia-Romagna region, and of RICA, the Italian section of the FADN (Farm Accountancy Data Network) database. In AGREA and RICA database a territorial aggregate is defined by four parameters: the province, the altitude, the farm type and the farm size. All farms that have the same four attributes belongs to the same cluster.

In our work we have considered only crop farms in flat areas in Emilia-Romagna. From AGREA database we have derived information about the total hectares allocated to each crop in the same cluster. From the RICA database we have used the information about crop production in each aggregate and the average specific crop variable costs and crop prices for each cluster. From the data on territorial aggregates we have constructed the representative farms[7] of the crop farms in the flat area of seven Emilia Romagna provinces (Piacenza, Parma, Reggio-Emilia, Modena, Bologna, Ferrara, Ravenna). The representative farms have been grouped into three samples according to the size of the farms they represent. The fourteen farms of the small sample are representative for the farms belonging to the two size classes of 0-10 hectares and 10-20 hectares of each provinces. The fourteen farms of the medium sample represent the farms belonging to the size classes of 30-50 hectares and 50-100 hectares. The large farm sample is composed by fourteen average farms of the size classes 100-300 hectares and more than 300 hectares.

As discussed before, in the empirical model the only crops considered are sugar beet, common wheat, corn and barley and it is assumed that all the farms grow all these crops. The farm Utilised Agricultural Area (UAA), the specific variable costs and the prices per unit of crop production of each farm are shown in Tables A3.1, A3.2 and A3.3 of Appendix A3.A. The time series data on monthly crop prices used in the variance-covariance matrix come

[7] The representative farm of a territorial aggregate has been constructed from the aggregated data. The allocation of land among crops in the representative farm has been determined according to the crop proportion in the aggregates. The variable costs and the crop prices of the representative farm belong to the average costs and crop prices of the territorial aggregates.

from the Chamber of Commerce of Bologna and by ISMEA data and cover the periods January 2004-december 2009 on a monthly basis. The payment for grassland introduced in the simulation has been set at 300 euro/ha which is the contribution for crop land converted to grassland or pasture under the Action 8 of AESs (agri-environmental schemes) according to the Rural Development Program (RDP) of Emilia-Romagna (Regione Emilia-Romagna, 2005).

3.7 RESULTS

In this section the results of the model estimation and of each simulated scenario will be presented for the three farm samples. The results widely discussed in this section comes by an estimation of the model by LS technique. The estimation results by GME are shown and briefly discussed in Appendix A3.C. The discussion on the estimate results will focus on the ability of the model to calibrate to the base year observed activity levels, on the estimation of the quadratic cost function and of shadow prices as well as on the estimation of the farmer's absolute and relative risk aversion coefficients.

The discussion of the simulation results will draw the attention on the share of land enrolled under agri-environmental grassland commitment as well as on the changes in the land allocation among crops under different scenarios of price volatility. The relationship between the crop price volatility and the share of land committed to grassland will be detected in order to investigate the role of grassland program as an option for the farmer to reduce income fluctuation. Simulation results also indicate the ability of the model to react to changes in parameter values.

Under scenarios of increasing volatility the relationship between the share of land contracted and the risk averse attitude of the farmers becomes clear. While for risk neutral farmers the share of land involved in grassland program does not change with a rise in crop price volatility, this share increases for risk averse farmers under scenarios of volatility growth. This pattern shows the potential role of the AESs as risk management tool, which is used in combination with an increase in land allocated to lowest-risk crops in medium and large farm samples.

3.7.1 Estimation results

In the subsections 3.7.1.1 – 3.7.1.3 the model estimates will be presented for each farm sample. The results show the calibration of the model and the ability to estimate reliable farmer's risk aversion coefficients.

3.7.1.1 Calibration of the model

In section 3.5 it has been shown that the shadow value, $\mathbf{w}$,of the economic equilibrium constraint (3.47) is equal to the shadow output quantity $\mathbf{x}$. Hence the comparison between the observed production $\bar{\mathbf{x}}$ and the shadow value $\mathbf{w}$ indicates the ability of the model to calibrate to the observed activity levels. The model calibrates well for all farms in the samples as the percentage deviation between the observed production vector, $\bar{\mathbf{x}}$, and the production resulting from solving the model, $\mathbf{x}$, is very small (Table A3.4). In the sample of small farms the highest deviation belongs to the production of barley in farm 11 (13.2%), while all the other deviations are smaller than 2.5% and most of them are lower than 0.3%. None of the farms in the medium farm sample shows a departure of $\mathbf{x}$ from $\bar{\mathbf{x}}$ larger than 0.95% and in the majority of them the percentage is lower than 0.04%. The model calibrates well also for the farms of the third sample, where the larger divergence is experienced by the production of barley for farm 3 (2.4%), while most of the other crop production shows a percentage divergence no larger than 0.05%.

3.7.1.2 Non-linear cost function and shadow prices

The non-linear cost function is represented by the term $\frac{1}{2}\mathbf{x}'\mathbf{Q}\mathbf{x}$ which is common to all farms of the same sample and by the farm specific term $\mathbf{u}'\mathbf{x}$ which indicates the individual farm deviation. $\mathbf{Q}$ and $\mathbf{u}$ are estimated in the model together with the shadow price of land, $\mathbf{y}$, and the shadow price of the implicit calibration constraint, $\boldsymbol{\lambda}$. The off-diagonal coefficients of the $\mathbf{Q}$ matrix indicate the relationship between the marginal cost of an activity and the crop production level of another activity. The estimated $\mathbf{Q}$ matrices (Table A3.5) show positive coefficients for all the activities in all the farm samples; this means that an increase in the production of a crop results in a rise in the marginal variable cost of the other crops.
The model is not able to reveal the shadow value of land for all farms. As shown in Table A3.6 land shadow prices are equal to zero for some farms. This may be related to the potential presence of a degeneracy in the model which cannot be cancelled out even by the introduction

of the perturbance term ε. Nevertheless, the lack of some land shadow values does not affect the model calibration. The introduction of prior information on the shadow value of land may help in the estimation of that shadow values; indeed, Heckelei and Wolff (2003) showed that the use of prior for resource shadow value by GME technique improves the estimation when the sample size is small.

Another divergence between the results of our model and the expected results of the standard three-step PMP model consists in the values of the shadow prices of the activity levels $\boldsymbol{\lambda}$. In the standard PMP model the shadow price associated to the least profitable activity should be equal to zero by construction, as this activity is bounded by the resource constraints. In our model some farms show a non-zero value of the shadow prices for all the activities (Table A3.7). This is not surprising as our model does not recover $\boldsymbol{\lambda}$ from a first phase but these shadow prices are estimated directly in the model, together with the resource shadow prices and the non-linear cost function.

3.7.1.3 Absolute and relative risk aversion coefficients

The farmer's absolute risk aversion coefficient, α, is directly estimated in the model, while the relative risk aversion coefficient can be calculated by multiplying α by the farm income resulting from the model.

The model estimates a neutral attitude towards risk for five farmers of the small farm sample (farms 4, 6, 8, 10 and 14), two farmers of the medium farm sample (farms 4 and 8) and five farmers of the large farm sample (farms 4, 5, 6, 8 and 14), while all the other farmers exhibit risk averse behaviour. Risk neutral farmers do not care about risk and the risk component in the model disappear for them. If we compare the absolute risk aversion coefficients of the risk averse farmers belonging to the different farm samples (Table 3.1) we notice that all the coefficients of the large farms and the majority of the coefficients of the medium farms are lower than the estimates of the small farms, while it is not possible to identify scale priorities between medium and large farm coefficients. Although our model is based on CARA preferences, this comparison seems to indicate the ability of the model to differentiate the value of the farmers' absolute risk aversion coefficients according to the level of farmers' wealth.

Table 3.1 Estimates of farmer's absolute and relative risk aversion coefficients

	Small farm sample		Medium farm sample		Large farm sample	
	Absolute risk aversion coefficient (α)	Relative risk aversion coefficient	Absolute risk aversion coefficient (α)	Relative risk aversion coefficient	Absolute risk aversion coefficient (α)	Relative risk aversion coefficient
1	0.001800	5.2410	0.000400	11.3560	0.000120	8.1050
2	0.000200	1.7280	0.000017	1.1850	0.000004	1.3570
3	0.000700	3.8470	0.000400	9.0240	0.000020	2.9600
4	0.000000	0.0000	0.000000	0.0000	0.000000	0.0000
5	0.002600	5.7380	0.000025	0.9510	0.000000	0.0000
6	0.000000	0.0000	0.000076	3.9920	0.000000	0.0000
7	0.000900	5.0380	0.000098	4.2120	0.000020	4.0850
8	0.000000	0.0000	0.000000	0.0000	0.000000	0.0000
9	0.001500	6.3790	0.000600	13.3550	0.000070	8.2110
10	0.000000	0.0000	0.000039	2.0870	0.000002	0.6350
11	0.001400	3.4220	0.000300	6.3180	0.000020	3.7450
12	0.000500	4.1060	0.000020	1.2680	0.000007	2.1010
13	0.000700	3.0090	0.000050	2.0570	0.000003	0.4280
14	0.000000	0.0000	0.000075	3.3500	0.000000	0.0000

Note: The absolute risk aversion coefficients are expressed in $€^{-1}$

In order to check the reliability of the model estimates for the farmer risk attitude we need to consider the relative risk aversion coefficients. While the absolute risk aversion coefficient is dependent on the unit of measurement and does not allow easy comparisons, the relative risk aversion coefficient is a dimensionless number, thus allowing comparison with a benchmark. Most scientific studies on farmers risk attitude have indicated values for the relative risk aversion coefficients between 0 and 7.5 (Chavas and Holt, 1996). In our model all the relative risk aversion estimates of the farmers belonging to the small farm sample are between 0 and 6.4. Three medium farms and two large farms exhibit values slightly above the suggested range. Given that few farmers deviate from the range indicated in the literature and the divergences are small, we can conclude that our model provides reliable estimates of the risk aversion coefficients.

3.7.2 Scenario Results

In this section the farmers' responses to the introduction of agri-environmental grassland as an option in the farm production plan will be evaluated in terms of land allocation change among crops and share of land allocated to grassland. The farmer's reactions will be investigated under different scenarios of crop price volatility in order to assess the relationship between volatility, farmer's attitude towards risk and participation to the AES under study. While scenario 1 analyses the effect of the introduction of the new environmental-friendly activity on the farm production plan setting the price volatility at the baseline situation, the other scenarios simulate different level of price variation. Tables 3.2, 3.3 and 3.4 present the farmland share allocated to committed grassland under the five scenarios for small, medium and large farms respectively. Tables A3.8 - A3.12 compare the farmland allocation in the baseline to the allocation in each scenario.

3.7.2.1 Scenario 1: baseline price volatility

In scenario 1 the price volatility is set at the level observed in the base year situation and the new activity, grassland under environmental commitment, is introduced as an option for the farmer.

Under this scenario most of the farmers commit a share of their land to grassland program independently of their attitude toward risk. This share in the farms' adopters varies from 9.3% to 45.9% in the small farm sample, from 4.3% to 39.1% in the medium farm sample and from 13.6% to 44.0% in the large farm sample.

The adoption not only leads to a conversion of cropland to grassland but also to a reallocation of the remaining land among crops. The model shows that when the farmer converts a plot of his land to grassland, sugar beet and barley are the crops mostly negatively affected (Table A3.8). Most of the farms of the small farm sample which decide to participate in the grassland program reallocate all their sugar beet and barley land (and partially their wheat land) to corn and grassland under environmental commitments. Two risk neutral farmers (farmers 10 and 14) reallocate their sugar beet and wheat land to corn, barley and grassland and just one farm experiences an increase in wheat production. In the medium farm sample barley exits all farm production plans of the participants. Wheat is negatively affected by the participation in all medium farms but one, while land allocated to corn rise. Land reallocation in the large farm sample is characterized by a cease in production of barley and wheat by all participant farms, as well as an increase in land allocated to corn.

The share of land involved in agri-environmental programme and the extent of substitution with crops depends on the baseline production plan and on the degree of farmer risk aversion. The adoption of grassland under environmental commitment by risk averse farmers substitutes mainly the less profitable crops, sugar beet and barley, and the highest-risk crop, wheat. The introduction of a new risk-free activity supports the shift of land towards corn which is the highest profitable activity. The risk neutral farmers who convert a plot of their land to grassland make the decision based on marginal profitability only as they do not care about risk. The share of land contracted by these farmers will be the same under the different scenarios of price volatility as their decisions are not affected by the risk level.

3.7.2.2 Scenario 2: no price volatility

In scenario 2 the crop price volatility is constrained at zero which corresponds to a situation without price risk. None of the farmers under scenario 2 contract an amount of grassland larger than the amount contracted under scenario 1 and many farmers in the zero risk situation do not participate in the AES (Tables 3.2, 3.3 and 3.4). The share of land contracted by risk neutral farmers as well as the land reallocation among crops is the same as in scenario 1.

In the small farm sample only two risk averse farmers (farm 2 and 12) participate in the AES and they contract a share of land smaller than the share contracted under scenario 1 (Table 3.2). Independent of the participation in the AES, all risk averse farmers reallocate their land among crops as a consequence of the change in price volatility (Table A3.9). The less profitable crops, sugar beet and barley, exits the production plans of most farmers and wheat production is significantly reduced. The land allocated to corn, which is the most profitable crops for the majority of farmers, increases and for two farms it more than doubles.

In the medium farm sample, only three risk averse farmers (farms 2, 6 and 12) allocate a share of their land to grassland under this scenario. As in the small farm sample, the production of barley and sugar beet disappears in most farmers' plans. The land allocated to corn rises and for some farms wheat production grows as well.

Four risk averse large farmers (farms 3, 7, 10 and 12) participate in the grassland program under the zero risk scenario and they shift land from barley and wheat to corn.

Under this scenario the farmer's choices are based only on marginal profitability of crops without taking into account the risk component. As a consequence, the less profitable and lower-risk crop, sugar beet, disappears in most farmers' production plans of small and medium farms and production shifts towards more profitable crops. The adoption of the AES depends only on the marginal profit and the risk does not play any role.

It is interesting to notice that most averse farmers who adopt the grassland program under this scenario exhibit a level of risk aversion smaller compared to the other farmers in their sample.

This low level of risk aversion together with the adoption of the environmental program may reveal that the participation for these farms is based mainly on a marginal profit evaluation rather than on a strategy against risk.

3.7.2.3 Scenario 3: half price volatility with respect to the baseline

If the volatility is set equal to half of the baseline volatility the amount of committed grassland increases as compared to the zero volatility scenario (scenario 2) but it is still lower than the land committed in scenario 1. In the small farm sample, eleven farmers are involved in the grassland program and they contract from 0.5% to 32.8% of their farmland. Nine medium farms commit to grassland a land share from 5.6% to 35.3%. All the large farms that are involved in the grassland program under the baseline scenario would be involved also if the price volatility was halved.

3.7.2.4 Scenario 4: price volatility 50% higher than the baseline

The crop price volatility in scenario 4 is set higher than the baseline volatility by 50%. While the share of land committed to grassland by risk neutral farmers is equal to the share committed under the previous price volatility scenarios, this share increases for risk averse farmers. The increase is highly dependent on the value of risk aversion coefficient of farmers. All risk averse farmers in the small farm sample participate in the grassland program and the share of farmland committed is larger by more than 50% than the share under scenario 1, with the exception of farm 2. In the medium farm sample the land committed by ten risk averse farmers is larger compared to the land committed under scenario 1 by a percentage which varies from 2.4% (farm 2) to 398.3 % (farm 10) and there is a farm which starts to contract (farm 13). If we look at the share of grassland under contract this varies from 21.5% (farm 10) to more than 50% of farmland (farms 1, 3, 9, 11). Seven risk averse large farms are involved in the AES under this scenario and their commitment concerns from 26.2% (farm 10) to 65.7% (farm 1) of farmland. Two risk averse farmers do not adopt the grassland program.
The increase in crop price volatility results in a rise in the amount of grassland committed and in a new allocation of land among crops which differs among samples. Most small farms decrease sugar beet, barley and partially wheat production, while the production of the high profitable corn increases (Table A3.11). Medium and large farms reallocate most of their wheat and barley land to sugar beet and agri-environmental grassland. It may be argued that medium and large farms adopt the grassland program as a risk management tool in

combination with an increase in the share of land allocated to the lowest-risk crop, sugar beet. Small farms adopt the grassland program as a strategy to reduce income fluctuation, while they do not consider the option to increase the production of sugar beet.

3.7.2.5 Scenario 5: double price volatility with respect to the baseline volatility

Scenario 5 is characterized by a level of crop price volatility double compared to the baseline. The high crop price volatility stimulate the participation in the grassland program of most farmers and in some cases the uptake involves more than half of the farmland. Medium and large farms increase also the share of land allocated to the low-risk sugar beet crop as a strategy against price risk; sugar beet does not appear to be a choice for the small farms, who prefer to adopt the grassland program as the only risk prevention strategy.

Under this scenario all risk averse farmers of the small farm sample adopt the grassland program and the adoption involves more than 50% of farmland for seven farms and even more than 70% of farmland for four farms (Table 3.2). The rate of participation is equal in the medium farm sample, where all risk averse farmers involve their land in the grassland program and the share of land contracted is larger than 50% of farmland for five of them (Table 3.3). The large farm sample confirms the trend of an higher share of land committed than in the other scenarios (Table 3.4). The increase in the share of agri-environmental grassland in this scenario compared to scenario 1 seems is related to the level of risk aversion of the farmers.

The reallocation of farmland among crops in this scenario follows the same pattern as it is in scenario 4. Indeed, while most medium and large farms combine the adoption of the grassland program with an increase in the share allocated to the less-risky sugar beet, small farms rely on the conversion of a share of farmland to grassland as the sole risk management strategy (Table A3.12).

The increase in the share of land committed to agri-environmental grassland when the crop price volatility rises shows that the adoption of the AES acts as an insurance against farmer's income risk.

Table 3.2 Farmland allocated to AES (grassland program) under different scenarios in the small farm sample

	Scenario 1		Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Ha under AES	Land share under AES	Ha under AES	Land share under AES	% change ha under AES sc2/sc1	Ha under AES	Land share under AES	% change ha under AES sc3/sc1	Ha under AES	Land share under AES	% change ha under AES sc4/sc1	Ha under AES	Land share under AES	% change ha under AES sc5/sc1
1	1.24	24.78	0.00	0.00	-100.0	0.00	0.00	-100.0	2.70	53.97	117.76	3.39	67.80	173.61
2	5.53	36.85	3.76	25.04	-32.04	4.84	32.28	-12.39	7.05	47.03	27.63	6.64	44.25	20.08
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	6.02	n.f.*	1.37	18.23	n.f
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.35	29.99	0.00	0.00	-100.0	0.03	0.55	-98.15	2.85	63.32	111.19	3.58	79.58	165.46
6	4.81	28.31	4.81	28.31	0.00	4.81	28.31	0.00	4.81	28.31	0.00	4.81	28.31	0.00
7	3.17	35.24	0.00	0.00	-100.0	1.33	14.77	-58.10	5.66	62.88	78.40	6.66	73.94	109.80
8	1.12	9.32	1.12	9.32	0.00	1.12	9.32	0.00	1.12	9.32	0.00	1.12	9.32	0.00
9	3.90	45.93	0.00	0.00	-100.0	1.97	23.15	-49.59	6.13	72.15	57.10	7.14	83.94	82.76
10	7.16	39.80	7.16	39.80	0.00	7.16	39.80	0.00	7.16	39.80	0.00	7.16	39.80	0.00
11	2.42	40.37	0.00	0.00	-100.0	1.33	22.09	-45.29	3.94	65.61	62.55	4.80	80.07	98.35
12	4.71	33.62	0.71	5.09	-84.85	3.35	23.89	-28.94	6.91	49.33	46.72	7.37	52.65	56.58
13	2.97	37.12	0.00	0.00	-100.0	1.92	24.03	-35.29	4.76	59.54	60.37	5.81	72.57	95.49
14	6.23	32.81	6.23	32.81	0.00	6.23	32.81	0.00	6.23	32.81	0.00	6.23	32.81	0.00

*n.f. indicates a division by zero

Table 3.3 Farmland allocated to AES (grassland program) under different scenarios in the medium farm sample

	Scenario 1		Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Ha under AES	Land share under AES	Ha under AES	Land share under AES	% change ha under AES sc2/sc1	Ha under AES	Land share under AES	% change ha under AES sc3/sc1	Ha under AES	Land share under AES	% change ha under AES sc4/sc1	Ha under AES	Land share under AES	% change ha under AES sc5/sc1
1	12.02	30.05	0.00	0.00	-100.00	3.53	8.83	-70.63	21.19	52.97	76.27	25.99	64.97	116.18
2	31.38	35.66	30.77	34.96	-1.96	31.07	35.31	-0.99	32.14	36.53	2.43	33.19	37.71	5.76
3	10.76	33.11	0.00	0.00	-100.00	1.97	6.07	-81.66	18.11	55.72	68.31	21.91	67.41	103.62
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.13	n.f.*
6	31.04	42.81	0.20	0.27	-99.36	21.91	30.22	-29.41	34.80	48.00	12.12	37.88	52.25	22.04
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.16	27.12	n.f.
8	28.61	31.44	28.61	31.44	0.00	28.61	31.44	0.00	28.61	31.44	0.00	28.61	31.44	0.00
9	11.45	30.13	0.00	0.00	-100.00	2.13	5.61	-81.38	20.97	55.17	83.11	25.87	68.09	125.97
10	2.53	4.32	0.00	0.00	-100.00	0.00	0.00	-100.00	12.59	21.52	398.26	18.30	31.28	624.02
11	16.03	39.09	0.00	0.00	-100.00	7.43	18.12	-53.65	25.42	62.00	58.59	29.27	71.39	82.62
12	15.98	19.97	4.47	5.59	-72.03	11.48	14.35	-28.13	22.22	27.78	39.09	25.38	31.73	58.87
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.74	20.95	n.f.	16.26	34.98	n.f.
14	21.43	34.84	0.00	0.00	-100.00	15.54	25.26	-27.49	24.71	40.18	15.32	27.86	45.30	30.02

*n.f. indicates a division by zero

Table 3.4. Farmland allocated to AES (grassland program) under different scenarios in the large farm sample

	Scenario 1		Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Ha under AES	Land share under AES	Ha under AES	Land share under AES	% change ha under AES sc2/sc1	Ha under AES	Land share under AES	% change ha under AES sc3/sc1	Ha under AES	Land share under AES	% change ha under AES sc4/sc1	Ha under AES	Land share under AES	% change ha under AES sc5/sc1
1	52.83	44.03	0.00	0.00	-100.0	27.68	23.07	-47.60	78.86	65.72	49.27	91.86	76.55	73.87
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.66	0.54	n.f.*
3	58.48	27.78	24.32	11.55	-58.42	43.94	20.87	-24.86	85.62	40.67	46.40	108.06	51.34	84.78
4	113.91	29.98	113.91	29.98	0.00	113.91	29.98	0.00	113.91	29.98	0.00	113.91	29.98	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	83.79	23.24	83.79	23.24	0.00	83.79	23.24	0.00	83.79	23.24	0.00	83.79	23.24	0.00
7	72.57	29.03	16.77	6.71	-76.90	55.32	22.13	-23.76	104.24	41.69	43.64	130.10	52.04	79.29
8	106.49	26.62	106.49	26.62	0.00	106.49	26.62	0.00	106.49	26.62	0.00	106.49	26.62	0.00
9	50.26	32.32	0.00	0.00	-100.00	23.08	14.84	-54.09	83.35	53.60	65.83	102.12	65.67	103.17
10	74.19	23.04	66.99	20.80	-9.71	70.46	21.88	-5.04	84.39	26.21	13.74	96.72	30.04	30.36
11	31.85	13.55	0.00	0.00	-100.00	7.38	3.14	-76.81	76.34	32.49	139.72	109.90	46.77	245.11
12	163.20	39.81	146.32	35.69	-10.35	154.97	37.80	-5.04	182.84	44.60	12.03	205.31	50.08	25.81
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	70.11	20.00	70.11	20.00	0.00	70.11	20.00	0.00	70.11	20.00	0.00	70.11	20.00	0.00

*n.f. indicates a division by zero

3.8 Discussion and Conclusions

In this chapter we have developed a new methodological approach which accommodates risk in a PMP framework. Risk modelling and calibration of mathematical programming models are two relevant issues in the analysis of farmer's optimal behaviour. The literature is still rather scarce in this area and our proposal represents an innovative approach compared to previous studies. We merged the first and the second phase of the PMP by using both the primal and dual relationships of a farmer expected utility maximisation problem. The farmer's absolute risk aversion coefficient is estimated endogenously in the model together with the farm non-linear cost function, the shadow prices of resources and the shadow prices of activities. The simultaneous estimation prevents from the critiques raised against the standard PMP approach. By the KKT conditions we have shown that the model calibrates to the base year observed activity levels without making any calibration constraint explicit.

Our model differs from an earlier attempt of Paris and Arfini (2000) who applied an exogenous risk aversion coefficient and from the proposal of Petsakos and Rozakis (2011) whose model non linear term is represented by the risk component only. Our approach is an extension of the work by Severini and Cortignani (2011): while they skipped the first phase of the PMP and they estimated directly the optimality conditions of the desired model, we merged the first linear phase with the second non linear phase. In addition, the estimation carried out by Severini and Cortignani introduces the deviations in the output level, while our deviations concern the individual departure from the common cost function. Despite these innovations, our model still makes some strong assumptions. For example, we assume that farmers exhibit CARA risk preferences and that income volatility is due only to the price changes, while yields are kept constant over time. It would be interesting to further develop the model by assuming DARA preferences and by introducing variable crop yields over time. In the latter it would be challenging to separate the effects of yield variation and price variation on farmer's behaviour.

We have provided an empirical application of our model on three representative farm samples differing by farm size. We showed that the model calibrates to the base year observed activity levels for all farms. Moreover, the values of the estimated coefficients of farmers' risk aversion are consistent with the range provided in the literature. Our proposal presents some weaknesses in the estimation of the shadow prices of resource and the shadow prices of activities. The land shadow price cannot be identified for all farms and for some farms the shadow prices of activities are different from zero for all the activities. The divergence of these results with respect to the expected results of the standard PMP may be explained by the different procedure we applied to get the shadow prices. Despite this divergence, the calibration ability of the model is not threatened. An extension of our model would consist in modelling and calibrating activities whose base year level is equal to zero in some farms according to the proposal of Paris and Arfini (2000).

Finally, we have performed some simulations to test the model's ability to represent the farmers' responses to changes in economic conditions as well as to investigate the role of agri-environmental grassland as a farmer's strategy to cope with risk. The simulated scenarios have represented the introduction of an AES, the option to convert a share of farmland to grassland, under different levels of crop price volatility. The idea is that the AES may represent an income risk management tool for the farmer, since they guarantee a fixed payment independent of the market conditions and of the crop yields.

The simulation results confirm the potential role of the grassland program as an insurance against farmer's income risk. The introduction of the option to participate in a grassland program when crop price volatility is set at the level of the baseline shifts the farmland allocation from the less profitable crops, sugar beet and barley, and from the highest-risk crop, wheat, towards grassland. While the share of farmland involved in the AES does not change under different volatility scenarios for risk neutral farmers, this share rises for risk averse farmers and this increase depends on the level of farmers' risk aversion. When the crop price volatility is doubled compared to the baseline most of the risk averse farmers would convert more than one third of their land to grassland program and for some of them this share is higher than 50%. The increase in the share of farmland committed to agri-environmental grassland leads to a reallocation of land among the other crops. When the crop price volatility increases less than 50% of the baseline, farmers tend to substitute sugar beet, barley and partially wheat with the risk-free grassland, while land allocated to corn rises. When price volatility is set to twice the baseline volatility the reallocation of land among crops changes. Under this scenario the medium and large farms seem to combine a growth in grassland participation with an increase in the share of land allocated to the low-risk crop, sugar beet, while the small farms seem to adopt grassland program as the only production strategy to manage price risk.

Given the lack of data and the complexity in simulating other AESs, such as the option of conversion to organic farming, we performed our simulations considering only the grassland option. Despite this limitation, the simulated scenarios show the ability of our proposal to model the farmer's reaction to changes in economic conditions. In addition, the simulations show the role of grassland program as a farm strategy to cope with risk. When more detailed data are available, it would be interesting to check this role for other AESs, such as the option to convert to organic farming. .

APPENDIX A3.A

Table A3.1 Total Utilized Agricultural Area (UAA, ha) in each farm

	Small farm sample	Medium farm sample	Large farm sample
1	5.0	5.5	7.4
2	15.0	14.2	20.6
3	7.5	10.0	14.1
4	13.0	15.9	23.2
5	4.5	9.4	11.3
6	17.0	21.8	28.9
7	9.0	15.6	19.9
8	12.0	19.1	25.1
9	8.5	16.8	20.1
10	18.0	24.8	32.6
11	6.0	16.7	18.6
12	14.0	24.5	29.8
13	8.0	20.5	24.1
14	19.0	31.2	40.1

Table A3.2 Average variable costs for each crop (euro/100kg)

	Small farm sample				Medium farm sample				Large farm sample			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
1	2.0	9.7	9.2	6.7	1.3	9.4	6.9	6.6	2.0	9.0	5.0	6.1
2	1.8	11.1	18.0	10.2	1.6	7.6	9.2	6.7	1.5	7.5	11.0	6.1
3	2.0	8.9	9.2	6.7	1.8	9.0	8.2	6.6	1.9	9.7	9.4	6.1
4	1.9	9.1	8.7	10.2	2.0	8.7	8.3	6.7	2.1	9.6	8.3	6.1
5	2.4	8.0	10.7	6.7	1.3	8.6	6.0	7.6	1.7	11.1	4.4	5.2
6	3.4	7.8	6.1	8.0	2.1	8.1	10.1	9.0	2.0	8.8	6.4	6.1
7	2.1	7.3	4.8	6.8	1.7	6.7	7.9	4.9	1.4	6.1	5.3	4.2
8	0.8	7.9	6.9	8.6	2.7	5.2	4.4	6.8	2.7	5.2	4.4	6.8
9	2.1	7.3	4.8	6.8	2.2	8.3	7.6	4.9	1.6	2.9	5.3	4.2
10	2.5	11.8	9.5	8.6	1.4	6.6	5.3	4.4	1.4	6.6	5.3	4.4
11	2.1	8.9	12.7	11.3	1.8	9.1	14.2	7.4	1.7	7.8	6.0	5.2
12	2.1	8.1	9.1	8.2	1.9	7.7	11.1	6.7	2.5	10.3	7.7	6.1
13	2.4	9.0	4.3	14.3	2.6	6.8	3.6	7.6	1.7	11.1	4.4	5.2
14	3.4	9.8	10.2	8.1	2.1	9.6	11.8	9.0	2.0	8.8	6.4	6.1

Table A3.3 Average crop prices (euro/100 kg)

	Small farm sample				Medium farm sample				Large farm sample			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
1	4.0	21.9	23.0	20.3	4.0	22.1	23.9	21.7	4.0	21.4	20.6	20.0
2	4.2	22.3	20.2	21.0	4.1	23.2	21.0	20.2	4.8	24.4	24.4	23.2
3	3.9	22.4	23.0	20.3	3.9	22.5	24.2	21.7	3.8	22.2	18.9	20.0
4	3.7	22.5	22.8	21.0	3.9	22.4	20.9	20.2	3.2	24.4	22.1	23.2
5	4.1	22.3	23.3	18.7	4.0	19.9	18.5	20.8	3.8	19.8	19.2	20.0
6	4.7	21.4	20.9	20.4	4.2	22.9	23.0	17.9	4.4	23.2	21.4	23.2
7	4.0	20.8	19.0	19.0	4.1	23.7	19.7	23.4	3.5	22.2	20.4	20.0
8	4.8	22.5	18.5	19.8	4.1	23.9	19.7	21.0	4.1	23.9	19.7	21.0
9	4.0	20.8	19.0	19.0	3.7	24.0	22.1	23.4	4.0	22.6	20.4	20.0
10	3.6	22.3	23.1	19.8	3.3	21.9	20.0	21.7	3.3	21.9	20.0	21.7
11	4.0	22.3	24.2	18.9	4.0	23.4	23.1	20.8	3.8	21.6	19.8	20.0
12	4.2	23.0	23.4	19.5	4.1	21.8	21.3	20.2	5.3	22.0	22.0	23.2
13	4.1	21.2	19.7	20.0	4.4	18.8	19.8	20.8	3.8	19.8	19.2	20.0
14	4.7	21.8	21.4	18.1	4.2	19.1	23.4	17.9	4.4	23.2	21.4	23.2

APPENDIX A3.B

Table A3.4 Calibration check of the model

	Crop production baseline, 100 kg				w, 100 kg				Percentage change $\bar{x}$ / w			
	Sugar beet	C.Wheat	Corn	Barley	Sugar beet	C.Wheat	Corn	Barley	Sugar beet	C.Wheat	Corn	Barley
Small farm												
1	249.3	168.9	90.1	11.4	249.7	168.0	90.9	11.7	0.14	-0.50	0.86	2.23
2	1392.0	470.8	239.2	21.7	1391.2	470.6	239.0	21.9	-0.06	-0.03	-0.08	1.27
3	247.6	172.5	281.9	5.3	247.4	172.4	281.9	5.4	-0.07	-0.06	-0.01	2.35
4	610.7	303.8	517.5	8.7	610.8	303.8	517.5	8.7	0.02	-0.01	0.00	0.03
5	79.5	138.5	92.6	12.0	79.6	138.2	93.0	12.0	0.04	-0.17	0.37	-0.42
6	592.5	563.6	457.0	30.0	592.7	563.5	456.9	30.0	0.04	-0.02	-0.03	0.08
7	243.5	218.9	222.6	57.1	243.9	218.9	222.7	57.0	0.13	0.00	0.04	-0.13
8	562.7	371.3	339.7	61.1	563.0	371.5	339.6	61.0	0.05	0.05	-0.02	-0.17
9	379.7	248.9	129.4	43.9	380.1	248.9	129.5	43.8	0.10	0.00	0.09	-0.18
10	1814.8	555.2	343.6	62.9	1814.8	555.1	343.6	62.8	0.00	-0.02	-0.01	-0.11
11	161.3	222.4	96.6	12.6	161.7	223.1	97.7	10.9	0.24	0.30	1.13	-13.21
12	828.6	469.3	269.5	23.1	828.9	469.3	269.7	22.9	0.03	0.00	0.06	-0.65
13	298.8	261.3	198.3	40.2	299.1	261.7	198.8	39.4	0.12	0.16	0.21	-1.99
14	916.6	513.0	478.1	77.0	914.7	511.7	476.8	76.6	-0.21	-0.26	-0.28	-0.59
Medium farm												
1	5045.7	1318.5	846.0	37.3	5046.0	1318.3	846.3	37.3	0.01	-0.02	0.03	-0.05
2	11047.1	2273.7	1706.1	160.6	11047.1	2273.8	1706.1	160.6	0.00	0.00	0.00	-0.03
3	2192.3	687.4	1279.7	20.8	2192.5	686.9	1280.1	21.0	0.01	-0.07	0.03	0.95
4	4616.3	1420.7	2428.9	45.2	4616.2	1420.8	2428.8	45.2	0.00	0.00	0.00	0.04
5	2086.8	1357.5	1405.0	67.6	2086.7	1357.4	1405.0	67.7	-0.01	-0.01	0.00	0.09
6	4050.0	1996.5	2085.7	151.9	4050.1	1996.7	2085.7	151.7	0.00	0.01	0.00	-0.11
7	3664.5	1351.8	1096.3	152.6	3664.6	1351.9	1096.2	152.6	0.00	0.01	-0.01	-0.02
8	7979.7	2759.2	2815.5	223.1	7979.6	2759.2	2814.9	223.0	0.00	0.00	-0.02	-0.04
9	4903.2	1043.3	617.6	97.7	4902.5	1043.2	617.6	97.8	-0.01	-0.01	0.00	0.12
10	6310.9	1730.5	1407.5	152.6	6310.9	1730.5	1407.5	152.6	0.00	0.00	0.00	0.00
11	2269.0	1381.4	757.1	44.8	2268.0	1381.0	757.2	45.1	-0.05	-0.03	0.02	0.60
12	3643.2	2841.4	1715.4	209.3	3643.2	2841.4	1715.4	209.3	0.00	0.00	0.00	-0.01
13	2081.6	1242.2	1723.6	195.5	2081.8	1242.1	1723.8	195.5	0.01	-0.01	0.01	0.02
14	5482.5	1357.8	2151.3	144.3	5482.3	1357.7	2151.4	144.3	0.00	-0.01	0.01	0.01
Large farms												
1	11334.2	3054.0	3413.7	182.4	11337.3	3049.4	3417.2	184.4	0.03	-0.15	0.10	1.07
2	31037.8	8617.5	4784.5	598.0	31037.5	8616.7	4785.7	597.7	0.00	-0.01	0.03	-0.06
3	15479.8	4507.9	8819.8	76.9	15472.5	4508.6	8816.5	78.7	-0.05	0.02	-0.04	2.41
4	34883.5	8213.9	14933.3	511.3	34881.9	8214.4	14932.6	511.3	-0.01	0.01	-0.01	0.01
5	9591.1	4682.9	4789.3	282.4	9592.4	4677.1	4793.0	285.4	0.01	-0.12	0.08	1.04
6	9422.0	8011.3	12835.9	1525.8	9423.4	8011.7	12835.7	1525.5	0.01	0.01	0.00	-0.02
7	16007.3	6958.3	8994.7	669.7	16008.3	6958.8	8995.0	669.1	0.01	0.01	0.00	-0.10
8	35075.5	12128.6	12375.8	980.5	35074.5	12126.7	12371.2	977.6	0.00	-0.02	-0.04	-0.29
9	10505.4	3323.8	4980.2	636.7	10507.9	3324.1	4981.6	635.2	0.02	0.01	0.03	-0.24
10	34736.8	9525.2	7747.4	840.1	34735.6	9524.9	7747.2	840.5	0.00	0.00	0.00	0.05
11	12457.2	7651.7	5019.7	595.4	12458.6	7651.3	5020.7	595.0	0.01	-0.01	0.02	-0.06
12	32761.5	11001.7	7429.4	1779.7	32762.4	11000.7	7429.8	1780.5	0.00	-0.01	0.01	0.05
13	8771.0	3809.2	5646.1	762.1	8772.4	3805.0	5649.4	763.7	0.02	-0.11	0.06	0.21
14	14309.5	7686.9	13093.9	677.9	14310.5	7686.7	13093.7	678.2	0.01	0.00	0.00	0.05

Table A3.5 Estimates of the Q matrices of the cost functions (10-3)

	Small farm sample				Medium farm sample				Large farm sample			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Sugar beet	0.03	0. 15	0. 27	0. 05	0. 02	0. 07	0. 05	0. 07	0. 07	0. 10	0. 09	0. 11
C. wheat	0.15	2.0	2.0	2.0	0. 07	0. 36	0. 29	0. 33	0. 10	0. 94	0. 82	0. 52
Corn	0.27	2.0	2.0	1.0	0. 05	0. 29	0. 47	0. 23	0. 09	0. 82	0. 84	0. 92
Barley	0.05	2.0	1.0	3.0	0. 07	0. 33	0. 23	0. 32	0. 11	0.052	0. 92	2.0

Table A3.6 Shadow price of land (y), euro

	Small farm sample	Medium farm sample	Large farm sample
1	206.8	0.00	0.00
2	14.28	0.00	473.10
3	309.72	63.56	92.90
4	308.14	302.77	2.80
5	70.72	420.67	445.80
6	0.00	0.00	157.90
7	101.29	412.86	12.40
8	255.15	0.00	0.00
9	34.01	0.00	163.50
10	0.00	279.95	134.40
11	0.00	0.00	248.20
12	0.00	104.76	0.00
13	0.00	340.82	419.50
14	0.00	0.00	192.80

Table A3.7 Shadow price of activities (λ), euro

	Small farm sample				Medium farm sample				Large farm sample			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
1	2.1	0.0	4.3	1.5	3.3	0.0	6.2	3.2	2.6	0.0	5.0	2.2
2	2.5	8.6	0.0	8.4	2.4	14.7	11.0	12.5	2.3	7.4	4.7	7.3
3	1.7	2.4	5.6	2.3	2.6	0.0	4.7	2.2	2.0	6.6	4.9	8.1
4	1.2	7.6	10.6	3.6	1.4	7.8	9.2	7.1	1.1	14.7	13.7	17.0
5	2.3	1.7	2.3	0.0	1.9	2.6	7.2	2.5	1.2	0.0	8.2	6.3
6	1.3	13.6	14.8	12.4	2.4	9.5	8.5	4.0	2.1	11.5	12.9	14.1
7	2.2	3.4	6.4	2.2	1.9	5.6	2.8	4.9	2.4	10.2	10.2	10.4
8	3.6	10.4	8.9	5.5	1.4	18.7	15.2	14.2	1.4	18.7	15.2	14.2
9	2.5	2.2	5.1	1.6	1.9	1.5	2.3	5.1	2.6	6.1	4.53	3.2
10	1.1	10.5	13.7	11.1	1.6	8.7	9.8	9.4	1.7	12.4	12.6	13.9
11	2.4	5.1	4.8	0.0	2.8	3.6	0.1	3.6	1.9	4.7	7.1	5.9
12	2.4	9.2	9.5	6.0	2.1	10.7	7.5	9.7	2.9	9.4	12.4	15.0
13	2.1	6.0	10.2	0.0	1.4	3.4	10.8	3.0	1.3	0.0	8.2	6.4
14	1.3	12.0	11.2	10.0	2.3	5.4	8.0	5.0	2.0	10.8	12.5	13.5

Table A3.8 Land allocation (ha) among crops in the baseline and in scenario 1

	Baseline				Scenario 1				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample												
1	0.48	3.15	1.13	0.25	0.00	2.11	1.65	0.00	-100.00	-33.01	46.71	-100.00
2	2.80	8.63	3.06	0.51	0.00	3.66	5.81	0.00	-100.00	-57.55	90.02	-100.00
3	0.48	3.39	3.52	0.11	0.48	3.39	3.52	0.11	0.00	0.00	0.00	0.00
4	1.12	5.71	5.96	0.21	1.12	5.71	5.96	0.21	0.00	0.00	0.00	0.00
5	0.13	2.61	1.48	0.28	0.00	1.95	1.20	0.00	-100.00	-25.13	-19.10	-100.00
6	1.19	9.91	5.26	0.64	0.00	5.63	6.56	0.00	-100.00	-43.22	24.65	-100.00
7	0.45	4.61	2.50	1.44	0.00	2.43	3.40	0.00	-100.00	-47.31	35.78	-100.00
8	0.87	6.07	3.70	1.36	0.00	6.68	4.20	0.00	-100.00	10.01	13.57	-100.00
9	0.70	5.24	1.46	1.11	0.00	1.67	2.92	0.00	-100.00	-68.10	100.96	-100.00
10	3.18	10.27	3.15	1.40	0.00	0.00	7.31	3.53	-100.00	-100.00	131.64	151.96
11	0.30	4.07	1.31	0.32	0.00	1.91	1.67	0.00	-100.00	-53.15	27.19	-100.00
12	1.50	8.69	3.27	0.54	0.00	4.15	5.15	0.00	-100.00	-52.28	57.21	-100.00
13	0.50	4.37	2.25	0.89	0.00	2.18	2.85	0.00	-100.00	-50.06	26.78	-100.00
14	1.84	10.06	5.47	1.64	0.00		8.65	4.12	-100.00	-100.00	58.28	151.44
Medium farm sample												
1	8.72	22.39	8.06	0.84	5.80	10.24	11.94	0.00	-33.41	-54.25	48.13	-100.00
2	21.12	42.13	21.39	3.37	34.16	0.00	22.46	0.00	61.75	-100.00	5.03	-100.00
3	4.01	13.09	14.93	0.47	1.44	0.00	18.20	0.00	-64.03	-83.94	21.89	-100.00
4	9.03	27.75	27.77	0.95	9.03	27.75	27.77	0.95	0.00	0.00	0.00	0.00
5	4.35	24.01	14.09	1.55	4.35	24.01	14.09	1.55	0.00	0.00	0.00	0.00
6	7.33	40.44	21.16	3.57	11.44	1.09	28.94	0.00	56.12	-97.32	36.76	-100.00
7	6.40	23.63	14.85	3.62	6.40	23.63	14.85	0.00	0.00	0.00	0.00	0.00
8	13.91	42.64	30.32	4.14	32.87	0.00	29.53	0.00	136.33	-100.00	-2.60	-100.00

Continued

Table A3.8 Continued

	Baseline				Scenario 1				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
9	8.18	19.74	7.77	2.32	5.37	0.00	10.85	0.00	-34.30	-47.67	39.67	-100.00
10	9.98	28.55	16.71	3.27	10.55	28.74	16.69	0.00	5.69	0.69	-0.14	-100.00
11	4.09	27.18	8.78	0.94	1.38	9.90	13.69	0.00	-66.32	-63.58	55.90	-100.00
12	8.57	46.29	20.75	4.39	15.65	25.93	22.45	0.00	82.56	-44.00	8.22	-100.00
13	3.77	22.23	16.02	4.48	3.77	22.23	16.02	4.48	0.00	0.00	0.00	0.00
14	9.92	24.37	23.82	3.39	12.09		27.98	0.00	21.92	-100.00	17.46	-100.00
Large farm sample												
1	21.80	59.04	35.50	3.66	8.73	0.00	58.44	0.00	-59.94	-100.00	64.61	-100.00
2	61.63	157.30	79.74	11.33	61.63	157.30	79.74	11.33	0.00	0.00	0.00	0.00
3	29.10	82.46	97.40	1.54	23.30	0.00	128.72	0.00	-19.92	-100.00	32.16	-100.00
4	56.46	156.02	157.84	9.69	56.17	0.00	209.92	0.00	-0.50	-100.00	33.00	-100.00
5	19.68	91.51	70.42	5.39	19.68	91.51	70.42	5.39	0.00	0.00	0.00	0.00
6	17.07	150.33	164.19	28.92	19.40	0.00	257.31	0.00	13.65	-100.00	56.71	-100.00
7	35.57	106.32	95.91	12.19	23.10	0.00	154.34	0.00	-35.08	-100.00	60.91	-100.00
8	61.13	187.42	133.26	18.19	61.83	0.00	231.69	0.00	1.14	-100.00	73.87	-100.00
9	23.47	67.33	53.11	11.59	14.84	0.00	90.39	0.00	-36.76	-100.00	70.22	-100.00
10	54.92	157.12	91.97	17.99	56.56	14.98	176.26	0.00	2.99	-90.47	91.66	-100.00
11	25.56	140.46	57.61	11.37	24.06	82.29	96.81	0.00	-5.89	-41.42	68.03	-100.00
12	61.31	232.41	82.55	33.73	57.89	0.00	0.00	0.00	-5.58	-100.00	128.85	-100.00
13	18.00	74.44	83.02	14.55	18.00	74.44	83.02	14.55	0.00	0.00	0.00	0.00
14	25.93	144.24	167.49	12.85	28.18	2.37	249.84	0.00	8.71	-98.36	49.17	-100.00

Table A3.9 Land allocation (ha) among crops in the baseline and in scenario 2

	Baseline				Scenario 2				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample												
1	0.48	3.15	1.13	0.25	0.00	2.10	2.90	0.00	-100.00	-33.32	157.64	-100.00
2	2.80	8.63	3.06	0.51	0.00	5.19	6.05	0.00	-100.00	-39.84	97.97	-100.00
3	0.48	3.39	3.52	0.11	0.00	2.42	5.08	0.00	-100.00	-28.58	44.18	-100.00
4	1.12	5.71	5.96	0.21	1.12	5.71	5.96	0.21	0.00	0.00	0.00	0.00
5	0.13	2.61	1.48	0.28	0.00	3.51	0.99	0.00	-100.00	34.57	-33.00	-100.00
6	1.19	9.91	5.26	0.64	0.00	5.63	6.56	0.00	-100.00	-43.22	24.65	-100.00
7	0.45	4.61	2.50	1.44	0.00	4.36	4.64	0.00	-100.00	-5.36	85.26	-100.00
8	0.87	6.07	3.70	1.36	0.00	6.68	4.20	0.00	-100.00	10.01	13.57	-100.00
9	0.70	5.24	1.46	1.11	0.00	3.98	4.52	0.00	-100.00	-24.08	210.72	-100.00
10	3.18	10.27	3.15	1.40	0.00	0.00	7.31	3.53	-100.00	-100.00	131.64	151.96
11	0.30	4.07	1.31	0.32	0.00	3.77	2.23	0.00	-100.00	-7.41	69.76	-100.00
12	1.50	8.69	3.27	0.54	0.00	7.64	5.64	0.00	-100.00	-12.02	72.36	-100.00
13	0.50	4.37	2.25	0.89	0.00	4.67	3.33	0.00	-100.00	6.94	48.22	-100.00
14	1.84	10.06	5.47	1.64	0.00	0.00	8.65	4.12	-100.00	-100.00	58.28	151.44
Medium farm sample												
1	8.72	22.39	8.06	0.84	0.00	18.11	21.89	0.00	-100.00	-19.12	171.72	-100.00
2	21.12	42.13	21.39	3.37	35.17	0.00	22.06	0.00	66.55	-100.00	3.16	-100.00
3	4.01	13.09	14.93	0.47	0.00	3.56	28.95	0.00	-100.00	-72.85	93.90	-100.00
4	9.03	27.75	27.77	0.95	9.03	27.75	27.77	0.95	0.00	0.00	0.00	0.00
5	4.35	24.01	14.09	1.55	0.00	28.88	15.12	0.00	-100.00	20.29	7.33	-100.00
6	7.33	40.44	21.16	3.57	0.00	44.01	28.30	0.00	-100.00	8.81	33.72	-100.00
7	6.40	23.63	14.85	3.62	0.00	33.92	14.58	0.00	-100.00	43.57	-1.83	-100.00
8	13.91	42.64	30.32	4.14	32.87	0.00	29.53	0.00	136.33	-100.00	-2.60	-100.00

Continued

Table A3.9 Continued

	Baseline				Scenario 2				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
9	8.18	19.74	7.77	2.32	0.00	16.58	21.42	0.00	-100.00	-15.99	175.78	-100.00
10	9.98	28.55	16.71	3.27	0.18	42.09	16.23	0.00	-98.19	47.46	-2.87	-100.00
11	4.09	27.18	8.78	0.94	0.00	20.69	20.31	0.00	-100.00	-23.90	131.26	-100.00
12	8.57	46.29	20.75	4.39	0.00	55.47	20.06	0.00	-100.00	19.83	-3.32	-100.00
13	3.77	22.23	16.02	4.48	0.00	27.85	18.65	0.00	-100.00	25.27	16.44	-100.00
14	9.92	24.37	23.82	3.39	0.00	33.77	27.73	0.00	-100.00	38.57	16.41	-100.00
Large farm sample												
1	21.80	59.04	35.50	3.66	0.00	0.00	120.00	0.00	-100.00	-100.00	238.02	-100.00
2	61.63	157.30	79.74	11.33	55.19	223.24	0.00	31.58	-10.46	41.92	-100.00	178.65
3	29.10	82.46	97.40	1.54	10.15	0.00	176.03	0.00	-65.11	-100.00	80.74	-100.00
4	56.46	156.02	157.84	9.69	56.17	0.00	209.92	0.00	-0.50	-100.00	33.00	-100.00
5	19.68	91.51	70.42	5.39	19.68	91.51	70.42	5.39	0.00	0.00	0.00	0.00
6	17.07	150.33	164.19	28.92	19.40	0.00	257.31	0.00	13.65	-100.00	56.71	-100.00
7	35.57	106.32	95.91	12.19	0.00	54.55	178.69	0.00	-100.00	-48.70	86.30	-100.00
8	61.13	187.42	133.26	18.19	61.83	0.00	231.69	0.00	1.14	-100.00	73.87	-100.00
9	23.47	67.33	53.11	11.59	0.00	0.00	155.50	0.00	-100.00	-100.00	192.82	-100.00
10	54.92	157.12	91.97	17.99	55.17	21.50	178.34	0.00	0.46	-86.32	93.92	-100.00
11	25.56	140.46	57.61	11.37	1.92	102.23	130.84	0.00	-92.47	-27.22	127.10	-100.00
12	61.31	232.41	82.55	33.73	52.26	0.00	211.42	0.00	-14.76	-100.00	156.12	-100.00
13	18.00	74.44	83.02	14.55	15.59	67.76	94.66	11.99	-13.39	-8.97	14.02	-17.58
14	25.93	144.24	167.49	12.85	28.18	2.37	249.84	0.00	8.71	-98.36	49.17	-100.00

Table A3.10 Land allocation (ha) among crops in the baseline and in scenario 3

	Baseline				Scenario 3				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample												
1	0.48	3.15	1.13	0.25	0.00	0.00	2.91	2.10	-100.00	-100.00	157.99	751.63
2	2.80	8.63	3.06	0.51	0.00	4.18	5.98	0.00	-100.00	-51.58	95.58	-100.00
3	0.48	3.39	3.52	0.11	0.00	0.00	5.25	2.25	-100.00	-100.00	48.92	1892.92
4	1.12	5.71	5.96	0.21	1.12	5.71	5.96	0.21	0.00	0.00	0.00	0.00
5	0.13	2.61	1.48	0.28	0.00	2.64	1.83	0.00	-100.00	1.46	23.55	-100.00
6	1.19	9.91	5.26	0.64	0.00	5.63	6.56	0.00	-100.00	-43.22	24.65	-100.00
7	0.45	4.61	2.50	1.44	0.00	0.00	4.63	3.04	-100.00	-100.00	84.94	110.82
8	0.87	6.07	3.70	1.36	0.00	6.68	4.20	0.00	-100.00	10.01	13.57	-100.00
9	0.70	5.24	1.46	1.11	0.00	0.00	4.07	2.47	-100.00	-100.00	179.52	122.27
10	3.18	10.27	3.15	1.40	0.00	0.00	7.31	3.53	-100.00	-100.00	131.64	151.96
11	0.30	4.07	1.31	0.32	0.00	2.61	2.07	0.00	-100.00	-36.02	57.50	-100.00
12	1.50	8.69	3.27	0.54	0.00	5.16	5.50	0.00	-100.00	-40.67	67.99	-100.00
13	0.50	4.37	2.25	0.89	0.00	2.92	3.16	0.00	-100.00	-33.10	40.48	-100.00
14	1.84	10.06	5.47	1.64	0.00	0.00	8.65	4.12	-100.00	-100.00	58.28	151.44
Medium farm sample												
1	8.72	22.39	8.06	0.84	4.34	17.67	14.47	0.00	-50.24	-21.09	79.55	-100.00
2	21.12	42.13	21.39	3.37	33.88		23.05	0.00	60.46	-100.00	7.76	-100.00
3	4.01	13.09	14.93	0.47	0.03	9.20	21.31	0.00	-99.37	-29.76	42.73	-100.00
4	9.03	27.75	27.77	0.95	9.03	27.75	27.77	0.95	0.00	0.00	0.00	0.00
5	4.35	24.01	14.09	1.55	1.26	28.24	14.50	0.00	-71.05	17.64	2.91	-100.00
6	7.33	40.44	21.16	3.57	6.80	14.58	29.21	0.00	-7.16	-63.96	38.06	-100.00
7	6.40	23.63	14.85	3.62	2.90	30.36	15.24	0.00	-54.68	28.48	2.65	-100.00
8	13.91	42.64	30.32	4.14	32.87		29.53	0.00	136.33	-100.00	-2.60	-100.00

Continued

Table A3.10 Continued

	Baseline				Scenario 3				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
9	8.18	19.74	7.77	2.32	4.90	16.58	14.39	0.00	-40.11	-16.01	85.32	-100.00
10	9.98	28.55	16.71	3.27	7.43	34.27	16.80	0.00	-25.54	20.07	0.54	-100.00
11	4.09	27.18	8.78	0.94	0.00	17.80	15.77	0.00	-100.00	-34.53	79.57	-100.00
12	8.57	46.29	20.75	4.39	7.52	39.53	21.46	0.00	-12.24	-14.60	3.44	-100.00
13	3.77	22.23	16.02	4.48	0.23	29.24	17.04	0.00	-94.03	31.50	6.38	-100.00
14	9.92	24.37	23.82	3.39	8.44	8.91	28.61	0.00	-14.88	-63.45	20.12	-100.00
Large farm sample												
1	21.80	59.04	35.50	3.66	7.82	0.00	84.50	0.00	-64.13	-100.00	138.02	-100.00
2	61.63	157.30	79.74	11.33	59.21	184.68	45.87	20.25	-3.93	17.41	-42.48	78.67
3	29.10	82.46	97.40	1.54	19.96	0.00	146.61	0.00	-31.43	-100.00	50.52	-100.00
4	56.46	156.02	157.84	9.69	56.17	0.00	209.92	0.00	-0.50	-100.00	33.00	-100.00
5	19.68	91.51	70.42	5.39	19.68	91.51	70.42	5.39	0.00	0.00	0.00	0.00
6	17.07	150.33	164.19	28.92	19.40	0.00	257.31	0.00	13.65	-100.00	56.71	-100.00
7	35.57	106.32	95.91	12.19	17.99	0.00	176.69	0.00	-49.44	-100.00	84.22	-100.00
8	61.13	187.42	133.26	18.19	61.83	0.00	231.69	0.00	1.14	-100.00	73.87	-100.00
9	23.47	67.33	53.11	11.59	11.21	0.00	121.22	0.00	-52.25	-100.00	128.26	-100.00
10	54.92	157.12	91.97	17.99	55.91	18.45	177.19	0.00	1.79	-88.26	92.67	-100.00
11	25.56	140.46	57.61	11.37	19.67	101.78	106.17	0.00	-23.05	-27.54	84.27	-100.00
12	61.31	232.41	82.55	33.73	55.70	0.00	199.33	0.00	-9.15	-100.00	141.47	-100.00
13	18.00	74.44	83.02	14.55	17.26	69.11	90.69	12.93	-4.08	-7.15	9.25	-11.13
14	25.93	144.24	167.49	12.85	28.18	2.37	249.84	0.00	8.71	-98.36	49.17	-100.00

Table A3.11 Land allocation (ha) among crops in the baseline and in scenario 4

	Baseline				Scenario 4				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample												
1	0.48	3.15	1.13	0.25	0.17	1.23	0.90	0.00	-63.75	-60.83	-20.52	-100.00
2	2.80	8.63	3.06	0.51	0.17	2.52	5.26	0.00	-94.11	-70.78	72.03	-100.00
3	0.48	3.39	3.52	0.11	2.02	3.55	1.48	0.00	325.21	4.78	-58.12	-100.00
4	1.12	5.71	5.96	0.21	1.12	5.71	5.96	0.21	0.00	0.00	0.00	0.00
5	0.13	2.61	1.48	0.28	0.00	1.10	0.56	0.00	-100.00	-57.98	-62.48	-100.00
6	1.19	9.91	5.26	0.64	0.00	5.63	6.56	0.00	-100.00	-43.22	24.65	-100.00
7	0.45	4.61	2.50	1.44	0.00	0.65	2.69	0.00	-100.00	-85.85	7.35	-100.00
8	0.87	6.07	3.70	1.36	0.00	6.68	4.20	0.00	-100.00	10.01	13.57	-100.00
9	0.70	5.24	1.46	1.11	0.00	0.22	2.15	0.00	-100.00	-95.90	47.90	-100.00
10	3.18	10.27	3.15	1.40	0.00	0.00	7.31	3.53	-100.00	-100.00	131.64	151.96
11	0.30	4.07	1.31	0.32	0.00	0.93	1.13	0.00	-100.00	-77.09	-13.94	-100.00
12	1.50	8.69	3.27	0.54	0.48	2.60	4.01	0.00	-68.24	-70.04	22.60	-100.00
13	0.50	4.37	2.25	0.89	0.00	0.92	2.31	0.00	-100.00	-78.83	2.89	-100.00
14	1.84	10.06	5.47	1.64	0.00	0.00	8.65	4.12	-100.00	-100.00	58.28	151.44
Medium farm sample												
1	8.72	22.39	8.06	0.84	7.33	2.81	8.67	0.00	-15.91	-87.45	7.64	-100.00
2	21.12	42.13	21.39	3.37	34.67	0.00	21.19	0.00	64.18	-100.00	-0.94	-100.00
3	4.01	13.09	14.93	0.47	3.22	0.00	11.17	0.00	-19.66	-100.00	-25.18	-100.00
4	9.03	27.75	27.77	0.95	9.03	27.75	27.77	0.95	0.00	0.00	0.00	0.00
5	4.35	24.01	14.09	1.55	11.56	0.00	14.63	17.81	165.57	-100.00	3.87	1048.47
6	7.33	40.44	21.16	3.57	15.10	0.00	22.61	0.00	106.02	-100.00	6.84	-100.00
7	6.40	23.63	14.85	3.62	12.30	0.00	14.08	22.13	92.08	-100.00	-5.18	510.85
8	13.91	42.64	30.32	4.14	32.87	0.00	29.53	0.00	136.33	-100.00	-2.60	-100.00

Continued

Table A3.11 Continued

	Baseline				Scenario 4				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
9	8.18	19.74	7.77	2.32	5.77	4.39	6.87	0.00	-29.45	-77.74	-11.53	-100.00
10	9.98	28.55	16.71	3.27	17.20	11.46	17.25	0.00	72.37	-59.87	3.27	-100.00
11	4.09	27.18	8.78	0.94	3.74	1.06	10.79	0.00	-8.59	-96.11	22.79	-100.00
12	8.57	46.29	20.75	4.39	26.76	7.36	23.66	0.00	212.23	-84.11	14.05	-100.00
13	3.77	22.23	16.02	4.48	11.57	10.06	15.13	0.00	207.09	-54.76	-5.55	-100.00
14	9.92	24.37	23.82	3.39	15.01	0.00	21.78	0.00	51.33	-100.00	-8.57	-100.00
Large farm sample												
1	21.80	59.04	35.50	3.66	10.27	0.00	30.87	0.00	-52.89	-100.00	-13.03	-100.00
2	61.63	157.30	79.74	11.33	67.54	118.18	124.29	0.00	9.58	-24.87	55.86	-100.00
3	29.10	82.46	97.40	1.54	30.02	0.00	94.86	0.00	3.17	-100.00	-2.61	-100.00
4	56.46	156.02	157.84	9.69	56.17	0.00	209.92	0.00	-0.50	-100.00	33.00	-100.00
5	19.68	91.51	70.42	5.39	19.68	91.51	70.42	5.39	0.00	0.00	0.00	0.00
6	17.07	150.33	164.19	28.92	19.40	0.00	257.31	0.00	13.65	-100.00	56.71	-100.00
7	35.57	106.32	95.91	12.19	33.37	0.00	112.39	0.00	-6.18	-100.00	17.18	-100.00
8	61.13	187.42	133.26	18.19	61.83	0.00	231.69	0.00	1.14	-100.00	73.87	-100.00
9	23.47	67.33	53.11	11.59	20.07	0.00	52.08	0.00	-14.50	-100.00	-1.93	-100.00
10	54.92	157.12	91.97	17.99	58.43	5.51	173.66	0.00	6.39	-96.49	88.83	-100.00
11	25.56	140.46	57.61	11.37	32.76	47.21	78.69	0.00	28.18	-66.39	36.58	-100.00
12	61.31	232.41	82.55	33.73	63.43	0.00	163.74	0.00	3.45	-100.00	98.35	-100.00
13	18.00	74.44	83.02	14.55	20.35	87.97	62.78	18.89	13.10	18.18	-24.38	29.88
14	25.93	144.24	167.49	12.85	28.18	2.37	249.84	0.00	8.71	-98.36	49.17	-100.00

Table A3.12 Land allocation (ha) among crops in the baseline and in scenario 5

	Baseline				Scenario 5				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample												
1	0.48	3.15	1.13	0.25	0.32	0.83	0.46	0.00	-33.75	-73.67	-58.88	-100.00
2	2.80	8.63	3.06	0.51	2.56	3.03	2.78	0.00	-8.68	-64.91	-9.19	-100.00
3	0.48	3.39	3.52	0.11	2.51	2.94	0.68	0.00	427.94	-13.17	-80.73	-100.00
4	1.12	5.71	5.96	0.21	1.12	5.71	5.96	0.21	0.00	0.00	0.00	0.00
5	0.13	2.61	1.48	0.28	0.00	0.65	0.27	0.00	-100.00	-75.13	-81.65	-100.00
6	1.19	9.91	5.26	0.64	0.00	5.63	6.56	0.00	-100.00	-43.22	24.65	-100.00
7	0.45	4.61	2.50	1.44	0.36	0.11	1.87	0.00	-19.33	-97.53	-25.24	-100.00
8	0.87	6.07	3.70	1.36	0.00	6.68	4.20	0.00	-100.00	10.01	13.57	-100.00
9	0.70	5.24	1.46	1.11	0.00	0.00	1.37	0.00	-100.00	-100.00	-6.19	-100.00
10	3.18	10.27	3.15	1.40	0.00	0.00	7.31	3.53	-100.00	-100.00	131.64	151.96
11	0.30	4.07	1.31	0.32	0.00	0.41	0.79	0.00	-100.00	-89.93	-40.21	-100.00
12	1.50	8.69	3.27	0.54	1.91	2.52	2.19	0.00	27.23	-70.95	-32.99	-100.00
13	0.50	4.37	2.25	0.89	0.17	0.30	1.73	0.00	-65.26	-93.22	-23.27	-100.00
14	1.84	10.06	5.47	1.64	0.00	0.00	8.65	4.12	-100.00	-100.00	58.28	151.44
Medium farm sample												
1	8.72	22.39	8.06	0.84	7.34	0.36	6.32	0.00	-15.84	-98.39	-21.60	-100.00
2	21.12	42.13	21.39	3.37	35.17	0.00	19.64	0.00	66.56	-100.00	-8.16	-100.00
3	4.01	13.09	14.93	0.47	3.76	0.00	6.84	0.00	-6.35	-100.00	-54.21	-100.00
4	9.03	27.75	27.77	0.95	9.03	27.75	27.77	0.95	0.00	0.00	0.00	0.00
5	4.35	24.01	14.09	1.55	16.28	0.00	12.33	14.89	274.07	-100.00	-12.50	860.54
6	7.33	40.44	21.16	3.57	17.48	0.00	17.15	0.00	138.51	-100.00	-18.97	-100.00
7	6.40	23.63	14.85	3.62	15.38	5.52	12.16	2.29	140.22	-76.66	-18.09	-36.80
8	13.91	42.64	30.32	4.14	32.87	0.00	29.53	0.00	136.33	-100.00	-2.60	-100.00

Continued

Table A3.12 Continued

	Baseline				Scenario 5				% change			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
9	8.18	19.74	7.77	2.32	5.36	2.27	4.50	0.00	-34.49	-88.51	-42.03	-100.00
10	9.98	28.55	16.71	3.27	20.37	2.86	16.98	0.00	104.12	-90.00	1.63	-100.00
11	4.09	27.18	8.78	0.94	4.49	0.00	7.24	0.00	9.77	-100.00	-17.56	-100.00
12	8.57	46.29	20.75	4.39	31.65	0.00	22.97	0.00	269.25	-100.00	10.71	-100.00
13	3.77	22.23	16.02	4.48	15.67	0.00	14.57	0.00	315.83	-100.00	-9.04	-100.00
14	9.92	24.37	23.82	3.39	16.99	0.00	16.66	0.00	71.25	-100.00	-30.08	-100.00
Large farm sample												
1	21.80	59.04	35.50	3.66	10.27	0.00	17.87	0.00	-52.87	-100.00	-49.66	-100.00
2	61.63	157.30	79.74	11.33	74.97	104.12	129.25	0.00	21.65	-33.81	62.09	-100.00
3	29.10	82.46	97.40	1.54	34.97	0.00	67.47	0.00	20.16	-100.00	-30.73	-100.00
4	56.46	156.02	157.84	9.69	56.17	0.00	209.92	0.00	-0.50	-100.00	33.00	-100.00
5	19.68	91.51	70.42	5.39	19.68	91.51	70.42	5.39	0.00	0.00	0.00	0.00
6	17.07	150.33	164.19	28.92	19.40	0.00	257.31	0.00	13.65	-100.00	56.71	-100.00
7	35.57	106.32	95.91	12.19	40.96	0.00	78.94	0.00	15.16	-100.00	-17.70	-100.00
8	61.13	187.42	133.26	18.19	61.83	0.00	231.69	0.00	1.14	-100.00	73.87	-100.00
9	23.47	67.33	53.11	11.59	21.74	0.00	31.64	0.00	-7.36	-100.00	-40.43	-100.00
10	54.92	157.12	91.97	17.99	60.92	0.00	164.36	0.00	10.93	-100.00	78.71	-100.00
11	25.56	140.46	57.61	11.37	39.03	25.66	60.41	0.00	52.69	-81.73	4.85	-100.00
12	61.31	232.41	82.55	33.73	69.49	0.00	135.19	0.00	13.35	-100.00	63.77	-100.00
13	18.00	74.44	83.02	14.55	24.12	105.26	36.11	24.52	34.03	41.40	-56.50	68.52
14	25.93	144.24	167.49	12.85	28.18	2.37	249.84	0.00	8.71	-98.36	49.17	-100.00

APPENDIX A3.C MAXIMUM ENTROPY RESULTS

In this Appendix we analyse the results of the model estimated by GME and the corresponding simulation scenarios. The model estimated by GME calibrates to the baseline activity levels as the deviation of the unknown output quantities, $\mathbf{x}$, from the observed quantity, $\bar{\mathbf{x}}$, is small (Table A3.13). The estimates of the shadow price of land (Table A3.15) differs from the one estimated by LS, as GME estimation is able to reveal a positive shadow price for all farms. The estimates of the shadow prices of activities are different from zero for all activities (Table A3.16). The GME estimation results in positive absolute risk aversion coefficients for all farmers in the samples and the relative coefficients are consistent with the range of 0-7.5 provided in the literature (Table A3.17). If we compare the absolute risk aversion coefficients of the farmers belonging to different samples, the coefficients of the large farms are smaller than the coefficients of the small farms and the coefficients of most medium farms. This path was also shown by LS estimation. The analysis of the relative risk aversion coefficients reveals that the large farms have a coefficients larger than all the small farms but one.

The model estimated by GME reacts stronger than the model estimated by LS to the changes in crop price volatility and to the introduction of the grassland program. In scenario 1 all the farms participate in the grassland program with a share of their land varying between 36.7% and 99.03% for small farms, from 31.3% to 64.7% for medium farms and from 28.5% to 58.3% for large farms (Tables A3.18, A3.19 and A3.20). The conversion of a share of farmland to grassland concerns mainly sugar beet and barley, which exit the production plans of most of the farms (Table A3.21). When the risk term is set equal to zero (scenario 2) only five small farms adopt the AES and they decrease the production of all the other crops. The non-participants re-organise their crop mix such that the production of sugar beet and barley disappears for most of them while corn production rises (A3.22). If crop price volatility is set higher than the baseline volatility (scenarios 4 and 5) the grassland program involves more than 68% of farmland in scenario 4 and more than 83% of farmland in scenario 5. When the volatility doubles compared to the baseline (scenario 5) most of the farms increase land allocation to agri-environmental grassland by more than 50% compared to the hectares committed in scenario 1 and in some of them this increase is larger than 100%. Land allocation to the other crops decreases substantially (Table A3.25). Although the simulated scenarios shows a stronger reaction compared to the responses simulated in the model estimated by LS estimation framework, the estimation by GME confirms the role of the grassland program as potential income risk management tool, since farms increase the share of land committed as a response to an increase in crop price volatility. In addition, sugar beet and barley are the crops most negatively affected by the introduction of the grassland program.

Table A3.13 Calibration check of the model

	Crop production baseline (x), 100kg				w, 100 kg				Percentage change $\bar{x}$ / w			
	Sugar beet	C.Wheat	Corn	Barley	Sugar beet	C.Wheat	Corn	Barley	Sugar beet	C.Wheat	Corn	Barley
Small farm sample												
1	249.3	168.9	90.1	11.4	247.3	169.6	92.2	12.0	-0.80	0.43	2.28	5.39
2	1391.9	470.8	239.2	21.7	1390.3	472.3	221.9	22.7	-0.12	0.32	-7.23	4.78
3	247.5	172.5	281.9	5.3	245.6	173.2	283.3	5.7	-0.81	0.39	0.50	7.76
4	610.7	303.8	517.5	8.7	608.6	304.2	518.6	8.0	-0.34	0.13	0.20	-7.31
5	79.5	138.5	92.6	12.0	77.3	139.7	94.3	12.1	-2.86	0.87	1.75	0.81
6	592.5	563.6	456.9	30.0	589.9	563.6	457.7	29.6	-0.43	0.01	0.16	-1.33
7	243.5	218.9	222.6	57.1	241.5	219.3	223.6	56.9	-0.82	0.21	0.45	-0.41
8	562.7	371.3	339.6	61.1	561.8	372.1	340.0	60.5	-0.16	0.22	0.09	-0.88
9	379.7	248.9	129.4	43.9	377.6	249.5	130.5	43.8	-0.54	0.21	0.85	-0.31
10	1814.8	555.2	343.6	62.9	1811.5	554.9	344.9	62.3	-0.18	-0.06	0.39	-0.94
11	161.3	222.4	96.6	12.6	159.3	223.4	99.8	10.4	-1.26	0.47	3.30	-17.90
12	828.6	469.3	269.5	23.1	826.9	469.9	270.8	22.4	-0.21	0.13	0.46	-3.00
13	298.8	261.3	198.3	40.2	296.6	262.2	199.9	36.3	-0.72	0.37	0.80	-9.68
14	916.6	513.0	478.1	77.0	913.9	513.0	478.6	76.1	-0.29	0.01	0.10	-1.20
Medium farm sample												
1	5045.7	1318.5	846.0	37.3	5044.4	1317.7	847.2	37.0	-0.03	-0.06	0.14	-0.84
2	11047.1	2273.7	1706.1	160.6	11045.5	2273.9	1705.8	160.0	-0.01	0.01	-0.01	-0.37
3	2192.2	687.4	1279.7	20.8	2190.6	686.8	1280.6	20.6	-0.08	-0.09	0.07	-1.30
4	4616.3	1420.7	2428.9	45.2	4614.5	1420.4	2428.9	44.7	-0.04	-0.02	0.00	-1.00
5	2086.8	1357.5	1405.0	67.6	2085.4	1356.8	1405.2	67.4	-0.07	-0.05	0.02	-0.37
6	4050.0	1996.5	2085.7	151.9	4048.3	1997.1	2086.7	149.2	-0.04	0.03	0.05	-1.78
7	3664.5	1351.8	1096.3	152.6	3663.1	1352.0	1095.5	152.9	-0.04	0.01	-0.07	0.16
8	7979.7	2759.2	2815.5	223.1	7977.6	2759.6	2815.5	222.2	-0.03	0.01	0.00	-0.40
9	4903.2	1043.3	617.6	97.7	4900.8	1043.3	617.8	97.9	-0.05	0.00	0.04	0.29
10	6310.8	1730.5	1407.5	152.6	6309.1	1730.2	1407.5	152.6	-0.03	-0.02	0.00	-0.03
11	2268.9	1381.4	757.1	44.8	2267.4	1381.5	756.6	44.5	-0.07	0.01	-0.07	-0.56
12	3643.2	2841.3	1715.4	209.3	3641.6	2841.3	1714.9	208.9	-0.05	0.00	-0.03	-0.20
13	2081.6	1242.2	1723.6	195.5	2079.8	1241.4	1724.4	194.9	-0.09	-0.07	0.05	-0.28
14	5482.5	1357.8	2151.3	144.3	5480.8	1357.2	2152.3	142.6	-0.03	-0.05	0.05	-1.14
Large farm sample												
1	11334.2	3054.0	3413.7	182.4	11332.46	3053.13	3414.34	182.00	-0.02	-0.03	0.02	-0.22
2	31037.8	8617.4	4784.5	598.0	31036.72	8617.31	4783.95	597.98	0.00	0.00	-0.01	-0.01
3	15479.8	4507.9	8819.8	76.9	15477.95	4507.51	8818.85	76.69	-0.01	-0.01	-0.01	-0.26
4	34883.5	8213.9	14933.3	511.2	34881.02	8213.06	14933.05	511.21	-0.01	-0.01	0.00	-0.01
5	9591.1	4682.8	4789.3	282.4	9589.36	4680.14	4789.88	282.82	-0.02	-0.06	0.01	0.15
6	9422.0	8011.3	12835.9	1525.8	9420.69	8010.17	12835.81	1525.75	-0.01	-0.01	0.00	0.00
7	16007.3	6958.3	8994.7	669.7	16005.66	6957.98	8994.72	669.22	-0.01	-0.01	0.00	-0.07
8	35075.5	12128.5	12375.8	980.5	35073.43	12128.68	12375.64	979.21	-0.01	0.00	0.00	-0.13
9	10505.4	3323.8	4980.1	636.7	10503.92	3323.89	4980.06	636.09	-0.01	0.00	0.00	-0.10
10	34736.8	9525.2	7747.4	840.1	34735.00	9524.63	7747.28	839.88	-0.01	-0.01	0.00	-0.02
11	12457.2	7651.7	5019.7	595.4	12455.59	7651.03	5019.71	595.03	-0.01	-0.01	0.00	-0.06
12	32761.4	11001.7	7429.4	1779.7	32760.23	10999.15	7429.81	1780.12	0.00	-0.02	0.01	0.02
13	8770.9	3809.2	5646.1	762.1	8769.23	3806.43	5646.70	762.50	-0.02	-0.07	0.01	0.05
14	14309.5	7686.9	13093.9	677.9	14308.08	7685.85	13093.82	677.91	-0.01	-0.01	0.00	0.00

Table A3.14 Estimates of the Q matrices of the cost functions

	Small farm sample				Medium farm sample				Large farm sample			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Sugar beet	2.7E-05	1.7E-15	1.7E-15	5.3E-16	3.0E-06	1.2E-18	1.3E-18	5.5E-19	6.9E-07	1.4E-20	1.6E-20	7.5E-21
C. wheat	1.7E-15	2.7E-04	1.4E-11	7.5E-12	1.2E-18	4.5E-05	4.9E-14	2.4E-14	1.4E-20	1.0E-05	5.5E-16	2.7E-16
Corn	1.7E-15	1.4E-11	3.6E-04	1.8E-11	1.3E-18	4.9E-14	5.1E-05	4.0E-14	1.6E-20	5.5E-16	6.8E-06	6.5E-17
Barley	5.3E-16	7.5E-12	1.8E-11	2.0E-03	5.5E-19	2.4E-14	4.0E-14	4.8E-04	7.5E-21	2.7E-16	6.5E-17	6.5E-05

Table A3.15 Shadow price of land (y), euro

	Small farm sample	Medium farm sample	Large farm sample
1	223.66	194.15	18.90
2	133.17	192.43	19.30
3	217.48	195.10	18.75
4	200.15	190.97	18.79
5	223.02	190.50	18.06
6	197.76	178.07	18.71
7	205.53	197.83	19.12
8	201.46	192.19	18.63
9	208.10	202.64	19.36
10	193.46	195.42	19.12
11	200.87	194.12	18.93
12	203.73	190.75	17.83
13	173.02	188.43	17.98
14	190.50	179.42	18.84

Table A3.16 Shadow price of activities (λ), euro

	Small farm sample				Medium farm sample				Large farm sample			
	Sugar beet	C. wheat	Corn	Barley	Sugar beet	C. wheat	Corn	Barle y	Sugar beet	C. wheat	Corn	Barle y
1	1.67	6.69	9.87	7.61	2.67	2.73	9.52	4.43	1.93	2.58	8.40	4.28
2	2.16	8.3	0.05	7.34	2.23	6.04	4.16	3.72	3.19	4.94	2.95	5.50
3	1.67	6.9	9.08	6.81	2.06	3.20	8.09	4.53	1.87	3.46	2.56	4.88
4	1.62	6.05	8.86	2.86	1.9	4.07	5.44	4.01	1.25	2.6	4.36	5.49
5	1.40	8.94	8.13	5.77	2.58	3.07	6.54	4.42	1.99	0.90	8.55	7.42
6	1.19	5.63	8.8	3.98	2.06	7.08	7.71	0.96	2.59	2.31	5.33	5.59
7	1.65	6.91	9.99	4.94	2.47	6.18	2.99	7.02	2.16	4.67	5.88	4.48
8	3.85	8.03	6.75	3.64	1.52	7.51	6.25	3.03	1.58	6.66	5.51	2.25
9	1.62	7.19	10.25	5.18	1.30	4.94	5.95	7.11	2.46	7.04	5.55	4.12
10	0.91	3.38	8.94	3.52	1.94	4.51	6.04	6.06	1.98	3.88	5.48	5.49
11	1.62	8.14	7.47	1.05	2.17	5.13	2.25	4.42	2.15	3.38	5.77	4.74
12	1.95	7.48	8.78	3.16	2.11	5.30	3.23	4.26	2.82	1.00	6.50	7.27
13	1.49	7.88	12.21	0.60	1.87	3.11	9.72	3.73	2.00	0.88	8.51	7.40
14	1.11	4.90	6.26	2.91	1.98	2.99	6.77	1.61	2.55	2.42	5.36	5.68

Table A3.17 Estimates of farmer's absolute and relative risk aversion coefficients

	Small farm sample		Medium farm sample		Large farm sample	
	Absolute risk aversion coefficient (α)	**Relative risk aversion coefficient**	**Absolute risk aversion coefficient (α)**	**Relative risk aversion coefficient**	**Absolute risk aversion coefficient (α)**	**Relative risk aversion coefficient**
1	0.000300	0.3840	0.000200	3.0610	0.000062	2.5510
2	0.000037	0.1040	0.000100	3.2680	0.000040	4.7610
3	0.000300	0.7020	0.000200	2.6610	0.000027	2.0610
4	0.000300	1.2000	0.000097	2.3800	0.000024	4.1850
5	0.000300	0.3220	0.000100	1.5660	0.000027	1.4560
6	0.000300	1.5830	0.000059	1.3350	0.000023	3.7090
7	0.000300	0.6680	0.000200	3.2800	0.000032	3.6170
8	0.000200	0.9990	0.000090	3.8120	0.000023	4.3490
9	0.000300	0.6020	0.000300	3.8280	0.000063	4.0830
10	0.000200	1.4370	0.000200	3.5740	0.000030	4.0660
11	0.000300	0.4020	0.000100	1.9740	0.000031	2.8190
12	0.000300	1.3190	0.000069	2.0730	0.000022	3.1540
13	0.000200	0.3110	0.000100	1.9000	0.000026	1.4480
14	0.000200	1.1420	0.000060	1.0940	0.000024	3.7390

Note: The absolute risk aversion coeeficients are expressed in $€^{-1}$

Table A3.18 Farmland allocated to AES (grassland program) under different scenarios in the small farm sample

	Scenario 1		Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Ha under AES	Land share under AES	Ha under AES	Land share under AES	% change ha under AES sc2/sc1	Ha under AES	Land share under AES	% change ha under AES sc3/sc1	Ha under AES	Land share under AES	% change ha under AES sc4/sc1	Ha under AES	Land share under AES	% change ha under AES sc5/sc1
1	4.06	81.20	0.92	18.42	-77.32	3.56	71.28	-12.22	4.57	91.30	12.44	4.75	94.92	16.90
2	14.86	99.03	14.85	98.99	-0.05	14.85	99.03	-0.01	14.86	99.04	0.01	14.86	99.06	0.03
3	4.39	58.49	0.00	0.00	-100.00	2.54	33.91	-42.03	5.74	76.55	30.86	6.48	86.42	47.73
4	6.25	48.10	0.00	0.00	-100.00	2.51	19.30	-59.86	9.54	73.42	52.63	10.97	84.35	75.36
5	4.24	94.18	3.45	76.67	-18.59	4.12	91.44	-2.90	4.36	96.87	2.86	4.42	98.22	4.29
6	6.24	36.71	0.00	0.00	-100.00	0.98	5.77	-84.28	11.66	68.60	86.86	14.18	83.39	127.13
7	6.35	70.55	0.00	0.00	-100.00	4.83	53.71	-23.86	7.55	83.86	18.88	8.14	90.49	28.27
8	5.44	45.36	0.00	0.00	-100.00	2.09	17.37	-61.70	8.88	73.98	63.06	10.39	86.59	90.87
9	6.72	79.08	0.00	0.00	-100.00	5.62	66.14	-16.36	7.59	89.34	12.97	7.97	93.72	18.51
10	7.75	43.07	0.00	0.00	-100.00	3.02	16.77	-61.06	12.39	68.85	59.85	14.52	80.65	87.24
11	5.12	85.25	2.61	43.54	-48.93	4.71	78.49	-7.92	5.55	92.41	8.41	5.74	95.73	12.30
12	6.48	46.26	0.00	0.00	-100.00	2.36	16.87	-63.53	10.30	73.55	59.00	12.00	85.68	85.22
13	7.16	89.46	6.55	81.84	-8.51	6.97	87.13	-2.61	7.46	93.20	4.18	7.66	95.73	7.01
14	9.78	51.47	0.00	0.00	-100.00	5.40	28.41	-44.81	14.61	76.87	49.35	16.68	87.79	70.55

Table A3.19 Farmland allocated to AES (grassland program) under different scenarios in the medium farm sample

	Scenario 1		Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Ha under AES	Land share under AES	Ha under AES	Land share under AES	% change ha under AES sc2/sc1	Ha under AES	Land share under AES	% change ha under AES sc3/sc1	Ha under AES	Land share under AES	% change ha under AES sc4/sc1	Ha under AES	Land share under AES	% change ha under AES sc5/sc1
1	20.23	50.58	0.00	0.00	-100.00	0.00	0.00	-100.00	32.63	81.58	61.30	36.44	91.09	80.09
2	35.16	39.96	0.00	0.00	-100.00	0.00	0.00	-100.00	63.51	72.16	80.60	74.56	84.73	112.05
3	15.27	46.97	0.00	0.00	-100.00	1.59	4.90	-89.57	24.71	76.02	61.85	28.43	87.48	86.25
4	32.27	49.27	0.00	0.00	-100.00	6.86	10.47	-78.75	50.16	76.57	55.41	57.20	87.32	77.23
5	21.21	48.21	0.00	0.00	-100.00	5.43	12.35	-74.39	34.62	78.69	63.22	38.94	88.50	83.57
6	44.22	60.99	0.00	0.00	-100.00	24.85	34.28	-43.80	59.14	81.57	33.73	64.99	89.64	46.96
7	20.09	41.42	0.00	0.00	-100.00	0.00	0.00	-100.00	35.76	73.72	77.99	41.84	86.28	108.30
8	28.52	31.34	0.00	0.00	-100.00	0.00	0.00	-100.00	65.18	71.63	128.60	77.68	85.36	172.42
9	16.98	44.67	0.00	0.00	-100.00	0.00	0.00	-100.00	30.45	80.13	79.36	34.39	90.50	102.59
10	21.59	36.91	0.00	0.00	-100.00	0.00	0.00	-100.00	44.07	75.33	104.11	51.02	87.22	136.32
11	19.88	48.49	0.00	0.00	-100.00	5.60	13.66	-71.83	31.75	77.45	59.72	36.35	88.67	82.85
12	30.50	38.12	0.00	0.00	-100.00	1.69	2.12	-94.45	56.15	70.18	84.10	67.05	83.81	119.86
13	22.45	48.29	0.00	0.00	-100.00	3.44	7.40	-84.68	36.12	77.67	60.86	40.91	87.99	82.22
14	39.81	64.73	0.00	0.00	-100.00	26.57	43.20	-33.26	49.95	81.22	25.48	55.02	89.46	38.21

Table A3.20 Farmland allocated to AES (grassland program) under different scenarios in the large farm sample

	Scenario 1		Scenario 2			Scenario 3			Scenario 4			Scenario 5		
	Ha under AES	Land share under AES	Ha under AES	Land share under AES	% change ha under AES sc2/sc1	Ha under AES	Land share under AES	% change ha under AES sc3/sc1	Ha under AES	Land share under AES	% change ha under AES sc4/sc1	Ha under AES	Land share under AES	% change ha under AES sc5/sc1
1	69.99	58.32	0.00	0.00	-100.00	30.16	25.13	-56.91	98.41	82.01	40.60	108.93	90.77	55.63
2	119.03	38.40	0.00	0.00	-100.00	0.00	0.00	-100.00	238.05	76.79	99.99	272.32	87.84	128.77
3	105.72	50.22	0.00	0.00	-100.00	24.81	11.79	-76.53	162.91	77.39	54.10	185.62	88.18	75.58
4	145.61	38.32	0.00	0.00	-100.00	0.00	0.00	-100.00	291.98	76.84	100.53	333.79	87.84	129.24
5	106.06	56.72	0.00	0.00	-100.00	50.47	26.99	-52.41	150.88	80.69	42.26	168.24	89.97	58.62
6	102.68	28.48	0.00	0.00	-100.00	0.00	0.00	-100.00	247.26	68.59	140.80	302.27	83.85	194.37
7	90.06	36.02	0.00	0.00	-100.00	0.00	0.00	-100.00	178.61	71.44	98.33	212.70	85.08	136.19
8	125.71	31.43	0.00	0.00	-100.00	0.00	0.00	-100.00	285.34	71.33	126.99	338.89	84.72	169.59
9	77.77	50.01	0.00	0.00	-100.00	0.47	0.30	-99.40	122.35	78.68	57.32	138.50	89.07	78.10
10	106.73	33.15	0.00	0.00	-100.00	0.00	0.00	-100.00	233.06	72.38	118.36	278.10	86.37	160.56
11	94.83	40.36	0.00	0.00	-100.00	0.00	0.00	-100.00	170.24	72.44	79.51	199.95	85.08	110.84
12	212.05	51.72	0.00	0.00	-100.00	24.54	5.99	-88.43	322.85	78.74	52.25	365.64	89.18	72.43
13	106.92	56.28	0.00	0.00	-100.00	46.87	24.67	-56.16	154.05	81.08	44.08	171.38	90.20	60.28
14	112.77	32.17	0.00	0.00	-100.00	0.00	0.00	-100.00	245.97	70.18	118.13	297.41	84.85	163.74

Table A3.21 Land allocation (ha) among crops in scenario 1 and percentage change respect to the baseline allocation

	Scenario 1				% change scenario 1/baseline			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample								
1	0.00	0.30	0.64	0.00	-100.00	-90.43	-43.30	-100.00
2	0.15	0.00	0.00	0.00	-94.81	-100.00	-100.00	-100.00
3	0.00	0.00	3.11	0.00	-100.00	-100.00	-11.64	-100.00
4	0.00	1.25	5.49	0.00	-100.00	-78.08	-7.83	-100.00
5	0.00	0.25	0.01	0.00	-100.00	-90.35	-99.28	-100.00
6	0.00	6.10	4.66	0.00	-100.00	-38.46	-11.45	-100.00
7	0.00	0.00	2.44	0.21	-100.00	-100.00	-2.58	-85.35
8	0.00	3.06	3.21	0.29	-100.00	-49.63	-13.31	-78.61
9	0.00	0.32	1.46	0.00	-100.00	-93.83	-0.02	-100.00
10	1.65	5.15	3.19	0.26	-48.09	-49.81	1.01	-81.58
11	0.00	0.67	0.22	0.00	-100.00	-83.55	-83.66	-100.00
12	0.05	4.76	2.71	0.00	-96.55	-45.22	-17.14	-100.00
13	0.00	0.00	0.84	0.00	-100.00	-100.00	-62.48	-100.00
14	0.00	3.79	4.80	0.63	-100.00	-62.34	-12.18	-61.37
Medium farm sample								
1	1.27	7.32	11.18	0.00	-85.38	-67.33	38.74	-100.00
2	8.99	22.83	21.03	0.00	-57.45	-45.82	-1.69	-100.00
3	0.00	0.00	17.24	0.00	-100.00	-100.00	15.46	-100.00
4	0.00	4.06	29.17	0.00	-100.00	-85.38	5.05	-100.00
5	0.00	6.92	15.87	0.00	-100.00	-71.18	12.63	-100.00
6	0.00	5.03	23.25	0.00	-100.00	-87.56	9.88	-100.00
7	0.00	14.21	14.20	0.00	-100.00	-39.84	-4.39	-100.00
8	3.63	28.56	29.17	1.13	-73.87	-33.03	-3.79	-72.75
9	2.48	8.01	10.53	0.00	-69.69	-59.40	35.63	-100.00
10	2.79	17.21	16.91	0.00	-72.09	-39.70	1.23	-100.00
11	0.00	9.85	11.27	0.00	-100.00	-63.78	28.35	-100.00
12	0.00	32.22	17.16	0.12	-100.00	-30.40	-17.31	-97.17
13	0.00	4.82	19.23	0.00	-100.00	-78.32	20.05	-100.00
14	0.00	0.00	21.69	0.00	-100.00	-100.00	-8.93	-100.00
Large farm sample								
1	0.00	0.00	50.01	0.00	-100.00	-100.00	40.88	-100.00
2	17.96	120.62	49.51	2.88	-70.86	-23.32	-37.92	-74.60
3	0.00	0.00	104.78	0.00	-100.00	-100.00	7.59	-100.00
4	14.63	47.16	172.61	0.00	-74.09	-69.78	9.36	-100.00
5	0.00	29.26	51.68	0.00	-100.00	-68.02	-26.62	-100.00
6	0.00	83.35	160.45	14.01	-100.00	-44.55	-2.28	-51.54
7	0.00	62.45	97.49	0.00	-100.00	-41.26	1.65	-100.00
8	15.86	128.51	129.92	0.00	-74.05	-31.43	-2.50	-100.00
9	0.00	0.00	75.61	2.13	-100.00	-100.00	42.37	-81.65
10	20.63	103.69	90.95	0.00	-62.44	-34.01	-1.11	-100.00
11	0.00	72.37	67.80	0.00	-100.00	-48.48	17.67	-100.00
12	0.00	75.93	105.40	16.62	-100.00	-67.33	27.69	-50.72
13	0.00	14.91	65.30	2.86	-100.00	-79.97	-21.34	-80.32
14	0.00	73.13	164.61	0.00	-100.00	-49.30	-1.72	-100.00

Table A3.22 Land allocation (ha) among crops in scenario 2 and percentage change respect to the baseline allocation

	Scenario 2				% change scenario2/baseline			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample								
1	0.00	2.48	1.60	0.00	-100.00	-21.14	41.74	-100.00
2	0.15	0.00	0.00	0.00	-94.59	-100.00	-100.00	-100.00
3	0.00	2.56	4.94	0.00	-100.00	-24.52	40.30	-100.00
4	0.00	4.65	8.35	0.00	-100.00	-18.56	40.05	-100.00
5	0.00	0.77	0.28	0.00	-100.00	-70.40	-81.22	-100.00
6	0.00	9.41	7.59	0.00	-100.00	-5.05	44.20	-100.00
7	0.00	3.89	4.42	0.69	-100.00	-15.51	76.51	-52.40
8	0.00	6.42	5.45	0.13	-100.00	5.81	47.23	-90.52
9	0.00	4.89	3.10	0.51	-100.00	-6.64	113.02	-54.30
10	0.01	10.93	6.43	0.63	-99.60	6.48	103.67	-54.93
11	0.00	2.38	1.00	0.00	-100.00	-41.48	-23.54	-100.00
12	0.00	8.63	5.37	0.00	-100.00	-0.69	64.08	-100.00
13	0.00	0.08	1.38	0.00	-100.00	-98.26	-38.77	-100.00
14	0.00	9.80	8.06	1.15	-100.00	-2.61	47.39	-29.88
Medium farm sample								
1	0.00	1.55	38.45	0.00	-100.00	-93.07	377.20	-100.00
2	0.00	39.65	48.35	0.00	-100.00	-5.88	126.05	-100.00
3	0.00	0.00	32.50	0.00	-100.00	-100.00	117.72	-100.00
4	0.00	8.10	57.40	0.00	-100.00	-70.81	106.70	-100.00
5	0.00	8.89	35.11	0.00	-100.00	-62.99	149.25	-100.00
6	0.00	26.98	45.52	0.00	-100.00	-33.29	115.14	-100.00
7	0.00	22.07	26.43	0.00	-100.00	-6.59	77.97	-100.00
8	0.00	37.34	53.66	0.00	-100.00	-12.43	77.01	-100.00
9	0.00	3.25	34.75	0.00	-100.00	-83.54	347.46	-100.00
10	0.00	22.06	36.44	0.00	-100.00	-22.71	118.08	-100.00
11	0.00	9.38	31.62	0.00	-100.00	-65.49	259.98	-100.00
12	0.00	47.88	32.12	0.00	-100.00	3.42	54.83	-100.00
13	0.00	2.55	43.95	0.00	-100.00	-88.54	174.43	-100.00
14	0.00	21.27	40.23	0.00	-100.00	-12.73	68.90	-100.00
Large farm sample								
1	0.00	0.00	120.00	0.00	-100.00	-100.00	238.02	-100.00
2	0.00	250.11	57.64	2.25	-100.00	59.01	-27.72	-80.14
3	0.00	0.00	210.50	0.00	-100.00	-100.00	116.13	-100.00
4	0.00	0.00	380.00	0.00	-100.00	-100.00	140.75	-100.00
5	0.00	62.71	124.29	0.00	-100.00	-31.47	76.50	-100.00
6	0.00	30.50	330.00	0.00	-100.00	-79.71	100.99	-100.00
7	0.00	23.63	226.37	0.00	-100.00	-77.78	136.02	-100.00
8	0.00	110.56	289.44	0.00	-100.00	-41.01	117.21	-100.00
9	0.00	0.00	155.50	0.00	-100.00	-100.00	192.82	-100.00
10	0.00	94.38	227.62	0.00	-100.00	-39.93	147.51	-100.00
11	0.00	15.33	219.67	0.00	-100.00	-89.09	281.28	-100.00
12	0.00	41.06	352.56	16.38	-100.00	-82.33	327.09	-51.43
13	0.00	44.33	141.58	4.09	-100.00	-40.45	70.54	-71.86
14	0.00	15.69	334.82	0.00	-100.00	-89.13	99.90	-100.00

Table A3.23 Land allocation (ha) among crops in scenario 3 and percentage change respect to the baseline allocation

	Scenario 3				% change scenario 3/baseline			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample								
1	0.00	0.61	0.83	0.00	-100.00	-80.62	-26.63	-100.00
2	0.15	0.00	0.00	0.00	-94.80	-100.00	-100.00	-100.00
3	0.00	1.12	3.84	0.00	-100.00	-67.07	9.03	-100.00
4	0.00	3.66	6.83	0.00	-100.00	-35.95	14.61	-100.00
5	0.00	0.32	0.06	0.00	-100.00	-87.55	-95.89	-100.00
6	0.00	9.27	6.45	0.30	-100.00	-6.47	22.51	-52.72
7	0.00	0.70	3.03	0.44	-100.00	-84.92	20.99	-69.40
8	0.00	4.93	4.30	0.69	-100.00	-18.85	16.22	-49.43
9	0.00	1.02	1.80	0.07	-100.00	-80.60	23.38	-94.08
10	1.95	7.92	4.33	0.77	-38.57	-22.83	37.40	-44.89
11	0.00	0.92	0.37	0.00	-100.00	-77.39	-71.87	-100.00
12	0.34	7.23	4.06	0.00	-77.35	-16.73	24.11	-100.00
13	0.00	0.00	1.03	0.00	-100.00	-100.00	-54.19	-100.00
14	0.04	6.43	6.08	1.05	-97.67	-36.09	11.26	-35.90
Medium farm sample								
1	5.34	16.26	18.40	0.00	-38.71	-27.39	128.40	-100.00
2	14.03	37.78	33.23	2.97	-33.56	-10.33	55.34	-11.78
3	0.00	5.06	25.85	0.00	-100.00	-61.36	73.17	-100.00
4	0.70	17.67	40.09	0.19	-92.26	-36.34	44.35	-79.54
5	0.00	15.73	22.84	0.00	-100.00	-34.48	62.11	-100.00
6	0.00	17.32	30.34	0.00	-100.00	-57.19	43.37	-100.00
7	1.61	21.65	24.14	1.11	-74.92	-8.37	62.54	-69.43
8	4.75	40.03	43.06	3.15	-65.84	-6.11	42.05	-23.84
9	5.22	13.76	18.38	0.64	-36.15	-30.30	136.62	-72.19
10	4.87	25.03	27.46	1.15	-51.23	-12.32	64.32	-64.84
11	0.00	17.19	18.21		-100.00	-36.76	107.32	-100.00
12	0.00	46.34	29.04	2.93	-100.00	0.09	39.96	-33.16
13	0.00	14.48	26.85	1.73	-100.00	-34.88	67.67	-61.45
14	0.00	6.73	28.21		-100.00	-72.40	18.42	-100.00
Large farm sample								
1	1.14	0.00	88.70	0.00	-94.77	-100.00	149.86	-100.00
2	29.92	150.31	111.47	18.30	-51.45	-4.44	39.79	61.47
3	0.00	26.92	158.77	0.00	-100.00	-67.35	63.01	-100.00
4	27.04	77.61	266.96	8.38	-52.10	-50.26	69.14	-13.48
5	0.00	47.00	88.68	0.86	-100.00	-48.65	25.92	-84.08
6	0.00	90.86	245.60	24.04	-100.00	-39.56	49.58	-16.86
7	0.00	79.90	165.05	5.06	-100.00	-24.85	72.08	-58.55
8	19.22	156.92	216.87	6.99	-68.55	-16.27	62.74	-61.58
9	6.57	0.00	128.08	20.39	-72.02	-100.00	141.17	75.89
10	27.82	129.50	164.68	0.00	-49.34	-17.58	79.06	-100.00
11	0.00	99.50	125.41	10.09	-100.00	-29.16	117.67	-11.23
12	26.53	144.70	177.54	36.69	-56.73	-37.74	115.07	8.78
13	0.00	30.19	102.69	10.25	-100.00	-59.45	23.70	-29.57
14	0.00	88.74	251.43	10.34	-100.00	-38.48	50.12	-19.53

Table A3.24 Land allocation (ha) among crops in scenario 4 and percentage change respect to the baseline allocation

	Scenario 4				% change scenario 4/baseline			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample								
1	0.00	0.00	0.44	0.00	-100.00	-100.00	-61.36	-100.00
2	0.14	0.00	0.00	0.00	-94.86	-100.00	-100.00	-100.00
3	0.00	0.00	1.76	0.00	-100.00	-100.00	-50.07	-100.00
4	0.00	0.00	3.46	0.00	-100.00	-100.00	-42.03	-100.00
5	0.00	0.14	0.00	0.00	-100.00	-94.60	-100.00	-100.00
6	0.00	2.61	2.73	0.00	-100.00	-73.67	-48.15	-100.00
7	0.00	0.00	1.45	0.00	-100.00	-100.00	-42.00	-100.00
8	0.00	1.08	2.05	0.00	-100.00	-82.25	-44.73	-100.00
9	0.00	0.00	0.91	0.00	-100.00	-100.00	-37.76	-100.00
10	1.39	2.25	1.97	0.00	-56.33	-78.11	-37.52	-100.00
11	0.00	0.40	0.06	0.00	-100.00	-90.23	-95.61	-100.00
12	0.00	2.33	1.38	0.00	-100.00	-73.24	-57.89	-100.00
13	0.00	0.00	0.54	0.00	-100.00	-100.00	-75.80	-100.00
14	0.00	0.85	3.34	0.20	-100.00	-91.53	-38.90	-87.60
Medium farm sample								
1	0.00	1.64	5.73	0.00	-100.00	-92.67	-28.94	-100.00
2	4.97	8.90	10.63	0.00	-76.46	-78.89	-50.30	-100.00
3	0.00	0.00	7.79	0.00	-100.00	-100.00	-47.79	-100.00
4	0.00	0.00	15.34	0.00	-100.00	-100.00	-44.74	-100.00
5	0.00	0.00	9.38	0.00	-100.00	-100.00	-33.44	-100.00
6	0.00	0.00	13.36	0.00	-100.00	-100.00	-36.84	-100.00
7	0.00	7.04	5.70	0.00	-100.00	-70.20	-61.59	-100.00
8	0.00	10.66	15.16	0.00	-100.00	-75.01	-50.00	-100.00
9	0.27	2.24	5.05	0.00	-96.74	-88.67	-34.97	-100.00
10	0.00	6.61	7.83	0.00	-100.00	-76.86	-53.15	-100.00
11	0.00	3.66	5.59	0.00	-100.00	-86.55	-36.37	-100.00
12	0.00	17.66	6.20	0.00	-100.00	-61.86	-70.13	-100.00
13	0.00	0.00	10.38	0.00	-100.00	-100.00	-35.17	-100.00
14	0.00	0.00	11.55	0.00	-100.00	-100.00	-51.51	-100.00
Large farm sample								
1	0.00	0.00	21.59	0.00	-100.00	-100.00	-39.17	-100.00
2	0.75	71.20	0.00	0.00	-98.79	-54.74	-100.00	-100.00
3	0.00	0.00	47.59	0.00	-100.00	-100.00	-51.14	-100.00
4	0.00	0.00	88.02	0.00	-100.00	-100.00	-44.24	-100.00
5	0.00	13.59	22.52	0.00	-100.00	-85.15	-68.02	-100.00
6	0.00	35.97	77.28	0.00	-100.00	-76.08	-52.94	-100.00
7	0.00	31.12	40.28	0.00	-100.00	-70.73	-58.01	-100.00
8	0.00	64.99	49.67	0.00	-100.00	-65.32	-62.72	-100.00
9	0.00	0.00	33.15	0.00	-100.00	-100.00	-37.57	-100.00
10	4.39	54.05	30.50	0.00	-92.01	-65.60	-66.83	-100.00
11	0.00	41.49	23.28	0.00	-100.00	-70.46	-59.60	-100.00
12	0.00	32.79	49.71	4.66	-100.00	-85.89	-39.78	-86.19
13	0.00	1.75	34.20	0.00	-100.00	-97.65	-58.80	-100.00
14	0.00	24.60	79.93	0.00	-100.00	-82.95	-52.28	-100.00

Table A3.25 Land allocation (ha) among crops in scenario 5 and percentage change respect to the baseline allocation

	Scenario 5				% chanhe scenario 5/ baseline			
	Sugar beet	C. Wheat	Corn	Barley	Sugar beet	C. Wheat	Corn	Barley
Small farm sample								
1	0.00	0.00	0.25	0.00	-100.00	-100.00	-77.46	-100.00
2	0.14	0.00	0.00	0.00	-94.96	-100.00	-100.00	-100.00
3	0.00	0.00	1.02	0.00	-100.00	-100.00	-71.09	-100.00
4	0.00	0.00	2.04	0.00	-100.00	-100.00	-65.87	-100.00
5	0.00	0.08	0.00	0.00	-100.00	-96.93	-100.00	-100.00
6	0.00	1.03	1.80	0.00	-100.00	-89.61	-65.89	-100.00
7	0.00	0.00	0.86	0.00	-100.00	-100.00	-65.81	-100.00
8	0.00	0.16	1.45	0.00	-100.00	-97.31	-60.92	-100.00
9	0.00	0.00	0.53	0.00	-100.00	-100.00	-63.33	-100.00
10	1.22	0.91	1.35	0.00	-61.56	-91.15	-57.11	-100.00
11	0.00	0.26	0.00	0.00	-100.00	-93.71	-100.00	-100.00
12	0.00	1.23	0.78	0.00	-100.00	-85.84	-76.33	-100.00
13	0.00	0.00	0.34	0.00	-100.00	-100.00	-84.82	-100.00
14	0.00	0.00	2.32	0.00	-100.00	-100.00	-57.54	-100.00
Medium farm sample								
1	0.00	0.18	3.39	0.00	-100.00	-99.21	-57.96	-100.00
2	3.31	3.79	6.34	0.00	-84.33	-91.00	-70.37	-100.00
3	0.00	0.00	4.07	0.00	-100.00	-100.00	-72.74	-100.00
4	0.00	0.00	8.30	0.00	-100.00	-100.00	-70.10	-100.00
5	0.00	0.00	5.06	0.00	-100.00	-100.00	-64.09	-100.00
6	0.00	0.00	7.51	0.00	-100.00	-100.00	-64.49	-100.00
7	0.00	4.03	2.63	0.00	-100.00	-82.97	-82.28	-100.00
8	0.00	4.22	9.10	0.00	-100.00	-90.10	-69.99	-100.00
9	0.00	0.80	2.81	0.00	-100.00	-95.94	-63.83	-100.00
10	0.00	3.28	4.20	0.00	-100.00	-88.52	-74.86	-100.00
11	0.00	1.40	3.25	0.00	-100.00	-94.85	-63.04	-100.00
12	0.00	11.04	1.91	0.00	-100.00	-76.15	-90.79	-100.00
13	0.00	0.00	5.59	0.00	-100.00	-100.00	-65.12	-100.00
14	0.00	0.00	6.48	0.00	-100.00	-100.00	-72.78	-100.00
Large farm sample								
1	0.00	0.00	11.08	0.00	-100.00	-100.00	-68.80	-100.00
2	0.00	37.68	0.00	0.00	-100.00	-76.04	-100.00	-100.00
3	0.00	0.00	24.88	0.00	-100.00	-100.00	-74.45	-100.00
4	0.00	0.00	46.21	0.00	-100.00	-100.00	-70.72	-100.00
5	0.00	7.29	11.48	0.00	-100.00	-92.04	-83.70	-100.00
6	0.00	15.72	42.51	0.00	-100.00	-89.54	-74.11	-100.00
7	0.00	17.89	19.41	0.00	-100.00	-83.18	-79.76	-100.00
8	0.00	40.42	20.69	0.00	-100.00	-78.44	-84.47	-100.00
9	0.00	0.00	17.00	0.00	-100.00	-100.00	-67.99	-100.00
10	0.00	33.15	10.75	0.00	-100.00	-78.90	-88.31	-100.00
11	0.00	26.71	8.35	0.00	-100.00	-80.99	-85.51	-100.00
12	0.00	16.11	27.49	0.76	-100.00	-93.07	-66.70	-97.75
13	0.00	0.00	18.62	0.00	-100.00	-100.00	-77.57	-100.00
14	0.00	7.48	45.61	0.00	-100.00	-94.82	-72.77	-100.00

CONCLUSIONS

Over the last decade the increasing connection between agriculture and the environment and the rising price volatility on agricultural markets has led to a new emphasis on agri-environmental policy instruments as well as to a search for new risk management strategies for EU farmers. The CAP has reinforced these trends as the EU budget allocated to the AESs has grown over the years and the support of farmer's income has shifted from market distorting mechanisms to direct payments to farmers. This focus will be the core of the CAP in the future as confirmed by the proposed reform of the CAP after 2013.

This thesis has dealt with both these issues by analysing the AESs from two viewpoints. First, the AESs have been investigated with respect to their traditional role of measures promoting environmentally-friendly practices while compensating the farmer for the income foregone; later their potential role as farmer's income stabilisers has also been explored. The evidence collected by answering the first research question (Chapter 2) have shown that the effects of the AESs on farmer's performances as well as its environmental effectiveness differ across Member States. Moreover, it seems that the amount of the AE payment is worth to be revised in some Member States. The answer to the second research question (Chapter 3) have outlined that the AESs seem to play an additional role besides the aforementioned one. Indeed, we have found that they may act as an income risk management tool available to farmers, especially in scenarios of high crop price volatility. Finally, from a methodological point of view, the approach adopted in Chapter 3 represents one of the few attempts of integrating risk in a farm level PMP model, allowing the use of a calibrated model in analysing farm behaviour under uncertainty.

The first research question addressed in this thesis shows the advantages of combining PSM with DID estimator in a non experimental setting as a way to remove the bias due to both observed and time-invariant unobserved variables when panel data are available. The results of our analysis highlight that the effects of AESs participation on farm's performances differ across Member States likely because of the heterogeneity of agricultural characteristics and natural resources as well as the variability in the AESs implementation. Although the FADN data does not make any discrimination across the different AESs, our results may have some policy implications. First, the level of the AE payment is worthy to be revised in some countries, since it does not seem to provide a fair compensation to the farmers for their income foregone arising from program's participation. This is especially true in Spain, where the participation in the AESs has resulted in a large decrease of farmers' income. The Italian and French participant farmers experience a decline in their income per hectare as well; however, their drop is not as sharp as the drop experienced in Spain. In Germany the AE payment seems to fairly compensate the income foregone of the participant farmers while in the UK the income per hectare is not negatively affected by AESs participation even in absence of the payment. This may explain why in Germany and UK the share of UAA under agri-environmental commitments is larger compared to the other countries considered. One may argue that a farmer is willing to participate in AESs only if he expects to increase his income by participation. However, the time lag between expectation and realisation may explain the actual negative impact on income of AESs adoption in some countries. In addition, once the farmer enters an AES is obliged to adopt it for at least five years.

The second main finding of the first study concerns the ability of the AESs to promote sustainable practices in some countries, while in others it does not seem to be successful. The promotion of environmentally-friendly practises seems to be effective in France and Italy, where the participation in the AESs supports crop diversification, the conversion of a share of farmland to grassland and the decline in per hectare fertiliser expenditure. Encouraging sustainable farming have been successful also in Germany and in the UK, while in Spain the design of the AESs does not seem to generate any environmental benefit. It is worth to remark that it would be interesting to conduct the same analysis on each AE measure separately when data were available. This may lead to more detailed policy implications.

The answer to the second research question of this thesis has led to the development of a new methodological approach to integrate price risk in a farm level PMP model. The approach shows some innovation compared to the few earlier attempts in this modelling area and a mathematical demonstration by the KKT conditions has proved its economic foundation. After a theoretical description of the model, its empirical application to three farm samples under different scenarios of crop price volatility has been implemented. The application aimed to check the calibration ability of the model and the ability in estimating farmer's risk aversion coefficient consistent with the literature as well as to perform simulation scenarios to investigate the potential role of a specific AES (the option to convert a share of farmland to grassland) as a farm strategy to cope with risk. The estimation results have proved the ability of the model to calibrate to the observed activity levels in the base year as well as to estimate the farm non-linear cost function and the values of the farmers' absolute risk aversion coefficients consistent with the literature. The simulated scenarios support the innovative viewpoint on AESs as a potential farmers' strategy to cope with income risk on agricultural markets characterized by high level of crop price volatility. While the share of farmland committed to grassland by risk neutral farmers is independent of the level of price volatility, the results of the simulations show an increase in this share for risk averse farmers when they face a rise in the price volatility and the extent of this increase depends on the degree of farmer's risk aversion. The adoption of grassland program and the change in crop price volatility lead to a reallocation of crops on the farm. When price volatility is constrained at zero or it is set at a low level converting a share of farmland to grassland program depends mainly on the crop marginal profit. Under these scenarios the production of the less profitable crops, sugar beet and barley, decreases while the production of the most profitable crop, corn, grows. When crop price volatility is set at high level (e.g. twice baseline volatility) most medium and large farms of the samples combine the adoption of the grassland program with an increase in the share allocated to the less-risky sugar beet, while small farms rely on the conversion of a share of farmland to grassland as the sole risk management strategy.

The use of AESs as a strategy against income fluctuation has been tested for grassland measures only. It would be interesting to check this potential role also for other AESs such as the option to converting to organic farming or to adopt crop diversification measures. We expect other AESs to contribute to income stabilisation, since they guarantee a share of farmers' income independent of the market fluctuations.

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