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Ph.D. Thesis

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Contents

Una evaluación de equilibrio general computable de los objetivos de reducción de emisiones de gases de efecto invernadero en España, incluyendo la incorporación de curvas de coste marginal de reducción

Resumen

En esta tesis se presenta un modelo modificado de Equilibrio General Computable (CGE) de la economía española, y se utiliza para explorar los efectos de la política de cambio climático en España, con referencia específica al sector agrícola. El capítulo 1 proporciona algunos antecedentes en torno a la amenaza del cambio climático y los intentos hasta ahora para reducir gases de efecto invernadero (GEI), especialmente en la Unión Europea (UE). El capítulo 2 presenta una revisión detallada de la literatura sobre las aplicaciones ambientales de los modelos CGE, incluyendo temas tales como el agotamiento de los combustibles fósiles y la política energética, y más recientemente, la reducción de emisiones de GEI, y los efectos del cambio climático. El capítulo 3 describe las diversas fuentes de datos utilizados en la construcción del modelo. La fuente más importante son las Tablas Input-Output (IO) suministradas por el Instituto Nacional de Estadística (INE). Otras fuentes de datos incluyen la Convención Marco de las Naciones Unidas sobre el Cambio Climático (CMNUCC) para las emisiones de gases de efecto invernadero procedentes de fuentes específicas, y el Fondo Español de Garantía Agraria (FEGA) para los valores de los subsidios agrícolas en España. El capítulo 4 está dedicado a una documentación completa del modelo Orani-ESP-Green (OEG), que se utiliza para ejecutar los distintos escenarios de política climática. El Capítulo 5 describe los escenarios que sirven para evaluar el impacto de las políticas alternativas modelizadas. El primero es un marco de referencia de continuidad –(en inglés, *'business as usual' baseline*)-, presentando un mundo en el que ni los gobiernos españoles ni extranjeros toman ninguna acción para mitigar las emisiones de gases de efecto invernadero. Todos los demás escenarios imponen compromisos de reducción de emisiones de España en virtud de la legislación del cambio climático de la UE. Esto se traduce en una reducción del 21% en el régimen de comercio de emisiones (ETS) entre 2005-2020, y una reducción del 10% en las emisiones del 'sector difuso' - transporte, desechos, los edificios y la agricultura - de acuerdo con la Decisión sobre esfuerzo compartido. Estas simulaciones se ejecutan en versiones del modelo con y sin curvas de coste marginal de reducción (CMR) para el sector agrícola, calibradas con datos de ingeniería relacionados con el potencial y el coste de diversas tecnologías de reducción. En este capítulo también se presentan los resultados, con una discusión de los principales impulsores, y las implicaciones de la incorporación de las curvas CMR en el modelo, las cuales constituyen una aportación metodológica importante. El Capítulo 6 presenta una serie de escenarios adicionales y resultados, extrayendo varias opciones para la reinversión de los ingresos procedentes de los impuestos ambientales para promover ciertos objetivos de política, por ejemplo el aumento del empleo rural. Capítulo 7 concluye con un resumen de los principales mensajes de la tesis, advertencias y recomendaciones para futuras investigaciones.

Conclusiones

Un resultado del capítulo 5 es que la extensión del modelo que incluye curvas CMR calibradas para la agricultura induce una modesta reducción en el coste en términos macroeconómicos de las restricciones a las emisiones en España en términos del PIB real (1,2% inferior a la línea de base en 2020 sin curvas CMR, 0.9% inferior con curvas CMR) y el empleo (1,4% inferior sin curvas CMR, 1,0% inferior con curvas CMR). Los datos para las curvas CMR sugieren que, comparando todas las actividades agrarias, hay más opciones de bajo coste para la reducción en el ganado que en los sectores de cultivos. Este hecho tiene implicaciones importantes de cara a los resultados del modelo, ya que la inclusión de las curvas CMR permite al sector ganadero reducir sus emisiones con menor coste, dando a los sectores de cultivos más margen para reducir sus emisiones menos, o incluso aumentarlos. Esto es importante porque en la versión pre-CMR del modelo, las emisiones del ganado sólo podían caer a través de una contracción de la producción, mientras que los sectores de los cultivos podían sustituir otros factores de la producción de fertilizantes contaminantes para reducir sus emisiones. Incluyendo las curvas CMR por lo tanto altera la carga de la reducción de emisiones en el sector agrícola de manera significativa. A pesar de esto, los aumentos de precios inducidos por las políticas y las contracciones de la producción se reducen de manera bastante uniforme en todos los sectores agrarios, dado que las emisiones agrarias siguen enfrentándose a una tasa de impuestos uniforme, aunque mucho menor en comparación con el experimento incluyendo las curvas CMR. Así, la caída de la producción en relación con el escenario de referencia (baseline) es de alrededor de un 20% mayor en el ganado que en los cultivos, y esto es un resultado consistente con o sin las curvas CMR. La inclusión de las curvas CMR reduce el coste directo de la política de reducción de emisiones para los agricultores (impuestos sobre emisiones más gastos de reducción) en alrededor de un 70%

Cuando se aplica la reducción de emisiones como un objetivo global, la concentración de la reducción de emisiones en el sector ganadero permite a ciertos productos claves de exportación españoles (frutas, verduras y aceitunas) un grado de holgura para aumentar su producción. Cuando cada industria agrícola específica tiene que reducir sus emisiones en un 10%, estos son los sectores para los cuales es más costoso. Como resultado del objetivo de reducción agregada de las emisiones por 10%, la muestra el mayor potencial para mejorar la balanza comercial española. En el otro extremo del espectro, para el ganado vacuno y la cría de ovino, que cuenta con la mayor reducción de las emisiones de todos los sectores agrarios en el marco del objetivo global, el objetivo de reducción del 10% aplicado específicamente no es vinculante, es decir, el impuesto sobre las emisiones en ese escenario es €0.

Los resultados del Capítulo 5 sugieren que se pueden derivar beneficios macroeconómicos de la utilización de esquemas de límites máximos y comercio de derechos de emisión, asumiendo que tal mecanismo fuese factible. En cualquier caso, la evidencia sugiere que un movimiento gradual hacia actividades menos intensivas en emisiones está ya en marcha en la agricultura española, y la política podría complementar esta tendencia si se permitiera a estos sectores una cierta flexibilidad para aumentar las emisiones, y hace un esfuerzo para concentrar la reducción en aquellos sectores donde es más barata.

Los resultados del capítulo 6 sugieren que la reinversión de los ingresos procedentes de los impuestos sobre emisiones agrícolas como subsidio de mano de obra poco cualificada sería la opción política más beneficiosa para la mejora del empleo y la balanza comercial. Hay dudas sobre la conveniencia de incentivar trabajos "poco cualificados" sin embargo, y el impacto que esto puede tener en la formación de capital humano. Si se consideran los costes políticos o administrativos de este enfoque como prohibitivamente altos, un subsidio a toda la mano de obra agrícola sería una buena segunda mejor opción para mejorar los costes de reducción de emisiones acordados. En realidad, por supuesto, una 'subvención' como ésta se implementaría como un recorte en los impuestos sobre la nómina, lo que aliviaría considerablemente la carga administrativa.

1. Introduction

1.1. The threat of climate change

Successive reports of the Intergovernmental Panel on Climate Change (IPCC) have established both the risks associated with climate change, and the scientific consensus that human action is a contributing factor. Some of the consequence of climate change include freshwater scarcity, river and coastal flooding, species extinction and loss of biodiversity, reduced fish stocks and crop yields with implications for global food production, increasing forest fires and extreme weather events such as heat-waves or extreme precipitation, and increased prevalence of food- and water-borne diseases (IPCC, 2014).

Humans contribute to climate change by burning fossil fuels which release carbon dioxide (CO2); by industrial processes which release methane (CH4), nitrous oxide (N2O) and other Greenhouse Gases (GHGs), and by land use change, which may release carbon stored in biomass. Data from various ice core reading stations show that atmospheric concentrations of each of these three gases fluctuated cyclically for hundreds of thousands of years during the prehistoric period, and have risen sharply to reach record levels since the 1950s[1] (though this result is less clear for nitrous oxide), while current NASA data suggests the mean global temperature has risen around 0.5°C from its average level in 1950-80[2].

As a Mediterranean country with some of the highest cities in Europe, and its southernmost point just nine miles from Africa, Spain faces specific risks from the changing climate. The National Plan for Adaptation to Climate Change (MAGRAMA, 2006) notes among them reduced precipitation leading to water scarcity; decreasing biodiversity, partly from the invasion of exotic species of flora; the damage extreme weather could do to human health and well-being, and its adverse effects on the tourist industry; dangers to coastal zones; increasing risk of forest fires, and reduced crop and livestock yields from rising temperatures.

1.2. Policy responses: global, regional, national

Since the signing of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, the global community has taken the need for mitigatory action ever more seriously. The first legally binding agreement on countries to reduce their GHG emissions, The Kyoto Protocol, was signed in 1997, committing signatories to specified reductions by 2012. Since then, all parties have agreed that global temperature change must be kept at or below a 2°C increase. In addition, a number of initiatives have emerged from the UNFCCC's annual Conference of Parties (COP) such as a 'green climate fund' to scale up climate financing for developing countries, a rulebook for reducing emissions from deforestation, and progress towards another

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[1] http://www.epa.gov/climatechange/science/indicators/ghg/ghg-concentrations.html

[2] http://climate.nasa.gov/vital-signs/global-temperature/

binding global agreement to replace the Kyoto Protocol. It is hoped this will be reached at the next COP meeting in Paris at the end of 2015.

As one of the few groups of countries which enters climate negotiations as a single bloc, the European Union (EU) has emerged as a leader in setting ambitious targets for reducing emissions, and devising innovative policies to bring those reductions about. Under Kyoto, the EU15 committed to reducing emissions to 92% of their 1990 levels by 2012 (UN, 1998) – a target which has recently been met. The (unilateral) commitment is now to reach 80% of 1990 levels by 2020, with proposed targets of 60% by 2030 and 5-20% by 2050 (European Commission, 2011). The EU's flagship policy for emissions reduction to date has been its Emissions Trading Scheme (ETS), which began in 2005. The scheme covers CO2 emissions from industry and energy generation, and has recently expanded to include aviation and chemical production. Emission permits are allocated to national governments which, initially, distributed them among polluting firms based on historic emissions (known as 'grandfathering'), though a move towards auctioning an increasing proportion of permits is underway. Permits are then traded among participants with the price dependent on demand and supply. The theory behind this 'cap-and-trade' approach is that abatement will occur in firms and industries where it can be done at the lowest cost, leading to an economically efficient outcome. The EU has been criticised for oversupplying the market though, and the permit price has generally remained well below a level where it could act as a significant incentive for firms to take action to reduce their emissions.

Responsible for 8% of EU emissions in 2007 (UNFCCC, 2015) Spain has a significant role to play in the move towards a low-carbon Europe. However, the somewhat volatile economic performance of the country over the last 20 years has often presented policy-makers with a challenge. A structurally high unemployment rate and low productivity relative to its Western European neighbours have left successive governments unwilling to take any action that might compromise economic growth, particularly during a period of 'convergence' to other, wealthier Member States in the last years of the 20th, and first of the 21st, centuries. As a result, Spanish emissions increased by around 50% between 1990 (the Kyoto base year) and 2007 (UNFCCC, 2015). Although they have fallen off more recently as a result of the financial crisis which began in 2008, by 2012 they were still 20% above 1990 levels – higher than Spain's Kyoto target of a 15% increase (UNFCCC, 2015). Nevertheless, in 2007 the government approved a Spanish Climate Change and Clean Energy Strategy, the stated objectives of which are to enable Spain to meet its climate change commitments and move the country towards energy consumption patterns which are compatible with sustainable development (MAGRAMA, 2007). However, in 2012-13 government support for renewable energy was significantly scaled back due to budget constraints (Dreblow et al., 2013). Those sectors not covered by the ETS have progressed towards the target of a 10% reduction between 2005 and 2020, but it is unclear the extent to which this is because of the crisis, and whether these emissions will continue to fall when economic growth returns.

1.3. The role of agriculture

Addressing the role that Spanish agriculture has to play in contributing to nationwide emissions reductions forms the central purpose of this thesis. In 2007, the benchmark year for this study, agriculture was responsible for 10% of total Spanish GHG emissions, and 61% of non-CO2 emissions [REF]. The imperative for action in the agricultural sector is very real, as it is likely to be the industry most dramatically affected by the changing climate, as changing landscapes and increasing extreme weather events lead to changes in soil yields and crop patterns, and pose risks to animal health, welfare and productivity.

Around half of the emissions under the 'agricultural' heading in UNFCCC data[3] is N2O from agricultural soils, a third is CH4 from enteric fermentation, and the remainder is mostly N2O from manure management, a composition which has remained relatively consistent since the data began in 1990. In 2012 overall agricultural emissions were back at almost exactly the same level they were at this base year, having reached a peak 16% higher this level in 2003, and dropped back down since then (UNFCCC, 2015). In broad terms this mirrors the pattern shown by total emissions (see above), although both the increases and the decreases are less pronounced in agricultural emissions (Figure 1.1), suggesting they are less susceptible to the vicissitudes of the economic cycle than are non-agricultural emissions.

Smith et al. (2012) present a comprehensive list of the mitigation options available in the agricultural sector. In croplands they include extending agronomic practices which increase the carbon and/nutrient retention in the soil, such as crop rotation or mulching; efficient application of nitrogen fertiliser; reduced or zero tillage to prevent soil disturbance; water management techniques to suppress N2O emissions and strategic drainage of paddy rice fields to reduce CH4 emissions. For livestock, they note the importance of grazing practices, which may determine whether livestock grazing acts to increase or reduce the carbon content of pasture. Additional measures for livestock include dietary modifications to reduce methane emissions from enteric fermentation, and breeding to improve productivity over the longer term. Anaerobic digestion plants and the improvement of storage facilities and can significantly reduce emissions from manure management.

An idea gaining momentum in policy circles at the moment is that of the 'bioeconomy' (M'barek et al., 2014). The term groups together those sections of the economy which are dependant in the first instance on raw materials grown on the land. Thus food and feed production, bioenergy and biochemicals are all part of the 'bioeconomy'. Its role is to produce renewable biological resources and convert them (including, importantly, the associated waste streams) into value added for the economy. This holistic approach sits well

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[3] http://unfccc.int/di/DetailedByParty.do

within the environmental economics and economic systems literature, where it is acknowledged that a sustainable system must not use renewable resources at a rate quicker than they are renewed, and must not produce more waste than the (in this case ecological) system can absorb. The bioeconomy approach seeks both to make the use of renewable resources more efficient, and to reduce waste outputs by converting them into productive resources. Abatement technologies which, for example, convert methane from cattle into energy through anaerobic digestion plants, or ensure that fertilisers are applied with the optimal timing and precision to reduce waste nitrous oxide, are part of this approach.

Despite the relatively small direct contribution of the agricultural sector to total emissions in a developed economy such as Spain, these developments have given a fresh impetus to research into issues around land use, and the contribution of agriculture to overall emissions reduction. This contribution sits within this strand of the environmental economics literature as a study of the potential for the abatement of agricultural emissions, set within the context of the policy-mandated emissions reductions faced by all sectors of the Spanish economy. The work would be greatly enriched by future research on the role of forestry and other forms of carbon sequestration, to complete the picture of an emerging, low-carbon bioeconomy.

1.4. Methodological framework: the OEG model

This study presents a Computable General Equilibrium (CGE) model designed for agricultural and environmental policy analysis, and uses it to assess the role of the Spanish agricultural sector in helping Spain to meet its EU mandated targets for reducing Greenhouse Gas (GHG) emissions by 2020. One objective of the study is to analyse the macroeconomic impacts on the Spanish economy from its shared commitment to reduce greenhouse gas emissions, which have been agreed at the EU level. The detailed treatment of agriculture in the model, however, makes it uniquely suitable for a focussed assessment of the ways in which agricultural emissions can contribute to the overall target. Thus the primary application of the model is an investigation of how emission reductions are distributed among different agricultural industries. A further application of the model is presented which evaluates a number of 'revenue recycling' options for using environmental tax revenues raised as a by-product of emissions reductions. These can be targeted towards achieving specific policy goals in the agricultural sector, such as increasing rural employment or food security, or promotion of the bioeconomy in Spain (M'barek et al., 2014).

The 'Orani-ESP-Green' (OEG) model is a single country, recursive dynamic, demand led CGE model based on a system of neoclassical final, intermediate and primary demand functions. It comes from the 'ORANI' suite of models (Horridge, 2000) and is a further modified version of the Spanish model 'Orani-ESP' (Philippidis, 2010). The model is supported by Input Output (IO) tables and national accounts data which enable the construction of a Social Accounting Matrix (SAM) for the benchmark year (2007). The comprehensive sectoral coverage of the model facilitates the analysis of policies which have implications for the whole economy, such as emissions reduction targets. In addition, it enables researchers to explore secondary effects which may not be obvious from cost-benefit analyses or partial equilibrium (PE) models. A detailed treatment of the agricultural sector has been maintained from the Orani-ESP model (Philippidis, 2010), meaning emissions targets in this industry can be analysed in conjunction with existing agricultural policy mechanisms such as the Common Agricultural Policy (CAP). The study is innovative in its incorporation of biophysical data on so-called 'end-of-pipe' abatement technologies which allow the incorporation of bottom-up Marginal Abatement Cost (MAC) curves for the agricultural sectors into the model. This allows for a considerable increase in the realism of simulations of industry response to emissions restrictions than is usually available in top-down CGE models.

The next chapter presents a detailed literature review of the history of environmental applications of CGE models, with the first part describing the most significant modelling innovations in this area, and the second focussing on the policy questions to which such models have been applied. A final section gives a much more concise overview of some of the recent literature on GHG mitigation options and costs in agriculture. Chapter 3 describes the challenges associated with constructing a database for use with the OEG model, which in this study is benchmarked to the year 2007. Chapter 4 gives a detailed outline of the structure and behavioural equations of the model, focussing particularly on the environmental extensions which form the basis of this study, and on the detailed treatment of the agricultural sector, which plays such a key role in simulation results. Chapters 5 and 6 present these results. In Chapter 5, the primary application of the model is presented: an analysis of the effects of EU-mandated reductions in GHG emissions on the Spanish economy generally, and on Spanish agriculture specifically. Two versions of the model are compared: one with calibrated MAC curves for agricultural emissions, one without; in order to isolate the effects of this addition to the model. Two policy options are also compared: a single target for aggregate agricultural emissions with a uniform emissions price, and a set of industry-specific targets, each with its associated emissions price. Chapter 6 compares various options for recycling the revenue raised from environmental taxes in the agricultural sector. Chapter 7 concludes.

2. Literature Review

2.1. Introduction

In the introduction to his survey of the use of Computable General Equilibrium (CGE) models in the analysis of environmental policy, Wajsman (1995) observes three main advantages. These are worth making a note of here, as they effectively serve to justify the majority of the studies which will be mentioned in this chapter, as well as framing the more detailed issues they seek to address.

Wajsman's first observation is that, in contrast to the private cost estimates widely used at his time of writing, general equilibrium analysis is based on the idea that agents modify their behaviour in response to changes in income and prices. To illustrate the point with an example, a carbon tax is likely to increase the price of petrol, causing consumer demand for petrol to fall, while demand for more fuel-efficient cars rises[4]. Within the (declining) petroleum sector, though, there is also likely to be a change in the structure of production, as firms seek to mitigate cost increases by substituting the most polluting fuels for 'cleaner' equivalents, such as ethanol. Failure to account for this adaptation potential will lead to overestimates of the cost of legislation.

Secondly, there may be important secondary effects on other industries not directly affected by the new tax. In the above example, growth in biofuels industries will mean increased competition for land, which will drive up costs in the agricultural sector, whilst manufacturing sectors may see their engineers depart for the automobile industry to work on fuel-efficiency. These indirect effects may serve to make environmental policies more or less costly, but in a world of finite resources they will be present.

Finally, use of the CGE method allows the modelling of various policies simultaneously. Given the often complex (and sometimes strained) relationship between environmental objectives and other policy goals (in relation to, for example, economic growth or income distribution), this is an important feature in analysing the impacts of legislation. To conclude the above example, this could include seeing how environmental targets interact with agricultural subsidies, or plans to reduce the budget deficit.

This chapter will review the use of CGE models in environmental analysis, focussing first on the major modelling advances, and then on the various policy and scenario applications which have been analysed. Section 2.2. traces the early days of general equilibrium modelling applications to energy and environmental issues, with particular focus on energy and fossil fuels, during and after the oil shocks of the 1970s, and on the treatment of dynamics in the economic models. Also included here are the major modelling developments of the 1990s, when the issue of global warming became a more pressing concern. These first energy/environment CGE applications are of great interest as, although the authors were often limited by

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[4] subject, of course, to the relevant price elasticities of demand.

computational facility, they are the first studies to acknowledge and describe the challenges associated with using general equilibrium models to tackle environmental problems. Many of the issues they highlighted then are still live debates today, and some will be addressed in this thesis. To take two examples, section 2.2. includes separate discussions on the issues of technological progress and environmental feedback effects in CGE models. Both of these have significant implications for the modelling of climate policy as they both play an important role in determining the ability of industries to reduce their GHG emissions in response to policy-induced price rises, or regulations. This section will also cover the complex issues of to what extent land-use change, forestry, and carbon sequestration have been addressed by CGE modellers, as these are all directly linked to the agricultural sector. Section 2.2. concludes with a more recent development in CGE models, namely, attempts to incorporate biophysical data on abatement technologies into what are essentially deterministic market models. This particular modelling extension constitutes a major advance of the current study.

Section 2.3. reviews the CGE literature relating to GHG mitigation costs, in some cases under different policy options. The studies included in this section analyse the Kyoto protocol, the EU's emissions reduction targets, various proposed and existing emissions trading schemes and options for specific uses for the revenues from environmental taxes. In light of the Spanish focus of this thesis, section 2.3. also reviews the relevant CGE literature with particular focus on the Spanish economy.

The third section moves away from economy-wide studies to focus solely on GHG mitigation in agriculture. The purpose of the current study is to explore the costs to the agricultural sector of meeting the mandated emissions reduction targets, so it is important to gain some understanding of the mitigation options available within agriculture, and how those are likely to affect policy decisions.

2.2. Modelling advances

2.2.1. Studying the process of change: the role of dynamics

Hudson and Jorgenson (1974) constructed a model which drew on both the econometric approach developed by Goldberger and Klein (1955) and the Input-Output analysis of Leontief (1941). Their purpose was to project a macroeconomic growth path for the U.S. economy, including inter-industry demands for intermediate inputs and factors of production determined by producer behaviour. This study demonstrates three principal uses of CGE in energy/environmental analysis: to project forward a 'business-as-usual' baseline, which allows analysts to explore the possible future structure of the economy in the absence of significant unforeseen changes; to analyse the impact of a given change in policy (in this case, energy taxes); and to estimate the level at which a policy (such as a tax) must be applied in order to meet a given objective (in this case, energy independence). These three uses will be seen repeatedly throughout the papers discussed below, and in this study.

The authors extended their work with an in depth analysis of the dynamic effects of energy policy on economic growth in Hudson and Jorgenson (1978), a subject also touched upon in Hazilla and Kopp (1990) and Adams et al. (2000a). The common thread in all three studies is that restrictions on energy use or pollution reduce economic output in the short run, and growth in the long run, by reducing the productivity of labour and capital, as both have less energy to work with. In the short run total output is a function of the stocks of these factors and their productivity, so reducing the latter causes a contraction in the productive capacity of the economy. In the long run lower capital returns discourage investment, and a lower real wage encourages workers to substitute leisure for labour (assuming an upward sloping labour supply curve). Thus in the long run both factor endowments and their productivities are reduced, resulting in a lower rate of growth than that which would have arisen in the absence of restrictions.

Another set of papers uses dynamic CGE models to explore the idea of 'optimal pathways' for greenhouse gas emissions over time (Nordhaus, 1990; Nordhaus, 1992; Hamdi-Cherif, 2012). These inter-temporal models aim to map the optimal level of emissions at any given point in the simulation period. Technological progress means abatement is relatively cheaper in later periods, but an environmental damage module means there is a net present value to avoided emissions in early periods as they do not add to stocks of pollutants. Martin and van Wijnbergen (1986) use a similar concept to map out an optimal use pathway for natural resource depletion, based on the seminal work on the subject by Hotelling (1931). This maps the rate at which a scarce resource is used up to the development of alternative technologies which do not rely on the resource and to the net present values of current and expected future returns to using the dwindling resource in different periods. These studies all have to deal with the question of the discount rate, i.e. the weight which the material welfare of future generations is given relative to that of the current generation. This is a difficult issue for economics as it concerns questions of ethics as well as efficiency – the Stern Report on Climate Change (Stern, 2007), for example, controversially used a discount rate of zero. It should be noted that (due largely to the short timeframe under consideration) the current study also implicitly assumes a discount rate of zero, such that a euro of consumption, after adjusting for inflation, provokes the same increase of utility in 2020 as it does in 2008.

Manne and Martins (1994), Dellink (2000) and Gerlagh et al. (2002) all compare results for their policy scenarios using different types of general equilibrium model: comparative static (CS), recursive dynamic (RD) and inter-temporal (IT). Dellink (2000) notes the difficulty of comparing results from the first (a single result for when the policy is applied essentially all at the same time) to those from the other two (results are given for each time period in the model, and policies can be applied in temporal stages). Nevertheless, the study finds the GDP loss from the environmental policies to be greatest in the CS model, as the abatement process depends on investment in alternative technologies and capital formation over time - a dynamic process which will always be limited in a CS model. A consistent finding across the studies mentioned is that the movement from an RD to an IT model has two effects on the inter-temporal distribution of emissions, and they pull in different directions. On the one hand, myopic agents in RD models tend to delay action to reduce emissions until later periods, meaning emissions are front-loaded. On the other hand, consumers with perfect foresight in IT models can predict the future price rises which will result from emissions restrictions, so they substitute relatively cheaper early-period consumption for its relatively more expensive later counterpart, which also acts to concentrate emissions in early periods. As a result it is unclear whether the inter-temporal distribution of emissions will be more even in RD or IT models. One unambiguous finding of the Gerlagh et al. (2002) study, supported by Paltsev et al. (2003), is that in policy scenarios which include the 'banking' of emissions permits for use in future periods, results from IT models suggest a much greater take-up of this option than do those from RD models. The current study uses a recursive-dynamic model, so some volatility in year-to-year results should be expected. Over the relatively short-term period under consideration the RD approach seems more appropriate as IT models frequently implicitly assume that the time horizon of consumers only extends over the period of the study, which in this case is just thirteen years.

2.2.2. Energy-economy models

Rutherford and Montgomery (1997), Böhringer (1998) and Böhringer and Rutherford (2008) all combine the 'bottom-up' detail of an energy model with the 'top-down' interactions of a CGE model. In the first paper the GE model derives energy demands which are an input into the partial equilibrium (PE) model used to derive energy prices, which then feedback into the GE model – an iterative process which repeats itself until the results of the two models converge. The latter two studies take complementarities present in the GE model and make them specific to the energy sector such that certain types of plants come online when their profits are zero (i.e. non-negative), and a non-zero price for a specific energy source emerges when demand reaches supply, with plant costs and capacities coming from bottom-up energy data.

An alternative way of simulating the energy sector in a CGE model is to focus on energy in the 'nested' production function that determines the degrees of substitution between the various factor and intermediate inputs for a given industry. The BMR model (Babiker et al., 1997) has an 'energy composite' used as an input along with other factors and non-energy inputs. Additional levels of the nested structure produce this composite from different energy sources, distinguishing between on the one hand electric and coal, and on the other hand oil and gas. This approach is very similar to that used in the current study.

Another model with an energy nest similar to that found in the Orani-ESP Green (OEG) model is the OECD's GREEN model (Burniaux et al., 1992; Lee et al., 1994). In this model the energy nest includes, like that in the BMR model, a top level where firms choose between an electricity composite and non-electrical energy. At the next level down the non-electrical composite divides into coal on one branch, and an oil and gas composite on the other, and at a further level down the oil and gas composite splits into those two fuels. This approach is also that adopted in the GTAP-E model (Burniaux and Truong, 2002), the MMRF-Green model (Adams et al., 2000b), and the ORANI model (Horridge et al., 1993) which forms the basis of the Spanish OEG model used in this study. By contrast, Hinchy and Hanslow (1996) use a 'technology bundle' approach. In this method, the top level of the nested production function is a Leontief function of the composite technology bundle, and a number of other intermediate inputs. The technology bundle composite is then a Constant Ratio of Elasticities of Substitution, Homothetic (CRESH) function of a number of discrete technology options, each of which is a Leontief function of factors of production, energy and, in some cases, natural resources.

Sue Wing (2006) uses a variant of the technology bundle approach and compares it to a smooth Constant Elasticity of Substitution (CES) function for electricity generation. The smooth ('top-down') production function distinguishes between fossil and non-fossil generation, with the former based on a CES between different types of fuel, which are then combined with material inputs and, higher up the nest, factors of production. In the generation of non-fossil electricity a composite of primary energy resources (wind, sun, uranium etc.) is combined with a capital-labour-materials composite at the top level of the nest. Total electricity generation is then a CES function of these two different types, with a high elasticity reflecting the homogeneity of the electricity produced. This treatment also separates the costs of transmission/distribution and other overheads in the sector from the generation itself. The author notes that given the Leontief functions for generation by each of the technology bundles, capital used in generation effectively becomes a fixed factor which represents the capacity of the given technology. Perfectly mobile capital would result in complete swings towards a single technology from even a small change in relative prices (the so-called 'flip-flop' problem), whilst perfectly immobile capital would forever limit the capacity of each technology to that available in the benchmark year. Thus a Constant Elasticity of Transformation (CET) function governs the movement of capital from malleable (for use in all other industries) to technology specific (for use in electricity generation) and back.

2.2.3. A Note on the Capital-Energy Relationship

The issue of whether capital and energy are complements or substitutes, and the strength and consistency of that relationship, has been an issue of much debate and experimention in the economics literature, and it remains a contentious one. Lachmann (1947) writes eloquently of how 'complementarity' essentially describes a specific plan – or how inputs are combined to achieve a specific objective (in our case, cost-minimisation), whilst 'substitution' refers to the ability to adjust that plan in the light of changing circumstances (in, for example, the macro- or policy-environment). Thus, many inputs are likely to be complementary in a static equilibrium, but substitutable in a dynamic movement towards a new equilibrium.

This idea poses no inherent difficulty for CGE models. The static equilibria are represented by the start- and end-points of the simulation, at which times the production structure of each industry is given. In the movement between those two points, inputs may be substitutes or may remain complements (i.e. have fixed

IO coefficients), with the ease of substitution likely to vary between industries and inputs. In fact, in many ways the use of CGE modelling *is* the study of the ability of the economy (made up of all its component agents) to adjust in the light of changing circumstances. Thus in the context of Professor Lachmann's distinction, the latter relationship is the crucial one.

2.2.4. Different pollutants and environmental feedback

One of the noted strengths of CGE models is their ability to model various policies and track numerous indicators and how they all interact with one another. Examples of this can be seen in those models which include various different pollutants, and how control policies for one of them can affect emissions of the others. Alfsen (1991), for example, includes 9 different pollutants in his model of Norway (based on the pioneering early work of Johansen (1964)), while Bergman (1991) simulates policy mandated restrictions on emissions of SOx and NOx in Sweden, and finds that CO2 emissions fall also as a result, suggesting they are complementary. Looking at the same issue from the other side, Rypdal et al. (2007) and Rive (2010) find that targets for reductions in CO2 emissions are likely to improve air quality by inadvertently causing a reduction in emissions of SO2, NOx and PM2.5.

In the environmental extension to his Input-Output framework, Leontief (1970) illustrated the importance of how pollution is assigned by taking the data for emissions by industry, and reallocating it on the basis of emissions embodied in final demands. In presenting, if only briefly, this form of analysis, Leontief showed an early form of the so-called 'farm to fork'[5] method of measuring total emissions associated with the production of a given agricultural commodity, which has recently become increasingly popular in academic and policy circles (FAO, 2010). In the same study he extended the notion of 'input-output coefficients' to 'discharge coefficients' which attach pollution to output or to the use of certain inputs in specific industries. A similar approach was adopted by Willett (1985), Conrad and Schöder (1991) and numerous studies since. Indeed for most emissions this is the method used in the current study, though for some sectors these discharge coefficients are not fixed (see section 2.2.7 below on end-of-pipe abatement).

In the DICE global climate change model, and its regional counterpart RICE, Nordhaus (1990) and Nordhaus and Yang (1996) include an environmental damage function which translates stocks of greenhouse gases in the atmosphere (which grow each year with emissions) into radiative forcing[6] which provokes a global temperature increase causing economic damage, the severity of which varies between industries. The GEM-E3 model (Capros et al., 2013) tracks the stocks of a number of different pollutants, and translates them into specific geographical areas and damage functions. Concentration of pollutants causes damages to

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[5] 'Farm-to-fork' is the basis for an EU project to increase efficiencies across the food supply chain, taking a holistic view of food production and distribution. See http://www.rfid-f2f.eu/.

[6] 'Radiative forcing' is a concept used to isolate anthropogenic from natural climate change. It translates into global surface temperature change through a simple linear function $\Delta T = \alpha RF$, where α represents climate sensitivity (Ramaswamy et al. 2001).

human health, soils, forests, buildings and territorial eco-systems. Other studies which include feedback mechanisms from the environment to the economy include Vennemo (1997) and Xie and Saltzman (2000). Both contain a negative relationship between increasing pollution and factor productivity, and a direct effect of pollution on utility. A more straightforward approach is taken by Gerlagh et al. (2002), which adds the cost of environmental restoration to government expenditure for nine different environmental problems, and ensures that a government defined level of 'sustainability' is reached for each one through the issuance of permits.

2.2.5. Land use change and forestry

Haksar (1997) and Persson and Munasinghe (1995) use CGE models to explore the effects of property rights and various taxes and subsidies on land use. Both studies account for two different causes of deforestation: loggers clearing the land for timber, and squatters clearing the land for sale to the agricultural sector. In the absence of property rights, neither of these agents account for the future value of the forest in their decisions as to how much deforestation to undertake, and neither labour nor capital used is taxed, since they form part of the informal economy. When property rights are defined, an 'opportunity value' is set on preserving the forest for future use, and capital and labour used to cut down trees enter the formal economy, and hence are taxed. A common finding is that while property rights do reduce deforestation dramatically, this result varies with the interest rate and the (exogenously set) opportunity value of the forest, while increasing costs as a result of factor taxes cause an increase in timber imports – essentially a 'deforestation leakage' problem, whereby trees are cut down in the rest of the world, rather than the domestic country.

Ahammad and Mi (2005) adapt the Global Trade and Environmental Model (GTEM) to include eighteen different land types based on Agro-Ecological Zones (AEZs). In addition, the stock of forest area is disaggregated by age, land class and management type, with different carbon densities associated with each. A CET function determines at the first level the movement of land between agriculture and forestry, and then at higher levels the movement of land between different agricultural uses. While most GHG emissions from agriculture are attached to fertiliser use or livestock output, emissions of N2O from soil disturbance are dependent on the area of land used for agriculture. Net emissions from forestry depend on the change in the carbon stock of forest land, which is a function of the area de- or re-forested, its timber yield, and associated carbon stocking density. Policies to regulate or tax emissions are thus likely to encourage forestry at the expense of agriculture by effectively subsidising land used in forestry and taxing the agricultural sector.

This approach is also used in Golub et al. (2009), with some variations. The paper contains a detailed treatment of the rate at which previously inaccessible forests are accessed depending on the land rents available and the cost of accessing land. Rents increase with the demand for crop, livestock and forestry products, which leads to a derived demand for land, while costs increase with the proportion of total land which has been accessed, reflecting the fact that as more land is demanded, the land coming into production is more marginal and so costs more to access. This leads to a Ricardian treatment of land rents whereby inaccessible land will be brought into production when the net present value of the land is equal to the cost of accessing it, so as accessed land increases, rents will rise on previously accessed land.

Bosello et al. (2010) use a CGE model to analyse the importance of the scheme 'Reducing Emissions from Deforestation or forest Degradation' (REDD) in EU emissions reduction targets for 2020. In their model avoided deforestation in Latin America, Sub-saharan Africa and South East Asia generates carbon permits which can be sold on the EU ETS market. This results in a transfer of payments from the EU to those regions, but also reduces land available for agriculture, and timber available for wood products. They find that the inclusion of REDD credits significantly reduces the ETS permit price, but also leads to an increase in the price of land, which is strongest in South East Asia, and timber, strongest in Sub-Saharan Africa.

A number of studies use CGE models to investigate the effects of the recent growth in biofuels production on land use change and on emissions reduction possibilities. One such paper is Birur et al., (2008), which modifies a version of the GTAP-E model to include biofuels used by both consumers and producers, and land use type by AEZ. The paper distinguishes between cereal- and sugar-based bioethanol and biodiesel from vegetable oil. Consumers in the model treat each type of biofuel as highly substitutable with petrol, whilst in the production process, ethanol is treated as a complement to petrol use, with an elasticity of substitution equal to zero. On the supply side, a CET function governs the ease with which land of each AEZ can move between different uses, with a much higher elasticity between different crop types than crops and pasture, or at the most extreme agriculture and forestry.

2.2.6. Technological change – progress in the study of progress

A history of endogenous technological change in economic modelling could easily fill its own literature review. The focus of this one, however, is the advances in the implementation of technology in CGE models, particularly (but not exclusively) when that has direct implications for how the economy adjusts to environmental legislation.

Sue Wing (2003) describes climate change as the "litmus test" of induced technical change (ITC), on the grounds that the current lack of large scale substitutes for fossil fuels mean that the costs of mitigation are likely to be high, and technological advances must play a central role. Nevertheless, extending CGE models to allow for ITC raises many challenges, some of which remain unsolved.

An early approach, used by Conrad and Henseler-Unger (1987), was to have newer capital more productive than the older capital it gradually replaced ('vintaging'), with the rate of replacement dependant on depreciation and investment. A more sophisticated alternative was that adopted by van Bergeijk et al. (1997), which modifies an established applied general equilibrium model of the Netherlands such that production capacity is a function of *effective* labour and *effective* capital. The former is composed of human-capital as well as labour itself, and the latter includes technology as well as physical capital. Human-capital is increasing in private investment, private and public spending on R&D, and public spending on education, whilst it is decreasing in marginal tax rates on labour – as these are a disincentive to invest in human-capital. The growth of technology-capital is purely dependent on R&D expenditure. Human capital increases the productivity of labour, and technology the productivity of physical capital. Despite the fact that it makes no mention of climate change, or carbon abatement potential, this study has been included because, in addressing human- and technology-capital, it opens the door to issues which, as the studies below show, have significant implications for the modelling of abatement potential, and thus the likely costs of environmental regulation, in a general equilibrium framework.

Goulder and Schneider (1999) essentially combine human- and technology-capital into a single factor called 'knowledge-capital', which contributes to output at the highest level of the production structure. They distinguish between 'spillover knowledge', which is non-excludable and indicates that firms are benefitting from industry-wide innovation, and 'appropriable knowledge' which is a direct function of firms' own spending on R&D. Both forms of knowledge capital are, to varying degrees, substitutable with all other inputs such that, as in van Bergeijk et al. (1997), R&D spurred technological innovation means that production can increase without a concomitant increase in the use of factors, energy, and intermediate inputs. A similar approach is adopted in Wang et al. (2009) in testing the effect of an R&D subsidy on the cost of abatement.

One point of interest from Goulder and Schneider (1999) is the treatment of energy. At the lowest level of the nested production function, firms have the ability to substitute between carbon energy and 'alternative' energy. The use of alternative energies by industry is initially small, but not insignificant, and the effect of a carbon tax (the scenario modelled by the paper) is felt both in the substitution away from carbon energy and towards the carbon-free alternative, and in the build-up of knowledge in the alternative energy sector relative to the carbon energy sector (as the latter has suffered a relative increase in its tax rate and so has fewer resources to devote to R&D), which results in a relative increase in the productivity of alternative energy. A possible alternative, demonstrated in Manne and Martins (1994), is to have one or more carbon-free 'backstop' technologies, which come into use either at a pre-specified point in time, or when the price of conventional energy reaches a certain trigger point. These decisions depend on modellers' expectations of structural change in energy markets during the simulation period. For the current short-to medium-term study (2007-2020), such change is not seen as a critical issue.

Sue Wing (2003) is forced to use a recursive dynamic model as his model is considerably more detailed than Goulder and Schneider's (1999), but he laments this necessity, and admits that "a forward-looking equilibrium model is the ideal test-bed for evaluating the effects of ITC" (Sue Wing, 2003, p11). In his model, industry R&D spending is a function of the relative prices of dirty and clean inputs and of industry output – as a larger industry has more resources to invest. Other key functions in this model include the change in the 'stock' of knowledge – which is increasing in R&D spending, and decreasing in the stock of accumulated knowledge – and the amount of this knowledge that is converted into a useful service for the industry – which is increasing in both the amount of knowledge and the industry price which represents the reward for knowledge. At the time it was written, Sue Wing (2003) represented the state of the art, and there has been little in the way of dramatic advances made since that study.

2.2.7. Marginal Abatement Cost (MAC) curves in CGE models

The question of how to determine expenditure on abatement of GHG emissions is addressed in various ways by the papers described below, but it should be borne in mind that this represents another example of the trade-off (ever-present in CGE modelling) between detail and realism on the one hand, and parsimony and workability on the other. As Hyman et al. (2003) observe, realistically each industry should have their own abatement sector with specific cost shares. Data considerations aside though, such a representation would add greatly to the complexity of the model, and the modeller must make a judgement as to whether the 'value-added' of this method would be worth it. Interestingly none of the studies described in this section adopt this approach, so each offers a different way of approximating abatement expenditures in order to include data from 'bottom up' abatement cost curves in 'top down' general equilibrium models.

A number of the papers already mentioned above include some approximation of end-of-pipe abatement options. Xie and Saltzman (2000), for example develop an Environmental Social Accounting Matrix (ESAM) for China based on the extended IO table in Leontief (1970). The ESAM includes intermediate and factor purchases for abatement by each industry in the model, as well as government purchases of pollution cleaning services. Bergman (1991), Conrad and Shröder (1991), Adams et al. (2000b) and the GRACE model (Rypdal et al., 2007; Rive, 2010) all allow firms to use additional quantities of factor and intermediate inputs to reduce pollution, but in none of these is such 'cleaning' the focus of the study.

An important early study on the inclusion of what has come to be known as 'end-of-pipe' abatement in CGE models was that by Nestor and Pasurka Jr (1995a; 1995b), who used detailed German data showing expenditure on specific abatement inputs to extend the IO tables to include both those which are internal to the firm (i.e. use the firm's own labour and capital), and intermediate inputs purchased from an external abatement sector. They note that CGE models offer a significant advantage in modelling environmental compliance as the costs of pollution reduction may be mitigated for those industries whose output is used in abatement activities. As an example, their results suggest that the (German) abatement sector is relatively energy intensive, such that the direct effects of environmental policy on the energy sectors are reduced by the increase in energy demand from the rest of the economy as abatement increases. In this study a government agency collects all abatement expenditure as a 'tax' and uses it to hire factors and buy inputs from the abatement sector.

In recent years, a number of researchers have treated emissions as a necessary input into production. One of the first studies to use this approach as a step towards incorporating MAC curves into a CGE model was Hyman et al. (2003), which treats emissions as an additional input within the production process by characterising CES possibilities between greenhouse gas emissions and the use of all 'other' inputs – intermediates and value added. Thus firms can reduce their emissions either by reducing their output, or by increasing their use of all conventional inputs relative to output. The elasticity of substitution between emissions and the conventional inputs composite is then calibrated for each industry to match its MAC curve. The most important implication of this approach, in the light of the current study, is that it implicitly assumes that abatement expenditures will have the same cost structure as the industry's production process. This is a significantly different approach to Nestor and Pasurka (1995a; 1995b), described above. Essentially for a given industry, j, the cost shares of abatement expenditure following the Nestor and Pasurka approach will be the same as those for abatement expenditures in any other industry i, whereas in the Hyman et al. (2003) approach, they will be the same as the production cost shares in industry j.

A number of papers (Dellink, 2000; Dellink et al., 2004; Dellink and van Ierland, 2006; Gerlagh et al., 2002) use detailed data on abatement options and their associated costs in the Netherlands to construct a single MAC curve for each environmental 'theme', such as climate change or acid rain. Thus all available technologies for the abatement of any greenhouse gas in any industry are included in the same MAC curve, which avoids the problem of a small number of data points in calibration. Similar to Hyman et al. (2003), pollution is treated as a necessary input into production, and an elasticity of substitution is calibrated to the MAC curve. However, in this case, the elasticity is not at the top level of the nest, but rather between abatement and abatable emissions. These papers also include a maximum technical abatement potential (based on the data on abatement technologies) such that a certain proportion of emissions is classified as 'unabatable'. These are produced in fixed proportions to output, as is the composite of abatable emissions and abatement measures. Like the Nestor and Pasurka (1995a; 1995b) approach, a single abatement sector provides 'abatement measures' to every industry for each environmental theme. In some respects this approach could thus be seen as an attempt to reconcile the two methods described above.

The current state of the art in this field is described in Kiuila and Rutherford (2013). The paper compares both the sector specific to the economy-wide approach to abatement, and the 'traditional' to the 'hybrid' approach. Briefly, the sector specific approach treats abatement as internal to each industry in the model. This can be seen as the optimal method, but can be limited by data availability (as in the current study). The economy-wide approach has an 'abatement sector', from which all other industries purchase abatement services, which assumes the cost structure of abatement technologies is constant across abating industries and gases. The traditional approach has a smooth (CES) production function for abatement, whilst the hybrid approach attempts to integrate stepwise MAC curves from bottom-up data through Leontief functions for specific technologies that become active when the emissions price reaches a certain level. The study suggests that at low levels of abatement, a smooth approximation gives similar results to the stepwise function. When abatement options reach their maximum potential though, the step function approaches infinity more immediately than the smooth curve, so at these higher levels of abatement the traditional approach may overestimate abatement potential. The method used in the current study (see chapter 4.8) uses a smooth calibrated MAC curve, so this result must be borne in mind if the model results suggest abatement ever reaches the technical potential shown in the bottom up data.

2.3. Policy and scenario applications

2.3.1. The impacts and costs of emissions reduction

Many of the early studies of environmental policy focussed on standards and restrictions on emissions. Their results are of particular interest to the current study since that is broadly the approach taken here.

Blitzer et al. (1994) use a single country CGE model of Egypt to explore the effects of both sector-specific and economy-wide emissions reductions. The study suggests, in a narrative which will be repeated throughout this section, that the cost of meeting emissions reduction targets rises more than proportionately with the required reduction. This result can be seen most clearly in studies such as Ellerman and Decaux (1998) and Wang et al. (2009), both of which use CGE models to construct MAC curves.[7] Both studies derive convex MAC curves, supporting the idea that the marginal cost of abatement for an economy is a positive function of the tightness of the emissions restriction. In addition, Paltsev et al. (2003) investigate the effect of tightening the target for emissions post-2016 by keeping them at 1990 levels, as opposed to 2000 levels. They find that the extra restriction more than doubles the permit price and welfare cost relative to the original results, though the paper does not say whether this is more or less than proportional to the increase in the emissions reduction.

In many ways, these results support (or are caused by) the neoclassical assumption that the cheapest options for reducing emissions (the so-called 'low hanging fruit') will be made use of first, thus the marginal cost of abatement rises with abatement. This result is found so consistently that it seems generally sound, but a note of caution is needed. Some abatement technologies (specific types of renewable energy, or carbon capture and storage, for example), may require high levels of initial investment to reach a 'tipping point', after which the marginal costs of spreading the technology (and the resulting abatement) may be significantly

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[7] This is a quite a different approach from those studies described in section 2.2.8, which take MAC curves for end-of-pipe abatement as an external input to the CGE model.

lower. If enough abatement technologies follow this pattern, the effect may be enough to cause a kink in the otherwise smoothly convex cost curve for emissions reductions. These complexities often relate to industry structure, and are difficult to include in a CGE context, but modellers should be aware that they are implicitly assuming perfect knowledge of the total (investment and operating) costs of emissions reduction options, and of their abatement potential. Results from Jorgenson and Wilcoxen (1991), for example, suggest that the (variable) operating costs of abatement technologies are dominated by the (fixed) investment costs, though in spite of this, the marginal cost of reductions is still increasing with the stringency of reductions.

A number of global CGE models have shown the importance of including non-CO2 gases by comparing scenarios where temperature or radiative forcing (footnote above) targets are met solely through reductions in CO2 emissions, to those where other GHGs could contribute to meeting the target (Hyman et al., 2003; Bernard et al, 2006; Tol, 2006). A significant, and consistent, finding across the papers was that non-CO2 gases are likely to contribute a relatively higher proportion of emissions reductions when the total target is less stringent. This is because abatement options for these gases tend to be cheaper than those for CO2, but technically limited. Thus as emissions reduction targets become more stringent, CO2 takes more of the burden – though obviously with some variation between regions. All the studies found that a consideration of non-CO2 gases can significantly reduce the cost of meeting overall targets, and this approach has become the normal method in the years since, and is the one used in the current study.

2.3.2. Permits, emissions trading schemes and coverage

Bergman (1991) and Rutherford (1992) were among the first studies to attach permits to fossil fuel combustion emissions and force an endogenous permit price to emerge by exogenously restricting the supply of permits. The main difference between the studies is that Bergman's model is of a country where all fossil fuels are imported (Sweden), so the price wedge resulting from the permit price is applied to the 'Cost, Insurance, Freight' (CIF) import price of fuels. Apart from this the approach taken in the two studies is very similar. Gerlagh et al. (2002) adopts the same method for a government-specified 'sustainable' level of pollution for nine environmental themes, with the supply of permits set to ensure these levels are met, and the market setting the permit price for each theme.

Bergman (1991) also finds that if pollutants are concentrated in a few sectors of the economy, the remaining sectors may actually benefit from pollution controls, as factors of production are released from the constricting sectors, bringing their price down. In contrast, Hazilla and Kopp (1990) find that introducing environmental regulations to only a few industries causes prices to rise, and production to fall, in every sector of the economy, as the regulated sectors are used as intermediate inputs in other industries. Both of these are the kind of secondary effects which are one of the strengths of CGE models, and this study will need to pay close attention to such effects in its reporting of results (see chapters 5 and 6).

On the same issue of how coverage of a permit scheme affects its results, a large number of studies include discussions on how the presence (or absence) of a single industry or region with significant low cost abatement potential impacts on the permit price and distribution of emissions reductions. Gurgel and Paltsev (2012), for example, exclude land use change from a simulated permit scheme for Brazil on these grounds. Emissions reductions in deforestation are extremely cheap ($1-3/tCO2) so including them in a cap and trade scheme would flood the market with cheap permits, meaning the energy and agricultural sectors would not have to reduce their emissions at all. Despite this exclusion, the paper finds that a permit scheme reduces the welfare loss associated with meeting emissions targets by around 50%, and the GDP loss by around 33%, relative to a scenario where each sector must individually reduce their emissions to hit the policy-mandated target. This is of great relevance to the current study where sector-specific reduction targets will be compared to a more aggregate single target analogous to a permit scheme. The usefulness of this study, and of the case of Brazil, is that the extreme cheapness of the (potential) abatement from avoided deforestation allows us to see quite clearly why a welfare improvement from cap-and-trade is an intuitive result. Had land use change been included in the permit scheme, the price of permits would have been very low, and emissions reductions would have been entirely focussed in that sector, which thus would have significantly over-achieved relative to its sectoral target. All other sectors would have underachieved by buying permits which would be cheaper than almost any abatement they could undertake themselves. The low permit price, and the lack of abatement, would have meant much smaller price rises in agriculture and energy, leading to a greatly reduced effect on welfare and GDP. All of this is because emissions are being focussed where the MAC is lowest – the cheapest abatement options are being made the most of, leaving a greater supply of permits to other sectors so the more expensive abatement options do not have to be. This is the principal behind a permit scheme or an aggregate reduction target, as opposed to sector-specific taxes. The results presented later in the present study will seek to investigate whether this is likely to be the case in the Spanish agricultural industry.

The global studies that came in the wake of the Kyoto Protocol all faced essentially the same issue of a single *region* (as opposed to a sector as above) which could undertake a high level of emissions abatement at much lower cost than the rest of the regions covered by the permit scheme. Van der Mensbrugghe (1998); Kainuma et al. (1999); Tulpulé et al. (1999) and Ellerman and Decaux (1998) all use CGE models to compare Annex I[8] and/or global emissions trading to regional carbon taxes with no cross-region emissions trading. The potential for emissions trading to reduce significantly the welfare loss associated with meeting the targets laid out in Kyoto is a consistent result across all three studies. Another consistent result is that the targets set for Eastern Europe and the Soviet Union will not be binding over the period covered by the agreement, so this region faces a zero carbon tax rate in regional tax scenarios, and is in fact the only exporter of emissions permits in trading scenarios. It is telling that a more recent study (Böhringer and Rutherford, 2010) went so

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[8] There are 42 listed Annex I countries: the current EU28, Australia, Belarus, Canada, Iceland, Japan, Liechtenstein, Monaco, New Zealand, Norway, Russia, Switzerland, Turkey, Ukraine and USA (UN 1998).

far as to exclude permit purchases from Russia in all emissions trading and found that when Russia is excluded, no significant welfare gains result from the move from region-specific emissions taxes to international emissions trading. This suggests that the welfare gains from trading in the previous three papers were at least partly a function of the abundant supply of permits from the EEFSU region, rather than the inherent benefits of trading over regional taxes. Again, this is of relevance in the current study, and is a topic that will be discussed in some detail in the results.

A particularly interesting result emerges from Ellerman and Decaux (1998).They find that the further away, in either direction, a country's autarkic MAC (i.e. the carbon tax in the absence of trading) is from the permit price when trading is introduced, the more the country benefits from trading. This seems intuitive in that those countries with relatively high abatement costs benefit from the lower price of the permits, and those with low abatement costs are able to sell permits at a significant profit. The result will be an interesting one to test in the comparison between sector specific taxes and cap-and-trade type schemes in the current study.

One of the stated advantages of CGE models is that they can simulate multiple policies simultaneously and be used to explore how these different policies interact with each other. Morris (2009) uses a CGE model of the U.S. to examine the effects of a cap-and-trade scheme and a 'Renewable Portfolio Standard' (RPS), which mandates that a minimum percentage of electricity come from renewable sources. The results suggest that in the presence of a cap-and-trade scheme to achieve a given emissions reduction, adding the RPS causes an additional welfare loss with no extra GHG mitigation. By adding the RPS on top of the cap-and-trade policy the modeller (/policy maker) is essentially mandating *how* a certain portion of the emissions reduction target is to be met (i.e. through carbon-free electricity) as opposed to allowing all abatement to occur where the marginal cost is lowest. Of course, if switching to renewable electricity was the cheapest way of meeting the emissions target, the RPS would be non-binding and adding it into the policy mix would have no effect on either welfare or the carbon price.

Another issue of interest in the current study is how industry- or country-specific targets (as opposed to permit trading schemes) affect industries or countries with low benchmark emissions intensities. Blitzer et al. (1994), for example, find that in the sector-specific case, stringent reductions are infeasible in the services sector due to a lack of substitution possibilities – forcing them to exempt services from reductions in those scenarios. In a similar vein, Paltsev et al. (2004) find that the high level of energy efficiency in Japan means that there are few cheap abatement options available as further efficiency improvements are likely to be expensive. The result is that Japan has the highest direct abatement costs of all Annex I regions in terms of \$/tCO2 abated. However, this does not translate into the highest welfare cost as the small size of the energy sector relative to total output means energy cost increase do not have such a significant effect on the rest of the economy, as they do in other Annex I countries where the energy sector is larger. Hence in the current study there may be some industries with low emissions intensities which need an extremely high carbon tax in order to meet an industry-specific reduction target, though this high tax may not translate into large price increases due to the same low emissions intensity that caused it.

Related to regions with cheap abatement options is the simulation of the Clean Development Mechanism (CDM) written into the Kyoto Protocol (Nijkamp et al., 2005), which enables Annex I countries to contribute to meeting their emission reduction target by investing in abatement initiatives in non-Annex I countries. The study simulates this by allowing domestic firms in Annex I countries to invest abroad in order to reduce the energy- or emissions-intensity of production in the host country and increase the supply of permits in the investing country.

Two studies present results relating to the decision as to whether permits should be auctioned, 'grandfathered' (distributed for free on the basis of historical emissions) or allocated in some other way (Bye and Nyborg, 1999; Edwards and Hutton, 2001). Both find that grandfathering permits acts as a significant barrier to entry to the industries in the permit scheme, as well as provoking windfall profits and a transfer of money from the public to the private sector. This is particularly true in Bye and Nyborg (1999) where the permit scheme replaces existing energy taxes but must be revenue neutral, so payroll taxes must increase to offset the lost tax revenues. The paper's principal contribution is the observation that in the design of policies for environmental taxation (and/or permit schemes), there are two kinds of efficiency that need to be borne in mind. One may be termed 'environmental efficiency' and consists in ensuring that pollution abatement happens where the cost of such abatement is lowest. The other ('tax efficiency' perhaps) concerns the effects of the tax on the general economy. The suggestion is that certain fuels are taxed more heavily than others due to low elasticities of demand. Reducing the tax rates on such fuels thus causes a significant loss in revenue which, *ceteris paribus,* must be raised by tax increases elsewhere. Of course, the suggestion that taxes on more inelastic goods are less distorting is moot, and will be discussed further in the analysis of the results presented here – specifically in relation to the effects of emissions policy on globally competitive Spanish export sectors, and the extent to which they should be protected from policy-induced price rises. Finally, the results from Edwards and Hutton (2001) suggest that when permits are auctioned, and the revenues are recycled as an output subsidy, there may be a 'double dividend', i.e. emissions reductions may be achieved in conjunction with some other policy goal, usually economic growth or increased employment. It is to such possibilities for revenue recycling that we now turn.

2.3.3. Revenue recycling

Alfsen (1991) and Gerlagh et al. (2002) both assume that environmental policies will be budget neutral – hence any revenues raised through taxing emissions are returned to the economy through a reduced rate of income or other taxes. This can be seen as a way of both gaining political support for environmental measures and ensuring they do not cause a net withdrawal from the economy.

Bovenberg and Goulder (1995) look at how energy taxes could be used to reduce U.S. income taxes in two different ways – a lump sum reduction, and a reduction in the marginal rate. They find that when the revenue is recycled through a reduction in marginal income tax rates, the long-term effect of a gas tax on GDP is actually positive, as it stimulates employment considerably more than the lump-sum reduction. Nevertheless in welfare terms a net cost to the tax reform remains in all scenarios. The authors suggest that this is because the environmental taxes are in reality implicit factor taxes, and so still have a distortionary effect. By contrast, Bye (2000) finds that as labour in Norway is heavily taxed, implementing an environmental tax and using the revenue to reduce the tax burden on labour can lead to a positive welfare effect – a 'double dividend' – in that country, as the fall in payroll taxes reduces distortions in the labour-leisure trade-off for workers, thus increasing employment, real incomes and consumption. These two results suggest that the likelihood of a double-dividend, defined by Bye (2000) as a positive non-environmental welfare effect from tax reform, is still a matter of some debate, and is likely to depend on the initial distortions in the economy. In addition, both papers include extensive discussions of the dynamic aspects of their results, which is another strength of the current study.

Conrad and Schröder (1991) find that when a single tax is applied to all emissions, and the revenues are returned as a lump-sum payment to households, employment and production fare better than when industry-specific standards for pollution abatement are applied, set at a level to ensure the overall reduction in emissions is consistent across the two scenarios. Employment and production still fall in absolute terms though, suggesting no double dividend. In Adams et al. (2000b) a permit scheme is simulated in which permits are auctioned and revenues recycled through a reduction in consumption taxes, but the study finds no double-dividend sufficient to reverse the overall negative effect on GDP and employment from the policy – a result also found by Edwards and Hutton (2001) in their comparable scenario.

2.3.4. Trade and carbon leakage

Burniaux et al. (1992) use the OECD-GREEN model described above to examine how distortions in global energy markets affect policies to reduce CO2 emissions. These distortions generally take the form of taxes in OECD countries, and subsidies in non-OECD countries, and this has a significant bearing on the results. They find that eliminating all energy taxes and subsidies globally is sufficient to reduce CO2 emissions by 18% on the baseline in 2050, and the falling world oil price resulting from reduced demand means even the non-OECD countries (with the exception of energy exporters) see a welfare improvement from the liberalisation. This paper highlights the importance of 'joined up thinking' in energy policies, and outlines the potential for the removal of existing energy subsidies to make a significant – if not entirely sufficient – difference to GHG emissions.

Maisonnave et al. (2012) explore the effects of (unilateral) EU climate policy on the cost to the EU of rising oil prices to 2030 – or *vice versa,* the effect that steep increases in the oil price have on the costs of EU climate policy. They find that climate policy reduces the cost of the high oil price by about a third or, alternatively, that a high oil price could reduce the cost of climate policy dramatically – by more than two thirds. The lesson here is twofold. First it is another warning to take care over baseline and scenario construction as the global oil price is just one variable that is likely to have a significant impact on results for how costly climate policies are. The second is a lesson for communicating a balanced picture of the effects of emissions reduction policies. CGE studies (including the current one) rarely measure the benefits of lower pollution, but this could be one of them that is easier to quantify. If fossil fuel prices are rising (and the evidence of the last few years suggests they are) then policies to reduce their use are likely to have an additional benefit on top of the environmental – especially in the case of an energy importer such as Spain.

Gerlagh et al. (2002) and Blitzer et al. (1994) both find that when emissions restrictions are applied unilaterally in a single country model, the comparative advantage of the country in question shifts towards less polluting products, and more emissions intensive products are increasingly imported from abroad, in a phenomenon known as ‘carbon leakage’. The picture is the most stark in Blitzer et al. (1994), with results suggesting that while oil would still be mined in Egypt in the presence of emissions restrictions, it would be exported to be refined, with the petroleum products then reimported.

Babiker et al. (1997) investigate two options for addressing carbon leakage when emissions restrictions are only applied to OECD countries: Border Tax Adjustments (BTAs) depending on the carbon content of imports, or restricting exports from countries which are not limiting their emissions. The first seems the most logical approach, and indeed it reduces carbon leakage to zero, and reduces the necessary permit price by around 10%. In welfare terms the losses to the OECD countries from the carbon tax are mitigated, but non-OECD countries suffer a welfare loss. These countries fare better under the export restriction scenarios, although this does not reduce the permit price, or carbon leakage rates by as much. This study reinforces the importance of the carbon leakage issue, as well as the need (and opportunity) to set emissions policy simulations in the context of other policies relevant to the period being studied – trade or agricultural policies for example.

Bosello et al. (2013) also study two options for mitigating carbon leakage, this time from the EU: BTAs on imports to tax them according to carbon content, and the assumption that non-EU countries will also face emissions restrictions. BTAs reduce GDP as the improved competitiveness of domestic production is balanced by increased costs for firms which import intermediate inputs – dependent on the degree to which imports are substitutes or complements to domestic production. Similarly, the imposition of emissions reduction policies in non-EU regions does not have an unambiguously positive effect in the EU, as the substitution effects towards EU exports is balanced by an income effect as global GDP growth is slowed, reducing trade volumes overall.

2.3.5. Spain

Bosello et al. (2013) also presents results for non-ETS emissions from each member state given an EU-wide uniform carbon tax on these emissions sufficient to meet the 10.6% reduction set for the period 2005-2020, and finds that the Spanish reduction is just 3.1%. This is clearly well below the EU average, and also below the Spanish target agreed in the Burden Sharing Agreement – very similar to the EU total at 10%. This suggests that abatement in these sectors is more expensive in Spain than the EU average – especially as it can only be assumed (this country-specific result is not shown in the study) that baseline GDP growth over the period will be lower in Spain than the EU average, so there is less upward pressure on emissions which thus, *ceteris paribus,* would be able to contribute more than the average to emissions reductions, were it not for prohibitively high abatement costs. On the same theme, Viguier et al. (2003) compare abatement costs across EU Member States for CO2 emissions, which are dominated by ETS industries, and find that here Spain is at the lower end of the spectrum. Of passing interest is Spain's (apparent) potential for relatively cheap CO2 abatement, but relatively expensive non-CO2 abatement, but the Viguier et al. (2003) finding also provides a useful suggestion for model validation. Data is now available on permit trading in the first two phases (2005-2012) of the scheme, and the current study includes the second phase (2008-2012). If Spanish abatement in ETS sectors is indeed lower than the EU average, the data should show Spain to be a net exporter of permits, and this should be reflected in the OEG results for the period.

Throughout the 1990s and early 2000s a series of papers used Input-Output analysis to increase understanding of the Spanish energy sector and the composition of CO2 emissions (Alcantara and Roca, 1995; Labandeira and Labeaga, 2002; Alcantara and Padilla, 2003). The use of CGE models in single country studies of how Spain can reduce its emissions, however, is a relatively recent phenomenon.

Given the structurally high unemployment rate in Spain, and its dramatic recent increase as a result of the financial crisis which began in 2008, it is perhaps unsurprising that two of the first Spanish CGE studies addressed the issue of how environmental tax revenues could be used to increase Spanish employment. Manresa and Sancho (2005) find that the effects of an energy tax with or without revenue recycled through social security payments depend crucially on assumptions around labour market flexibility. When revenue is not recycled, the more (less) flexible the unemployment rate (real wage) becomes, the greater the welfare loss from the tax, as it causes a contraction in output, and thus employment. When revenue is recycled this effect is reversed as the lower social security payments act to increase employment when it is allowed to rise.

Faehn et al. (2009) use a comparative static model to introduce a notional 25% reduction in permits and explore specific options for revenue recycling to increase employment. They find that when revenue is returned as a lump sum payment to households, the ('expansion') effect of contracting industries reducing employment is stronger than the substitution effect towards labour in the face of rising energy costs. Thus the overall effect is a fall in labour demand, which is mainly felt through a reduction in the real wage (approx 2.5%), suggesting labour supply is relatively inelastic in their model. When the revenue is recycled instead through a reduction in labour taxes there is instead a small increase in the real wage (3% relative to the benchmark), and an even smaller reduction in the unemployment rate. Their third scenario channels the permit revenues specifically through reductions in taxes on unskilled labour. They offer four justifications for considering this as a policy option. The first is for distributional reasons. The second is that at the time the study was written, the unemployment rate amongst unskilled workers was twice that among skilled workers. The third is that fossil fuel industries are relatively intensive in unskilled labour, so environmental policy is likely to increase the pool of unemployed unskilled labour. The fourth is that since unskilled labour taxes are a higher proportion of wages, the effects of reducing the tax will be greater in proportional terms than it would be for skilled workers. In spite of all these, the authors find that reducing only unskilled labour taxes actually increases the unemployment rate overall, whilst obviously decreasing that for unskilled labour. The reasons for this are interesting. Clearly each industry is substituting away from skilled and towards unskilled labour, and the whole economy is shifting towards sectors which are intensive in unskilled labour (agriculture, textiles, wood products and certain service industries), but a third effect is felt as a result of the substitution between unskilled labour and capital. In industries where these two factors are both used heavily, there is a movement towards unskilled labour and thus a release of capital onto the market. The capital price falls, so those industries which use skilled labour and capital begin to substitute more of the latter in place of the former. This reduction in demand for skilled labour dominates the increase in demand for unskilled labour such that overall employment falls. Naturally this effect should be reversed when the permit revenues are used to reduce only the tax rates on skilled labour, and to an extent it is. A general pattern in the economy, however, is that industries which are relatively intensive in capital are more likely to use significant amounts of unskilled than skilled labour. Thus the reduction in the capital price is larger when unskilled labour taxes are reduced than when those for skilled labour are. As a result, whilst the former leads to a fall in skilled employment which more than matches the rise in unskilled – meaning an overall rise in unemployment – in the latter scenario (tax reduction for skilled workers) the fall in employment of unskilled workers does not match the rise in employment for skilled workers, meaning the overall unemployment rate falls. Thus the results suggest that, while revenue recycling focussed on unskilled workers could induce a 'double dividend' (environmental benefits and economic welfare gain – but no fall in unemployment), focussing such tax relief on skilled workers could induce a 'triple dividend' (both of the above *plus* reduced unemployment). This offers some interesting avenues for the current study to pursue in terms of options for revenue recycling. Nevertheless, the most positive macroeconomic results come from the scenario where permit revenues are returned through a reduction in labour taxes for all types of labour.

A third CGE study of Spain (Labandeira and Rodríguez, 2010) starts from a position where Spain must reduce its CO2 emissions by 16% in the two years to 2012 in order to meet its commitments agreed under the Kyoto Protocol and the Burden Sharing Agreement. They find that if these reductions come solely from the ETS sectors, with grandfathering they cause a 0.7% fall in GDP and a 0.3% fall in welfare – which could both be halved by extending the market to cover all industrial emissions. Interestingly, when the market is extended, the ETS sectors are all net sellers of permits, suggesting they are the industries with the lowest cost abatement options. For our purposes, it is useful to note that agriculture is a net buyer of permits (albeit a small one), suggesting abatement costs in the sector are slightly above the Spanish average.

The first Spanish CGE study to include all six GHGs covered by the Kyoto Protocol is González-Eguino (2011a), using a model developed in González-Eguino (2006). The paper uses an inter-temporal equilibrium model to compare a no-action baseline to a scenario where Spain meets its 2012 commitments under the Burden Sharing Agreement, and then emissions stay at this level until 2050. By the end of the period in 2050, consumption is just 0.75% lower than in the 'Business-as-Usual' baseline, while GDP is 1.2% lower and investment 2.5% lower. The relative resilience of consumption is due largely to the increasing weight of the service sector in meeting household demand, and its relatively low carbon intensity. By contrast, investment tends to be concentrated in more carbon intensive sectors and suffers accordingly. This result supports the projections of other commentators (Jackson and Victor, 2011) who write of the need for modern economies to shift more towards labour-intensive services and away from manufacturing in the face of increasingly scarce resources (including emissions). Agriculture is one of a number of industries with an output fall in 2050 of 2-3% relative to the baseline, supporting the result from the previous study that the cost of abatement in agriculture is around, or perhaps slightly above, the Spanish average. The necessary permit price for keeping emissions at their 2008-12 levels (1990 + 15%) is €92/tCO2e in 2050, and this converts to a level of emissions 51% lower than that in the baseline in that year. Another paper by the same author (González-Eguino, 2011b) compares different market-based instruments for reducing emissions, finding that the bigger the distance between the product being taxed or restricted and the pollutant, the greater the cost of the policy.

Gallestegui et al. (2012) use a static, single country model to compare four different distributions of emissions reductions in Spain. In the Cost Effective Distribution (CED) a uniform carbon tax rate is applied to all emissions in order to achieve the desired aggregate target. In this scenario, reductions are dominated by the ETS sectors at low levels of total mitigation, though this is progressively less the case as the restrictions become tighter. This suggests that although the lowest cost abatement options are to be found in the industries covered by the ETS, in absolute terms this abatement potential is limited, and in the presence of more severe emissions targets the non-ETS sectors will need to play an increasing role. The Egalitarian Distribution (ED – emissions reduction come 50% from ETS and 50% from non-ETS) and Proportional

Emissions Distribution (PED – emissions reductions are proportional to benchmark emissions, thus 44% from ETS and 56% from non-ETS) give similar, if slightly worse, macroeconomic results to CED, as the distributions are actually relatively similar. The final scenario where emissions reductions are shared out according to benchmark output is the most severe. The ETS sectors account for just 10% of output, so the non-ETS sectors must contribute 90% of emissions reductions in this scenario, and the GDP loss is around three times that in CED as a result. The paper also investigates alternative options for reducing non-ETS emissions, given that a carbon tax could be difficult to enforce due to data availability issues. This is an important caveat to the current study, which implicitly assumes carbon taxes are easy to calculate and enforce, and which could explore some more practical alternatives in a similar vein. The paper finds, however, that replacing the carbon tax with an energy, oil, or electricity tax increases GDP loss by around 25%, 100% and 300% respectively, for a given emissions reduction target.

In his Ph.D. thesis, De Schoutheete (2012) uses a CGE model of Spain to explore various options for fiscal reform, including carbon and energy taxes being used to replace revenues from reductions in social security, VAT, personal or corporate income tax rates. One of the purposes of the study is to investigate the possibilities for a double dividend in Spain. It finds only two scenarios where this is the case. Both scenarios include reductions in employer social security contributions, with the lost revenue made up for either (i) solely by a carbon tax, or (ii) by a combined carbon and energy tax. The former case drives a deeper reduction in emissions, while the increases in GDP and employment are similar for the two. A particularly interesting result from this study, and one that comes directly from the broad range of fiscal reforms considered, is that 'the key for economic efficiency is not so much in the nature of the energy taxes themselves, but rather in their tax policy counterparts' (De Schoutheete, 2012, p243). Revenue recycling, when it is considered, has been treated as something of an add-on to environmental policy. The author suggests here, based on his results, that how revenues are recycled is in fact central to the economic costs (and hence, political feasibility) of any policies to reduce emissions. This is both a challenge and an exhortation to the current study to take extremely seriously the questions around how the money taken out of the economy through emissions taxes is reintroduced to meet specific policy goals and/or remove existing distortions. This is the focus of Chapter 6. of this study.

2.4. Agricultural Emissions Mitigation

The focus of this review now moves away from general equilibrium studies of the whole economy to try to build up an idea from the literature of the possibilities around GHG mitigation in European and Spanish agriculture. Unlike the previous sections of this chapter, the purpose is by no means to present a systematic history of all studies that have contributed to the current state of the art. The aim is rather to take a few key examples from the literature in order to make a broad picture of the situation, such that the results of this study can be placed in a wider context. Many of the studies cited use partial equilibrium, or even more micro techniques to model the agricultural industry in detail, and thus may capture certain details which are difficult to simulate in a CGE model. Their results thus serve as an important vehicle for checking the veracity of the results of the current study.

On a global scale, The US Environmental Protection Agency (EPA) produced a detailed review of the state of non-CO2 emissions from different sources and regions (EPA, 2006), with a large section devoted to agriculture. The report made a number of interesting observations. Firstly, that around 10% of global agricultural emissions in 2020 could be mitigated with a zero carbon price. These are the so-called 'no-regrets' options that could increase farmers' incomes at the same time as reducing emissions. These provide something of a dilemma for the neoclassical CGE model of the current study, as the assumption of cost minimisation implies an assumption that these options have already been implemented. In reality, there must exist some barriers to information or implementation that has prevented them from being taken up. It could be argued that in the OEG model these 'hidden' costs are converted into private 'visible' costs, but no-regrets options do make it difficult to calibrate MAC curves for use in CGE models (as the current study does) and in reality they are usually ignored. The figure for the EU is close to, but slightly below, the global average at around 8% of current agricultural emissions. For the EU, as for the world, no regrets options are more prevalent in croplands than livestock emissions, but as the abatement requirement increases, livestock offers more technical potential with feed additives and various options for anaerobic digestion plants. A follow up report has recently been produced (EPA, 2013), which suggests lower levels of no-regrets options – around 4% of 2020 emissions in the EU. The relative cost structures of cropland and livestock mitigation in the EU are broadly consistent across the two reports. A look at the European agricultural MAC curves (Figure 2.1.) from the two reports suggest that abatement has become more expensive in the seven years between the 2006 results and those from 2013, or more correctly that the potential for abatement has roughly halved. In reality the projected baseline, of which the abatement measured on the X axis is a percentage, has grown slightly – by around 5% - but not nearly enough to explain the whole reduction in abatement potential. Figure 2.1. clearly shows that both curves have shifted to the left, meaning abatement potential for any given cost has fallen, rather than up, which would suggest that the cost of any given abatement has increased. In some ways these amount to the same thing, but here it suggests that as time has passed and more information has become available, the abatement potential of specific technologies has been revised downwards, whereas a shift upwards of the curve would imply cost increases in specific technologies that could be explained by economic factors. This finding is broadly supported by Table 7 in Smith et al. (2008), which estimates agricultural mitigation potential across the world and compares those estimates with previous studies (including EPA, 2006). The more recent estimates of abatement potential of specific technologies are almost always downward revisions of earlier estimates, suggesting a trend that increasing information has reduced levels of estimated technically feasible abatement.

Moving on to focus on the distribution of mitigation costs and potentials across the EU, Perez et al. (2012) use a number of different policy scenarios, and the Common Agricultural Policy Regionalised Impact (CAPRI) modelling system to see how different countries and agricultural sectors respond to different approaches to emissions reduction. When each Member State must reduce its emissions by a uniform 20% by 2020, Spanish emissions are weighted toward CH4 compared to N2O by a factor of around 3:2, suggesting livestock is shouldering somewhat more of the abatement burden than croplands. In fact, this conclusion can be drawn with some degree of precision, since all agricultural methane emissions in Spain come from livestock[9], whilst the only nitrous oxide emissions not from croplands are those attached to manure management, which all the evidence suggests are impossible to abate. A slight weighting of abatement towards methane is also present in the EU aggregate results, whilst it tends to be Northern European Member States (Finland, Sweden, Germany, UK, Netherlands) which have more of a weighting towards N2O reduction. In Europe the average herd size across all cattle activities is projected to decrease by 22% - around three times the fall in Utilised Agricultural Area for cropland at 7%. An additional scenario imposes an aggregate reduction on total agricultural emissions in the EU, with a uniform emissions price and, effectively, a permit trading scheme. In this scenario Spain reduces its emissions by more than the EU average (around 20% more than the EU15 average, or 25% more than that for the EU27), making it a net seller of permits. This suggests Spanish agricultural abatement is cheaper than the EU average. The difference is particularly marked in CH4 emissions, where Spain sees the greatest reductions of any Member State. Indeed, the reduction in N2O emissions is slightly less than the EU15 average, though still greater than that for the EU27. The suggestion that mitigation of livestock emissions in Spain might be the cheapest in Europe is supported by a further scenario which sets a tax solely on livestock emissions, which again shows Spain with the largest abatement in methane emissions.

2.5. Conclusion

This review of the use of CGE models in environmental policy analysis has highlighted four central reasons for the suitability of the OEG model for this purpose.

The first is that it can be put to multiple uses. The model can be used to project forward a given baseline, such as one in which no action is taken to restrict Spanish GHG emissions. It can analyse the least cost ways of achieving a given policy objective, such as reducing emissions in line with mandated targets. It can assess the effects of a given policy change, such as recycling the revenue from emissions taxes through certain channels. All of these possibilities are made us of in the current study, so the versatility of CGE models proves a significant advantage.

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[9] apart from a negligible amount from rice growing.

The second is the potential for dynamic analysis. The recursive dynamic nature of the OEG model greatly increases the realism of policy simulation relative to a comparative static model as specific policies can be introduced or changed during the simulation period. In addition, it enables the modeller to explore how certain results evolve over the time period under consideration. Thus a policy shock which begins in the first period may, for example, begin to affect rates of return immediately, then gradually feed into investment decisions, which eventually begin to impact on economic growth over the medium term, which itself then has an effect on rates of return. These evolving feedback loops open new possibilities for deeper economic analysis than would be possible in a comparative static model.

The third is the ability to deal with multiple pollutants and policies. The OEG model, in contrast to many such studies, includes emissions of all non-CO2 greenhouse gases mentioned in the Kyoto Protocol. Given the well documented potential for much radiative forcing to be avoided through abatement of these gases (see above), and in particular their dominance in total agricultural emissions, these are crucial for a full analysis of abatement potential in the agricultural sector.

Finally the ability of the model to simulate induced technical change in relation to end-of-pipe abatement options in the agricultural sector makes it ideal for use in this study. The inclusion of marginal abatement cost curves calibrated to bottom-up data on the costs and abatement potentials of various technologies is a significant advance in improving the realism of climate change mitigation analysis. In particular it enables a full picture to emerge of how emissions reductions may be distributed among agricultural sectors based on the abatement options available to them. Omitting this abatement potential would lead to an overestimation of the cost of achieving the mandated reductions in greenhouse gases.

Given its suitability for the current purpose, the OEG model will be used in a number of different ways in the current study. The primary purpose is to provide estimates of the cost of emissions reduction targets to the agricultural sector in Spain. This fills a gap in the literature as no Spanish CGE study of EU climate change policy has yet provided such a detailed treatment of what is, in terms of employment and exports, an important economic activity in Spain. A secondary purpose is to explore the likely distribution of emissions reductions among specific Spanish agricultural activities, such that the overall target is met, including a comparison of industry-specific targets and a simulated cap and trade scheme for agricultural emissions. A final application will follow many of the studies mentioned above in assessing different revenue recycling options in relation to the potential for a ‘double dividend’ from emissions reductions. Before these applications of the model are described however, in Chapters 5 and 6, the next two chapters fully describe the data sources used (Chapter 3) and the structure of the OEG model (Chapter 4).

3. Data and parameters

3.1. Introduction

This chapter outlines the process of using data from Spanish national accounts, emissions submissions to the United Nation Framework Convention on Climate Change (UNFCCC), and various other data sources, to construct a database for use in the Orani-ESP Green (OEG) model in 2007, the benchmark year for this study. The Input-Output (IO) tables which form the backbone of the national accounts are made available with a considerable time lag due to the labour intensity of their compilation by the Instituto Nacional de Estadistica (INE, 2011). As a result, 2007 was the most recent year available when the project outlined in this study began. In addition, using 2007 as the benchmark offers the advantage that the simulation period begins with the start of the financial crisis in Spain, meaning this dramatic event in Spanish economic life can be included fully in the model simulations.

Additional work is needed on the IO accounts to disaggregate agricultural sector columns, including their expenditure on inputs, and commoditiy rows, including their sales to intermediate sectors and final demands. Greenhouse gas emissions must also be disaggregated and 'mapped' from the headings given by the UNFCCC to the industry classifications used in OEG, and attached to specific 'drivers' such as input use or the production process. Agricultural Marginal Abatement Cost (MAC) curves are constructed from bottom-up data provided by the International Institute for Applied Systems Analysis (IIASA) to model abatement potential. Further tasks include the extension of IO data to include institutional accounts in the construction of a Social Accounting Matrix (SAM), and the parameterisation of the model, including relevant behavioural elasticities.

Section 3.2. gives a brief explanation of the standard data format used in models (like OEG) based on the 'ORANI-G' framework. The next two sections describe the work needed on the IO tables, with labour and taxes covered in 3.3., while 3.4. is devoted to the disaggregation of agricultural and food processing activities and commodities. Section 3.5. describes a similar process for the 'Make' matrix of the IO tables, while 3.6. explains how these are extended using institutional accounts to build a SAM. Section 3.7. explains how emissions data is incorporated into the OEG database. Sections 3.8. and 3.9. give the sources for the parameters used in the model, with the former describing elasticity parameters, and the latter those related to agricultural policy modelling. Section 3.10. explains the process of calibrating MAC curves for use in the OEG model, and section 3.11. concludes.

3.2. Standard data format for Orani models

As explained in the model description below (Chapter 4), the Orani-ESP-Green (OEG) model is a heavily modified version of the ORANI-G model (Horridge et al., 1993), and a detailed description of the data construction tasks can be found in Philippidis and Sanjuán (2009a). The basic templates required for the construction of the OEG variant on ORANI-G are presented in Figure 3.1. below. The absorption matrix has as its column headings the purchasing agents in the model, labelled from 1 to 6, with 1 as intermediate purchases by firms, 2 as investment purchases, 3 as household consumption, 4 as exports, 5 as government purchases, and 6 as stocks and inventories. The row headings describe the inputs used by those agents, with BAS as basic flows, MAR as the attached margins (trade and transport etc.), TAX as sales taxes, LAB, CAP and LND as labour, capital and land respectively, PTX as production taxes, and OCT as other costs. Thus V1BAS, for example, refers to intermediate purchases by firms at basic prices, while V3TAX is VAT on private consumption purchases. The basic flows can come from domestically produced goods, or imports, though only domestic goods are produced for export. The 'margins' row gives expenditures on wholesale and retail trade, and transport costs attached to purchases of each specific good, whilst 'taxes' shows sales tax values. Beneath those come the use values of three primary factors, followed by production taxes and 'other costs' (zero flows in the standard format, but a useful instrument for the model extensions detailed below), with these last five rows only applicable to producers. The make matrix shows that each 'i' industry can produce any of the 'c' commodities in the model. The number of industries and commodities is set by the aggregation procedure, but the model used here can go to a maximum of 112 industries and 146 commodities. Finally, the tariff matrix shows that tariff rates vary with commodity, but are constant across users.

3.3. Input-Output (IO) tables

The principal source of data for the tables outlined above is the IO table for the Spanish economy, which is compiled by the Spanish National Statistics Institute (www.ine.es). The absorption matrix – also known as the 'Use Table' – shows the flow of commodities from production – the inputs used including factors of production and intermediates – to use – either as intermediates themselves, as final demands or as investment goods. Within this framework, there are two further issues which can be accounted for: the different prices relevant to each good or service, and the various locations commodities can be sourced from.

'Basic prices' represent the factory gate prices of goods and services, i.e. the cost per unit of all intermediate inputs and value-added used in the production process, including direct taxes on production. The use table is also given in 'purchasers' prices', which are the prices paid for the product at its destination point – inclusive of indirect (sales) taxes on the use of the commodity, and the cost of 'margins' (trade costs, transport to bring the good or service to market, etc.). Figure 3.2. gives an illustrative example for a 4 commodity by 3 industry model of a use matrix split by source, and a corresponding make matrix. In this example, values are given at basic prices, with indirect taxes and margins disaggregated out into separate rows. By convention, the basic prices of imports are 'cost insurance freight' (cif) prices, whilst import tariffs are classified as indirect taxes, and are thus included in the values at purchasers' prices. In the case of exports, again, values at basic prices are exclusive of any export taxes or subsidies,[10] whilst export values at purchasers' prices correspond to 'free on board' (fob) prices.

In the use table (Figure 3.2.), the rows show the supply of commodity c, whilst the columns represent the different sources of demand, which can be intermediate demands by specific industries, or final demands such as household consumption. The row totals thus give total supplies of a given commodity, whilst the column totals give total demands by a given industry or final demand source – all at basic prices. Despite being purely illustrative, Figure 3.2. is useful because, like the IO tables used in the OEG model and those presented by INE for Spain, it is not square – i.e. commodities ≠ industries. In this case it is because in addition to the three commodities which match with industries (agriculture, manufacturing, services), the extra commodity 'margins' is disaggregated into a separate row. The Spanish IO tables show 118 commodities and 75 industries, whilst those from which the OEG aggregations are drawn include 146 commodities and 112 industries. Extra rows in the table are devoted to production taxes, and two components of value added – labour costs and gross operating surplus, which includes gross returns on capital and land as well as pre-tax profits.

Readers will note the absence of imported factors of production. For labour, this does not deny the existence of migration, but neither does it differentiate between Spanish and migrant workers. Foreign investment is accounted for in the data, although the capital it creates is not distinguished by source. A growing literature exists on the potential for IO tables, and CGE models, to deal more fully with international factor mobility (Nana and Poot, 1996; Giesecke, 2002), but these issues lie outside the scope of this study. Another point to note from Figure 3.2. is the absence of imports of final goods destined for re-export. Whilst this does not preclude the use of imported intermediates in the production of goods which are then exported, it does mean Spain's re-exports are assumed to be zero. Finally, the 'margins' commodity row includes both 'direct' and 'indirect' use of margins, where the former refers to the direct purchase of margins by intermediate or final demand, and the latter the use of margins in facilitating the purchase of other goods.

By accounting convention in ORANI models, total use demands by industry (i.e. total costs) must be equal to total production. Thus the column totals in the (domestic + imported) use table must be equal to the column totals in the make matrix – in Figure 3.2. these are 17, 128 and 94 for agriculture, manufacturing and services respectively. Similarly, the supply of domestic commodities in the second use table – the row totals of 14, 103, 56 and 66 - must be equal to the domestic supplies given in the row totals of the make matrix. In Figure 3.2. the make matrix is not diagonal – there are non-zero values in some of the off-diagonals. This is

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[10] A subsidy shows as a negative tax in the data.

also the case in both the Spanish IO tables, and signifies the existence of multi-product industries. This will be covered in more detail below, but the immediate consequence is that the row and column totals do not necessarily match in the make matrix.

As noted above, the use tables are presented in both basic and purchasers' prices. Additional tables include use of margins by commodity and indirect taxes by commodity and industry. These are all useful in the construction of the matrices for margins and indirect taxes shown in the second and third rows of Figure 3.1.

3.3.1. Tax and margin matrices

Subtracting the basic price from the purchasers' price use matrix gives a 'price wedge' matrix of the sum of indirect taxes and margins (TM) for 118 rows (one for each commodity) and 82 columns (one for each industry plus seven final demands – private household, non-profit, government, investment, stocks, EU exports and non-EU exports). In the purchasers' price matrix, the margins row only includes direct use, whilst indirect use of margins, along with indirect taxes, are spread among the non-margin commodities.

Exploring the IO tables for Spain, the following commodity rows are judged to be margin commodities – some commercial margins, some trade margins:

- Row 64 – wholesale and trade services;
- Row 65 – retail services;
- Row 66 – railway transport services;
- Row 67 – other land transport services;
- Row 68 – sea transport services;
- Row 70 – storage and warehouse services;
- Row 71 – other transport services.

One of these – retail services – shows in the make matrix a TM value equal to the negative of the basic prices value, and hence a purchasers' price value of zero. This means that this commodity is only used indirectly – i.e. in the purchase of other intermediate inputs. At the other extreme, two of the above – storage and warehouse services and other transport services – show a zero value in the TM rows, implying that there is no indirect usage of these margins, only direct use.

3.3.2. Labour use by occupation and industry

Spanish Labour Force Survey (LFS) data – available on the INE website – includes numbers of people employed in 17 industry aggregates, across 10 occupation groupings. In addition, the IO tables include numbers of PAID and numbers of FULL TIME PAID employees across the 75 industries in the tables. The shares in this 75 industry matrix are used to convert the LFS 10 occupations by 17 industries data into a 10 occupations by 75 industries matrix, which is then scaled such that the total numbers for each industry match those in the IO data for total employed persons, which includes both paid and non-paid[11].

This 10x75 matrix for total labour by occupation and industry is converted to one for paid labour using the shares of paid vs. non-paid labour for each industry from the IO data. This assumes the ratio is constant across occupation types, which is a limitation of the data available. The matrix for paid labour is then further divided into one for full-time and one for part-time employees, using the full-time share data, again included in the IO tables. The LFS data includes average gross salaries – full-time and part-time – across the 10 occupation types, so these can be multiplied by the numbers of people employed to give total full-time and part-time wage bills for each occupation and industry. These two matrices are added together to give a 10x75 wage bill matrix, which is then scaled such that the industry total wage bills match those in the IO tables.

3.4. Agro-food commodities and activities

In the IO tables produced by INE, agriculture is covered by 3 commodity rows (crops, livestock and agricultural services), and a single activity column, whilst food and drink is divided into 7 commodities (meat products, dairy products, fats and oils, animal feed, other food, alcoholic drinks and non-alcoholic drinks) and 4 activities (meat production, dairy production, other food production and drink production). Given the agricultural focus of this study, and the significant difference in emissions abatement options between different agricultural industries, further disaggregation of the agro-food commodities and activities is a critical part of data construction for this model.

3.4.1. The agricultural intermediates sub-matrix

An initial point of departure for the disaggregation of primary agricultural activity is the NACE Rev. 2 classification on which the Eurostat agricultural accounts are based (European Commission, 2008). From this emerge 28 primary agricultural sectors, listed in Table 3.1.

The first step in this process is to convert the data for intermediate input usage in agriculture from a single industry in the IO table, to the 28 subsectors given in Table 3.1. Given its proximity to the reference year, this procedure is greatly aided by secondary data taken from the 'Red Contable Agraria Nacional (RECAN)[12], which was published until 2005 by the Ministerio de Agricultura, Alimentacion, y Medioambiente (formally MAPA, then MARM, now MAGRAMA), and provides a breakdown of both value added and intermediate input costs for a number of representative farm activities. The classification of 'representative' farm activities concords well in general with the 28 activities in Table 3.1., though in some cases additional assumptions are necessary. For example, in the RECAN heading "all cereals except rice" which covers four

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[11] The discrepancy between total employed persons and total PAID employed persons tends to be largest in agriculture, where a significant proportion of family labour is used.

[12] http://www.magrama.gob.es/es/estadistica/temas/estadisticas-agrarias/economia/red-contable-recan/#para1

activities in the OEG classification (wheat, barley, maize and other cereals), it is assumed that all cereals sectors (except rice) have the same cost composition.

The values of production at basic prices for the 28 agricultural activities in 2007 are taken from Eurostat (2009), and split between value-added and intermediate inputs. The intermediate total for each industry is then split into 13 specific inputs for each industry according to the cost shares from RECAN, which leaves a 13x28 intermediate input matrix for agricultural activities (at basic prices).

These 13 intermediate inputs must be further disaggregated into the 118 commodities used in the IO tables. In the agricultural column, 43 of these 118 possible intermediates are in fact zero entries; nevertheless, some judgement is needed in distributing the 13 commodities from RECAN amongst the remaining 75 in the IO tables. Fortunately, MAGRAMA provides, in chapter 22 of its Anuario de Estadistica Agroalimentaria (MAGRAMA, 2008) a more detailed decomposition of the RECAN inputs. The end result here is a 118x28x2 matrix showing the use of 118 intermediate inputs across 28 agricultural activities, with the inputs coming from two sources, domestic and imported – the shares for which are included in the IO tables. The row use shares from this basic price matrix are applied to the column aggregates for agricultural taxes and margins which, when added to the basic price matrix, can form a matrix at purchasers' prices. The same row shares are also used to disaggregate the basic price, tax, and margins data for the agricultural investment column.

3.4.2. The food intermediates sub-matrix

Disaggregating the food processing activities in the IO table is made simpler by the fact that there are more of them to begin with in the source IO data from INE – four, compared to the one primary agricultural activity – but made more complicated by the relative lack of additional secondary data sources. In order to gain a sense of how specific downstream food processing activities (and hence relative food price changes) are being affected by environmental policies aimed at reducing agricultural emissions, though, some disaggregation is required, such that the 'meat' aggregate be split into five different activities, and 'other food' be divided into oils and fats, sugar processing, animal feed, and a residual. A companion list to Table 3.1 for processed food activities is given in Table 3.2 (note that dairy and drinks are already separate entries in the IO table provided by INE).

The disaggregation of meat activities presents a challenge due to a scarcity of available detailed cost structure data. Examining the IO use table (basic prices), 60% of intermediate inputs for the processed meat sectors are from upstream livestock sectors, so these inputs can be easily matched – cattle to beef, pigs to pork, etc. The remaining 40% of intermediate purchases are divided according to the same use shares as employed in the agricultural Social Accounting Matrix (SAM) for Spain elaborated by Müller et al. (2009)[13].

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[13] The disadvantage of this approach is that the SAM for Spain is benchmarked to the year 2000. Thus, the approach adopted implicitly assumes technical co-efficients for that year.

This results in a 118x11x2 intermediate use matrix for the 11 food industries in the model, with the domestic/imported shares again coming directly from the IO tables. As was the case for primary agricultural activities, the row use shares from this basic price matrix are used to calculate tax and margin matrices, and an investment matrix for the 11 food industries (along with investment taxes and margins).

The only other disaggregation needed in the processed food sector is the division of the 'other food' aggregate into the four categories given above. Output shares for the four activities come from chapter 23 ('the food industry and the environment') of the Anuario de Estadistica Agroalimentaria (MAGRAMA 2008).

3.4.3. The agro-food commodity rows

Intermediate demands for agro-food commodities: The process begins with dividing the single 'arable' commodity used by the 22 crop sectors among the 22 new crop commodities. This is done by using the same technical coefficients for specific agricultural activities in Spain documented in Müller et al. (2009), although the same caveat applies (see footnote 13). This gives a diagonal 22x22 intermediate input matrix for all arable commodities and sectors. The same assumption is used for the livestock commodities (pigs used by the pig industry etc.), giving a 6x6 intermediate input matrix for livestock commodities and activities. Any use of livestock commodities in arable sectors is divided according to Eurostat output shares, as is any use of arable commodities by livestock activities. Most non-agro-food industries show zero values for their purchases of primary agricultural goods, but for those non agro-food activities that do employ agro-food intermediate inputs, use of the arable or livestock aggregate commodity is divided amongst the newly disaggregated commodities using the shares of each commodity in total arable or livestock production.

Meat commodity use across all columns is split using commodity output shares, and the assumption of a diagonal matrix is again applied for the meat commodities by meat industries intermediates submatrix. Oils and fats, dairy, drinks and animal feeds are disaggregated in the IO tables, so processed sugar is taken out of 'other food' also using commodity output shares. DATACOMEX trade data (Ministerio de Industria, Comercio y Turismo, 2009) showing intra- and extra-EU imports is used to split arable imports among the various crops, and livestock imports among the different types of animals for each of the two sources.

Private household demands for agro-food commodities are divided using Eurostat domestic output shares for the primary agricultural goods, whilst the Encuesta de Presupuestos Familiares (INE, 2009) provides data on household purchases of different food products. DATACOMEX trade data is used to divide imports into intra- and extra-EU imports.

Government and non-profit demands for agro-food commodities are all zero in the IO accounts for Spain. **Stock purchases** of primary agricultural commodities were divided using Eurostat's agricultural balance sheets (Eurostat, 2009) whilst for processed food commodities, stock purchases of dairy products, oils and fats, animal feed, and alcoholic and non-alcoholic drinks are given in the IO table. It is assumed that all ‘other food’ stock purchases are of processed sugar, with stock purchases of meat divided between pork and beef as part of the balancing procedure of the database.

Investment demands for agro-food commodities are zero for all imported investment goods, and for all food rows in the domestic investment matrix. Arable and livestock investment purchases are disaggregated into the 28 agricultural commodities using Eurostat domestic output shares. As with intermediate purchases, a diagonal matrix is then assumed for arable commodities and another one for livestock goods such that, for example, all arable purchases of wheat as an investment good are assigned to the wheat industry, whilst all livestock investment in pigs is assigned to the pig industry. Finally the basic value use shares of agro-food purchases from domestic sources are used to calculate the corresponding values of taxes and margins.

3.4.4. Agricultural support

The Fondo Español de Garantía Agraria (FEGA) (MAGRAMA, 2009) provides detailed data on annual agricultural payments. These are used, along with the basic value shares, to divide the aggregate agricultural taxes and subsidies in the IO tables between industries, and to apportion them between capital payments, land payments, and commodity payments in the model. Specifically, **land based subsidy payments** are largely made up of the Single Farm Payment (SFP) which constitutes an ever increasing share of agricultural support as the simulation period progresses. **Capital based payments** are reduced during the period, but initially contain some agenda 2000 headage payments on livestock and raw milk production, vineyard restructuring and investment aids. Finally **production subsidies** in the model include, from the FEGA data, ‘production subsidies’ (e.g., olive oil payment, wine payment), ‘additional marketing and distribution support measures both on domestic and foreign sales’ (especially in fruit), ‘storage aids’, ‘other expenditures’, ‘fraud or overpayments’ (negative entry) and ‘traceability and quality control costs’. Where necessary these are split employing output cost shares, whilst the target totals in the primary agricultural industries are implemented directly into the land and capital subsidy wedges.

3.5. Disaggregating the make matrix

The ‘make’ matrix shows the total domestic production of each commodity c, by each industry i. The evolution of this matrix maps the supply response of domestic industries to the changing demand conditions in the model. For the database to balance, the row (commodity) totals in the make matrix must be equal to the total usage of domestic commodities, including margins, and the column (industry) totals must be equal to the column totals in the input use matrix. The make matrix from the Spanish IO tables shows that some industries produce two or more commodities (the matrix is not diagonal). This does not mean data manipulation is needed, as multi-product technology is a feature of the standard ORANI model framework. However, given the disaggregations described above to the agro-food sectors, some work is needed on the MAKE matrix to make it consistent with the use matrices.

3.5.1. Primary agriculture

In its original form, the make matrix gives the value of production of arable and livestock products by the agricultural industry. The production costs by industry derived above are used to subdivide the aggregate commodities produced by agriculture into the 22 arable and 6 livestock goods corresponding to the activities listed in Table 3.1. The assumption is made that each primary agricultural commodity is only produced by its matching industry (wheat made by the wheat industry etc.), which gives a diagonal agricultural sub-matrix of 28 commodities and 28 industries. From the IO make matrix, the industry 'agriculture' also produces the commodities agricultural services, non-residential properties, wholesale, retail, research and development and cultural and sport services. Production of these remaining commodities is divided according to the production costs shares among the 28 primary agricultural industries derived above. Finally, there are some non-agricultural industries which produce arable and livestock products, namely the forestry, wholesale, retail, public administration and 'non-market activities' sectors. Production from these industries is divided among the 28 primary agricultural commodities using the domestic commodity supply share derived above (Eurostat, 2009).

3.5.2. Processed food

The five meat production industries are also split out according to their production cost shares, and the assumption of diagonality (beef produced by the beef industry, etc.) allows the division of the single meat aggregate commodity into the five more specific products. Production cost shares are also used to assign non-meat commodity production among the various meat industries, and domestic commodity supply shares are used to divide the production of meat by non-meat industries amongst the five commodities, where such production occurs in the IO make matrix.

In the 'other food' aggregate, the rows 'vegetable oils and fats' and 'animal feeds' are already disaggregated in the IO make matrix. These are assumed to be entirely produced by the vegetable oils and fats and animal feeds industries respectively. The 'other food' row is divided between the industries 'processed sugar' and 'other food' using production cost shares, which are also used to split the remaining commodity rows among the four industry columns. Non-food industry production of vegetable oils and fats and animal feeds is already disaggregated, so all that remains to be done is to divide non-food industry production of processed sugar and other food between those two using commodity supply shares, similar to the process for primary agricultural commodities above.

3.6. Institutional accounts and the Social Accounting Matrix (SAM)

The Social Accounting Matrix (SAM) is based on the same accounting principles as the IO table described above. The SAM effectively serves as an IO table for institutional account flows such that total aggregate receipts for a given institution (the row total) equal total aggregate payments (the column total) in any given year. The matrix is presented in its conceptual form in Figure 3.3a and with Spanish data from the benchmark year (2007) in Figure 3.3b. The table is arranged to show the values of transfers from agents across the top to those down the left hand side. To take an example, looking down the column entitled HH for 'households' shows us that the representative private household pays production activities 'V3BAS' and 'V3MAR'. They also pay government V3TAX and a number of other taxes, namely income and estate (INCTAX), property (PROPTAX) and inheritance taxes (HERTAX), which three together make up total household taxes (V0HHTAX); social security contributions (SOCSEC("recp")) and a residual of other taxes (OTHER("recp")). Household savings (HHSAVE) are treated as a transfer to investment, whilst consumption of imports is effectively a transfer from Spanish households to the Rest of the World account (RoW). From the various rows under the 'Households' heading on the left hand side of the table, it can be seen that transfers to households include factor incomes and government transfers, including social security payments and social loans. Given that expenditure on inventories and NGOs is extracted from household transfers, the sum total of those four columns must equal the total from the rows showing transfers to households. In 2007 this figure was around €1.1bn for Spain[14]. Given the use of multiple data sources, there is a slight incompatibility between row and column sums in the final SAM, resulting in the need for a balancing program using row and sum techniques (Horridge, 2003)[15].

3.7. Emissions data

3.7.1. Overview

Emissions data is taken from the United Nations Framework Convention on Climate Change (UNFCCC, 2015), which disaggregates emissions of the six Greenhouse Gases (GHGs) covered by the Kyoto Protocol (CO2, CH4, N2O, HFCs, PFCs, HS6) into seven categories (fuel combustion, fugitive emissions, industrial processes, solvent and other products, land use and forestry, waste and agriculture) with more detailed sub-categories. A brief description of how each of these categories is incorporated into the OEG model database is given in sections 3.7.2. to 3.7.7. below. The data is provided by national governments annually in 'National Inventory Reports' (for a group of so-called 'Annex I'[16] countries, which includes Spain). A full list of emissions by source and industry (where appropriate) can be found in Table 3.3 below, though it should be noted that net emissions from Land Use, Land Use Change and Forestry (LULUCF) are not currently included in the OEG model, as policy documents suggest that the Spanish government is not planning to make much use of carbon sequestration in meeting EU-mandated emissions targets (Ministerio de Industria, Comercio y Turismo, 2007). If this changes in the future, this could be an area of further work.

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[14] All figures to populate the fiscal component of the institutional accounts for the benchmark year taken from the website http://www.ine.es/daco/daco42/cne00/dacocne_b00.htm

[15] As the differences in row and column sums are small, the perceived weaknesses of a row and sum approach against a more flexible maximum entropy balancing program, are minimised (Horridge 2003)

[16] See footnote 8 in Chapter 2 for a full list of Annex I countries.

Given that the reference year for the OEG model data is 2007, a summary of the Spanish submission for that year is given in Table 3.4. The majority of Spanish emissions covered are CO2 (84%), much of which is due to fuel combustion activities. At the bottom of the Table, N2O and CH4 are converted into CO2 equivalent gigagrams (Gg CO2e).[17] Note that the conversion coefficient for N2O is 310, compared with 21 for CH4. This is because the Global Warming Potential (GWP) of N2O is much higher than that of CH4[18]. The total level of emissions from economic activities (excluding LULUCF) in 2007 is 432,090Gg of CO2e. The task that faces the modeller is to incorporate these gases into the OEG database. It is necessary to tie specific sources of GHGs to their economic activity as well as make assumptions regarding the logical choice of 'driver' for these emissions over successive time periods. A full list of the 'drivers' attached to each source of emissions is given in Table 3.3.

3.7.2. Fuel combustion emissions

Fuel combustion emissions are first divided into those from energy industries, those from manufacturing, those from transport and others.

3.7.2.1. Energy industries

There are five energy industries in the model – coal mining, oil extraction, petrol refining, electricity generation and gas distribution – and six commodities – coal, crude oil, crude gas, petrol, electricity, and gas distribution. Based on Ludena (2007) and the Spanish IO tables, a matrix is drawn up which categorises use of each commodity by each industry as either non-emitting (NE), emitting (E), transformative (T – also non-emitting) or a zero flow in the IO database. This matrix is shown in Table 3.5. The UNFCCC data distinguishes between four different types of fuels: 'solid' (coal in the OEG model database), 'liquid' (petrol – note from Table 3.5. that no emissions are attached to the combustion of crude oil by energy industries), 'gas' (crude gas and gas distribution) and 'other' (in the data this covers biomass emissions, which are excluded from the OEG model database). International Energy Agency (IEA, 2012) data on energy flows is combined with energy commodity use by energy industries from the Spanish IO tables, and emissions factors from the UNFCCC (2015) to assign emissions among those fuels and industries labelled 'E' in Table 3.5.

3.7.2.2. Manufacturing

Following the same assignation above for solid, liquid and gas fuels, the UNFCCC data divides manufacturing emissions into six industry groups. The first three – iron and steel, non-ferrous metals,

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[17] The CO2e for HFCs, PFCs and SF6 are already calculated. These have very high GWPs (see next footnote) of 11,700, 6,500 and 23,900, respectively.

[18] In technical language, the GWP is a relative quantifiable measure of heat trapping (direct or indirect effects) over a specific time horizon from the emission of one unit mass, (e.g., a Gg), compared to the benchmark gas CO2. Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences the atmospheric lifetimes of other gases. Note that all non-CO2 gases have a greater GWP than CO2.

chemicals – correspond exactly with industries in the IO table. The remaining three – pulp paper and printing, food processing and beverages, other – are assigned to their component IO activities by value shares in fuel usage. The same applies to the division between emissions on domestic and imported fuels across all these industries.

3.7.2.3. Transport

The disaggregation of IEA (2012) data on energy use in the transport sector matches that from the Spanish IO tables – road, rail, ship and air transport. As a result, it can be combined with UNFCCC (2015) emissions factors to derive emissions by fuel and transport industry. The resultant emissions quantities concord closely with the UNFCCC totals. Finally, emissions from household private car use of petrol are taken out of the road transport industry and assigned to private household use of those fuels.

3.7.2.4. Other

The UNFCCC database divides this last category into three sources of fuel combustion: 'commercial and institutional', 'residential', 'agriculture, forestry and fisheries'. The first category covers all remaining service industries in the OEG model database, which are distributed according to fuel cost share data by industry from the Spanish IO tables, as are those for agricultural industries, forestry and fisheries. Finally, household emissions are augmented by those private vehicle emissions mentioned above, and distributed between domestic and imported fuel use by expenditure shares.

3.7.3. Fugitive emissions

Fugitive emissions are clearly disaggregated in the UNFCCC (2015) database between coal mining, and oil and gas extraction, which is sufficient for the OEG model database. As these emissions are assigned to the production process, there is no need to distinguish between domestic and imported emissions.

3.7.4. Industrial process emissions

Similarly to fugitive emissions, industrial process emissions are all associated with Spanish industries so there is no need for a domestic/import division. The allocation across industries draws on detailed work by the U.S. EPA to map IPCC emissions data to the sectors used in the Global Trade Analysis Project (GTAP) model, and to appropriate drivers (Rose et al., 2007). The majority of emissions under this heading fall very easily into either the cement, metallurgy, chemicals or electrical machinery industries.

3.7.5. Solvent and other products emissions

As can be seen in Table 3.3, solvent emissions are all attached to the chemical industry. Again these are all Spanish industrial emissions so there is no domestic/import split.

3.7.6. Waste emissions

The UNFCCC database distinguishes between the management of wastewater, sludge spreading, and waste incineration and waste disposal on landfills. By contrast, the Spanish IO tables divide waste activities into market and non-market sanitation services. As each of the three UNFCCC categories could fit into both of these, the waste total is assigned by output shares in the IO tables, with no imported emissions once again.

3.7.7. Agricultural emissions

Agricultural emissions are divided by the UNFCCC database into those from enteric fermentation, manure management, rice cultivation, agricultural soils, burning of savannas, field burning of agricultural residues and 'other'. The first two are broken down by specific livestock industries, so can be easily assigned to livestock activities in the OEG model database. Emissions from rice cultivation are equally uncomplicated. Agricultural soil emissions of N2O must be distributed among the crops sectors, which is done using data on land area by crop (MAGRAMA, 2008) and nitrogen necessity for each crop (MAGRAMA, 2010) – a measure of the nitrogen intensity of the cultivation of different crops. Multiplying this by the land area gives total nitrogen usage by crop, the shares of which are used to assign 'direct' and 'indirect' emissions from agricultural soils as shown in the UNFCCC database. The remaining agricultural soil emissions are entitled 'pasture, range and paddock' and are thus distributed among livestock sectors according to data on the nitrogen intensity of manure from different animals, and animal populations (MAGRAMA, 2008). Burning of savannas and 'other' both show zero emissions for Spain in the database, while the methane and nitrous oxide emissions under field burning of agricultural residues are shared out amongst the relevant crops by 2007 land share.

3.8. Elasticity parameters

Having created a consistent OEG database for the year 2007, the next task is to choose appropriate supply and demand response parameters for the model. In particular, CGE models require estimates of elasticities of substitution/transformation for each of the levels of the demand and supply nests, expenditure elasticities for private household demands and export demand elasticities. Unfortunately, a common (and valid) criticism of these models is that there is a dearth of available and up to date estimates, which means that the modeller is forced to borrow estimates from other models or other available literature sources. As a possible future line of research, a rigorous revision of these elasticity estimates for the Spanish economy would constitute an important development in the model's evolution. As a quick reference, a full list of elasticities in the OEG model, with their sources, can be found in Table 3.6.

In the top part of the production nest, there is an elasticity of substitution between a composite value added and energy (and fertiliser for agricultural industries – see Chapter 4.) input and a composite intermediate input. Due to a lack of empirical estimates, most CGE models assume a Leontief treatment, where inputs are employed in fixed proportions and are unresponsive to price changes. In this model, we continue this tradition for the non-agricultural industries, whilst elasticities between intermediate inputs and value added for the agricultural industries are taken from the GTAP-AGR model (Keeney and Hertel, 2005). Attempts to implement these elasticities in the non-agricultural industries resulted in exaggerated output changes in OEG model results.

The industry substitution elasticities between labour, land, other costs and the capital-energy composite input in the value added nest are taken from the GTAP database (Narayanan et al., 2012), whilst the elasticity of substitution between labour occupations within an industry employs double the elasticity values of the aggregate value added nest (for lack of better information). The capital-energy sub-nest (capital-energy-fertiliser in the agricultural industries) substitution elasticities are taken from a module of the GTAP-E model (Birur et al., 2008), which extends the standard GTAP model to incorporate energy usage, carbon markets and permit trading.

The essential nature of energy in the production structure implies an inelastic demand, which is reflected in the substitution estimates in Birur et al. (2008). The estimates in their paper are revisions of the original GTAP-E estimates (Burniaux and Truong, 2002), which were found to be too elastic. Birur et al. (2008) employ evidence from Beckman et al. (2011) for their revisions. Thus, the elasticity of substitution between capital and the energy composite input is 0.5. The substitution elasticity between electrical energy, coal energy and the non-electrical-coal energy composite is 0.5. The substitution elasticity between non-electrical non-coal energy sources is 0.25.

In the intermediate inputs nest, both for industry and investment demands, the elasticities of substitution are the same as those in the latest GTAP version 8 database for Spain (Narayanan et al. 2012)[19]. Thus, in the upper nest, there are Armington elasticities (Armington, 1969) of substitution between domestic and composite imported intermediate inputs, whilst in the lower nest the elasticities of substitution between EU and non-EU imports are double those of the upper nest.[20]

Constant elasticities of transformation (CET) govern the transfer of land between agricultural using industries. In the OEG model, the three tiered nested structure assumes that the substitutability of land allocation differs by land use (see Chapter 4. for a fuller discussion). Using this structure, one may specify an increasing degree of transformation between land types, where the more distinct are the agricultural activities (moving up the tree), the smaller are the transformation elasticities. Thus, following sensitivity analysis and in the absence of more reliable estimates, in the top tier of the land nest, the CET between permanent pastures

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[19] Those for Spain are from the group of 'developed' country estimates.

[20] The Armington nest differentiates imports by region of origin employing an elasticity of substitution less than infinity. This prevents total specialisation effects, although it also has implications for the terms of trade.

and composite livestock and cereals/oilseeds land usage[21] is 0.001. In the second tier, the CET between livestock, and composite cereals and oilseeds land usage is 0.05. In the bottom tier of the nest, the CET between cereals, oilseeds, feed crops, textiles and primary sugar is 1. Supply elasticities for highly skilled, skilled and unskilled labour are based on Spanish estimates in Fernandez-Val (2003).

Following Keeney and Hertel's (2005) work on GTAP-AGR, additional CET elasticities control the transference of labour and capital between agricultural and non agricultural uses. The idea is to capture the observed wage and rent differentials between agricultural and non-agricultural sectors. Thus, in the OEG model a borrowed value of 0.5 is employed. Similarly, given the non-diagonal MAKE matrix, there is the possibility of multi-product industries in the model, which requires a CET estimate of how responsive an industry is in switching between the production of two or more outputs. Once again, in the absence of credible alternatives, the OEG model employs the standard ORANI model estimate for Australia of 0.5 (Horridge, 2000).

In the private household demand nests, the top nest incorporates a Linear Expenditure System (LES) function to apportion expenditures over aggregate (i.e., domestic plus imported) commodities. The OEG model also explicitly models the substitution possibilities between energy demands. Thus, the top nest divides the representative household's LES demand into energy and non-energy commodities. To calibrate the function, estimates of expenditure elasticities are required. Thus, for agro-food commodities, expenditure elasticity estimates are borrowed from a study of Italian households (Moro and Sckokai, 2000). In addition to the expenditure elasticities, an estimate of the FRISCH parameter (Frisch, 1959) is required. The FRISCH parameter measures the ratio between total and supernumerary (luxury good) expenditure. Employing data for Australian households,[22] Dixon and Lluch (1977) estimated a FRISCH value of 1.82 for average income households – this is applied to the representative household in the model.

Energy demands are a CES aggregate of coal, oil, gas, electricity and petroleum. Once again, household demands are inelastic such that the elasticity of substitution is 0.1 (taken from Birur et al., 2008, based on estimates in Beckman et al., 2011). In the lower nests, private household CES substitution elasticities between domestic and import composites, and those between EU and non-EU imports are taken from the GTAP model database (Narayanan et al. 2012). As with the intermediate and investment CES demands, the upper level elasticity estimates are double the lower nest values.

The demand for exports is a decreasing linear function of free on board export prices. This elasticity of demand for exports is assumed to be -5. Moreover, the supply of exports is a two stage CET nest where supply is determined between domestic and composite export routes in the upper nest, before being allocated

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[21] Potatoes, sugar, textile crops, other industrial crops, feed crops, grapes for wine, olives for oil, vegetables, flowers, table olives, dry fruit, table grapes, other fruit, citrus, tropical, other crops.

[22] As a developed economy, this serves as a sufficient proxy for Spanish household behaviour.

between EU and non-EU export routes. In both cases, following the standard ORANI treatment, the CET elasticities are assumed to have a value of 20.[23] Finally, the land supply parameters are estimated 'in-house' employing a non-linear maximum least squares approach. This is discussed further in section 4.4.1 below.

3.9. Agricultural policy parameters

The sugar and milk quota mechanisms are modelled within the OEG model (see section 4.7.2.2). In terms of data support, estimates are required of the quota fill rates and the size of the quota rent (if the quota is binding). In the case of milk, the rent estimate was taken from Jongeneel and Tononi (2008), which is based on the findings of the AGMEMOD European project.[24] In the report, it is estimated that Spain has a positive milk quota rent estimate, which implies that the quota is binding. Jongeneel and Tononi (2008) estimate that rents constitute 29.5% of the total value of milk production. This estimate is employed in the model database, whilst the 'other costs' component of raw milk costs is reduced to compensate. For the sugar sector, EU15 rents data suggests that Spanish sugar production is relatively uncompetitive in Europe, resulting in zero rents. This implies that the quota is not binding. We assume that only 80% of the allowable sugar quota is filled in Spain.

3.10. Marginal abatement cost curves

Two sets of data are needed for the construction of a Marginal Abatement Cost (MAC) curve for a given agricultural industry[25]: the abatement potential of each of the available technologies which could reduce emissions from that industry and the costs associated with each of those technologies.

With reference to the former, the International Institute for Applied Systems Analysis (IIASA) has developed a tool called the Greenhouse gas and Air Pollution Interactions and Synergies (GAINS) model (IIASA, 2015[26]), the website of which provides, for a number of scenarios, emissions factors for each of the industries, sources, and mitigation options listed in Figure 3.4. below. Where differences exist between scenarios, they are generally small, so in these cases a simple mean is taken. With reference to the costs of adoption, the GAINS model also supplies estimates for each available mitigation technology. This data is slightly more complicated than the emissions factors, as it includes figures for three different rates of interest: 4%, 10% and 20%. In the OEG model, the assumed 'normal' rate of return for the whole economy is lower than any of these at 2.5%. Historic data shows that since the European Central Bank began setting interest

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[23] The high elasticity implies that the commodity is relatively homogeneous across different export routes.

[24] AGMEMOD is an EU funded project which sets out to construct partial equilibrium agricultural models for each of the 27 members of the EU and selected candidate countries (http://www.agmemod.eu/).

[25] In its current form, the OEG model only includes MAC curves for GHG emissions from agriculture.

[26] http://gains.iiasa.ac.at/models/index.html

rates in January 1999, the base rate has never risen above 4.75%, and has spent four fifths of that time below 4%[27]. As a result, from the options offered in the GAINS data, the cost figures at 4% were used.

The emissions factors are given in kilotonnes (kt) of methane/nitrous oxide per unit of activity – in this case millions of animals or kt of nitrogen fertiliser used – while the cost data is given in euros per unit of activity. For compatibility with the OEG model, some simple calculations are needed to convert these into different units. Thus, the emissions factors are first combined with the 100 year Global Warming Potentials (GWP – see footnote 18) of methane and nitrous oxide to convert them to carbon dioxide equivalents (CO2e). The cost of a given technology per unit of activity can then be divided by the corresponding reduction in emissions per unit of activity, to give the cost of the technology per tonne of CO2 equivalent abated – the desired format for model compatibility.

3.11. Conclusion

This chapter presents a detailed account of the main steps required to build a CGE database from an array of secondary data sources – principally national accounts for Input-Output tables and the Social Accounting Matrix, UNFCCC data for greenhouse gas emissions, and various estimates from the literature for behavioural parameters. The chapter also illustrates the necessary checks, balances, data searches and time needed in undertaking such a labour intensive task. Nevertheless, this task is of central importance in this study, not least because the results of any model are only as good as the data construction techniques and behavioural parameters employed. Despite this, as has been described above, where data is not available, assumption must be employed to distribute cost shares in split sectors (e.g. agriculture), apportion taxes and margins to sectors and commodities from different sources, and distribute emissions to specific activities. These limitations should be understood when examining the model results.

In addition, the data is a snapshot in time, not in any way intended to represent the evolution of, or trends in, any of the variables described. This puts additional pressure on the construction of well designed contemporary scenarios using historical data observations which are as accurate as possible, as well as plausible forecasts of future trends (see Chapter 5). This is particularly pertinent when capturing changes in the macroeconomic and CAP policy environment post 2007.

In the next chapter we move on to examine the structure of the OEG model itself. This forms the second part of a comprehensive description of the methodology used in this study, of which this chapter forms the first part.

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[27] http://www.bde.es/webbde/es/estadis/infoest/tipos/tipos.html

4. The model

4.1. Introduction

The Orani-ESP-Green (OEG) model is an extended version of ORANI-ESP, documented in Philippidis and Sanjuán (2009), which in turn was based on the ORANI-G model of Australia – fully documented in Horridge (2000). ORANI-ESP is a single country neoclassical, comparative static, Computable General Equilibrium (CGE) model of the Spanish economy, with a particular focus on the agricultural sectors, and modelling the various mechanisms of the Common Agricultural Policy (CAP). The OEG model maintains these features, but the model is now 'recursive dynamic', including both backward-looking adaptive investment expectations and capital accumulation – both of which are explained in section 4.2.1 below. In addition, the extended model develops an area which had been lacking in earlier versions – Greenhouse Gas (GHG) emissions, and climate change policy mechanisms.

As these two closely related features are the most recent additions to the model, their documentation can be found at the end of this section. The initial drivers of production decisions and resource allocation in the model are the six sources of final demand, thus section 4.2. of this chapter describes each of these in turn. This leads into an explanation of the production structure(s) used in the model in part 4.3., as these determines how the final demands are met. The production process provides employment for the factors of production, and section 4.4. provides a description of the various factor markets in the model, including their supply functions. Part 4.5. explains the various prices and taxes (excluding environmental taxes) included in the model, whilst section 4.6. is devoted to the process of market clearing and reaching general equilibrium. Given the agricultural focus of the study, part 4.7. details the agricultural extensions, including modifications to the production structure, and the addition of various CAP instruments. Finally, section 4.8. gives a full description of the extensions made to include GHG emissions, and options for climate change policy modelling.

4.2. Final demands

As noted above, the model includes six sources of final demand. The most sophisticated, and hence those with the most detailed descriptions here, are investment and household demand. Sections 4.2.3 and 4.2.4 are devoted to the remaining two components of Keynesian aggregate demand – exports and government spending – while a single section covers the two remaining final demands – stocks and non-profit enterprises.

4.2.1. Investment demand

In the default OEG model, the capital stock of each industry grows (shrinks) in proportion to the amount by which the expected industry rate of return is above (below) a 'normal' rate of return, which contains both an economy-wide and industry-specific component. The first step is to establish the investment/capital ratio from the following percentage change equation:

$$\boldsymbol{gro_i = x2tot_i - x1cap_i}^{28} \tag{1}$$

where $\boldsymbol{x1cap_i}$ is capital use in industry i, which is determined by that industry's investment in period t-1, and the production function (see section 4.3.3 below). Note that here and throughout this document, lower case letters denote percentage change variables, whilst upper case letters denote levels variables. Industry investment in period t, $\boldsymbol{x2tot_i}$, is the variable determined by the above equation, whilst capital growth, $\boldsymbol{gro_i}$, has an exogenous component, $\boldsymbol{gtrend_i}$, and an endogenous component which depends on the sensitivity of investment to deviations in the expected rate of return from an exogenous 'normal' rate of return:

$$\boldsymbol{gro_i = gtrend_i + ALPHA_i * [1 - (GROSSGRO_i/GROMAX_i)] * mratio_i} \tag{2}$$

where $\boldsymbol{gtrend_i}$ is the 'trend' capital growth in industry i, $\boldsymbol{ALPHA_i}$ is the investment elasticity in response to changes in expected returns, $\boldsymbol{GROSSGRO_i}$ is the current ratio of the value of investment to the value of the capital stock and $\boldsymbol{GROMAX_i}$ is a maximum value for this ratio, such that if this maximum is reached, the expression in parenthesis is one, the bracketed expression collapses to zero, and an increase in the industry's expected return will not cause an additional increase in its investment/capital ratio (Dixon and Rimmer, 2002). This ensures that rates of return which temporarily rise extremely high do not provoke unrealistic swings in investment. The final variable on the right hand side is the ratio of expected to 'normal' returns for industry i, determined by the equation

$$\boldsymbol{mratio_i = gretexp_i - rnorm_i - rnorm\_mac} \tag{3}$$

where $\boldsymbol{rnorm_i}$ is an industry-specific 'normal' rate of return, $\boldsymbol{rnorm\_mac}$ its macroeconomic counterpart, and $\boldsymbol{gretexp_i}$ is the expected rate of return in industry i. Under assumptions of backward looking adaptive expectations by investors, this is a weighted average of the expected rate of return in the previous period, and the actual rate of return in the current period, with a 67% weight being given to the former and 33% to the latter (Dixon and Rimmer, 2002):

$$\boldsymbol{GRETEXP_i = \left[\left({}^2/_3\right) * GRETEXP0_i\right] + \left[\left({}^1/_3\right) * DELGRET_i\right]} \tag{4}$$

Note that this equation is written into the model in levels terms and linearised by GEMPACK (Harrison et al., 2014). $\boldsymbol{DELGRET_i}$ is the change in the actual rate of return, which is a function of the rental price of capital, and the price of investment:

$$\boldsymbol{DELGRET_i = 0.01 * GROSSRET_i * [p1cap_i - p2tot_i]} \tag{5}$$

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[28] It should be noted that throughout the model, and this document, when a number follows a quantity (x), price (p) or value (w) variable, or a value coefficient (V), the numbers refer to purchases by the following agents: 1 = industry; 2 = investment; 3 = household; 4 = export; 5 = government; 6 = stocks; 8 = non-profit

where $\boldsymbol{GROSSRET_i}$ is the rate of return to capital in industry i in levels terms, $\boldsymbol{p1cap_i}$ is the percentage change in the rental price of capital, and $\boldsymbol{p2tot_i}$ is the percentage change in the price of investment.

Thus the relative prices of capital and investment determine the actual rate of return for each industry which, together with the previous period's expected rate of return, determines the current expected rate of return. The ratio of this to the (exogenous) 'normal' rate of return determines the capital growth (i.e., investment/capital) ratio which, in turn, determines investment, since capital has been set by the previous year's investment (see section 4.4.3 below for an explanation of the capital accumulation mechanism).

An additional condition is placed on the value (in current prices) of overall investment by the neoclassical macro closure described in section 4.6.3 below. Briefly, this ensures that any mismatch of investment to domestic saving on the capital account must be compensated by an equal difference between the value of exports and imports on the current account, to ensure a net balance of payments of zero.

4.2.2. Household consumption demand

Similarly to investment, aggregate household demand is generally either exogenous or heavily influenced by the macro environment, as rising (falling) incomes mean households have more (less) money to spend. The model uses a Stone-Geary Linear Expenditure System (LES) with a Klein-Rubin utility function. This treatment of consumption demands has been a popular choice amongst CGE modellers (Dixon et al., 1982; Nganou 2004; Jussila et al., 2012), due partly to its parsimonious demands for parameter estimates, and partly to the flexibility it offers in allowing average budget shares for each good to vary with prices and income – a feature which has taken on greater importance with the advent of dynamic CGE models. Nevertheless, it should be borne in mind that whilst *average* budget shares can vary in the LES, *marginal* budget shares remain constant, i.e. Engel curves are linear. This position has been critiqued by (among others) Rimmer and Powell (1994) and Missaglia and de Boer (2006), both of which offer alternatives to the LES with non-linear Engel curves. Their principle criticism is that as incomes rise over the long-term, the marginal budget shares of high-tech goods and services are likely to increase, whilst the marginal budget shares of basic goods such as food and energy are likely to decrease – particularly in developing countries. For a medium-term (13 years) simulation of a developed country (Spain), however, questions remain as to how much of a problem this is, and how much of a priority modifying the demand system should be. For the time being, the LES is used with the caveat that movements towards (away from) high-tech goods and services as incomes rise (fall) may be low-end estimates.

The nested consumption function for private households is presented in Figure 4.1. In short, households maximise a Klein-Rubin utility function:

$$\boldsymbol{U = \prod_c \{X3\_S_c - X3SUB_c\}^{S3LUX_c}} \qquad \textbf{(6)}$$

where $\boldsymbol{X3\_S_c}$ is the total consumption of commodity c and $\boldsymbol{X3SUB_c}$ is the 'subsistence' level of consumption of the same commodity. Utility only comes from 'supernumerary' consumption of each good – i.e. consumption above and beyond the subsistence level. $\boldsymbol{S3LUX_c}$ is the share of commodity c in additional supernumerary expenditure – i.e. the marginal budget share. Whilst these are fixed, the LES treatment does allow *average* budget shares to change with income, as noted above. This is especially important for the simulations which follow as they are based on a particularly turbulent period for Spanish household incomes, so it is important that overall budget shares for basic goods are allowed to rise as incomes fall, and then fall off again during the (hoped for) recovery.

For the representative household, either luxury consumption at current prices or total consumption at constant prices must be fixed and adjusted exogenously, and the choice of which largely depends on the availability of data and projections. Either way, the variable not fixed will be a function of prices and the Frisch parameter, which calculates the ratio of total to luxury expenditure in the following formula:

$$\boldsymbol{FRISCH = V3TOT/\ V3LUX} \tag{7}$$

where $\boldsymbol{V3TOT}$ is the value of total consumption, and $\boldsymbol{V3LUX}$ that of supernumerary consumption. Overall luxury expenditure for the household is then distributed amongst the various commodities in order to maximise the utility function shown in equation 6 above.

Aggregate disposable income for the household is determined by total factor incomes, net of social security payments and direct taxes, according to the following equation:

$$\boldsymbol{[DISPOSY * disposinc] = [V0HHINC * w0hhinc] - [SOCSEC("recp") * gov\_ss("recp")] - [V0HHTAX * w0hhtax]} \tag{8}$$

where $\boldsymbol{DISPOSY}$ and $\boldsymbol{disposinc}$ are, respectively, the levels and percentage change terms for disposable income, $\boldsymbol{V0HHINC}$ and $\boldsymbol{w0hhinc}$ those for gross household income, $\boldsymbol{SOCSEC("recp")}$ and $\boldsymbol{gov\_ss("recp")}$ social security payments to government (see section 3.6.), and $\boldsymbol{V0HHTAX}$ and $\boldsymbol{w0hhtax}$ household direct taxes.. The total value of household disposable income is apportioned between consumption and household saving, in the equation:

$$\boldsymbol{[V0HHSAVE * w0hhsave] = [DISPOSINC * disposinc] - [V3TOT\_H * w3tot\_h]} \tag{9}$$

where $\boldsymbol{V0HHSAVE}$ and $\boldsymbol{w0hhsave}$ are the levels and percentage change terms for household saving and $\boldsymbol{V3TOT\_H}$ and $\boldsymbol{w3tot\_h}$ are those for household consumption. The household saving here calculated provides the funds for investment according to the neoclassical macroeconomic closure described in section 4.6.3 below. The household savings rate is not fixed, but rather behaves as a residual, adjusting to consumption expenditure, factor incomes, and tax rates.

4.2.3. Export demand

The demand curve faced by total exports in the model can be shifted by adjusting a macroeconomic variable to simulate changes in global economic conditions. Alternatively, if aggregate export data is readily available, this shifter variable can be swapped with aggregate exports, which can then be exogenously shocked according to the data. Export goods are divided into two groups – those which face individual demand functions, and those which face the collective export demand function. Broadly speaking, the groups mirror the tradeable/non-tradeable split. Both groups face standard downward-sloping demand curves from the EU and the rest of the world, such that as export price rises (falls), demand falls (rises). For individual export goods, this is captured by the equation:

$$\boldsymbol{x4_{c,s} - f4q_{c,s} - f4q\_trad = EXP\_ELAST_{c,s} * [p4_{c,s} - phi - f4p_{c,s}]} \tag{10}$$

with the 'f' variables as shifters on the quantity (q) and price (p) of exports, $\boldsymbol{EXP\_ELAST_{c,s}}$ as the price elasticity of demand for exports, $\boldsymbol{x4_{c,s}}$ and $\boldsymbol{p4_{c,s}}$ as the demand for and price of exports of commodity c to destination s, and $\boldsymbol{phi}$ as the exchange rate.

The supply of exports, meanwhile, is governed by a nested Constant Elasticity of Transformation (CET) function, which determines the share of each commodity that is sold on the domestic market, and the share that is exported to each destination (EU and the rest of the world). At the top level of the nested CET function the supply equation is

$$\boldsymbol{x4\_s_c = x0com_c + (\tau_c * [p0com_c - pe\_s_c])} \tag{11}$$

where $\boldsymbol{x4\_s_c}$ is the supply of exports of commodity c across all destinations, $\boldsymbol{x0com_c}$ is the total production of commodity c, $\boldsymbol{\tau_c}$ is the elasticity of transformation between production for the domestic and export markets, $\boldsymbol{p0com_c}$ is the composite price of commodity c across destinations, and $\boldsymbol{pe\_s_c}$ is the composite price of exports of commodity c across the two export destinations (EU and rest of the world), determined by the equation:

$$\boldsymbol{[V4BAS\_SRC_c * pe\_s_c] = sum\{s, SRC1, [V4BAS_{c,s} * pe_{c,s}]\}} \tag{12}$$

with $\boldsymbol{V4BAS_{c,s}}$ as the value at basic prices of exports of commodity c to destination s, $\boldsymbol{V4BAS\_SRC_c}$ as this value summed across both destinations, and $\boldsymbol{pe_{c,s}}$ as the basic export price before taxes and margins – the additions of these wedges is described in section 4.5.1. The elasticity of transformation is a high (and negative) number, as it is assumed that producers have no strong preference as to whether they sell in domestic or export markets (Chapter 3.8). At the second level of the nest, the equation which determines whether exports are sold to the EU or to the rest of the world is similar:

$$\boldsymbol{x4_{c,s} = x4\_s_c + (\tau_c * [pe\_s_c - pe_{c,s}])} \tag{13}$$

with $\boldsymbol{x4_{c,s}}$ and $\boldsymbol{pe_{c,s}}$ being the destination-specific supply and price of exports respectively.

4.2.4. Government demand

Aggregate government spending is a function of GDP, government revenue from taxation, and the ratio of the budget deficit to GDP, as shown in equation 14:

$$\mathbf{100} * \boldsymbol{V0GDPEXP} * \boldsymbol{delbudrat} = [\boldsymbol{GOVTREV} * \boldsymbol{w0govt\_t}] - [\boldsymbol{GOVTEXP} * \boldsymbol{w0govt\_g}] - [[\boldsymbol{GOVTREV} - \boldsymbol{GOVTEXP}] * \boldsymbol{w0gdpexp}] \quad \textbf{(14)}$$

where $\boldsymbol{V0GDPEXP}$ and $\boldsymbol{w0gdpexp}$ are, respectively, the levels and percentage change terms for nominal GDP, $\boldsymbol{GOVTREV}$ and $\boldsymbol{w0govt\_t}$ are those for government revenue, $\boldsymbol{GOVTEXP}$ and $\boldsymbol{w0govt\_g}$ those for government expenditure, and $\boldsymbol{delbudrat}$ is the percentage change in the ratio of the budget deficit to GDP.This equation means that, depending on the availability of data and forecasts, the overall percentage change in government spending (real or nominal – the two are separated only by prices) can be shocked, leaving the (levels) change in the deficit/GDP ratio endogenous. Alternatively, the variable $\boldsymbol{delbudrat}$ can be exogenously shocked, meaning government spending adjusts endogenously according to that change (see below), and to movements in GDP and revenue.

The components of government revenue are laid out in the following equation:

$$[\boldsymbol{GOVTREV} * \boldsymbol{w0govt\_t}] = [\boldsymbol{V0HHTAX} * \boldsymbol{w0hhtax}] + [\boldsymbol{SOCSEC}(''\boldsymbol{recp}'') * \boldsymbol{gov\_ss}(''\boldsymbol{recp}'')] + [\boldsymbol{OTHERS}(''\boldsymbol{recp}'') * \boldsymbol{gov\_o}(''\boldsymbol{recp}'')] \quad \textbf{(15)}$$

where $\boldsymbol{V0TAX\_CSI}$ is the sum of all indirect taxes on sales, $\boldsymbol{V0HHTAX}$ is the sum of all income and inheritance taxes on households, $\boldsymbol{SOCSEC}(''\boldsymbol{recp}'')$ represents government receipts from social security contributions, and $\boldsymbol{OTHERS}(''\boldsymbol{recp}'')$ total government receipts from other sources (see section 3.5), with the lower case equivalents being the same variables in percentage change terms. Indirect tax revenues vary with the value of sales in the economy. Income tax receipts rise and fall with income, and can also be changed by an exogenous shifter variable which mimics a change in the income tax rate – though without any effect on incentives to work as the model does not currently include a work/leisure trade-off for labour. The final two components of government revenue can be shifted, but in the absence of such a shock simply move in line with the consumer price index (CPI).

On the other side, the components of government expenditure are as follows:

$$[\boldsymbol{GOVTEXP} * \boldsymbol{w0govt_g}] = [\boldsymbol{V5TOT} * \boldsymbol{w5tot}] + [\boldsymbol{V2TOT\_G} * \boldsymbol{gov\_inv}] + [\boldsymbol{SOCSEC}(''\boldsymbol{expend}'') * \boldsymbol{gov\_ss}(''\boldsymbol{expend}'')] + [\boldsymbol{OTHERS}(''\boldsymbol{expend}'') * \boldsymbol{gov\_o}(''\boldsymbol{expend}'')] \quad \textbf{(16)}$$

where $\boldsymbol{V5TOT}$ represents government purchases, $\boldsymbol{V2TOT\_G}$ is government investment for industry, $\boldsymbol{SOCSEC}(''\boldsymbol{expend}'')$ is government expenditure on social security, and $\boldsymbol{OTHERS}(''\boldsymbol{expend}'')$ is all other government expenditure, and lower case versions are again percentage change equivalents of the same. Similar to the revenue side, social security and others rise and fall in line with the CPI, but can be shifted. Government investment is also a function of the same shifter variable, as well increasing with private investment in the economy. This shifter variable, exogenous by default, can be 'swapped' with the variable for the ratio of the budget deficit to GDP, which would normally be endogenous. Thus government expenditure, in the form of social security payments, government investment, and other expenditure, would adjust subject to shocks to the deficit/GDP ratio.

4.2.5. Stocks and NGO demand

Two sources of final demand remain, but each of them is small relative to the components of aggregate demand described so far. In the absence of an explicit shock, stocks of each commodity rise or fall in line with domestic production of that commodity – the exceptions to this are processed sugar and dairy products, which will be explained in the description of intervention prices in section 4.7.2.3 below. Similarly, unless otherwise shocked, aggregate non-profit demands change in line with aggregate household consumption, with some movement between goods in response to relative price changes.

4.3. Production

Having described the sources of final demand, the focus shifts to exploring how this demand is met. While final demands will only occupy a few columns on an input-output table, the bulk of the table will be dedicated to the intermediate demands for goods and services by firms producing other goods and services. Similarly, if the results of the model simulations which follow are to be understandable, it is crucial to lay out a clear exposition of the production structure that lies at the heart of the OEG model. This section begins with an introduction to the nested Constant Elasticity of Substitution (CES) function used in this and many other CGE models. Moving through this nested structure means that demands for intermediate inputs, primary factors and energy can each be described in turn. This will lead into the next section, the focus of which is factor markets and incomes.

4.3.1. Production structure

The OEG model allows for the possibility of single industries producing multiple commodities, as well as using multiple inputs in the production process. Each industry's decision as to which commodities to produce, like that of whether to produce for the domestic or export market (see section 4.2.3 above), is governed by a Constant Elasticity of Transformation (CET) function which mimics firms' revenue maximising behaviour. This is captured in the equation:

$$\boldsymbol{q1_{c,i} = x1tot_i + SIGMA1OUT_i * [p0com_c - p1tot_i]} \qquad \textbf{(17)}$$

where $\boldsymbol{q1_{c,i}}$ is the production of commodity c by industry i, $\boldsymbol{x1tot_i}$ is total production in industry i, $\boldsymbol{SIGMA1OUT_i}$ is the elasticity of transformation between different commodities in response to changes in relative prices, $\boldsymbol{p0com_c}$ is the basic price of commodity c, and $\boldsymbol{p1tot_i}$ is the industry-wide price of production in industry i.

On the other side, the nested CES function means industries face a Hicksian cost-minimisation problem, given the level of demand for the good(s) they produce, and the relative prices of all the inputs they use – both of which are determined by the economic conditions of the simulation. Specifically, the nesting structure allows the modeller a good deal of flexibility in capturing the fact that some inputs are more substitutable than others, as shall be seen. In the simulations to be run in this study, the production structure is slightly more complex for agricultural than for non-agricultural industries. Here, the non-agricultural structure is described, with the agricultural version explained in section 4.7 below. A diagrammatic representation of what follows can be found in Figure 4.2.

The top level of the nested structure determines the shares of each intermediate input, and the primary factor-energy composite, according to the following equations:

$$\boldsymbol{x1prim_i - [a1prim_i + a1tot_i] = x1tot_i - SIGMA1T_i * [[p1prim_i + a1prim_i] - [p1cst_i + a1tot_i]]} \tag{18}$$

$$\boldsymbol{x1\_s_{c,i} - \left[a1\_s_{c,i} + a1tot_i\right] = x1tot_i - SIGMA1T_i * \left[\left[p1\_s_{c,i} + a1\_s_{c,i}\right] - [p1cst_i + a1tot_i]\right]} \tag{19}$$

where $\boldsymbol{x1prim_i}$ and $\boldsymbol{x1\_s_i}$ are, respectively, the demand in industry i for the primary factor composite, and intermediate input c, with $\boldsymbol{p1prim_i}$ and $\boldsymbol{p1\_s_{c,i}}$ as their respective prices, $\boldsymbol{SIGMA1T_i}$ as the elasticity of substitution at this top level of the nest, $\boldsymbol{p1cst_i}$ as the cost of production in the industry, and the $a1$ variables are exogenous shifters which represent technological progress. As noted in Chapter 3, in the non-agricultural industries, $SIGMA1T_i$ is equal to zero, so at this level of the nest inputs are used in fixed proportions (in the absence of productivity shocks).

4.3.2. Intermediate inputs

All industries must decide the domestic/import shares for each intermediate input they use, as well as the EU/RoW shares for imports. These are determined by the following equations of the production function:

$$\boldsymbol{x1dom_{c,i} - a1dom_{c,i} = x1\_s_{c,i} - SIGMA1_i * [p1dom_{c,i} + a1dom_{c,i} - p1\_s_{c,i}]} \tag{20}$$

This first equation describes demands for domestically sourced inputs of commodity c to industry i ($\boldsymbol{x1dom_{c,i}}$), as a function of the total demand for (non-source-specific) inputs of that commodity ($\boldsymbol{x1\_s_{c,i}}$), the Armington elasticity of substitution between domestic and imported inputs ($\boldsymbol{SIGMA1_i}$), and the price of that input if bought on the domestic market ($\boldsymbol{p1dom_{c,i}}$), relative to the composite price of the input across all sources ($\boldsymbol{p1\_s_{c,i}}$), with the $a1$ variables again as productivity shifters. This composite price is a weighted average of the domestic and import prices such that:

$$\boldsymbol{[V1PUR\_TOT_{c,i} * p1\_s_{c,i}] = [V1PUR\_DOM_{c,i} * p1dom_{c,i}] + [V1PUR_{IMP_{c,i}} * p1imp_{c,i}]} \quad \textbf{(21)}$$

where the $\boldsymbol{V1PUR}$ coefficients are the values at purchases prices of, respectively, total purchases of commodity c by industry i, domestic purchases, and imports of the same. Imports can be sourced from the EU or from the rest of the world, and the variable $\boldsymbol{p1imp_{c,i}}$ is itself a composite of the price from these two sources – weighted by value using the same method as equation 21 above. Demand for composite imports from all sources is determined by the following equation, similar to that for domestic demands:

$$\boldsymbol{x1imp_{c,i} - a1imp_{c,i} = x1\_s_{c,i} - SIGMA1 * [p1imp_{c,i} + a1imp_{c,i} - p1\_s_{c,i}]} \quad \textbf{(22)}$$

whilst at the lowest level of the nest, demands for each input from a specific foreign source is determined by the equation:

$$\boldsymbol{x1_{c,s,i} - a1_{c,s,i} = x1\_imp_{c,i} - (2 * SIGMA1 * [p1_{c,s,i} + a1_{c,s,i} - p1imp_{c,i}])} \quad \textbf{(23)}$$

What all these equations mean is that at each level of the nested structure, demand is dependant partly on the demand on the next level up, so for example industry i's demand for domestically produced commodity c is partly dependant on industry i's *total* demand for commodity c – this is analogous to the income effect in a consumption function. There is also a substitution effect though, which means that the shares of inputs sourced domestically and from imports will change in response to relative price changes on the various markets where these inputs can be purchased. The degree of this responsiveness to relative price changes is captured in the parameter $\boldsymbol{SIGMA1}$, which occurs in most of the equations above. This parameter is known as the Armington Elasticity (Armington, 1969), and captures the fact that domestically produced goods and imports are not perfect substitutes for each other. The higher the Armington elasticity, the closer the goods are to being homogenous, hence why the elasticity is multiplied by 2 at the level where imports are split between those from the EU and those from the rest of the world. The sources of the Armington elasticities, along with those of all other elasticities of substitution used in the OEG model, have been described in Chapter 3 above.

4.3.3. Primary factor use

The primary factor composite comprises labour, land (agricultural sectors only), and the capital-energy composite. More detail will be given on the supply of each of these factors of production in section 4.4 below, but their relative demands as inputs for a given industry depend on their relative prices and the elasticity of substitution, as shown in the following equations for, respectively, land, labour, and the capital energy composite:

$$\boldsymbol{x1lnd_i - a1lnd_i = x1prim_i - SIGMA1PRIM_i * [p1lnd_i + a1lnd_i - p1prim_i]} \quad \textbf{(24)}$$

$$\boldsymbol{x1lab\_o_i - a1lab\_o_i = x1prim_i - SIGMA1PRIM_i * [p1lab\_o_i + a1lab\_o_i - p1prim_i]} \quad \textbf{(25)}$$

$$\boldsymbol{x1ke_i - a1ke_i = x1prim_i - SIGMA1PRIM_i * [p1ke_i + a1ke_i - p1prim_i]} \quad \textbf{(26)}$$

where $\boldsymbol{x1lnd_i}$, $\boldsymbol{x1lab\_o_i}$ and $\boldsymbol{x1ke_i}$ are the demands for land, labour, and the capital-energy composite respectively, $\boldsymbol{p1lnd_i}$, $\boldsymbol{p1lab\_o_i}$ and $\boldsymbol{p1ke_i}$ are the corresponding factor prices, $\boldsymbol{x1prim_i}$ and $\boldsymbol{p1prim_i}$ are the demand for, and price of, the primary factor composite, and the $a1$ variables are tech-change shifters. The elasticities of substitution between primary factors ($\boldsymbol{SIGMA1PRIM_i}$) range from very inelastic (0.2 for the coal and oil sectors) to relatively elastic (1.5 for many of the manufacturing sectors), with a description of where these estimates come from given in Chapter 3 above.

The nested structure includes an additional layer for the relationship between capital and energy. The nature of this relationship has been a live debate in the economic literature for a number of years, the principal question being whether the two are complements or substitutes and, if the latter, to what extent (Koetse et al., 2008). Empirical estimates of the relationship have ranged from strong substitutes to strong complements (Burniaux and Truong, 2002), due to the variation in time periods considered (short run elasticities may be quite different to long run elasticities). For simplicity, and through sensitivity analysis, the OEG model uses the GTAP-E value of 0.5 for the elasticity of substitution between capital and energy ($\boldsymbol{SIGMA1KE_i}$). The relevant equations for demands for capital and the energy composite are:

$$\boldsymbol{x1cap_i - a1cap_i = x1ke_i - SIGMA1KE_i * [p1cap_i + a1cap_i - p1ke_i]} \quad \textbf{(27)}$$

$$\boldsymbol{x1egy_i - a1egy_i = x1ke_i - SIGMA1KE_i * [p1egy_i + a1egy_i - p1ke_i]} \quad \textbf{(28)}$$

where $\boldsymbol{x1cap_i, p1cap_i}$, $\boldsymbol{x1egy_i}$ and $\boldsymbol{p1egy_i}$ are the demands for, and prices of, capital and energy respectively, and the $a1$ variables represent technological advances specific to those inputs.

4.3.4. Energy use

The treatment of energy demands within the production structure is also based on the GTAP-E model (Birur et al., 2008), with the energy composite divided at the top level into electricity, coal, and a composite of all other sources of energy, with the following associated demand equations:

$$\boldsymbol{x1\_s_{c,i} - a1\_s_{c,i} = x1egy_i - SIGMA1EGY_i * \left[p1\_s_{c,i} + a1\_s_{c,i} - p1egy_i\right]} \quad \textbf{(29)}$$

where the c commodities in this case are electricity and coal, and the variables follow the pattern above, with $\boldsymbol{x1\_s_{c,i}}$ as demand from industry i for the domestic/imported composite of the good, $\boldsymbol{a1\_s_{c,i}}$ as exogenous technological change (productivity), $\boldsymbol{p1\_s_{c,i}}$ as the price, and $\boldsymbol{SIGMA1EGY_i}$ as the elasticity of substitution between electricity, coal, and other sources of energy. Demand for the composite of all other energy commodities is given by the equation:

$$\boldsymbol{x1necegy_i = x1egy_i - SIGMA1EGY_i * [p1necegy_i - p1egy_i]} \tag{30}$$

where $\boldsymbol{x1necegy_i}$ and $\boldsymbol{p1necegy_i}$ are the demand for, and price of, the non-electricity-coal energy composite. The composite price at this level is determined by the equation:

$$\boldsymbol{V1PURNECEGY_i * p1necegy_i = sum\{c, NECEGY, V1PURTOT_{c,i} * [p1\_s_{c,i} + a1\_s_{c,i}]\}} \tag{31}$$

which defines the composite price ($\boldsymbol{p1necegy_i}$) as a value weighted average of the prices of each of its components – gas, oil and refined fuels ($\boldsymbol{p1\_s_{c,i}}$).

The next level down gives the demand functions for each of these three goods:

$$\boldsymbol{x1\_s_{c,i} - a1\_s_{c,i} = x1necegy_i - SIGMA2EGY_i * [p1\_s_{c,i} + a1\_s_{c,i} - p1necegy_i]} \tag{32}$$

where $\boldsymbol{x1\_s_{c,i}}$ represents, in this case, the demands for the gas, oil and refined fuel commodities, $\boldsymbol{p1\_s_{c,i}}$ their prices, and $\boldsymbol{SIGMA2EGY_i}$ the elasticity of substitution between them.

As is the case with the non-energy intermediate goods described in 4.3.2. above, an Armington elasticity determines the ease with which imported energy goods will substitute for domestic varieties, and *vice-versa.* These elasticities tend to be low for energy goods, as for the primary energy sources (coal, crude oil, natural gas), domestic supply cannot simply be increased in the face of world price rises. The secondary energy goods (electricity, petrol, gas distribution), on the other hand, tend to be much more domestically sourced, and likely to remain so as they largely relate to distribution.

4.4. Factor markets and incomes

A crucial part of the circular flow at the heart of all CGE models is the payments from firms to primary factors, which then stimulate the final demands described in section 4.2 above. Results analysis of the simulations described below will be incomplete in the absence of a detailed understanding of how incomes from, and employment of, labour, capital and land are determined in the model. Thus it is important to give a full description of the mechanisms controlling the supply of each of these factors – with those controlling their demand having been discussed in section 4.3.3 above.

4.4.1. Land supply

Given the agricultural focus of this study, an important aspect of the model is the econometrically estimated land supply function. This feature, based on the work of Tabeau et al. (2006) and van Meijl and van Tongeren (2002), and described in Philippidis and Sanján (2009b), characterises the price responsiveness of aggregate land supply in Spain, based on yield data for all the different regions of the country. Biophysical, area, and yield data are taken from Fischer et al. (2001). The yield data is sorted from highest to lowest, and the land price variable is defined as the inverse of the yield. Cumulative area farmed increases with price (i.e.

the land with the highest yield is farmed first), giving an upward sloping supply curve. Given that land supply cannot increase beyond a certain point, regardless of the economic conditions, an asymptote is also included, placing a maximum on the available land for cultivation.

For implementation into the model, this takes the following form:

$$\boldsymbol{PLANDREAL1\_L} = [[\frac{\boldsymbol{B}}{\boldsymbol{1-QR1\_L}}] - \boldsymbol{C}]^{\boldsymbol{1/\rho}} \tag{33}$$

which is a rearrangement of the non-linear function giving area as an increasing function of rent:

$$\boldsymbol{QR1\_L} = \boldsymbol{1} - [\boldsymbol{B}/(\boldsymbol{C} + \boldsymbol{PLANDREAL1\_L^{\rho}})] \tag{34}$$

where $\boldsymbol{B}$, $\boldsymbol{C}$ and $\boldsymbol{\rho}$ are econometrically estimated parameters, $\boldsymbol{QR1\_L}$ is the quantity of land area being used, and $\boldsymbol{PLANDREAL1\_L}$ is the land price.

The ease with which land can move between alternative uses in response to changes in relative rental prices is governed by a nested Constant Elasticity of Transformation (CET) function. This reflects the reality that changing land from, e.g. wheat to barley cultivation is significantly easier than from wheat production to pig farming. Following Tabeau et al. (2006), land using activities are split into three groups: cereals, oilseeds and protein crops (COP); field crops and permanent pastures (FCP); and 'other agricultural activities', which includes fruit, vegetables, vineyards and pig and poultry farming.

At the top level of the nest, supply is determined for the 'field crops and pasture' composite, which includes cereals, oilseeds and protein crops, as well as the extensive livestock sectors:

$$\boldsymbol{qfcp} = \boldsymbol{x1lnd\_i} + \boldsymbol{CETLND} * [\boldsymbol{p1lndm\_i} - \boldsymbol{pfcp}] \tag{35}$$

where $\boldsymbol{qfcp}$ is land supply to the field crops and pastures composite, $\boldsymbol{x1lnd\_i}$ is total land supply, $\boldsymbol{CETLND}$ is the elasticity of transformation at this level (the lowest in the nested structure), $\boldsymbol{p1lndm\_i}$ is the aggregate (market) price of land, and $\boldsymbol{pfcp}$ is the composite price of land in the field crops and pastures section, calculated as a value-weighted average of prices in the livestock and cereals, oilseeds and protein crop sectors as follows:

$$\begin{gathered}[\boldsymbol{V1LNDFCPM\_I} * \boldsymbol{pfcp}] = \boldsymbol{sum}\{\boldsymbol{i}, \boldsymbol{LVSK}, \boldsymbol{V1LNDM_i} * [\boldsymbol{p1lndm_i} + \boldsymbol{a1lndsup_i}]\} + \\ [\boldsymbol{V1LNDCOPM_I} * \boldsymbol{pcop}]\end{gathered} \tag{36}$$

where $\boldsymbol{V1LNDFCPM\_I}$ is the value of land in the field crops and pastures composite, $\boldsymbol{V1LNDM_i}$ and $\boldsymbol{p1lndm_i}$ are the industry-specific values and prices of land in, in this case, the livestock sectors, and $\boldsymbol{V1LNDCOPM\_I}$ and $\boldsymbol{pcop}$ are the total value and composite price of land used for cereals, oilseeds and proteins. At this level of the nesting structure land not used by the FCP composite is distributed among other agricultural activities according to the equation:

$$q1lnd_{i,rest} = x1lnd\_i + CETLND * [p1lndm\_i - \{p1lndm_{i,rest} + a1lndsup_{i,rest}\}] \quad (37)$$

where $qlnd_i$ is land supply to industry i, $p1lndm_i$ is the market price of land used in industry i, and $a1lndsup_i$ is an industry-specific tech-change variable for land.

The next level of the nest determines the land supply to the COP composite, and to the individual livestock sectors. The former is determined by the equation:

$$qcop = qfcp + CETLND2 * [pfcp - pcop] \quad (38)$$

and the latter by the equation:

$$q1lnd_{i,livestock} = qfcp + CETLND2 * \left[pfcp - \left\{p1lndm_{i,livestock} + a1lndsup_{i,livestock}\right\}\right] \quad (39)$$

with $CETLND2$, the elasticity of transformation at this level, set higher than $CETLND$, and $pcop$ as the composite price of land in the cereals, oilseeds and protein crops sectors, which again is a value weighted average of land prices in the relevant industries:

$$V1LNDCOPM\_I * pcop = sum\{i, COP, V1LNDM_i * [p1lndm_i + a1lndsup_i] \quad (40)$$

The COP group forms the bottom level of the nested structure, with the highest elasticity of transformation, and supply to each industry in this group governed by the equation:

$$qlnd_i = qcop + CETLND3 * [pcop - \{p1lndm_i + a1lndsup_i\}] \quad (41)$$

4.4.2. The labour market

Labour in the model is aggregated to 4 different types ('highly skilled', 'skilled', 'unskilled' and 'armed forces'). From the demand side, then, this adds an extra level to the nested structure as firms decide how their total workforce should be split amongst the different labour types. This is determined by the following equation, similar to many of those listed in section 4.3 above:

$$x1lab_{i,o} = x1lab\_o_i - SIGMA1LAB_i * \left[p1lab_{i,o} - p1lab\_o_i\right] \quad (42)$$

which shows that labour type o, used by industry i ($x1lab_{i,o}$) is dependent partly on overall demand for labour in industry i ($x1lab\_o_i$), and partly on the price of labour type o relative to other labour types in that industry ($p1lab_{i,o} - p1lab\_o_i$). The responsiveness of demand to the change in price is, as ever, captured by the elasticity, in this case $SIGMA1LAB_i$, which varies across industries.

On the supply side, each of the four labour types has an upward sloping supply curve, with varying elasticities of supply. This is expressed in the following equation:

$$x1lab\_i_o = SIGMA2LAB_o * [p1lab\_i_o - p3tot\_h] \quad (43)$$

where $\boldsymbol{SIGMA2LAB_o}$ is the elasticity of supply of labour in occupation o (Fernandez-Val 2003), meaning the nominal wage relative to the Consumer Price Index ($\boldsymbol{p3tot\_h}$) – the real wage – is what determines the change in the availability of labour in each occupation. Again it should be noted that no work/leisure trade-off is included in the model, meaning that in prosperous economic conditions the economy can essentially draw an infinite amount of workers (or 'work-hours') into production with no cost to the welfare of society. With the current high unemployment rate in Spain, this does not seem like an unrealistic assumption. The elasticity of supply is the lowest for highly skilled labour, reflecting the increased training needs of this group, and highest for unskilled labour. This should be borne in mind during the reporting of results as it means the effects of an economic expansion or contraction or likely to be felt more in the wages of highly skilled labour (price effect), and in the employment of unskilled labour (quantity effect).

4.4.3. Capital markets and investment

The supply of capital in each industry is determined by the level of net investment in that industry the previous year. This process is implemented in the model through the following two equations:

$$\boldsymbol{0.01 * CAPSTOCK\_OLDP_i * x1cap_i = CAPADD_i} \tag{44}$$

$$\boldsymbol{CAPADD_i = V2TOT_i - [DPRC_i * CAPSTOCK_i]} \tag{45}$$

where $\boldsymbol{x1cap_i}$ is the percentage change in the use of capital by industry i determined within the value added nest (see section 4.3.3), $\boldsymbol{CAPADD_i}$ is the levels change in the same, $\boldsymbol{V2TOT_i}$ is gross investment in industry i, $\boldsymbol{DPRC_i}$ is the rate of depreciation, and $\boldsymbol{CAPSTOCK_i}$is the level of capital stock, with the suffix $"\_OLDP"$ indicating that it is being measured at the previous period's price level. The level of $\boldsymbol{CAPSTOCK_i}$ in the base data is set as the rental value of capital used in the industry ($\boldsymbol{V1CAP_i}$) divided by the industry rate of return. Intuitively this means that the rental value of capital is equal to the stock of capital employed multiplied by the rate of return. Thus for example a capital stock of €1,000,000 with a rental rate of 5% would give a rental value of €50,000 for capital used in the industry. In the model the capital stock value is updated by both the quantity and price of capital employed in the industry each year. Equations 44 and 45 together describe the capital accumulation mechanism in the model. Equation 45 ensures that capital accumulation in period t is equal to net investment from period t-1, and equation 44 converts that to a percentage change for updating the capital stock, and for factor availability for the production function.

The consequence of this treatment is that in each industry, capital used in period t is fixed by the level of investment in period t-1. In the short-term then, the supply of capital is perfectly inelastic, and the demand for capital – a derived demand from industry output, which also depends on the price of other inputs – must be equal to the supply, with the rental price of capital ($\boldsymbol{p1cap_i}$) adjusting to ensure that this is the case. This is the link to one of the principal recursive-dynamic elements of the model, since if industrial demand for capital is strong (weak) compared to the scarce (abundant) supply of capital in the industry from the previous period's investment, then the rental price of capital will have to rise (fall) to discourage (encourage) demand so that it equals supply. As described in section 4.2.1., the rental price of capital feeds into the actual rate of return which, with some lag, feeds into the expected rates of return, which in turn determine the level of investment. Thus a relative scarcity (glut) of capital in a specific industry will, over time, attract more (less) investment and hence more (less) capital into that industry, and bring rental prices back down (up).

4.5. Prices

The model contains a large number of price variables, as each commodity has a price for every source of final demand (see section 4.2. above), every source of origin (domestic or imported) and, in the case of those used as intermediate or investment goods, every industry. Indirect taxes associated with emissions regulations will be described in detail in section 4.8. below, and the treatment of indirect taxes on household purchases will be left until section 4.8.3. due to the inclusion of revenue recycling options, which add an extra level of complexity. This section thus describes production taxes and taxes on sales to agents other than private households, which contribute to price changes in slightly different ways.

4.5.1. Purchasers' prices

Purchasers' prices are the products of basic prices and the 'powers' of all relevant indirect taxes, plus the value of any margins associated with the commodity flow. The tax 'power' is defined as one plus the tax rate, or the price inclusive of the tax divided by the price exclusive of the tax. This variable will be greater than one for a tax, and less than one for a subsidy (in effect, a negative tax).The equations below cover intermediate, investment and export goods as well as purchases by government and the non-profit sector. For clarity, the numbers one to eight are used to differentiate among the various purchasing agents in the model, as noted in footnote 28.

$$[\boldsymbol{V1PUR}_{c,s,i} * \boldsymbol{p1}_{c,s,i}] = \left[[\boldsymbol{V1BAS}_{c,s,i} + \boldsymbol{V1TAX}_{c,s,i}] * [\boldsymbol{p0}_{c,s} + \boldsymbol{t1}_{c,s,i}]\right] + [\boldsymbol{V1MAR}_{c,s,i} * [\boldsymbol{p0mar} + \boldsymbol{a1mar}_{c,s,i}]] \quad (46)$$

where $\boldsymbol{V1PUR}_{c,s,i}$ refers to the value at purchasers' prices, $\boldsymbol{V1BAS}_{c,s,i}$the value at basic prices, $\boldsymbol{V1TAX}_{c,s,i}$ the value of taxes, $\boldsymbol{V1MAR}_{c,s,i}$ the value of margins, $\boldsymbol{p1}_{c,s,i}$ the purchasers' price, $\boldsymbol{t1}_{c,s,i}$ the power of the tax, and $\boldsymbol{a1mar}_{c,s,i}$ a tech-change variable for margins on commodity c from source s to industry i. Meanwhile $\boldsymbol{p0}_{c,s}$is the basic price of commodity c from source s and $\boldsymbol{p0mar}$ is the price of margins. This equation is repeated below to define the purchase price of investment goods:

$$[\boldsymbol{V2PUR}_{c,s,i} * \boldsymbol{p2}_{c,s,i}] = \left[[\boldsymbol{V2BAS}_{c,s,i} + \boldsymbol{V2TAX}_{c,s,i}] * [\boldsymbol{p0}_{c,s} + \boldsymbol{t2}_{c,s,i}]\right] + [\boldsymbol{V2MAR}_{c,s,i} * [\boldsymbol{p0mar} + \boldsymbol{a2mar}_{c,s,i}]] \quad (47)$$

the purchasers' price of exports:

$$[V4PUR_{c,s} * p4_{c,s}] = \left[[V4BAS_{c,s} + V4TAX_{c,s}] * [pe_{c,s} + t4_{c,s}]\right] + [V4MAR_{c,s} * [p0mar + a4mar_{c,s}]] \tag{48}$$

the purchasers' price of government acquisitions:

$$[V5PUR_{c,s} * p5_{c,s}] = \left[\left[V5BAS_{c,s} + V5TAX_{c,s}\right] * \left[p0_{c,s} + t5_{c,s}\right]\right] + \left[V5MAR_{c,s} * \left[p0mar + a5mar_{c,s}\right]\right] \tag{49}$$

and the purchasers' price in the non-profit sector:

$$[V8PUR_{c,s} * p8_{c,s}] = \left[\left[V8BAS_{c,s} + V8TAX_{c,s}\right] * \left[p0_{c,s} + t8_{c,s}\right]\right] + \left[V8MAR_{c,s} * \left[p0mar + a8mar_{c,s}\right]\right] \tag{50}$$

4.5.2. Non-environmental taxes

All of the tax 'powers' in the equations above are composed mainly of 'shifter' variables which can be shocked. These equations follow the pattern:

$$t1_{c,s,i} = f0tax_{c} + f1tax\_csi + t1b_{c,s,i} \tag{51}$$

where $t1_{c,s,i}$ is the overall power of the tax, $f0tax_{c}$ is a commodity specific sales tax shifter which changes the tax rate on sales of a given commodity from all sources and to all destinations, $f1tax\_csi$ is a shifter for the tax rate on all intermediate purchases, and $t1b_{c,s,i}$ is a shifter for the tax rate specific to purchases of commodity c from source s to industry i. The presence of multiple shifters with different indices offers a good deal of flexibility, and also the potential for one or more of them to be swapped with endogenous variables. One example of this in the current study is the swapping of $t1b_{c,s,i}$ with the change in the *value* of the sales tax (such that the tax power adjusts endogenously) in order to shock certain agricultural payments on specific input uses. This is a useful option in cases where data on tax (or subsidy) *values* are more readily available than data on tax *rates*.

The final link needed to connect the tax rates to the rest of the economy is to convert them into values. For (non-environmental) taxes on intermediate inputs, this is done using the following equation (which is replicated for taxes on investment, export, government and non-profit purchases):

$$delV1TAX_{c,s,i} = \left[0.01 * V1TAX_{c,s,i} * \left[x1_{c,s,i} + p0_{c,s}\right]\right] + \left[0.01 * \left[V1BAS_{c,s,i} + V1TAX_{c,s,i}\right] * t1_{c,s,i}\right] \tag{52}$$

where $delV1TAX_{c,s,i}$ is the (levels) change in the value of the sales tax on purchases of good c from source s by industry i. The taxes, now in value form, can thus be added into government revenue and used for public expenditures or deficit reduction in the manner set out in section 4.2.4 above.

In addition to indirect taxes on sales, the model includes direct taxes on production for which the method is necessarily slightly different. The non-environmental component of this[29] is determined by an exogenous tax rate, according to the equation:

$$\boldsymbol{delV1PTX_i = [PTXRATE_i * delV1CST_i] + [V1CST_i * delPTXRATE_i]} \qquad \textbf{(53)}$$

where $\boldsymbol{delV1PTX_i}$ is the change in the value of the production tax, $\boldsymbol{PTXRATE_i}$ is the rate of the production tax, $\boldsymbol{delV1CST_i}$ is the change in the value of production excluding the tax, with $\boldsymbol{V1CST_i}$ as the corresponding levels coefficient, and $\boldsymbol{delPTXRATE_i}$ **is** the (exogenous) change in the production tax rate. The value of the tax is then added into the total cost of production in the equation

$$\boldsymbol{delV1TOT_i = delV1CST_i + delV1PTX_i + delV1LNDTAX_i + delV1CAPTAX_i + delV1LABTAX\_O_i + delV1OCT_i + delRENT_i} \qquad \textbf{(54)}$$

where $\boldsymbol{delV1TOT_i}$ is the change in total value of production by industry i, $\boldsymbol{delV1LNDTAX_i}$, $\boldsymbol{delV1CAPTAX_i}$ and $\boldsymbol{delV1LABTAX\_O_i}$ are changes in factor taxes, $\boldsymbol{delV1OCT_i}$ is the change in 'other costs' in the industry[30], and $\boldsymbol{delRENT_i}$ is the change in rents arising from quotas[31]. It should be noted here that tax values on land and capital may be exogenous for the agricultural industries so they can be shocked according to Common Agricultural Policy (CAP) payments, or endogenous for non-agricultural industries, in which case they adjust according to their use by that industry, and the (exogenous) tax power attached. Labour taxes are kept at zero except in the case of 'revenue recycling' from environmental taxes – see section 4.8.3. below[32]. This change in the value of production then translates to a change in prices through the equation:

$$\boldsymbol{V1TOT_i * [p1tot_i + x1tot_i] = 100 * delV1TOT_i} \qquad \textbf{(55)}$$

such that the value of production ($\boldsymbol{V1TOT_i}$) is equal to the unit cost of production ($\boldsymbol{p1tot_i}$) times the quantity ($\boldsymbol{x1tot_i}$) , thus if the tax on production increases the total cost of production, the repercussion in terms of higher costs per unit is felt in the final industry price.

4.6. Equilibrium

4.6.1. Market clearance equations

The market clearing equations ensure that demand in the domestic market for both domestically produced goods and imports must be equal to the supply of each for all commodities. This is guaranteed by the following two equations:

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[29] For a description of the tax on process emissions see section 4.8.2. below.

[30] This is used principally for modelling grandfathered ETS permits and emissions abatement costs – see section 4.8. below.

[31] Only applicable in the milk and sugar sectors – see section 4.7.2. below.

[32] Note that income taxes are included as a tax on household income, not on labour *per se*.

$$0.01 * DOMSALES_c * x0dom_c = sum\{u, LOCUSER, delsale_{c,"dom",u}\} \quad (56)$$

$$0.01 * V0IMP_{c,s} * x0imp_{c,s} = sum\{u, LOCUSER, delsale_{c,s,u}\} \quad (57)$$

where $DOMSALES_c$ and $x0dom_c$ are the value and quantity of domestic sales of domestically produced goods, $V0IMP_{c,s}$ and $x0imp_{c,s}$ are the value and quantity of domestic sales of imported goods and $LOCUSER$ is the set of "local users" i.e. the destinations for goods in the domestic market – intermediates, investment, households, government purchases, stocks and the non-profit sector. Thus the right hand side of the equations above is the change in the quantity of total sales of commodity c from (equation 56) domestic production and (equation 57) imports from the EU and the rest of the world. On the left hand side, $x0dom_c$ is the supply of commodity c to the domestic market, as opposed to that to the export market described in section 4.2.3. above.

4.6.2. Aggregate income and expenditure

Nominal GDP from the income side is the total of all factor payments to households, including rents, indirect taxes, and 'other costs'. Hence the equation in percentage change terms is as follows:

$$[V0GDPINC * w0gdpinc] = [V1PRIM_I * w1prim_i] + [100 * delV0TAX_{CSI}] + [100 * delRENT_I] - [100 * delV0PERMIT\_IMP] \quad (58)$$

where $V0GDPINC$ and $w0gdpinc$ are the levels and percentage change terms for nominal GDP from the income side, $V1PRIM\_I$ and $w1prim\_i$ are those for the value of factor incomes, and $delV0TAX\_CSI$, $delRENT\_I$ and $delV0PERMIT\_IMP$ are the levels changes in tax revenues, milk and sugar quota rent income and total expenditure on emissions permit imports (see section 4.8.2 below)[33]. This last term on the right hand side ensures that money spent on purchasing emissions permits from other EU countries is subtracted from national income – this value is not accounted for in any of the other terms on the right hand side.

This value should be equal to nominal GDP from the expenditure side, which is the total of all the components of Keynesian aggregate demand (C+I+G+X-M). In the language of the OEG model, this macro condition is expressed as:

$$[V0GDPEXP * x0gdpexp] = [V3TOT\_H * x3tot\_h] + [V2TOT\_I * x2tot\_i] + [V5TOT * x5tot] + [V8TOT * x8tot] + [V6TOT * x6tot] + [V4TOT * x4tot] - [V0CIF\_C * x0cif\_c] - [MAC\_PERMTAX * 100 * c\_E\_PERMIMP] \quad (59)$$

where $V0GDPEXP$ and $x0gdpexp$ are, respectively, nominal (levels terms) and real (percentage change) GDP from the expenditure side, $x3tot\_h$ is the percentage change in real household consumption, $x2tot\_i$ that for real investment, $x5tot$ real government spending, $x8tot$ real non-profit spending, $x6tot$ real

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[33] note that this value could be negative in the case of Spain being a net exporter of emissions permits.

inventories purchases, $\boldsymbol{x4tot}$ real exports and $\boldsymbol{x0cif\_c}$ real imports – all weighted by their value equivalents. Again, the last term ensures that imports of emissions permits are subtracted, where $\boldsymbol{MAC\_PERMTAX}$ is the price, and $\boldsymbol{E\_PERMIMP}$ the quantity of permit imports. Note that whilst the calculation for aggregate income was in nominal (value) terms, that for aggregate expenditure is in real terms. In order to compare the two, the percentage change in aggregate expenditure quantity index is added to the percentage change in an aggregate expenditure price index ($\boldsymbol{p0gdpexp}$) which is calculated as follows:

$$\boldsymbol{[V0GDPEXP * p0gdpexp] = [V3TOT\_H * p3tot\_h] + [V2TOT\_I * p2tot\_i] + [V5TOT * p5tot] + [V8TOT * p8tot] + [V6TOT * p6tot] + [V4TOT * p4tot] - [V0CIF\_C * p0cif\_c] - [c\_MAC\_PERMTAX * 100 * E\_PERMIMP]} \qquad \textbf{(60)}$$

Thus the percentage change in nominal GDP from the expenditure side is equal to that in real GDP added to that in the price index:

$$\boldsymbol{w0gdpexp = x0gdpexp + p0gdpexp} \qquad \textbf{(61)}$$

Given that all domestic markets should clear and all incomes are exhausted on demands (including savings), the changes in the values of GDP from the income and expenditure sides should be equal.

4.6.3. Macroeconomic closure

The model uses a neoclassical macroeconomic closure. As stated above, if all domestic markets clear, then the current account (exports minus imports) should be balanced by the residual on the capital account (savings minus investment). This identity which ensures a net balance of payments of zero is captured in the following equation:

$$\boldsymbol{NONV0HHSAVE = V4TOT - V0CIF\_C + V2TOT\_I - V0HHSAVE} \qquad \textbf{(62)}$$

Thus, any shortfall in the current account balance ($\boldsymbol{V4TOT - V0CIF\_C}$) and household saving ($\boldsymbol{V0HHSAVE}$) in covering investment ($\boldsymbol{V2TOT\_I}$) must be met by non-household saving ($\boldsymbol{NONV0HHSAVE}$) – i.e. saving by government, non-profit institutions etc. Macroeconomic saving, which is the sum of household and non-household saving, is thus sufficient to cover investment plus the current account surplus (capital account deficit).

4.7. Agricultural extensions

4.7.1. Production structure

As noted above, the model has two different production structures – one for primary agricultural industries (excluding processed food industries) and one for all other industries. While the non-agricultural structure (described in section 4.3.1 above) has a Leontief function for the top nest of intermediate inputs and the primary factor composite, the agricultural industries have a non-zero elasticity of substitution between inputs at this level.[34] In addition, in the agricultural production structure, chemical fertilizer is moved from the intermediate input nest to the capital-energy (now capital-energy-fertiliser) nest. This development means that the model allows farmers some degree of flexibility in using extra capital and/or energy to abate their nitrous oxide emissions from chemical fertilizers, as well as some scope for using extra labour or land to reduce their fertilizer intensity, in the face of environmental policy which penalises the use of GHG emitting inputs. The OEG model also follows the GTAP-AGR model (Keeney and Hertel, 2005) in adding an additional nest for the livestock sectors, allowing some substitutability between feed inputs. Moreover, by providing a more detailed picture of crop demands, this is a step towards modelling the effects which different feeds can have on methane emissions from livestock, which is one of the objectives for future development of the model. In modelling terms, the current treatment is captured by the equation:

$$\boldsymbol{x1feed_i - a1feed_i + a1mat_i = x1mat_i - [SIGMA1T_i * [p1feed_i + a1feed_i - p1mat_i + a1mat_i]} \qquad \textbf{(63)}$$

where $\boldsymbol{x1feed_i}$ is demand for the feed composite in (livestock) industry i, $\boldsymbol{p1feed_i}$ is the price of the feed composite, $\boldsymbol{x1mat_i}$ is the composite demand for all intermediate inputs, $\boldsymbol{p1mat_i}$ is the composite price of the same and the $\boldsymbol{a1}$ variables are productivity shifters.

4.7.2. The Common Agricultural Policy (CAP)

The ORANI-ESP model, on which OEG is based, was developed specifically to allow realistic simulation of CAP reform proposals and agricultural trade agreements. As a result, the modelling of the various aspects of the CAP is one of the strengths of the model. From the size of the payments made under the CAP, it is clear that they will have a significant impact on farmers' production decisions, and so cannot be viewed as independent of emissions reduction policies in the agricultural sector. Indeed, as will be explored in the simulation results, the interaction between the CAP and environmental policies forms a crucial part of the story which emerges from this study. As a result, it is important to give a full description of the CAP mechanisms included in the OEG model.

4.7.2.1. Direct payments

The transition from payments coupled to production of specific crops to decoupled payments attached to agricultural land began in Spain in 2006. In modelling terms this Single Farm Payment (SFP) has taken the form of a subsidy on land, which necessitates three distinct price variables (with associated value coefficients) for land used in each industry[35]. The first variable, p1lndm, is the market, or owners' price of land – i.e. the price incorporating all subsidies of any kind. This is the price at which land is bought and sold, but not the

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[34] There exists a version of the model in which this level of the nested structure is a Leontief function for *all* industries, and the agricultural sector is highly aggregated, but given the agricultural focus of the simulations run, the model described above is the one used.

[35] Land is exclusively used by agricultural industries in the OEG model.

price at which it is rented out, as it is the owners, not the tenants, who benefit from the subsidy. Thus the second price, p1lnd, is the rental price of land to the agent (i.e., the farmer). This is the price net of any subsidies, and is the key variable in the decisions made by agricultural industries as to how land intensive their production should be, as it is the price at which land is rented out. In levels terms, this means we can say the following:

$$\boldsymbol{P1LND = P1LNDM * T1LND} \tag{64}$$

i.e. the rental price of land ($\boldsymbol{P1LND}$) is the product of the market price ($\boldsymbol{P1LNDM}$) and the combined power of total land subsidies (coupled plus decoupled - $\boldsymbol{T1LND}$). Note that since all 'T' variables are *tax* powers, in the presence of a subsidy the power is less than one, hence $\boldsymbol{P1LND \leq P1LNDM}$. If an industry benefits from neither decoupled nor coupled payments then the two prices will be equal.

In order to reduce coupled, and increase decoupled, payments over the simulation period, an additional price variable is needed which represents the price including the decoupled, but not the coupled, subsidy. This variable is called p1lndL in the model, and enables us to say the following in levels terms:

$$\boldsymbol{P1LNDL = P1LNDM * T1LND\_DC} \tag{65}$$

$$\boldsymbol{P1LND = P1LNDL * T1LND\_C} \tag{66}$$

where $\boldsymbol{T1LND\_DC}$ is the tax power associated with the decoupled subsidy, and $\boldsymbol{T1LND\_C}$ that associated with the coupled subsidy – thus $\boldsymbol{P1LND \leq P1LNDL \leq P1LNDM}$. These two wedges are converted, using the values coefficients, into subsidy values. As data on the *value* of CAP payments is more readily available than that for the subsidy *rates*, the values are made exogenous and shocked, and the 'tax' powers adjust endogenously.

A complicating factor is the issue of how to apply the Single Farm Payment (SFP – i.e. the decoupled subsidy). In theory the payment is independent of production, so could be applied simply as a lump-sum payment to the farm household – which would negate the need for the 'decoupled' price wedge described above. To receive the payment, though, farmers must keep the land in "good agricultural and environmental condition"(European Council, 2009), and with the "Greening of the CAP" proposals for the 2014-2020 period (European Parliament, 2013), it looks like conditionality will play an increasing role in the SFP. The benefit of modelling the payments as a uniform land subsidy is that it should be more or less production neutral, avoid cross commodity effects (i.e. no increase in the production of wheat at the expense of oilseeds, for example), and the value of the SFP will be fully capitalised into the land price – which is what is observed in reality. This suggests the payment should not be modelled as completely disassociated from production of any kind.

As a means, then, of finding a line between these contrasting narratives of the 'decoupled' payment, the SFP receiving sectors[36] are separated into four groups of similar activities: cereals and oilseeds, fruit and vegetables, other crops, and livestock. For each of these groups the value of the coupled subsidy which is removed each year is reapplied at a uniform rate on land used across the group. This means that the movement from coupled to decoupled payments is much more likely to cause (for example) an uncompetitive wheat farmer to start growing barley, than cause her to become a dairy farmer. In modelling terms, this means that the power of the decoupled subsidy $\boldsymbol{T1LND\_DC}$ from the equations above takes a different value for each group, but the same value for each industry within a group.

4.7.2.2. Production quotas

In OEG, sugar and milk quotas use the same microeconomic framework. In the context of sugar, the advantage of this approach is that it does correctly characterise quota as an additional factor of production and also captures the binding/non-binding status of the quota mechanism. However, this treatment does not capture all of the nuances of the EU sugar policy, namely, the self financing principle and the A, B and C quota rates/price differentials which still applied in the 2007 reference year, though have been phased out since.

Both milk and sugar are split into raw and processed commodities in the OEG database, and the quotas are applied to the raw products. The model uses GEMPACK's complementarity slack code (Bach and Pearson, 1996) which allows the exogenous setting of a quota limit which may be binding or non-binding depending on production (Lips and Reider, 2005). Quota rents are only present when the quota is binding, and they are inserted as an additional factor of production which drives a wedge between the marginal cost of production and the market price, as by definition when the quota is binding demand exceeds supply. When the ratio of production to quota is less than one (non-binding), no rents will accrue to producers, and an increase in the quota will have no effect. When the ratio is one, rents will accrue, and production will only be able to increase if the quota is increased.

4.7.2.3. Export subsidies and intervention prices

The treatment of export subsidies and intervention prices has been somewhat simplified in the OEG model compared to that found in the ORANI-ESP model (Philippidis and Sanjuán, 2009b), such that, where relevant[37], export subsidy values are kept exogenous and adjusted according to data on agricultural payments.

In contrast to the production quotas described above, intervention prices in the milk and sugar sectors are attached to the processed products, as it is these downstream products which are traded, rather than the

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[36] Pig farming, for example, receives no subsidy in Spain.

[37] Commodities which receive export subsidies in Spain are as follows: cereals, potatoes, vegetables, fruit, beef meat, dairy products, processed sugar and alcoholic beverages.

primary commodities. Here another complementarity is employed, such that an exogenous intervention price can be set by the modeller. The starting ratio of the commodity price to the intervention price is also set in the base data of the model. If this ratio remains above 1, then stock purchases will remain at 0, whilst if the commodity price falls to the intervention price (the ratio is equal to 1) then stock purchases will be triggered up to a maximum of 5% of total commodity supply.

4.8. Climate change module

The principal modification to the ORANI-ESP model, for the purposes of this study, is the climate change module. This includes comprehensive coverage of Spanish GHG emissions (see section 3.7.), which are linked to various 'drivers' within the model, a broad range of policy options for emissions reductions, including both carbon taxes and 'cap-and-trade' schemes, and the incorporation of marginal abatement cost (MAC) curves for agricultural emissions, allowing for a more detailed analysis of the technological possibilities for emissions reduction than is often the case in similar studies. Given the agricultural focus of this study, the MAC treatment has not (yet) been extended to the non-agricultural sectors.

4.8.1. Emissions drivers

As noted in Chapter 3, one of the great advantages of using UNFCCC data on greenhouse gas emissions is the high level of detail on the various sources of emissions. This enables a good degree of realism in linking emissions to the relevant 'drivers' in the model. In this context the word 'drivers' refers to the specific economic activities during which greenhouse gases are emitted. These may be the use of a specific input – as in the case of fossil fuel combustion, or the application of nitrogen-based fertilisers for crop-growing – or they may be the production process itself – as is the case in the production of cement, or metals – or they may come from a household activity, such as petrol use in cars, or natural gas used for central heating systems.

Table 3.3. contains a comprehensive list of the emissions in the model and their relevant drivers. Within the agricultural sector it is worth noting that both methane from enteric fermentation, and methane and nitrous oxide from manure management have all been linked to output in the relevant livestock sector. An alternative would be to link these emissions to capital, on the assumption that in this instance 'capital' refers to the animals themselves. This is the approach taken by Golub et al. (2009). However, since investment in capital for abatement is one of the principal ways farmers can reduce their emissions, this approach could lead to an unintended feedback loop, and confusing results from the OEG model.

The UNFCCC data makes use of the concept of 'emissions factors'. These are essentially the quantity of greenhouse gas emissions per unit used of the relevant input, or per unit of production. Thus it could be emissions per head of cattle, per kg of fertiliser, per litre of petrol, per kg of cement produced etc. If in the model, all emissions moved in direct proportion to the relevant driver, this would imply fixed emissions factors, since a 10% rise in, for example, petrol or fertiliser use, would result in a 10% rise in emissions from that source. This is, in fact, the case for all non-agricultural emissions in the model, but the treatment for agricultural emissions is more detailed (see section 4.8.4.2 below). Some accounting for changes in emissions factors in the non-agricultural sectors would be a useful addition to enhance the overall realism of the model, but currently the assumption is made that these remain constant.

4.8.2. Taxes, permits, and the price mechanism

The OEG model offers two principal ways of controlling emissions from any given industry, input, or greenhouse gas, or from any different combination or agglomeration of any of the above. They are, in the language of policy-makers, 'carbon taxes', and 'cap-and-trade' schemes.

The first option is to leave emissions endogenous, and apply an exogenous tax per tonne of carbon dioxide equivalent (CO2e) of the relevant GHG(s). An emissions tax (or 'carbon tax' as this option has come to be known in policy circles), can be applied at any level, from a specific gas, fuel and industry, up to the whole Spanish economy. The model also allows for differing carbon tax rates to be applied by sector, input or gas. This could be useful for a scenario in which a common carbon tax rate is agreed for all emissions, but certain 'strategic', or economically important sectors are protected, and face a lower tax rate than the rest of the economy.

The second option is to have an endogenous emissions price, which is forced to rise as either emissions are exogenised and forced down, or a binding quota is placed on emissions by means of a 'complementarity' which causes an emissions price variable to rise if the ceiling is hit. The modelling of both of these methods will be explained, but first a word as to their relative merits, and why a combination of the two is currently being used in the OEG model.

From a policy (or 'real-world') perspective, the quota system should be seen as the ideal method of modelling a cap-and-trade scheme for the simple reason that GHG emissions may fall 'naturally' (i.e. as a result of factors which have nothing to do with environmental policy), and exogenising them denies this possibility. Thus it is better to leave them endogenous, and impose a limit which they cannot exceed, rather than exogenously fixing them to meet the policy target. Depending on the economic conditions, this latter option could in theory induce a negative tax (a subsidy on emissions), as a situation may arise where emissions would endogenously have decreased by more than the amount by which they are being forced down, leading to a carbon subsidy rather than tax emerging in the model solution. Imposing a binding quota causes no such problems as emissions are free to rise and fall naturally in response to economic conditions, until they hit the ceiling. At that point an endogenous emissions tax emerges at a level necessary to keep emissions at the ceiling limit – this tax will always be non-negative.

However, in modelling terms, the quota method is computationally more expensive than exogenising emissions, as it necessitates the introduction of a complementarity for each quota introduced, which can slow simulation execution times. Thus, modellers must be careful with how many quotas they introduce, and if individual limits are to be imposed on a large number of industries, or specific sources of emissions, it is advisable to fix emissions and allow the relevant emissions tax to rise or fall as necessary – whilst keeping a careful eye out to make sure all emissions tax rates are non-negative. If negative taxes are observed (i.e. carbon subsidy), the relevant emissions can be re-endogenised as they are clearly falling 'naturally' by more than enough to meet whatever target they face. The extent to which this study makes use of the two strategies will be explained in the simulation descriptions to follow (Chapter 5).

Under either of the two strategies, though, the interpretation is still that of a cap-and-trade system in which all emitters covered by the scheme face a limit on their aggregate emissions. The emissions tax is thus determined by the supply of permits (which depends on the limit set), and their demand (which depends on how important emitting activities are to the industries/households covered by the scheme, and whether their production/income is rising over the period). In the face of a cap-and-trade scheme, there are three things which will tend to result in a high permit price: a stringent cap; strong economic growth in the sectors covered; difficulty in substituting away from polluting inputs.

Keeping in mind the dangers of complementarities and the fixed emissions method discussed above, the model offers as much flexibility in cap-and-trade simulations as it does for carbon taxes, i.e. they can be applied at any level from a single industry or emitting activity up to the level of the entire economy. In addition, any combination of carbon taxes and cap-and-trade can be used within a simulation, the only qualifier being that the two cannot be applied simultaneously on the same emitting activity, as if emissions are endogenous the associated carbon tax rate must be exogenous, and *vice versa*.

Under both schemes, the end result is, in modelling terms, a tax – a non-negative wedge between market and agents' prices. This tax must be introduced into the model in such a way that it a) does not interfere with any other taxes in operation, but is applied in addition to them and b) has the potential to modify the behaviour of those being taxed. For clarity, another distinction must be made, this time between emissions which are the result of the use of a specific input – for which the tax will look similar to a sales tax – and 'process' emissions, which come from the production process itself – for which the tax will look similar to a production tax (see section 4.5.2 above).

In the 2007 data for Spain (Chapter 3), just over 80% of emissions are linked to a specific input – petrol, coal, gas, oil, or nitrogen fertiliser. For these emissions, the carbon tax is added at the point of sale of the relevant input. To do this, the value of the carbon tax is first calculated as the quantity of emissions of greenhouse gas g (in CO2e) from commodity c, used by industry i ($E\_INTINP_{g,c,s,i}$)[38], multiplied by the carbon tax ($PRICE\_E\_INT_{g,c,i,}$) in euros per tonne of CO2e (€/tCO2e). This value is then divided by the value of purchases excluding the carbon tax ($V1PUR\_NE\_L_{c,s,i}$). When added to 1, this gives the power of the carbon tax ($T1\_E_{c,s,i}$):

$$T1\_E_{c,s,i} = 1 + \left[\frac{sum\{g,GHG,[PRICE\_E\_INT_{g,c,i,}*E\_INTINP_{g,c,s,i}]\}}{V1PUR\_NE\_L_{c,s,i}}\right] \tag{67}$$

This carbon tax power is the variable which drives a wedge between what used to be the agents' price (the price inclusive of all other taxes), and the new agents' price (the price inclusive of all other taxes plus the carbon tax), with the latter being the price which industries use in their decisions regarding the use of inputs in the production process. Thus the carbon tax feeds into the wider model through increasing the price of polluting inputs, which discourages their use. Meanwhile the revenues raised from the carbon tax(es) are added into the government revenue calculation, as with any other tax.

Similar to the 'sales tax' above, the first step in implementing a carbon tax levied on process emissions is to calculate the value of the tax by multiplying the quantity of emissions of greenhouse gas g in sector i ($E\_OUT_{g,i}$) by the respective emissions price ($PRICE\_E\_OUT_{g,i}$). Again, this value is converted into a power ($T1PTX\_E_i$) by dividing it by the value of production inclusive of all costs except the carbon tax ($V1TOT\_NE\_L_i$) and adding 1:

$$T1PTX\_E_i = 1 + \left[\frac{sum\{g,GHG,[PRICE\_E\_OUT_{g,i}*E\_OUT_{g,i}]\}}{V1TOT\_NE\_L_i}\right] \tag{68}$$

This tax power is converted into a value through the following equation:

$$V1PTX\_E_i = [V1TOT\_NE_i * T1PTX\_E_i] - V1TOT\_NE_i \tag{69}$$

where $V1PTX\_E_i$ is the value of taxes on production emissions in industry i, and $V1TOT\_NE_i$ is the total value of production in that industry before the addition of the emissions tax. This levels variable is converted to a change variable, to give the change in the value of the tax, which in turn increases the overall cost of production in that industry through the equation:

$$delV1TOT_i = delV1TOT\_NE_i + delV1PTX\_E_i \tag{70}$$

where $delV1TOT_i$ is the change in the value of production including the tax, $delV1TOT\_NE_i$ is change in the value of production excluding the tax, and $delV1PTX\_E_i$ is the change in the value of the tax. Thus process emissions, when a carbon tax is applied, will raise the whole cost of production in an industry, leading to a direct contractionary effect on output, as there are no substitution options available. This is in contrast to

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[38] This method also applies to household purchases, but for simplicity the example described here is industrial.

emissions linked to use of a specific input, where a tax will cause firms (and households) to substitute away from the relevant input as its price rises.

4.8.3. Revenue recycling

The model also includes some options for revenue recycling. Much has been written within the so-called 'double-dividend' literature on the potential for using revenue raised from environmental taxes to either lower the tax burden in other areas, or pursue a specific policy goal such as poverty reduction or full employment (Faehn et al., 2009). In its current form the model is able to recycle revenue through a reduction in VAT for households to encourage consumption, or through a subsidy on labour taxes to reduce unemployment. In both cases, the first step is to specify the revenues to be recycled – equations 71 and 72 respectively. In the example here this includes those from emissions taxes levied on agricultural industries, as this is the scenario run in Chapter 6 (see below). This can however be changed at the modeller's discretion:

$$\boldsymbol{delVAT\_RR = SWIT\_VATREC * \sum_i^{AGR} delV0TAX\_EMIT_i} \qquad (71)$$

$$\boldsymbol{delLAB\_RR = SWIT\_LABREC * \sum_i^{AGR} delV0TAX\_EMIT_i} \qquad (72)$$

where $\boldsymbol{delVAT\_RR}$ and $\boldsymbol{delLAB\_RR}$ are the annual change in the values of revenue to be recycled through the consumption subsidy and the labour subsidy respectively. The first variables on the right hand side are the switch variables which the modeller uses to activate or deactivate each form of revenue recycling. This can be done either before or during the simulation. Note that to have both switched to 1 would result in total recycled revenue double that of the revenue raised. Thus if both channels are to be used simultaneously, with equal weighting, each switch variable should be set to 0.5. $\sum_i^{AGR} delV0TAX\_EMIT_i$ gives the change in the total value of emissions taxes in all primary agricultural sectors.

For the consumption subsidy, the next step is to define the commodities and sources which will benefit from the subsidy. For this purpose a dummy variable is attached to each commodity purchased by households, and each of the three sources (domestic, imported from EU, imported from RoW), which is set to one for those commodities and sources to which the subsidy applies, and 0 for those to which it does not. Again, these can be set before the simulation and/or changed during it.

The subsidy acts as an additional wedge between the price paid by households and that received by producers. As a result, a number of new price and tax variables are needed. In essence, all those equations which previously calculated the variables $\boldsymbol{p3_{c,s}}$, $\boldsymbol{t3_{c,s}}$, $\boldsymbol{V3PUR_{c,s}}$, $\boldsymbol{V3TAX_{c,s}}$ and $\boldsymbol{delV3TAX_{c,s}}$, following the same pattern as other purchases in the model described in section 4.5. above, now calculate those variables before the application of the subsidy. These are renamed, respectively, $\boldsymbol{p3\_PRERR_{c,s}}$, $\boldsymbol{t3\_PRERR_{c,s}}$, $\boldsymbol{V3PUR\_PRERR_{c,s}}$, $\boldsymbol{V3TAX\_PRERR_{c,s}}$ and $\boldsymbol{delV3TAX\_PRERR_{c,s}}$.

For those commodities and sources which do not benefit from the subsidy, the two sets of variables are equal. The total revenue to be recycled in this way is distributed amongst those that do in the following equation:

$$delVAT\_RR = \sum_{c}^{COMRR} \sum_{s}^{SRCRR} -delV3TAX\_RR_{c,s} \tag{73}$$

where $COMRR$ and $SRCRR$ are, respectively, those commodities and sources to which the subsidy is applied, and $delV3TAX\_RR_{c,s}$ is the value of the subsidy on commodity c from source s (note that $delVAT\_RR$ will be a positive value, and $delV3TAX\_RR_{c,s}$ must be a negative tax. A single variable ($t3\_RR$) ensures that the power of the subsidy is uniform across all the commodities and sources to which it applied, and is calculated from the value of the subsidy in the following equation:

$$delV3TAX\_RR_{c,s} = \big[0.01 * V3TAX\_RR_{c,s} * [x3_{c,s} + p3\_PRERR_{c,s}]\big] + \big[0.01 * [V3PUR\_PRERR_{c,s} + V3TAX\_RR_{c,s}] * t3\_RR\big] \tag{74}$$

with $0 \leq t3\_RR \leq 1$ and $delV3TAX\_RR_{c,s} \leq 0$. The subsidy then feeds into the purchasers' price faced by consumers in the following equation:

$$[V3PUR_{c,s} * p3_{c,s}] = \big[[V3PUR\_PRERR_{c,s} + V3TAX\_RR_{c,s}] * [p3\_PRERR_{c,s} + t3\_RR]\big] \tag{75}$$

Similarly for the labour subsidy, once the value of the subsidy is calculated, the next step is to use dummy variables to define the occupations (low-skilled, skilled, highly-skilled) and industries the recycled revenue is applied. Here the subsidy acts as a wedge between the price paid for labour by employers and that received by employees, such that the latter is greater than the former.

The aggregate labour subsidy ($delLAB\_RR$) is distributed among participating occupations ($OCCRR$) and industries ($INDRR$) to in the equation

$$delLAB\_RR = \sum_{i}^{INDRR} \sum_{o}^{OCCRR} -delV1LABTAX_{i,o} \tag{76}$$

As in the VAT subsidy above, a single 'tax power' variable ($t1lab\_RR$) ensures that the power of the subsidy is uniform across all occupations and industries involved. The occupation- and industry-specific power of the subsidy ($t1lab_{i,o}$) is set to 0 for all non-participating labour. For participating labour, the power is translated into a subsidy value ($delV1LABTAX_{i,o}$):

$$delV1LABTAX_{i,o} = \big(0.01 * [V1LAB_{i,o} - V1LABM_{i,o}] * [p1labm_{i,o} + x1lab_{i,o}]\big) + \big(0.01 * [V1LABM_{i,o} + [V1LAB_{i,o} - V1LABM_{i,o}] * t1lab_{i,o}\big) \tag{77}$$

and drives a wedge between the price paid by employers ($\boldsymbol{p1lab_{i,o}}$) and that received by workers ($\boldsymbol{p1labm_{i,o}}$):

$$[\boldsymbol{V1LAB_{i,o}} * \boldsymbol{p1lab_{i,o}}] = \left[[\boldsymbol{V1LABM_{i,o}} + [\boldsymbol{V1LAB_{i,o}} - \boldsymbol{V1LABM_{i,o}}] * [\boldsymbol{p1labm_{i,o}} + \boldsymbol{t1lab_{i,o}}]\right] \quad \textbf{(78)}$$

4.8.4. Agricultural Marginal Abatement Cost (MAC) curves

One of the principal innovations of this study is the implementation of agricultural end-of-pipe abatement through MAC curves calibrated to bottom-up data on the costs and potentials of various abatement technologies. Abatement by each agricultural industry in each period is derived from the emissions tax, and the MAC curve which gives the price of abatement as an increasing function of the proportion of emissions abated, up to some technical maximum. The assumption is that that polluters (in this case, farmers) will take up the cheapest options for abatement first, and that they will abate up to the point at which the marginal cost of abating one extra ton of CO2e is equal to its 'marginal revenue' in terms of avoided tax resulting from lower emissions. Both assumptions follow from the underlying assumption of cost minimising behaviour. Thus, assuming perfect information, farmers will continue along the marginal abatement curve until the cost of abatement, in €/tCO2e, is equal to the carbon tax they face, also in €/tCO2e. It should be noted that perfect information is clearly not a realistic assumption, but the results presented below are essentially a 'best-case' scenario of how emissions reductions *could* be allocated in order to minimise cost – they are not a prediction or forecast of how such reductions *will* be allocated in reality. In essence, the assumption follows the neoclassical behavioural rule for technology uptake. This section first describes how the level of abatement is calculated in the model, then how this affects emissions factors and, through them, the quantity of emissions, before concluding with an explanation of how expenditure on abatement equipment is added to farmers' costs.

4.8.4.1. Abatement

Chapter 3 describes how agricultural MAC curves were constructed from data from IIASA's GAINS model, and how these were used to calibrate end-of-pipe abatement parameters for the OEG model. These parameters are calibrated such that the MAC curves in the model match, as closely as possible, those derived from the GAINS data. The calibrated curves are shown in Figures 4.4. and 4.5. The functional form found to be most suitable is based on that of De Cara and Jayet (2011) and is shown in equation 79:

$$\boldsymbol{ABATE_{g,c,i}} = \boldsymbol{\bar{\alpha}} * [\mathbf{1} - \boldsymbol{e}]^{[-[[1+PRICE_{g,c,i}/\tau]^{\beta}} \quad \textbf{(79)}$$

where $\boldsymbol{\bar{\alpha}}$, $\boldsymbol{\tau}$ and $\boldsymbol{\beta}$ are the three calibrated parameters, $\boldsymbol{ABATE_{g,c,i}}$ is the proportion of emissions of gas g, from use of input c in industry i which is abated, with $\mathbf{0} \leq \boldsymbol{ABATE_{g,c,i}} \leq \mathbf{1}$, and $\boldsymbol{PRICE_{g,c,i}}$ is the price of the same, in €/CO2e. This maps the potential and cost for abatement over the whole simulation run. To derive the level of abatement which takes place in any given period (***b-a*** in Figure 4.6.), and its cost, the model must be aware of any abatement which has taken place in previous periods (***a*** in Figure 4.6.). A modelling convention which will be frequently used throughout this section is to have a coefficient which at the beginning of each period takes the closing value of the relevant variable (in this case the level of abatement) from the previous period and stays constant at that level throughout the current period. Meanwhile a (levels) variable representing the current period value is calculated during the current period, and its closing value updates the coefficient at the start of the next period. Taking methane emissions from the livestock sector as an example, the degree of abatement undertaken in period t is given by the levels variable $\boldsymbol{ABATE\_OUT_{t,g,i}}$, while that which was undertaken in period t-1 is given by the coefficient $\boldsymbol{ABATE\_OUT_{t-1,g,i}}$, with $\boldsymbol{ABATE\_OUT_{t,g,i}}$ at the end of period t becoming the starting value for period t+1. Similarly, the cumulative index of abatement undertaken since the beginning of the simulation run, up to and including period t-1 is given by coefficient $\boldsymbol{ABATE\_OUT\_IX_{t-1,g,i}}$, while the same index up to and including period t is given by the levels variable $\boldsymbol{ABATE\_OUT\_IX_{t,g,i}}$. Note that all of the above are measured as a proportion of total emissions.

Thus the abatement undertaken in each period must be added to the cumulative total for all previous periods to give the cumulative total for abatement up to and including the current time period:

$$\boldsymbol{ABATE\_OUT\_IX_{t,g,i} = ABATE\_OUT\_IX_{t-1,g,i} + ABATE\_OUT_{t,g,i}} \tag{80}$$

The abatement undertaken is dependent on the function in equation 79 above, but in order to measure the level of abatement in the current period, the cumulative total of abatement from all previous periods must be subtracted:

$$\boldsymbol{ABATE\_OUT_{t,g,i} = [\bar{\alpha} * \Big[1 - e]^{[-[[1+PRICE_{t,g,c,i}/\tau]^{\beta}}\Big] - ABATE\_OUT\_IX_{t-1,g,i}} \tag{81}$$

where the bracketed expression can be seen as ***b*** in Figure 4.6., and the last variable on the right hand side as ***a***. Substituting this expression for current period abatement into equation 80 above gives the MAC curve, as both measure the total degree of abatement over the whole simulation period.

4.8.4.2. Emissions factors

Emissions factors measure the emissions attached to each unit of production or of a specific input used (see section 3.10. above). In the OEG model, methane emissions factors per head of livestock, and those for nitrous oxide per kilogramme of fertiliser used are made up of two components (all other emissions factors remain constant by assumption as they have no end-of-pipe abatement option). One part of the emissions factor is an exogenous 'trend' component. This is taken from the annual average change in emissions factors over the period prior to the simulation start point: 1990-2007. Fertiliser emissions factors show no change over this period, so in the crops sectors the trend component is constant. For methane emissions the increases or decreases are generally small, the exception being dairy cattle, which increases at an average of 1.8% a year. The second component of the emissions factor is the endogenous end-of-pipe abatement undertaken in response to emissions restrictions and the resultant environmental taxes, which is described above. Thus in a given period t the calculation for a given emissions factor (staying with the livestock example) takes the form:

$$\boldsymbol{EF\_REAL\_OUT_{t,g,i} = EF\_REAL\_OUT_{t-1,g,i} * [\frac{EF\_TREND\_OU_{t,g,i}}{EF\_TREND\_OU_{t-1,g,i}}] * [1 - ABATE\_OUT_{t,g,i}]} \quad \textbf{(82)}$$

where, following the convention outlined above, the variable $\boldsymbol{EF\_REAL\_OUT_{t,g,i}}$ is the emissions factor in the current period, the coefficient $\boldsymbol{EF\_REAL\_OUT_{t-1,g,i}}$ is that from the last period, $\boldsymbol{EF\_TREND\_OU_{t,g,i}}$ and $\boldsymbol{EF\_TREND\_OU_{t-1,g,i}}$ are the equivalents for the exogenous trend component, and $\boldsymbol{ABATE\_OUT_{t,g,i}}$ is the proportion of emissions abated this period. Thus the current period emissions factor is equal to that for the previous period adjusted for current period abatement and the trend.

These emissions factors help determine the quantity of emissions according to the following equation, in levels terms:

$$\boldsymbol{E\_OUT_{t,g,i} = X1TOT_{t,i} * EF\_REAL\_OUT_{t,g,i}} \quad \textbf{(83)}$$

where $\boldsymbol{E\_OUT_{t,g,i}}$ represents emissions attached to output in the current period, and $\boldsymbol{X1TOT_{t,i}}$ the level of output. Emissions attached to fertiliser use are calculated using the same type of equation, except that input use ($\boldsymbol{X1_{t,c,s,i}}$) replaces output. Thus as abatement rises in response to a rising carbon price, the emissions factor falls and 'end-of-pipe' emissions are reduced, though absolute reductions or increases in emissions will also be a function of the level of demand for polluting inputs, or the level of production if emissions are attached to output (i.e. the relevant 'driver').

4.8.4.3. Abatement expenditure

The equations described above are sufficient in themselves to determine the abatement decisions of farmers based on the cost function of the available technologies, and the policy environment which determines the burden of carbon taxes. However, with no further additions to the model, these equations would mean that farmers are essentially able to abate for free. The hypothetical cost of abatement would play a role in their decision, but once they have made that decision, they would never actually pay that cost. Thus, the model needs an additional mechanism to ensure this cost is paid by farmers.

The first step is to calculate how much each agricultural industry has spent on abatement in a given period. Ideally this should be equal to the area under the MAC curve (the definite integral) from the level of abatement in the previous period to that in the current period. However the GEMPACK software does not include an integral function in its code, and the functional form used to calibrate the MAC curve has proved too complex for manually inserting the integral into the model. A linear approximation is adopted as the next best alternative. Looking at the illustrative example in Figure 4.6., expenditure should be equal to the quantity of abatement undertaken ($\boldsymbol{b_t - a_{t-1}}$), multiplied by the price at each point along the curve, which is c at the beginning of the period rising to d at the end. Thus the calculation for approximated expenditure in the period is:

$$\boldsymbol{c_{t-1}[b_t - a_{t-1}] + \frac{[[d_t - c_{t-1}][b_t - a_{t-1}]]}{2}} \tag{84}$$

with the first expression as the rectangle which multiplies the quantity of abatement ($\boldsymbol{b_t - a_{t-1}}$) by the beginning of the period price ($\boldsymbol{c_{t-1}}$), and the second expression as the triangle which multiplies that same quantity of abatement by the incremental increase in price ($\boldsymbol{d_t - c_{t-1}}$) over the period.

Note that in all equations prior to equation 84, 'abatement' has been measured as a proportion of total emissions, but now the absolute quantity of emissions abated in tonnes of CO2 equivalent (tCO2e) is needed. For the example of methane emissions from livestock used above, this is calculated in equation 85:

$$\boldsymbol{ABATE\_OUT\_Q_{t,g,i} = ABATE\_OUT_{t,g,i} * E\_OUT_{t,g,i}} \tag{85}$$

where $\boldsymbol{ABATE\_OUT\_Q_{t,g,i}}$ is the quantity of emissions abated in the current period ($\boldsymbol{b_t - a_{t-1}}$) of gas g in industry i. This can now be inserted into equation 84 above, which in the model appears as follows:

$$\boldsymbol{ABATE\_EXP_{t,i} = sum\{g, CH4, [ABATE\_OUT\_Q_{t,g,i} * PRICE\_E\_OUT_{t-1,g,i}]\} + [sum\{g, CH4, [ABATE\_OUT\_Q_{t,g,i} * [PRICE\_E\_OUT_{t,g,i} - PRICE\_E\_OUT_{t-1,g,i}]]\} * 0.5]} \tag{86}$$

which is simply a specific form of equation 84, with $\boldsymbol{ABATE\_EXP_{t,i}}$ as abatement expenditure in the current period in industry i. With this calculated for each period, the closing value from the previous period is added to the capital stock in the current period, so in the agricultural industries, equations 44 and 45 become

$$\boldsymbol{CAPADD_{t,i} = V2TOT_{t-1,i} + ABATE\_EXP_{t-1,i} - (CAPSTOK_{t,i} * DPRC_{t,i})} \tag{87}$$

$$\boldsymbol{0.01 * CAPSTOK\_OLDP_{t,i} * x1cap_{t,i} = CAPADD_{t,i}} \tag{88}$$

Equation 86 states that the value of capital added to each industry's capital stock in the current period ($\boldsymbol{CAPADD_{t,i}}$) is equal to the gross investment from the previous period excluding abatement expenditure ($\boldsymbol{V2TOT_{t-1,i}}$), plus the amount spent on abatement technologies in the previous period ($\boldsymbol{ABATE\_EXP_{t-1,i}}$), minus depreciation of the existing capital stock ($\boldsymbol{CAPSTOK_{t,i} * DPRC_{t,i}}$). Equation 87 is used to determine real supply of capital by industry ($\boldsymbol{x1cap_{t,i}}$), and can be rearranged as:

$$\boldsymbol{x1cap_{t,i} = \frac{CAPADD_{t,i}}{CAPSTOK\_OLDP_{t,i}} * 100} \quad (89)$$

i.e. the percentage change in the real supply of capital is equal to the value added to the capital stock, as a percentage of the existing capital stock, at constant prices. This supply of capital must be equal to the demand for capital described in section 4.3.3. above.

At this point the model includes a calibrated MAC curve which determines how much farmers will abate, a calculation of how much this abatement costs, and a and a mechanism by which this expenditure is added to the farmers' capital stock. In the absence of further modelling modifications, farmers would have to pay the rental rate in order to *use* the abatement capital, but there would be no cost in the *creation* of that equipment. The supply curve of capital would effectively have moved outwards, given an (essentially) exogenous increase in the capital stock. Early model tests support this. The price of capital falls relative to earlier versions of the model, and there is a substitution effect towards capital from other factors. The farmers are not getting a free good in the sense that they must pay to use this capital, but it is created from nothing, so in this sense there is a free good. There is no cost to the economy of investing in abatement technologies – only to firms in using them. Thus as an important final step, the value of abatement expenditure by each industry – equal to the value added to the capital stock – is added to the industry's production costs through the 'other costs' variable:

$$\boldsymbol{delV1OCT_{t,i} = c\_ABATE\_EXP_{t,i}} \quad (90)$$

where $\boldsymbol{delV1OCT_{t,i}}$ is the change in 'other costs' for (agricultural) industry i, and $\boldsymbol{c\_ABATE\_EXP_{t,i}}$ is that industry's change in abatement expenditure. This ensures that industries pay the price of investing in new abatement equipment, as well as the running costs of using it.

4.9. Conclusions

This chapter has presented the behavioural equations and structure of the OEG model, which will be used in the following two chapters to analyse various policies for reducing Spanish GHG emissions to meet EU-mandated targets for the year 2020. The construction of a CGE model is a complex process which involves a number of decisions on the part of the modeller. In this chapter, for example, it has been pointed out that as OEG is a recursive-dynamic, rather than inter-temporal model, capital formation can only be based on backward-looking expectations, while some may point to the more general lack of sophistication in the modelling of capital/financial markets, given how complex they are in the real world. Consumption behaviour is based on a single representative household, which precludes analysis of distributional impacts in the current study. Labour supply does not include a labour-leisure tradeoff on the part of workers, meaning in theory it could increase indefinitely given ever-increasing real wages.

Any economic model involves tradeoffs between realism and parsimony. As has been seen in Chapter 2, the modeller must select what they believe to be the key aspects of the model for the questions they wish to analyse, and focus on those. For an agricultural study of short- to medium-term time horizon, in a country with high structural (and extremely high temporary) unemployment, each of the issues raised in the paragraph above was felt to be of secondary importance. Nevertheless, they should always be borne in mind when considering simulation results. These results are presented in Chapters 5 and 6. This chapter, together with Chapter 3, completes the full documentation of the OEG model and database.

5. Meeting EU emissions reduction targets

5.1. Introduction

The first application of the OEG model is to analyse the effects of agreed emissions reductions on the agricultural sector over the period 2007-2020. This translates to a reduction of 10% of 2005 levels in agriculture, set in the context of the same reduction for other emissions classified as 'diffuse' – i.e. those from transport, waste and buildings (see section 5.3.4. and European Parliament 2009a), and an exogenous price of emissions permits for those industries covered by the European Union's Emissions Trading Scheme (EU ETS). Details on ETS sectoral coverage are given in Table 5.1 (see also European Parliament 2003 and 2009b), while the exogenous price is based on the 'small country assumption' that Spanish demand for, or supply of permits to or from the EU market does not affect their price.

The 112 industries and 146 commodities in the OEG model are aggregated as shown in Table 5.2. and 5.3. (detailed descriptions of the agricultural and food activities in the model can be found in Tables 3.1. and 3.2.). The aggregation is biased toward agriculture and food as this constitutes the focus of the study, but the energy sector is also demarcated into component industries, as are the 'diffuse' sectors and those covered by the ETS. In summary, attention is paid to those key industries which are the focus of emissions reduction targets, whilst those of less relevance are aggregated into broad composites such as 'other manufacturing' and 'services'.

The following section highlights some features of the benchmark data and parameterisation of the model which are pertinent to the discussion of the results that follows at the end of this chapter. Section 5.3. describes the baseline closure, including the policy context relating to the Common Agricultural Policy (CAP) mechanisms and explains the different policy scenarios (1-3). Section 5.4. gives an overview of the macroeconomic results while 5.5 focuses on the various different results for the agricultural sector. The pattern throughout both of these sections is to present a brief analysis of the baseline results first as a foundation against which the policy scenario results can then be compared. Section 5.6. presents the key conclusions of the chapter.

5.2. Benchmark data analysis

5.2.1. Emissions allocation

As noted in Chapter 2, Leontief (1970) was the first to include pollution within the Input-Output (IO) accounting framework, and he recognised that the distribution of emissions in the economy could look quite different depending on how those emissions are assigned and calculated. Thus before the running of any scenarios, we begin this chapter with a brief IO analysis of how emissions in the current study are distributed.

In the benchmark data, emissions are initially assigned by industry (as well as being attached to specific inputs), and this picture is presented in Figure 5.1a.

For the alternative distribution of emissions (Figure 5.1b), any commodities destined for intermediate use essentially 'carry' the emissions used in their production into those commodities for which they are being used to produce so that the total of 432 million metric tonnes (Mmt) CO2 equivalent which Spain emitted in 2007 is embodied directly or indirectly within a final demand commodity. Essentially, in Figure 5.1a emissions are assigned to production, while in 5.1b they are assigned to consumption. For ease of comparison, the two distributions are presented side-by-side in Figure 5.1 and whilst there are some consistencies (the preponderance of manufacturing and energy emissions for example), there are also significant differences. One such difference is the significant transfer of emissions from the primary agricultural sectors (particularly livestock) in Figure 5.1a to the food processing sector in 5.1b. In practical terms this is obvious as consumers do not demand unprocessed cattle, for example, so almost all livestock emissions become embodied in the processed meat commodities for which there is significant final demand. This pattern is repeated in the service sector. Industrial process emissions are non-existent in the service sector, and even those from fuel use are small relative to the size of the sector, but when the emissions embodied in all intermediate inputs used by service industries (machinery, electricity, transport etc.) are included in service commodities, they account for around 15% of total emissions. A cursory glance at the benchmark emissions data might suggest that the food processing and service sectors are likely to be relatively unaffected by emissions restrictions due to their low levels of industrial emissions. Figure 5.1b suggests that such a conclusion would be premature. The final products of both contain a significant amount of embodied emissions, and thus their adaptation to environmental policies (particularly that of food processing) is an important part of the results presented in this chapter. Most significant data sources (including those used in this study) and the major emissions targets (such as the EU's Emissions Trading Scheme) currently follow the approach of Figure 5.1a in assigning emissions to production rather than consumption, so this is the method used in this study. If this were a global study, however, there would be serious distributional issues to consider, as at the international level there may be significant divergence between the two (Bastionani et al., 2004).

5.2.2. Agricultural emissions in Spain

Having made that distinction, all future references to emissions will attach them to industries and direct use of combustibles or fertiliser, rather than embodied emissions in final demands. By this measure, agricultural industries in 2007 were responsible for 53Mmt of Carbon Dioxide Equivalent (CO2e) – around 12% of Spain's total of 432Mmt[39]. Food production adds another 3.75Mmt – less than 1% of the Spanish total. Agricultural emissions are dominated by methane (CH4) and nitrous oxide (N2O) – indeed when

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[39] This total excludes net emissions from land use change, as does the figure for agriculture.

emissions of non-CO2 GHG emissions only are considered, the proportion coming from agriculture rises dramatically to 59%.

The breakdown of agricultural emissions can be seen in Figure 5.2. Cattle (including dairy cattle) and sheep contribute over a third of the agricultural total, while the combined livestock emissions are over half the total. Among the crops sectors, emissions from cereals production are significant, but olive growing is the single industry with the largest emissions, with over 10% of the agricultural total.

Another measure of how polluting is an industry is the 'emissions intensity' – the quantity of GHGs emitted per euro of industry output[40]. These figures are presented in Table 5.4., which shows fruit and vegetable growing to be the least emissions intensive agricultural activities, emitting 0.59 and 0.14kgCO2e/€ respectively, compared to 1.72 for cereals, and 3.78 for olives. It should be noted that the fruit aggregate masks some significant differences, as it includes grapes (1.88kgCO2e/€) and citrus (0.27kgCO2e/€). The table suggests cattle and sheep farming are more emissions intensive than pig and poultry farming, but less so than olive growing. A study was mentioned in Chapter 2 which found that for Japan, a low benchmark level of energy-intensity was something of a mixed blessing in meeting emissions reduction targets (Paltsev et al., 2004). While substitution possibilities to save energy are few, meaning remaining abatement options tend to be high cost, the smallness of the energy sector meant policy-induced energy price rises do not have severe impacts on the rest of the economy. In this study similar effects may be observed on a much smaller scale. While fruit and vegetable growers may find it more difficult to reduce the relatively small amount of emissions they do produce, that same smallness means the increase in total costs from any tax on emissions will be less (in proportional terms) than in an industry with a high emissions intensity. This brings us to the importance of where emissions come from, and how emissions from different sources can be abated.

5.2.3. Emissions factors and Marginal Abatement Cost (MAC) curves

As well as the quantity of emissions associated with each agricultural industry, it is useful to be aware of where those emissions come from, as this has implications for their abatement possibilities. Emissions which come from petrol combustion, for example, are difficult to mitigate as petrol is the only non-electric source of energy used in significant quantities by farmers, so substitution possibilities are limited. The emissions factors coming from combustion are very small in the livestock sectors – around 0.3-6% (not shown). In the crops sectors they are considerably higher. Olives have the lowest proportion, at around 13%, whilst for the cereals and fruit and vegetables sectors, about one-third of emissions come from fuel combustion, and in the remainder of the crops sectors the average is almost one-half. These energy emissions cannot be reduced through the 'end-of-pipe' abatement measures described in Chapter 4. All the evidence suggests that N2O from manure is impossible to abate (Smith et al. 2008 for example, makes no mention of the possibility of

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[40] The concept should be treated with some caution as the denominator is a value in euros. Thus the 'emissions intensity' of a good changes with its price, which is somewhat misleading.

abating such emissions). If these N2O emissions are added to those from fuel combustion, it brings the proportion of livestock sector emissions which are impossible to abate up to around 21%, much closer to the average for crops.

For the remainder – N2O emissions from fertiliser use in crop growing, and CH4 from enteric fermentation and manure management in livestock – the ease of abatement is governed by the MAC curves, shown in Figure 4.4 and 4.5. The first thing to notice from these graphs is how much cheaper abatement is in livestock than crops at any point up to the technically feasible maximum (around 25%). Considering the emissions reduction target of 10%, this means end-of-pipe abatement is likely to be heavily concentrated in livestock emissions. Some approximate calculations show how much this effect could dominate the results: The graph suggests that 20% of livestock methane emissions could be abated for less than €10/tCO2e. This translates to 4.6MmtCO2e, or 8.6% of total agricultural emissions in the benchmark. If this were the case, the crops sectors would have to contribute very little abatement in a scenario where the 10% reduction is an aggregate target applied to the agricultural total. If each agricultural industry must meet the 10% target, it means that target is likely to be easily met in the livestock sectors, meaning some relatively low cost abatement opportunities may not be taken up, whilst the crops sectors are forced to engage in relatively expensive abatement options. The expectation is that this will increase the overall cost of industry-specific targets relative to that of a single aggregate target for the agricultural sector.

5.3. Scenarios

5.3.1. The baseline closure

The baseline contains neither restrictions on Greenhouse Gas (GHG) emissions nor any kind of emissions tax. Whilst this is clearly unrealistic, the purpose is to give a counterfactual in order to isolate the effects of environmental policy in the results from all following scenarios.

The model 'closure' refers to the decision made by the modeller as to which variables should be 'exogenous' (i.e. fixed in the absence of an externally applied 'shock') and which should be 'endogenous' (determined within the model by the equations, parameters and exogenous variables it comprises). As well as the mathematical constraint that the total number of variables must be equal to the sum of the number of equations and the number of exogenous variables (i.e. each endogenous variable must have an associated equation), modellers must consider the time frame of the simulations being run (e.g. a short run closure where factor endowments are fixed, or a long run closure where factor returns are fixed and endowments vary), and the structural features of the economy under consideration (e.g. strong trade union bargaining power may cause wage rigidities).

The model closure does not have to be the same in different scenarios, and in the current study it is not. This section describes that used for the baseline, those of other scenarios will be described in later sections. One thing which must remain constant across scenarios though is the *numeraire*. This is a single price variable which is held constant and against which all the relative price changes shown in the results are measured. Given Spain's participation in the European Currency Union (the euro), the exchange rate will be used as the *numeraire* in all scenarios presented in this study. The variables chosen to be exogenous in the baseline can broadly be divided into six groups: macroeconomic variables; productivity and taste changes; CAP payments and mechanisms; world energy prices; emissions factors; inactive emissions taxes.

Macroeconomic variables refers to changes in the components of the aggregate demand (AD) function[41]. In order to avoid over-specifying the AD function, real GDP growth, as well as aggregate expenditures for households, investment and exports are shocked exogenously according to historic data and projections. Government expenditures adjust endogenously to exogenous shocks to Spain's deficit/GDP ratio (again, based on historic data and projections). The change in aggregate imports adjusts subject to changes in real GDP on the one hand, and the component changes in AD expenditures on the other. The evolution of these variables will be described more in section 5.4 below.

Productivity variables may be attached to the use of certain factors or inputs, or may refer to Hicks-neutral total factor productivity (TFP) in a given industry. In this case TFP is shocked according to projections from Ludena et al. (2007), whilst an exogenous **taste change** variable captures the shift in consumer preferences from red toward white meat (OECD, 2009).

The evolution of **CAP payments** over the period is described in section 5.3.2 below. Due to data availability issues, the exogenous variables are the values, as opposed to the rates, of subsidies, and they are applied to factors (land and capital), intermediate inputs, output and exports. Other exogenous **CAP mechanisms** include production quotas and intervention prices for certain goods. A fuller description of these mechanisms is provided in Chapter 4.

It is assumed that Spain is a small (relatively) open economy. Thus, **world prices** are held exogenous, whilst historical data and projections are employed to shock fossil fuel prices. Their evolution over the period is described in section 5.3.3 below.

Emissions factors refer to the emissions attached to a unit of output, or use of a specific input. As detailed in chapter 4 they are composed of both a 'trend' element and one which captures so called 'end-of-pipe' abatement. The trend component is exogenous and is included in the baseline for consistency. The trend is calibrated from UNFCCC data on emissions factors from 1990-2007 (UNFCCC, 2015) – the latter being the year in which the period of the current study starts, and projected forward to 2020. As noted in Chapter 4, the trend changes are mostly negligible except for dairy cattle sector, which sees relatively significant growth.

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[41] GDP by expenditure is measured as the sum of household consumption, government expenditure, investment expenditure and export expenditure, less import expenditure – see section 4.6.2.

Emissions taxes form an important part of the OEG model, and in the baseline they must be kept exogenous so they can be held at zero. As noted, this ensures that the baseline is free from any restrictions on emissions, so their effects can be isolated in all remaining scenarios.

5.3.2. The Common Agricultural Policy (CAP)

With the agricultural focus of this study, a realistic representation of the agricultural sector requires some consideration of the CAP. The policy shocks to the CAP are unchanged across all scenarios, including the baseline, in order to fully isolate the effects of emissions restrictions in agriculture.

From 2007-2013, CAP payments are adjusted according to detailed data from FEGA (2010). This period includes the almost complete decoupling of payments in Spain, with the only remaining coupled payment – the Suckler Cow Premium – decoupled in 2015[42]. Figure 5. 3. shows that payments to both cereals and livestock[43] (the two most emissions intensive agricultural sectors) fall owing to the shift from market support to decoupling, whilst the opposite is true in fruits and vegetables (for a detailed description of how the Single Farm Payment (SFP) is applied in the model, see chapter 4). Whilst these sectors are not as emissions intensive as cereals or livestock, they are significant emitters due to the scale on which they are produced in Spain. As noted above, olive production, which falls into the second group in Figure 5.3., also carries a weighty contribution to Spanish agricultural emissions, and the net subsidy loss in that group is much smaller than that in cereals or livestock. These subsidy changes suggest, *a priori,* that in the baseline cereals and livestock emissions may grow at a slower rate than those of olives, fruit and vegetables, and this is in fact the case (see section 5.5.1.1.).

5.3.3. Energy prices

The evolution of world fossil fuel prices, constant across all scenarios, is shown in Figure 5.5 (IEA, 2015). The world economic slowdown in 2009 provoked a contraction in demand which reduced the price, and there is some evidence of the current (2014) fall in the oil price. The fact that over the period coal has the biggest price rise will be of some benefit in meeting the emissions targets, as it is the most emissions intensive of the fossil fuels. As a caveat to the current study it is important to point out the absence of renewable energies such as wind, solar or geothermal in the model. A similar study with a greater macroeconomic (or energy) focus would need to address this, but in the context of the agricultural results presented here, it is not seen as a major omission.

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[42] Due to data limitations, no account is made for article 68 – that some farmers are allowed to re-couple a portion of their payments to agricultural activities, within certain limits.

[43] 'Livestock' here refers to cattle (both dairy and non-dairy) and sheep. Neither pigs nor poultry receive significant levels of CAP support in Spain.

5.3.4. Policy scenarios

While the most realistic scenario from a policy perspective would be a single 10% reduction target for aggregate diffuse emissions, the fact that end-of-pipe abatement in the model is exclusively available to agricultural sectors means that in such a scenario emissions reductions would be unrealistically biased towards agriculture. Emissions from two of the other diffuse sectors, transport and buildings, are dominated by carbon dioxide, for which end-of-pipe abatement options are limited. The remaining diffuse sector is waste, which is associated with a high proportion of methane emissions. A brief look at the data from the GAINS model used to compile the agricultural MAC curves included in the model (Chapter 3) suggests that at low levels of abatement (under 20%) the cost of abating waste emissions is greater than that for livestock Figure 4.5.), but lower than that for crop emissions (Figure 4.4.). A future study of diffuse sector emissions could use a version of the OEG model with end-of-pipe abatement available in the waste industry, a less detailed treatment of the agricultural sector, and some exploration of technology options in transport (e.g. more fuel efficient or electric vehicles) and buildings (investment in insulation), but this lies beyond the scope of the current study. As a second-best solution we ensure that emissions from the three non-agric diffuse sectors are each reduced by 10%, and run three different scenarios for agricultural emissions. The majority of non-diffuse emissions are CO2 and are covered by the ETS, for which an exogenous permit price is shocked according to data and projections. Spain has a domestic allowance of permits, but can also import or export them depending on demand relative to the domestic supply.

The key features of each scenario are shown in Table 5.5. **Scenario 1** does not include the calibrated MAC curves for end-of-pipe abatement of agricultural emissions, in order that the effect of these can be isolated in **scenario 2**. All other features are constant across these two scenarios, with a 10% reduction in aggregate agricultural emissions, and the emergence of a single agricultural emissions price. This could be likened to an emissions trading scheme applied to agricultural emissions in isolation from any other emissions targets or permit trading schemes. Alternatively it could be seen as a hypothetical exercise in finding the 'optimal' distribution of reductions across agricultural industries, with and without end-of-pipe abatement. Those industries with a cost of abatement higher than the agricultural average will reduce emissions by less than 10%, with the slack taken up by industries with cheaper abatement options. **Scenario 3** precludes this possibility by requiring each one of ten agricultural subgroups (Table 5.6) to meet the 10% target. As a result, ten different agricultural emissions prices emerge, although in some cases the 10% reduction may be non-binding, resulting in an emissions price of zero.

5.4. Macroeconomic results

5.4.1. The baseline

5.4.1.1. The financial crisis

As shown in Figure 5.5., current projections (IMF, 2014) suggest real GDP in Spain will not return to its 2007 level until 2020. For some of the components of aggregate demand, namely private consumption and investment, the impact of the financial crisis has been even more severe, whilst others – government spending and trade, have had a countercyclical effect. Government spending was increased during the crisis years specifically for this purpose, and the improvement in the balance of trade is likely to be a result of the crisis-induced real depreciation taking place in Spain at the moment. A nominal deprecation is impossible given Spain's membership of a currency union, but the fall in wages and other costs of production, coupled with the increased productivity which has come as a side-effect of high unemployment (Maroto and Cuadrado, 2014), has lowered the price of Spanish goods, making them both more competitive abroad and more resistant to competition from imports in the domestic market. Thus in Figure 5.5. we see strong growth in exports, and an initial decline in imports, although this is followed by an upturn as Spanish household consumption picks up in the later years of the simulation period.

This has implications for the agricultural results of this study, as it will benefit those industries with a high proportion of sales for export, such as fruit and vegetables as well as processed pork. The increasing demand for exports is likely to drive up the prices of these goods, making the option to reduce emissions by contracting output relatively more expensive than in other sectors. Indeed, as has been noted, fruit and vegetables are among the least emissions intensive agricultural industries, and the Spanish pig sector – like all livestock industries – can make significant end-of-pipe abatements at relatively low cost, suggesting that neither of these important Spanish export industries should be hindered too severely by environmental policy-induced price rises damaging their competitiveness.

5.4.1.2. Emissions

Figure 5.6. shows the evolution of agricultural, total diffuse, and ETS emissions, as well as total Spanish emissions, over the baseline simulation period. The line representing agricultural emissions is significantly less volatile than the others, suggesting the 'natural' decline in overall Spanish emissions as a result of the financial crisis will have a limited impact on emissions from agriculture. This is borne out by UNFCCC data from 2007-2012 (Figure 5.7.) which shows agricultural emissions broadly maintaining their 2007 level through the crisis, whilst emissions from all other sources (except waste) are substantially reduced. This is due to the low income elasticity of demand for food, which protects the agricultural sector to some extent in times of falling incomes (Bourne et al., 2012). In the current Spanish context this highlights the need for the current study, as it poses an extra challenge for agriculture in contributing to overall emissions targets.

5.4.2. Scenarios 1-3

The agri-food sector comprises just 5.1% of Spanish GDP by value added in the 2007 benchmark data. Given that the treatment of the rest of the economy is constant across all three scenarios, it is as expected that there are no major differences in macroeconomic results between them. There are some differences though, as can be seen in Table 5.7, which presents the results for the components of aggregate demand in the different scenarios. The results suggest the emissions restrictions cause real GDP to fall by around 1% over the period, relative to the unrestricted baseline. As expected, the introduction of end-of-pipe abatement options for agricultural emissions reduces the cost to GDP of the environmental policies and the concomitant price increase as well. Indeed it is this relative fall in domestic prices, moving from scenario 1 to 2, which provokes the increase in exports and decrease in imports between the two scenarios.

Real investment also rises with the inclusion of end-of-pipe abatement. As expenditure on abatement capital is not measured as 'investment' in the model, it could be expected that adding this feature would have something of a crowding out effect, increasing the supply of capital and hence reducing the rate of return. If this effect is present, the results suggest it is dominated by the expansionary effect resulting from lower abatement costs and hence smaller falls in production. Like all results mentioned in this section, a fuller discussion of this phenomenon in the agricultural industries can be found in section 5.5 below. The final thing to note before the focus moves exclusively to agri-food is the difference in results between scenarios 2 and 3. In broad terms the cost of the sector-specific targets seems greater than that of the single aggregate target, with larger falls in GDP and exports, and a greater increase in prices. This again will be returned to in some detail below.

5.5. Agricultural results

5.5.1. The distribution of emissions reductions

5.5.1.1 Baseline: No restrictions on emissions

Figure 5.8. shows the change in emissions in the baseline for each agricultural group over the simulation period. The strongest growth is in vegetables, followed by fruit and olives. Dairy cattle also witnesses relatively strong growth in emissions due to its rising emissions factor (see above). Meanwhile cereal emissions grow by less than 10% over the period, and those from cattle and sheep fall by around 15%, both due in part to the reduced net subsidy going to those sectors as a result of the CAP reforms described in section 5.3.2. above, and Figure 5.3.

These results form the basis of those to be presented in later scenarios. Examining the baseline trends, it can be seen, for example, that a target for the cattle and sheep industry to reduce its emissions by 10% over the time period will not be binding, whilst the same target for the vegetables sector will be highly restrictive.

Similarly, if a single 10% reduction target is applied to aggregate agricultural emissions, olives, fruit and vegetables are likely to contribute less than the average to the overall reduction. On the other hand, on the basis of the results presented here, it could be argued that the CAP reforms are complementary to emissions targets, as they are encouraging production in less emissions intensive industries such as fruit and vegetables.

5.5.1.2. Scenario 1: 10% reduction in aggregate agricultural emissions, no end of pipe abatement

Having discussed the baseline results above, the first thing to notice is that in scenario 1, emissions reductions are concentrated in the cereals and cattle and sheep sectors, with other crops being the only other industry to contribute more than the 10% average across agriculture (Figure 5.9.). The reductions in the cattle and sheep sector are largely due to the poor performance of this industry in the baseline. A general pattern in moving from the baseline to scenario 1, however, is that the change in emissions between the two scenarios tends to be greater in the crops than in the livestock sectors, with overall fertiliser emissions from the crops sectors 23.5% lower than the baseline in scenario 1 (not shown), and enteric fermentation and manure management emissions from livestock just 5.6% lower. This is because in the absence of end-of-pipe abatement options, the only two ways for emissions to fall are substitution away from polluting inputs and a contraction in output. In the OEG model, livestock emissions are attached to output (Table 3.3.), so the substitution option is only available to the crops sectors, which have some flexibility to reduce their fertiliser use if they increase their use of other inputs such as land, labour or capital. This extra abatement option explains why the introduction of an emissions tax provokes a bigger emissions reduction in the crops than the livestock sectors. Taken in isolation, the effect of this substitution would be to increase the pressure on primary factors. However, the substitution effect towards factor use in the crops sectors takes place in the context of agricultural (and other) industries contracting relative to the baseline, so the 'expansion' effect is to lower factor prices, which will be explored more in section 5.5.4. below.

5.5.1.3. Scenario 2: 10% reduction in aggregate agricultural emissions, with end of pipe abatement

The only difference between scenarios 1 and 2 is the inclusion of end-of-pipe abatement options from the calibrated MAC curves, and the effect is to concentrate emissions reductions in the livestock sectors, allowing the crops sectors to increase their emissions relative to scenario 1 such that the overall 10% reduction target for aggregate agricultural emissions is still met. In section 5.2.3 above (and Figures 5.4. and 5.5.) it was noted that at low levels of abatement, there are cheaper options available in livestock emissions (largely feed changes) than in the crops sectors. Thus the relatively low emissions price necessary to meet the prescribed target (see below) provokes more abatement in the former than the latter. This can be seen in Table 5.8. which shows how emissions factors change in the different scenarios. Note that owing to data restrictions, it is only possible to calibrate two MAC curves – one for N2O fertiliser emissions, one for CH4 livestock emissions. As a result, the single agricultural emissions price in scenario 2 means end-of-pipe abatement as a proportion of total emissions is constant across crops sectors, while the variance in 'trend' emissions factors across the livestock sectors mean the results for these industries are similar, but not exactly the same. With that in mind, the first column of Table 5.8. shows how significant the end-of-pipe abatement is in the livestock sectors in scenario 2, with emissions factors around 22% lower in 2020 than they are in the baseline/scenario 1. In contrast, those for the crops sectors fall much less, and are just 2.6% lower than the baseline/scenario 1 in 2020. This explains the result that the inclusion of end-of-pipe abatement focuses emissions reductions in the livestock sectors in the presence of a single 10% target for aggregate agricultural emissions.

5.5.1.4. Scenario 3: 10% emissions reduction in all agricultural sectors, with end of pipe abatement

The difference between scenarios 2 and 3 is that in the former emissions reductions can vary between agricultural sectors as long as the overall 10% target is met, whereas in the latter each subgroup of agricultural industries is forced to meet the 10% target itself. As can be seen in Figure 5.9. this actually results in an overall reduction of slightly more than 10%, as for cattle and sheep emissions the target is non-binding, and emissions actually fall by 14%, whilst all other agricultural emissions fall by 10%. The movement from scenario 2 to 3 is thus beneficial for those industries which were overshooting the 10% target in scenario 2 (cattle and sheep, and pigs), whilst those industries with the highest emissions in scenario 2 (vegetables, fruit and olives) will find the enforced 10% target in scenario 3 the most stringent. To see this reflected in the results, attention now turns to the emissions taxes necessary in each scenario.

5.5.2. Emissions taxes

In the baseline emissions are unrestricted, so the emissions tax remains at zero. In scenarios 1 and 2, the single target for a reduction in aggregate agricultural emissions results in a uniform tax rate per tonne of CO2 equivalent (€/tCO2e) across all agricultural emissions. In both scenarios this tax rises as the period progresses and the emissions restriction tightens. By 2020 the necessary tax has reached €85/tCO2e in scenario 1, but this is greatly reduced by the addition of end-of-pipe abatement, to €23/tCO2e in scenario 2. It should be noted that this does not necessarily mean that meeting the target is 85/23 times cheaper for farmers in scenario 2, as they face the cost of investment in abatement equipment, which is absent in scenario 1. Nevertheless, the presence of end-of-pipe abatement does mean that the emissions tax necessary to bring emissions down to the policy-mandated levels is much lower, as a given tax now provokes a much higher degree of abatement.

Scenario 3 is unique in that each subgroup of agricultural industries faces a specific emissions tax necessary to force each of them to reduce their emissions by 10%. In general it is to be expected that those industries with the highest emissions in scenario 2 will face the highest emissions taxes in scenario 3, as they are the ones for which abatement is most costly, given the baseline economic conditions and the MAC curve data, and in general this is the case. As shown in Table 5.9., vegetable growing has the largest emissions increase in scenario 2, and the second highest emissions tax in scenario 3, whilst the greatest emissions reduction in scenario 2 is in cattle and sheep, and this is the only industry to face a zero emissions price in scenario 3. In general the livestock sectors tend to have lower emissions taxes in scenario 3, the exception being poultry farming. The total emissions from this sector are small, but they also include a relatively high proportion of energy emissions, meaning the MAC curves for livestock are barely applicable. As has been noted above, energy emissions are hard to abate, and thus the high emissions tax necessary to force poultry emissions down 10%. Given the low emissions intensity of this sector, it remains to be seen if this high tax rate feeds into a significant impact on price and output in this industry.

The total direct costs of each scenario to different agricultural groups are shown in Table 5.10. These are calculated as the sum of environmental taxes and abatement expenditure, both cumulative over the simulation period. The results show that the introduction of end-of-pipe abatement dramatically reduces the cost to the agricultural sector as a whole from over €14 billion in scenario 1 to just under €4 billion in scenario 2 – a fall of around 70%. The activity-specific targets in scenario 3 raise the total cost back up to €6.2 billion, suggesting there are macroeconomic gains to be made from having a single uniform emissions price – a cap-and-trade scheme, as laid out in Weitzman (1974). Only the non-poultry livestock sectors benefit from the activity specific targets for the reasons discussed above. To fill out this emerging picture, the focus now turns to the effects each scenario has on agricultural prices and production.

5.5.3. Price and output effects

5.5.3.1. Baseline: No restrictions on emissions

The price and output changes over the baseline simulation period can be seen in Table 5.11. The largest price increases are in the cattle and sheep sectors as a result of the decoupling of CAP payments (see above), and output falls as a result in these sectors. Sugar also suffers from CAP reforms in terms of the falling intervention price which provokes a dramatic fall in output in the sector. Many of the other non-cereal crop sectors see some growth in output over the period as output holds up during the financial crisis (see above) and benefits from the growing economy (particularly exports) in the later years of the period. The cereals sectors are not strong in export markets, so they are less well positioned to benefit from the upturn in exports. With the exception of barley, they are also competing with a high level of imports, making demand for the domestic product highly sensitive to price rises. As a result, output of all cereals except barley falls in the baseline. The price rise in milk appears to be at the lower end of price increases, perhaps because of the abolition of the milk quota in 2015. The still significant increase in the price of milk suggests, however, that this will not have a dramatic effect on simulation results.

5.5.3.2. Scenario 1: 10% reduction in aggregate agricultural emissions, no end of pipe abatement

In scenario 1, the price effects of the uniform agricultural emissions tax of €85/tCO2e can mostly be traced back to the emissions intensities of different agricultural industries. Thus olive growing is the most emissions intensive agricultural activity (Table 5.4), for example, and has the largest price increase, whilst some of the fruit sectors, vegetables and poultry have the lowest emissions intensities and the lowest price increases (Figure 5.10.). Note that in scenario 1, prices do increase in all sectors relative to the baseline. In no sector are the direct (inflationary) effects of emissions taxes and rising energy prices more than compensated for by the (deflationary) effect of an increased pool of factors of production and inputs being released by other contracting industries. The results are also clearly influenced by the evolving situation in the baseline. As CAP payments are decoupled, cattle and sheep are the two agricultural sectors with the highest baseline price rises. The emissions tax is a specific, rather than an *ad-valorem* tax, albeit one which varies depending on the emissions of the industry, so as the pre-tax price rises, the power of the tax gets smaller. As a result, despite having the highest GHG content per euro of production in 2007 after olives, and being unable to reduce their emissions by any means other than slowing output in scenario 1, the percentage price increases resulting from the tax in the cattle and sheep sectors are lower than those for barley, rice or grapes, all of which have lower emissions intensities and some ability to substitute away from their polluting inputs.

The output effects of the emissions taxes implemented to meet policy mandated reduction targets depend on the price effects described above, and on the price elasticities of demand for each agricultural commodity. These in turn depend on the various sales destinations for each commodity – those destined for competitive export markets for example are likely to be see a bigger contraction from a given price increase than those used as an input to processed food production in local markets. Olives presents a clear example of this, as of all crops in Spain it has the largest proportion destined for further processing (save raw sugar), and despite the price of olives rising by almost double that of any other agricultural product in scenario 1, the fall in output is, at around 9%, smaller than that for most cereals and grapes (Figure 5.11.). Another factor is competition from imports. Within the cereals sectors for example, the price increase in barley is almost as large as that in rice, but the reduction in rice output is around six times that of barley output. This is because in the benchmark 2007 data, just 2% of barley used in Spain is imported whilst for rice the figure is 20%. This means that while barley imports may increase over the period (they do, by 165% in absolute terms, or 64% relative to the baseline), they do so from a much smaller base. By the end of the period, and in scenario 1, these figures have increased to just 4% for barley, and 46% for rice.

In general the livestock industries sell a higher proportion of their produce for further processing than do the crops sectors, and as a result the output falls are less severe in these activities, despite relatively high emissions intensities and price increases. In scenario 1, the composite fall in total production in the livestock industries works out as 4.7% over the period compared to a 5.7% fall in crop growing. Due in part to the difficulties in transporting fresh meat, and in part to Spaniards taste for local produce, the domestic livestock sectors face a low degree of competition from imports, which also contributes to the relatively small falls in output resulting from relatively large price increases. Among the livestock industries, output falls are largest in non-dairy cattle (7.3%) and sheep (6%) as these are the most emissions intensive, and suffer the largest price increases. By contrast poultry farming is among the least emissions intensive of all agricultural activities and the output fall in this industry is just 2.7% relative to the baseline in scenario 1.

In summary, the picture from scenario 1 is that in the absence of end-of-pipe abatement measures the price effects of emissions restrictions are heaviest in the most emissions intensive sectors (olives, cereals, cattle and sheep) but production of those commodities with small trade volumes (barley, cattle and sheep) is relatively protected by the price inelasticity of demand. By contrast, those industries with much lower emissions intensities (vegetables, fruit (excluding grapes) and poultry) see relatively little impact from the emissions taxes, with price increases of around 2-3% relative to the baseline, and output falls of similar magnitude.

5.5.3.3. Scenario 2: 10% reduction in aggregate agricultural emissions, with end of pipe abatement

Introducing end-of-pipe abatement options in scenario 2 reduces the price increase from the emissions restriction in every agricultural industry compared to scenario 1 (Figure 5.10). This is intuitive as emissions taxes and the total cost to farmers of meeting the targets are lower in scenario 2. In addition, in the second scenario the money invested in abatement equipment is converted into capital, and thus remains on the farm, lowering the emissions factor of future production, and hence the rate of future emissions taxes.

Looking at scenario 2 relative to the baseline, olives remain the commodity with the largest price increase, but it has been significantly reduced from 49% to 14%. The industries with the smallest price increases remain vegetables, fruit (excluding grapes) and poultry, where the low emissions intensity, coupled with the low emissions tax rate of €23/tCO2e in this scenario, mean policy-induced price increases are very low indeed, at less than 1% by 2020 relative to the baseline. The overall price index for crop production falls from 10.2% up on the baseline in scenario 1 to 3.2% up in scenario 2, whilst the comparable figures for livestock are 10% to 2.8%. The production results follow from those for prices, with the falls in production in all sectors smaller than they were in scenario 1 (Figure 5.11.). On aggregate, the change in scenarios is not enough to reverse the pattern seen previously that composite crop production falls by more (5.7% in scenario 1) than that for livestock (4.7%). In scenario 2 these reductions in output have become 1.9% and 1.6 % respectively.

5.5.3.4. Scenario 3: 10% emissions reduction in all agricultural sectors, with end of pipe abatement

Scenario 3 changes the picture quite significantly compared to that presented in the other two scenarios. The first thing to notice is that for the livestock sectors the effect of this scenario is a very small increase in prices relative to the baseline (Figure 5.10.). For two of these industries (cattle and sheep) this is because their 10% reduction target is non-binding (as noted above), meaning an emissions tax never emerges for these activities. They are thus able to take advantage of the falling cost of inputs resulting from other agricultural industries' shrinking production. This is true also of dairy cattle and poultry, the difference being that in these sectors the emissions target is binding. Indeed, at €412/tCO2e (Table 5.9), the emissions tax for poultry is the largest of all agricultural industries. When this was noted above, the question was posed whether this large emissions tax would dominate the low emissions intensity of poultry farming and cause a significant price rise in this low-emitting sector. This remains an open question. At around 5%, neither the price increase nor the output fall may seem especially large, but both are significantly greater than those produced by scenario 2 in this sector. By contrast, despite strong baseline growth in its emissions factor, raw milk production does not need a high tax to ensure it meets the 10% target, and the resultant price increase and output decrease are small. The difference between these two sectors is in the source of emissions. A much higher proportion of dairy cattle emissions are methane than is the case for poultry, where fuel combustion emissions dominate. Thus abatement options are much more limited, and costly, in the poultry sector.

Similarly to poultry farming, vegetable growing – another activity with a relatively low emissions intensity, and a high proportion of emissions from energy use, and one thus unable to benefit from end-of-pipe abatement – also needs a high emissions tax to force it to meet its target, and this does have a significant impact on price and output in this industry. This is because vegetable production sees strong baseline growth in emissions over the period – 42% relative to 2007 levels. As a result vegetable emissions have a long way to go in order to meet the 10% reduction target, and some increase in price and resultant contraction in output are inevitable. The same is true of the fruit sectors which saw the smallest price and output effects in scenarios 1 and 2 (all except grapes). These scenarios effectively acted as an emissions tax in these low emissions activities, and in the face of strong growth in demand they were able to swallow the tax without it affecting output significantly – especially in scenario 2 where the tax rate was significantly lower. Scenario 3 places binding restriction on their emissions though, and the effect is felt more severely. This has implications for Spanish policy-makers as fruit and vegetables are important export sectors – between them accounting for 30% of Spanish agrifood exports, or just over 3% of total exports, by value in 2007 (own calculations).

The cereals sectors present an interesting case study of the value of using a dynamic model for this study, when comparing the results from scenario 3 to those from scenario 2. From 2013 onwards, the emissions tax provoked by the cereals target in scenario 3 is higher than the uniform agricultural emissions tax in scenario 2. One consequence of this is that over a seven year period, the cereals sectors undertake more end-of-pipe abatement than they did in scenario 2. As a result the emissions factor attached to fertiliser use in these sectors falls more in scenario 3 (Table 5.8), and the effect of emissions taxes on industry prices and output becomes less, as the emissions intensity of the industry falls. Thus by 2020, despite a cereals emissions tax in scenario 3 of €30/tCO2e – 30% higher than the agricultural emissions tax of €23/tCO2e in scenario 2 – the overall price increases of all cereals are only marginally bigger in scenario 3 than they are in scenario 2, as are the reductions in output. Emissions from cereals fall by more in scenario 3 than 2 as well, which suggests that over an extended time period, in this particular case, deeper emissions cuts are not necessarily more costly. Particularly if they are implemented at an early stage they may provoke abatement investment which, by reducing emissions factors, reduces the extent to which producers are penalised by emissions restrictions in later periods.

The overall effect of scenario 3 is to reduce significantly the burden of abatement in the livestock sectors, and share it evenly among all agricultural activities. Of course this means that the stringency of the policy is felt more keenly in those activities with either strong baseline growth or high costs of abatement. The next step is to investigate the implication of this for agricultural employment, and use of capital and land in the sector.

5.5.4. Factor markets and farm incomes

A closer look at the price effects of emissions restrictions suggests that across scenarios 1-3, agricultural price increases are driven by the rising price of energy and, in the crops sectors, fertiliser (Table 5.12). Both of these inputs are in the value-added nest in the OEG model, rather than the intermediate input nest. As a result, the large increase in the cost of these inputs provokes a substitution effect towards land, labour and capital across all scenarios. However, in scenario 1 this effect is frequently dominated by a negative 'expansion' effect, whereby contracting industry output results in reduced factor demand (Table 5.13.).

In the short term, capital supply for each industry is determined purely by investment in the previous period. Labour of each type (highly skilled, skilled, low skilled) is perfectly mobile across sectors, whilst land mobility is higher between similar activities than very different ones. In terms of aggregate endowments, total capital stock is determined by investment, which is lower in each of the policy scenarios than the baseline (Table 5.7.). Each type of labour has a linear supply curve, with low-skilled (highly-skilled) labour the most (least) supply elastic. The large increases in energy prices relative to the baseline, and their indirect effects on the prices of other household goods, mean a fall in aggregate real wages is a consistent result across all scenarios. This results in reduced supply of all types of labour relative to the baseline, with the contraction largest in price-elastic low-skilled labour. As a result the price of this kind of labour holds up better, meaning the substitution effect towards it is weaker than that to other labour types. Finally, all registered agricultural land is assumed to be in use, and land use is only modelled in agricultural sectors. Thus the kinked land supply curve (Chapter 4) means the aggregate agricultural land endowment cannot increase, and increased demand for agricultural land will simply cause a price increase. A large enough contraction in demand could cause a reduction in land use, but this is not applicable in the current scenarios, suggesting that despite the contractions in agricultural output resulting from the emissions reduction policy, they will not be severe enough to cause any land currently in use to be left fallow.

In summary, the introduction of emissions restrictions with no possibilities for end-of-pipe abatement causes a significant contraction in factor demands and returns relative to the baseline[44]. This is mitigated by the substitution effect towards primary factors in the presence of strong increases in the price of energy and fertiliser, though the (negative) expansion effect still dominates. Including end-of-pipe abatement for agriculture in scenario 2 mitigates both of these effects somewhat in these industries, while forcing each agricultural subgroup to meet the 10% target for itself in scenario 3 tends to reduce factor demands relative to scenario 2 as the emissions tax, and hence the contraction in output, is larger in most agricultural sectors. This is borne out at the macro level, albeit on a smaller scale as end-of-pipe abatement is limited to agricultural emissions, as can be seen in Table 5.14.

5.5.4.1 Baseline: No emissions restrictions

All agricultural industries show a substitution towards primary factors and away from intermediate inputs over the baseline simulation period, as the increases in the price of the primary factor composite is always smaller than that for total industry costs (not shown). There is strong competition for land, given the aggregate restriction, with the sharpest increases in both land use and returns in the expanding sectors such as fruit and vegetables and olives, while there is also some substitution towards land in the contracting livestock sectors as their formerly coupled payments, which were tied to capital, become decoupled. A small uniform fall in nominal agricultural wages means all industries increase their use of labour relative to total production, whilst at the other extreme capital supply is inelastic so large price changes are accompanied by relatively small movements in demand for this factor. Specifically, the livestock sectors substitute away from capital because of the decoupling mentioned above, and the expanding industries also reduce their capital use relative to output as the unresponsiveness of supply makes it more expensive than other factors, whilst for the contracting sectors that same unresponsiveness makes it relatively cheaper, as supply does not respond quickly to falling demand.

5.5.4.2. Scenario 1: 10% reduction in aggregate agricultural emissions, no end of pipe abatement

In spite of the inclusion of energy and fertiliser as 'factors', and the sharp price increases in both in this scenario (Table 5.12), the overall price of the factor composite still increases by less than the total cost of production in all agricultural sectors in this scenario, though the difference between the two is usually less than in the baseline (not shown). As explained above, the effect of the emissions restriction is to cause a contraction in output relative to the baseline, but this negative 'expansion' effect is balanced by a substitution effect towards the three primary factors as energy and fertiliser become more expensive. Thus the overall

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[44] with the usual disclaimers about the exclusion of damages to factor productivity from the effects of anthropogenic climate change (Chapter 2).

effect depends on the emissions intensity of the sector, with highly intensive sectors such as olives increasing their use of primary factors relative to the baseline, and the opposite occurring in sectors with low emissions intensities such as vegetables and poultry (Table 5.13). Due to the inelastic supply response of capital noted above, this effect is mainly seen in the returns to capital (market price) rather than the quantity demanded.

5.5.4.3. Scenario 2: 10% reduction in aggregate agricultural emissions, with end of pipe abatement

As a result of the lower emissions tax in scenario 2, energy and fertiliser price increases are considerably smaller than those in scenario 1, whilst still greater than those in the baseline (Table 5.12). This means both a smaller contraction in output, and hence factor demand, but also less of a substitution effect towards the primary factors and away from energy and fertiliser. Overall the price of land and demand for agricultural labour and capital rise slightly relative to scenario 1, which suggests that the expansion effect dominates the substitution effect, though in the case of capital this is at least partly because this includes the use of abatement equipment which is classified as 'capital'. Looking at the results in Table 5.13, it may seem surprising that the inclusion of capital for emissions abatement in scenario 2 does not cause a larger increase in capital use relative to scenario 1. When we consider that total expenditure on agricultural abatement over the period is €159.1 million though (Table 5.15.), and the total value of agricultural capital in the benchmark year is €7.2 billion, the small impact seems more reasonable.

5.5.4.4. Scenario 3: 10% emissions reduction in all agricultural sectors, with end of pipe abatement

The emissions tax necessary in scenario 3 is higher than that for scenario 2 in all the crops sectors, as well as poultry. Thus the increases in the price of energy and fertiliser are greater for all these industries relative to scenario 2, though only in vegetable growing and poultry farming do energy prices rise above the increase seen in scenario 1 (Table 5.12) – two sectors which are explored in the emissions section above. As has been shown, in general terms the negative expansion effect on factor demand from the industries contracting tends to outweigh the substitution effect towards primary factors and away from energy and fertiliser. Thus the movement from scenario 2 to 3 provokes small reductions in the demand for land, labour and capital across the crops and poultry sectors (Table 5.13). In contrast the remaining livestock sectors face lower emissions taxes in scenario 3 compared with scenario 2, or no tax at all in the case of cattle and sheep, so in relative terms, each activity expands their demand for primary factors, as well as that for energy. This is enough to push the land price, and overall demand for agricultural labour and capital, up by a very small amount relative to scenario 2 (not shown).

These results have important implications for household consumption patterns and welfare effects, as will be explored in the next section.

5.5.5. Food prices and consumer utility

Along with factor incomes, the other key component in consumption patterns and utility is prices. Given the agricultural focus of this study, the focus here is on food prices, after noting from Table 5.7. that in scenario 1 the overall Consumer Price Index (CPI) rises by 2% relative to the baseline, and this increase is 1.5% in scenario 2 and 1.6% in scenario 3.

The same story is magnified in the aggregate food price index (Table 5.16), which (in comparison with the baseline) rises 6.1% in scenario 1, 2% in scenario 2 and 3.2% in scenario 3. The fact that food prices rise by more than the general price index, even when agricultural emissions benefit exclusively from end-of-pipe abatement options, is indicative of the high emissions intensities of most agricultural activities relative to the Spanish average (Table 5.4.). Looking at Table 5.16., in scenario 1 the biggest price increases are in the most emissions intensive sectors, namely olives and processed red meat (derived from cattle and sheep, which are both emissions intensive), whilst vegetables have a much smaller price increase. As noted above, the livestock sectors benefit most from the addition of end-of-pipe abatement technologies, so the relative fall in the price increase when moving from scenario 1 to 2 is large in processed meats. Olives also see a dramatic reduction in price between the two scenarios, though they maintain the greatest price increase of all food commodities – indeed the general ranking of price increases is largely unchanged. This is not the case in scenario 3 where, although olives still show the greatest price increase by some distance, that for the red meat sectors in particular is greatly reduced (remember that cattle and sheep face no emissions tax in this scenario), whilst low emissions intensive products like fruit and vegetables now show the greatest price increases after olives. This is because of the high emissions taxes needed to force these expanding sectors to reduce their emissions by 10% in scenario 3 (see section 5.5.2).

The responses of household consumption to these price increases are shown in Table 5.17, and offer few surprises, with the biggest reductions in demand in olives and red meat, and the smallest in sugar. An approximate calculation to give an idea of the price elasticities of household demand of the various food commodities does reveal some interesting insights though. Simply dividing the percentage decrease in luxury consumption (subsistence consumption is independent of price changes) by the percentage increase in price – both relative to the baseline – is very imperfect, but does present a sketch of the relative 'general equilibrium' elasticities, which are presented in Table 5.18. The generally higher elasticities in scenario 2 compared to scenario 1 are to be expected as price increases are smaller in the former. Of even greater interest though is the fact that the two commodities with the lowest elasticities of demand are alcohol and sugar – both of which have certain addictive qualities and are generally considered to be price inelastic. Meanwhile those commodities with a large number of substitutes (‘other crops’, which is mainly beans and other pulses, potatoes and poultry) show the highest price elasticities of demand, as supported by economic theory.

In the aggregate, the price elasticity of demand for food must on the whole be lower than that for general consumption, as a consistent result across the scenarios is that despite the higher price rises in food mentioned above, the utility loss from food consumption is always smaller than that from general consumption (Table 5.19). Note that utility does not include subsistence expenditure, of which food has a higher share than the average consumption good (not shown). This lends further support to the overall trend that in the face of emissions restrictions and the resultant rise in prices, Spanish food consumption should hold up relatively well.

5.6. Conclusions

This chapter has described the primary application of the OEG model in this study – an analysis of the impact on Spanish agriculture, within the wider Spanish economy, of the EU-mandated GHG emissions reductions targets sets for 2020. The chapter has first assessed the contribution of a crucial development of the OEG model – namely the incorporation of MAC curves for agriculture – by running simulations with and without this innovation and comparing the results. It was found that their inclusion induces a modest reduction in the macroeconomic cost of the emissions restrictions to Spain in terms of both real GDP (1.2% lower than the baseline in 2020 without MAC curves, 0.9% lower with), and employment (1.4% lower without, 1.0% lower with). Focussing on the agricultural sector, the addition of MAC curves tend to concentrate emissions reductions in the livestock sectors as the data suggests they have more low-cost abatement options than do the crops sectors. The emissions tax necessary to meet the 10% reduction target for agriculture as a 'diffuse' sector falls from €85/tCOe without the MAC curves to €23/tCO2e with, and the projected total direct cost to farmers of the policy (emissions taxes plus the cost of abatement equipment) falls by around 70%. Policy-induced price increases and output reductions are reduced fairly evenly across all agricultural sectors, as the single emissions target for aggregate agricultural emissions means reductions can still be focussed where they are cheapest. Thus the fall in output relative to the baseline is around 20% greater in livestock than that in crops, and this is a consistent result with or without the MAC curves.

Overall, the inclusion of end-of-pipe abatement options represents a significant step forward for the OEG model in terms of the realism of simulations of emissions reductions in agriculture, and has been shown to affect the results of such simulations significantly.

In addition, this chapter has used the extended OEG model to analyse two policy options for ensuring the agricultural emissions reduction target is met. The first (scenario 2) sets a single target for aggregate agricultural emissions, with a uniform emissions tax rate, and allows reductions to be distributed depending on the relative costs of abatement – analogous to a cap-and trade scheme among agricultural industries, with all permits auctioned at the market price. The second (scenario 3) divides agriculture into 10 subsectors and forces each of them to reduce their emissions by 10%. The results suggest that in scenario 2, as noted above, emissions reductions are concentrated in the livestock sectors, which allows certain key

Spanish export commodities such as fruit, vegetables and olives, a degree of slack to increase their production. In scenario 3 this is no longer the case, and they become the agricultural industries for whom meeting the 10% target is the most costly. Indeed, a consistent pattern is that those industries which reduce their emissions by more than the average (10%) in scenario 2 face a less than average emissions tax (€23/tCO2e) and *vice versa.* At the most extreme, for cattle and sheep farming, which has the largest reduction in emissions of all agricultural sectors in scenario 2, the 10% reduction target in scenario 3 is non-binding, meaning the emissions tax in that scenario is 0.

In general the costs of the emissions restrictions in terms of welfare, GDP, employment and, particularly, agricultural output and farm incomes, are smaller in scenario 2 than scenario 3, lending support to the idea that there are efficiency gains from using a cap-and-trade scheme to focus emissions reductions where they can be made at the lowest cost. An important caveat is that the OEG model does not account for the administration costs of running such a scheme, though it is a moot point as to whether these would be significantly greater than those associated with ensuring each agricultural activity meets a specific emissions reduction target. Such a cap-and-trade scheme appears to work in conjunction with the trend in Spanish agriculture of a moderate expansion in certain key crop sectors relative to livestock. These crop sectors – particularly fruit and vegetables – are among the least emissions intensive agricultural products, so their expansion is likely to help Spain to meet its GHG targets more easily – though it may raise other environmental concerns beyond the reach of this study.

An unambiguous finding from all scenarios is that there is a cost to the Spanish economy, and to employment, associated with meeting the EU-mandated targets. Avoiding such a cost (i.e. growing the economy or increasing employment at the same time as reducing emissions) has come to be known as a 'double dividend', and the next chapter explores two policy options for recycling the revenue raise from environmental taxes to assess whether it may be possible in Spain.

6. Options for revenue recycling

6.1. Introduction: revenue recycling and the 'double dividend'

The assumption behind the experiments presented in this chapter is that the Spanish government ring-fences some of the revenues raised from agricultural emissions taxes for a specific purpose. This has come to be known as 'revenue recycling' (Parry, 2001) and is frequently talked about in relation to a so-called 'double dividend' (Goulder, 1995) i.e. achieving a specific goal in addition to the environmental target which is the primary objective of policy. These secondary policy goals are usually large-scale objectives such as increasing economic growth or employment. A full review of CGE simulations of revenue recycling options, and how they have informed the debate around the existence of a double dividend, can be found in Chapter 2. Given the agricultural focus of the current study, only emissions tax revenues from the agricultural sector are recycled, and all policy options considered work by promoting Spanish agriculture in different ways. The scenarios presented here are motivated by worrying trends in unemployment and rural depopulation, as well as concerns over food security, and the opportunities presented by what is coming to be known as the 'bioeconomy' (M'barek et al., 2014).

In each scenario described in Chapter 5, the revenues raised from environmental taxes were distributed between existing government spending and reducing the budget deficit. Thus by 2020 in scenario 2, for example, the value of government spending was 1.1% higher than in the baseline, while the deficit was €8bn smaller which, in the presence of falling GDP, resulted in a deficit-GDP ratio just 0.01% lower than the baseline. The scenarios to be tested in this chapter are presented in Table 6.1. They include, for comparison, one without any kind of revenue recycling, (scenario 1 from Chapter 5), one scenario where the revenue raised from agricultural emissions taxes is applied as a subsidy to all primary agricultural sectors ('All'), one where it is applied only to low-skilled agricultural labourers ('Low-skilled'), and one where it is recycled as a subsidy on private household purchases of domestic agrifood products ('Food subsidy'). Note that in all scenarios discussed in this chapter, emissions restrictions will take the same form as those in scenario 1 from Chapter 5 – a single 10% reduction for aggregate agricultural emissions, rather than a uniform 10% reduction for each agricultural sub-sector.

The relatively high unemployment rate in Spain was seen as a concern even before the onset of the current financial crisis in 2007 (Blanchard and Jimeno, 1995). The steep rise in unemployment during the crisis has driven the issue to the top of the political and media agenda in the country, and has resulted in numerous studies looking at specific impacts, such as those on mental health (Gili et al., 2013), and the danger of hysteresis, whereby short-term unemployment carries the risk of turning into long-term unemployability (Ramón, 2011).

Rural depopulation in Spain has increasingly become a topic for academic discussion in the past decade (Sáez, Pinilla, and Ayuda, 2001; Collantes and Pinilla, 2011; Collantes et al., 2014). A Government report from 2010 noted that the percentage of Spaniards living in rural areas has fallen steadily from 21% in 1990 to less than 18% in 2008 (MAGRAMA, 2010b), despite an earlier sharp fall from 1950 to 1990 according to Collantes and Pinilla (2011). The same report finds that the average age and the percentage of people living below the poverty line are both higher in rural areas, and estimates that the median rural income is around €3,000 a year lower than its urban counterpart. In a different section of the same report, twenty one measures for sustainable rural development are laid out under five themes (MAGRAMA, 2010b). The policy options considered in this study fall under Theme 1: 'Economic activity and employment', and the measures 'Support for regional agriculture', 'Fomentation of economic activity in a rural contexts' and 'Creation and sustainability of employment.'

The following section explains how a labour subsidy drives a wedge between the wage paid by employers (the agents' price of labour) and that received by workers (the market price). Section 6.3 similarly explores how the food subsidy reduces the market price on final (i.e., private household) demands for food, while increasing the agents' price received by consumers. In both cases the distribution of the subsidy will depend on the price elasticities of supply and demand. Section 6.4 compares the results from each revenue recycling option, looking in particular at macroeconomic impacts, the labour market, household food consumption and utility, agricultural production and emissions, and the trade balance. Section 6.5 concludes.

6.2. Increasing employment: agricultural labour subsidy

Given the agricultural focus of the current study, the labour subsidy is only applied to primary agricultural industries. This approach is further justified by the fact that it is the revenues from agricultural emissions taxes which are being recycled, and that, at least since the beginning of the financial crisis, the agricultural unemployment rate has almost always been above that for the whole economy (Figure 6.1). The scenarios here are inspired by those of Fæhn, Gómez-Plana, and Kverndokk (2009), in that there is one where the labour subsidy is applied to all types of labour and one where it is only applied to 'low-skilled' workers. As a policy, the latter would present some administrative challenges, but could be justified on distributional grounds, or by the fact that the unemployment rate amongst low-skilled workers is consistently almost double that of skilled workers (Lago et al., 2013).

The agricultural labour subsidy introduces a wedge between the price of labour as paid by employers (the 'agents' price') and that as received by workers (the 'market price'), such that the former is reduced and the latter increased relative to the pre-subsidy situation – Figure 6.2. The effect of a subsidy on wages and employment will depend on the price elasticities of both demand and supply for labour. If labour demand is particularly elastic (Figures 6.2a and 6.2c), the subsidy will encourage firms to hire workers, diluting the reduction in the cost of labour to industry, while an inelastic demand for labour (Figures 6.2b and 6.2d) means the subsidy will result in a greater reduction of labour costs. Similarly, if the supply of labour is price elastic (Figures 6.2a and 6.2b), more labour will be drawn into the market by the subsidy, meaning a smaller wage effect for workers than when labour supply is inelastic (Figures 6.2c and 6.2d).

Linked to the effects on wages and employment is the issue of who benefits from the subsidy. To what extent is it a subsidy on employees and to what extent on employers? In the case of employees, the principal effect will be to increase nominal wages, and thus household incomes and thus demand for consumer goods, whilst (assuming a positive marginal propensity to save) greater funds will be available for investment. Higher worker incomes will also increase import demands. For employers, the main effect will be to reduce industry costs, making Spanish goods more competitive on global markets and leading again to an increase in real household incomes – through price reductions rather than a nominal wage increase. In this case the subsidy would improve the balance of trade by both increasing exports and reducing imports.

Looking at Figure 6.2, before the subsidy, the labour cost to the firms is equal to the total payments to workers – the rectangle 0P1aQ1. The introduction of the subsidy increases the total payments to workers to the rectangle 0PmbQ2, while the labour cost to the firm is now 0PacQ2. The distribution of the subsidy between existing and new workers and firms will thus depend on the elasticities. An inelastic supply of labour and an elastic demand (Figure 6.2c.) presents the most extreme case of increased wages received by workers, while an elastic supply and inelastic demand (Figure 6.2b.) is likely to be where firm labour costs are most reduced.

Looking at the demand side, the nested production function used in the OEG model means some calculations are necessary to determine whether the different types of labour are overall substitutes or complements. Using the formula from Burniaux and Truong (2002), and derived by Keller (1980), the 'outer' (or total) elasticity of substitution can be calculated as follows:

$$\boldsymbol{\sigma_{lab\_outer} = \sigma_{lab\_inner}/S_{lab} - \left[\sigma_{prim} * \left[\frac{1}{S_{lab}} - \frac{1}{S_{prim}}\right]\right] - \left[\sigma_T * \left[\frac{1}{S_{prim}} - \frac{1}{S_{tot}}\right]\right]} \qquad \textbf{(91)}$$

where $\boldsymbol{\sigma_{lab\_outer}}$ is the total elasticity of substitution between labour types, $\boldsymbol{\sigma_{lab\_inner}}$ is that given at the lower level of the nested structure (see chapter 4), $\boldsymbol{\sigma_{prim}}$ is the elasticity of substitution between primary factors and σ_T that between primary factors and material inputs, while $\boldsymbol{S_{lab}}$, $\boldsymbol{S_{prim}}$ and $\boldsymbol{S_{tot}}$ are, respectively, the cost shares of labour, primary factors, and all inputs in total production (the last being equal to 1). The results of these calculations are shown for selected industries in the first column of Table 6.2. Although the different types of labour are certainly substitutes for all industries, it is striking how much lower the elasticities are for agricultural than non-agricultural industries. This suggests that in the scenarios where the subsidy is applied exclusively to low-skilled labour, there will be less scope for the agricultural industries to increase their use of low-skilled workers at the expense of more skilled workers than if there would be in other industries is the same policy were to be applied to all sectors. Meanwhile the wages of low-skilled workers may rise significantly relative to their more highly-skilled counterparts as a result of the labour subsidy – though this may be offset by the relative elasticities of supply as seen below.

Having shown the degree of substitutability between labour types, it will now be useful to look at the total price elasticities of demand for labour across different industries. This can be calculated from the following equation:

$$\boldsymbol{\varepsilon_{lab} = -\sigma_{lab} + [S_{lab} * [\sigma_{lab} - 1]]} \qquad \textbf{(92)}$$

with the results shown in the second column of Table 6.2. Again, they suggest that the demand for labour is less price elastic in the agricultural sectors than in the economy as a whole. As a result it is to be expected that the subsidy on agricultural labour will have more of an impact reducing labour costs for firms than increasing wages received by workers – i.e. the agents' price is likely to fall by more than the market price rises (Figure 6.2).

Examining labour supply, low-skilled labour is more elastic than high-skilled in the OEG model (see chapter 3). This suggests that amongst low-skilled (highly-skilled) workers the subsidy will have more of an employment (wage) effect, which will obviously be accentuated when the subsidy is applied to low-skilled workers exclusively. In summary, highly-skilled agricultural labour can be described by Figure 6.2d – low price elasticity of demand, low price elasticity of supply – while low-skilled agricultural labour looks more like Figure 6.2b – low price elasticity of demand, high price elasticity of supply.

6.3. Combating rural depopulation: Food subsidy

The second policy option considered for using environmental tax revenues to stimulate rural employment and combat rural depopulation is a subsidy on food purchases[45] by private households. The rationale for this is that agriculture is overwhelmingly a rural industry, so a domestic subsidy[46] is likely to increase economic activity in the countryside, with the caveat that agriculture is obviously not the only rural industry in Spain. The extent to which this is actually the case depends partly on the price elasticity of demand for food, and partly on the extent to which domestically produced food commodities are competing with imports. In section 5.5.5. it was shown that the price elasticity of food tends to be lower than that for non-food commodities, which leads us to expect that the subsidy would have more of an impact on prices (and hence real wages) than on food consumption. In contrast, since agricultural and food commodities tend to be relatively homogenous, compared with non-food commodities, they have relatively high Armington elasticities, particularly processed sugar, meat and dairy products (first column of Table 6.3.), meaning a subsidy on household purchases of Spanish food could have a significant impact on the balance of trade, as

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[45] Due to existing taxes, in some cases this translates to a tax reduction rather than a subsidy in absolute terms.

[46] No export subsidies are considered as these would be illegal under EU and global trade rules.

imports are readily substituted for domestic goods. While exports may be reduced as domestic suppliers increase their presence in local markets, this is likely to be outweighed by the reduction in imports caused by the domestic price fall, leading to an overall improvement in the trade balance. This effect should be greater in those commodities which are more exposed to competition from imports, such as alcoholic drinks, fruit, dairy products and processed sugar (second column of Table 6.3).

6.4. Results: comparing the policy options

6.4.1. Macroeconomic results

Table 6.4. shows the results from each scenario for the components of aggregate demand. All revenue recycling options reduce the fall in GDP growth provoked by the emissions restrictions, with the greatest effect coming when the subsidy is focussed exclusively on low-skilled labour, in contrast to the result to that found in Fæhn, Gómez-Plana, and Kverndokk (2009). This is because in that study the subsidy is applied to all industries, not just agriculture. Agricultural industries tend to use a relatively high proportion of unskilled labour compared to the rest of the economy, so as well as the substitution effect towards low-skilled from skilled labour, the expansion effect is greater as agricultural industries tend to do better in this scenario (see section 6.4.4.). The food subsidy is the least effective in stimulating economic growth. In none of the scenarios though is the revenue recycled sufficient to cancel out the fall in GDP growth completely, suggesting that in that sense there is no pure double dividend which combines emissions reductions with economic growth (employment results are discussed below).

The two immediate consequences of the agricultural labour subsidy scenarios are an increase in the wage received by workers, and a reduction in the wage costs to firms, reducing the costs of production. These two are explored in more detail below, but in macroeconomic terms, the former serves to increase demand though a rise in household disposable income, whilst the latter serves to reduces prices, making Spanish goods more competitive on world markets and relative to imports. Note that in these two scenarios ('All' and 'Low-skilled'), the increases in investment and exports relative to the scenario with no revenue recycling are noticeably larger than that in private consumption, while this is not the case in the 'Food subsidy' scenario.

In effect, by reducing the overall costs of production in the agricultural sector, the labour subsidy improves the overall economic climate. Increases in household incomes from higher wages lead to increases in savings and hence investment, while increased exports and import substitution improves the trade balance on agricultural and food products (see below). As the food subsidy only affects purchases by households, the macroeconomic impact is muted somewhat, as private household consumption is just one source of demand among many, comprising around 30% of agrifood sales. This is illustrated by Figure 6.3., which shows investment over time relative to the baseline in the different scenarios. Overall the emissions restrictions have a depressive effect on investment as rising prices worsen the economic climate relative to the no-action baseline (Chapter 5). This result suggests that the agricultural labour subsidy scenarios are significantly more effective at mitigating this unintended consequence of emissions reductions than the food subsidy, as they lift investment significantly closer to the baseline than does the latter. Along with the trade effects (see section 6.4.5) this explains why the overall reduction in real GDP is smaller in the agricultural labour subsidy than the food subsidy scenarios.

6.4.2. The labour market

The first column of Table 6.5 shows that, in the absence of revenue recycling, the contractionary effects of emissions restrictions on employment are greatest among low-skilled workers, as they are the least-trained workers in the economy, so are the most likely to leave work or be made redundant when the economy contracts (Chapter 5). For the same reason, these workers are the most likely to enter work quickly when the economy expands, and the second column shows that they witness the largest recovery in employment when revenue is recycled through the wages of all agricultural workers. As a result, it is to be expected that focussing the subsidy on low-skilled workers would, of all the scenarios, drive the greatest increase in overall employment – and the third column of Table 6.5. confirms this. Note that in this scenario employment increases (albeit by a very small amount) relative to the baseline (no emissions restrictions), suggesting there may be pure double dividend in terms of employment. Figure 6.4. reveals the closeness and ambiguity of this result however, as it shows that over the simulation period, employment in the 'low-skilled' scenario is sometimes above and sometimes below the baseline. While the 'low skilled' scenario provokes the largest increase in employment, the rise in wages is greater when the agricultural labour subsidy is applied to all labour types (Table 6.6.), confirming the hypothesis described above (section 6.2.) that the more (in) elastic the labour supply, the more the effect of the subsidy will be to increase employment (wages).

This result is starkly shown by looking at the effects of the agricultural labour subsidy on employment and wages in non-agricultural industries. Table 6.5. shows that regardless of how the subsidy is applied (to all workers, or just the low-skilled), the increase in employment of non-agricultural workers relative to the 'No RR' scenario is very small for highly skilled and skilled workers, and much larger for low-skilled workers. This is because the rise in the aggregate wage encourages more of the low-skilled unemployed back into work (note that by assumption, the labour curve is upward sloping – see Chapter 4). This would be an obvious result when the subsidy is only applied to low-skilled workers, but when the subsidy is applied to all (agricultural) workers, the same is true for skilled and highly skilled non-agricultural workers to a much lesser extent (Table 6.5). The picture is clarified by Table 6.6, which shows that the *wages* of non-agricultural skilled and highly skilled workers fall by much less than those for low-skilled workers. In general terms, the effect of the agricultural labour subsidy is expansionary, as it lowers input costs even to non-agricultural industries. For workers in these industries, the differing elasticities of supply determine whether the impact is principally felt through an increase in employment (low-skilled workers) or wages (skilled and highly skilled workers).

The ‘Food subsidy’ scenario improves employment relative to the ‘No RR’ scenario, particularly in the agricultural sector, but not by anywhere near as much as the agricultural labour subsidy scenarios, while wages are also the lowest in this option, perhaps because the reduced cost of living from the direct subsidy to household food purchases mean wages can fall without adversely affecting the labour supply.

As well as being important in their own right, the response of labour returns – and those to other factors – to the different revenue recycling options are key results in the model as they will drive both household saving, which provides the funds for investment (see macroeconomic results above) and consumption. Our attention now turns to household food consumption and the resulting utility.

6.4.3. Food prices and consumption

Table 6.7. shows the net tax rates in the model on the biggest food commodities by value of household purchases, with and without the reduction in sales taxes to households. It can be seen that recycling the revenue from emissions taxes on agrifood industries translates to approximately a five percentage point reduction in the tax rate. For some commodities, notably alcohol, this is a small reduction given the high level of the initial tax rate. For others though, particularly fruit and vegetables, the revenue recycling is enough to eliminate the sales tax entirely, and convert it into a small subsidy – indeed the tax rate for all agrifood commodities averages at 0.0% after the application of the subsidy.

As seen in the previous chapter, the tendency of the emissions restrictions is to raise prices throughout the economy, whilst food prices rise by more than the average. Table 6.8. (again, for the ten biggest food commodities by household purchases) shows that the agricultural labour subsidy significantly reduces this rise in overall food prices, whilst in the food subsidy scenario, the food price index is 1.5% lower than the baseline by 2020. In the agricultural labour subsidy scenarios the price falls are biggest in fruit and vegetables whilst for the remaining commodities the agricultural labour subsidy has only a second order effect as it lowers the cost of, for example, cattle farming, which is then an input into the beef industry.

For most food commodities, the food subsidy is sufficient to turn a small reduction in household consumption relative to the baseline into a small increase (Table 6.9.), whilst the labour subsidy only has this effect on vegetables and fruit consumption due to their large price falls. This could be presented as a double dividend of sorts if the Spanish government saw maintaining or improving nutrition levels in the presence of emissions restrictions as a policy goal. The effect on the household budget share of food is more ambiguous than had been expected, as increasing demand and falling prices pull in different directions. Thus the average budget share of all food products rises from 15.7% in the benchmark year (2007) to 18.5% in 2020 in the absence of any revenue recycling, while the labour subsidy provokes a slight fall to 18.3%, and the food subsidy to 18.1% in 2020 (not shown). This is partly due to the low price elasticity of demand for food products in the Linear Expenditure System which governs household consumption decisions in the OEG model. This means that as prices rise in the presence of emissions restrictions, food consumption decreases by less than that for non-food products (see chapter 5), leading to an increased budget share for food. For the same reason, the increase in overall food consumption caused by the subsidies is relatively small, so the effect of the fall in food prices dominates in budget share terms, with the proportion devoted to food shrinking overall.

The increase in consumption becomes more marked when the results are split into domestic and imported food (Table 6.10.). Food imports have benefited from increasing domestic prices in the absence of revenue recycling, so the food subsidy serves to reverse this trend and provoke an import substitution effect in favour of domestic food. The consequences of this for the Spanish trade balance are explored in 6.4.5. below, but first our attention turns to agricultural production.

6.4.4. Agricultural production and emissions

Figure 6.5 presents the effect of each scenario on output in selected agricultural industries. The most obvious result is that all industries do significantly better under the agricultural labour subsidy scenarios than when revenue is recycled through a food subsidy to households, with the improvement most marked in the crops sectors. This is because they tend to be more directly exposed to world markets than the livestock sectors. A look at the benchmark data suggests that the sum of imports and exports as a proportion of total purchases in 2007 was around 47% for crops, and just 7% for primary livestock (Table 6.11). As a result, the price falls caused by the agricultural labour subsidy are more effective in stimulating crop than livestock production. This is mirrored in the land use changes relative to the baseline shown in Figure 6.6. The kinked land supply curve employed in the OEG model (Chapter 4) means the total land used for agriculture in Spain cannot increase beyond the registered area, so if one agricultural activity increases its land use it must be at the expense of another. Figure 6.6 shows that in both agricultural labour subsidy scenarios, land use is lower in all livestock sectors than when there is no revenue recycling. The only crop sectors which do not increase their land use are barley and olives – the two crop sectors where the sum of imports and exports make up the lowest proportion of total purchases (Table 6.11).

In terms of the distribution of emissions reductions, the effect of all revenue recycling schemes, (particularly the agricultural labour subsidy scenario), is to further concentrate reductions in cereals and olives sectors which were already witnessing the largest reductions relative to the baseline (Figure 6.7.). This is because revenue recycling stimulates activity in the agricultural sectors (as seen in the results described so far), which means a higher carbon price is necessary to ensure that the 10% reduction target for agricultural emissions by 2020 is still met. This higher carbon price has the biggest impact on cereals and olives as they are the most emissions intensive crops sectors (Table 5.4.). The further reductions in these two heavily emitting sectors allows other agricultural activities some slack to increase their emissions relative to the 'No RR' scenario, such that the aggregate target is still met.

6.4.5. The trade balance

As mentioned above, all revenue recycling options have implications for Spain's trade balance, with the food subsidy favouring domestic production at the expense of imports, and the agricultural labour subsidy having both this effect and reducing the costs of production for Spanish agriculture, making exports more competitive. This can be seen in Table 6.12. which shows both the macro and agrifood trade balances in 2020 under the various scenarios. The results suggest that each of the revenue recycling scenarios improves the trade balance by between €800-900 million relative to the 'No RR' scenario. Interestingly, focussing the agricultural labour subsidy on low-skilled labour produces an additional total trade balance improvement of around €100 million relative to either of the other revenue recycling options. This suggests that the secondary effects of the subsidy on non-agrifood sectors are greatest in this scenario. Of course the corollary of this result is that the 'Low-skilled' scenario witnesses the largest fall in the terms of trade, at 3%, as it is this scenario which provokes the biggest cost reductions for Spanish industries. While the numbers are close enough to be questionable, a tentative result from this is that if one of the goals of the Spanish government is to improve its trade balance, then recycling the revenue as a subsidy on low-skilled labour – even if only in the agricultural sector – may be the best way of achieving this.

Table 6.13. shows how quantities of the top ten agrifood exports (by value in the benchmark year) fare relative to the baseline in each scenario. Note from the last column that exports fall by more when the revenue is recycled as a subsidy on household food purchases than when it is not recycled at all, for all of the items except alcohol. As mentioned above, the pre-existing tax on household purchases of alcohol is dramatically larger than that on any other food product, so in percentage terms the subsidy-induced price fall is much smaller than that for other foods. This suggests that one of the effects of the food subsidy is to divert production from exports to satisfying the increased demand from households in the domestic market, an effect which is muted in alcoholic drink production. Exports of all of the commodities are significantly improved by recycling the revenue as an agricultural labour subsidy, and improved slightly by giving it to low-skilled workers only, as this option reduces production costs the most for reasons given above.

6.5. Conclusions

This chapter has presented three options for recycling the revenue raised from emissions taxes in the agricultural sector: a subsidy on all agricultural labour, a subsidy on low-skilled agricultural labour, and a subsidy (or VAT reduction) on private household purchases of domestic agrifood products. The objectives of each are to increase employment, promote food security, and invest in the bioeconomy in Spain. The emissions reductions are held constant across the scenario such that the target to reduce aggregate agricultural emissions by 10% between 2005 and 2020 is met, without specifying the contribution from each agricultural activity – similar to scenario 1 in Chapter 5.

The results can be summarised through the supply and demand effects of each policy option. The food subsidy increases private household demand for food through a substitution effect, as it becomes cheaper relative to non-food products and food imports, and through an income effect, as household real incomes rise in the presence of food price falls, increasing household demand for all consumer goods. Both of these are present also in the agricultural labour subsidy scenarios, but the substitution effect is weaker, as the food price falls are smaller, and the income effect is greater, as real incomes are pulled up by both rising nominal incomes and falling prices. On the supply side, the food subsidy increases the supply to domestic markets but reduces that for export markets, as Spanish producers concentrate more on the domestic market in the face of rising market prices. The agricultural labour subsidy scenarios are the only ones which actually lower the cost of production, making Spanish firms more competitive on both domestic and global markets. They also encourage workers into the agricultural sector, although the results suggests these are likely to be previously unemployed labourers. The non-agricultural industries are themselves expanding and demanding more workers as the whole economy grows relative to the scenario in which there is no revenue recycling.

This growth is present in all three of the revenue recycling scenarios, but is weakest when a food subsidy is applied, and strongest when the emissions tax revenues are channelled through a subsidy on low-skilled, agricultural labour. In reality, the administrative and political costs of applying such a specific labour subsidy may be prohibitively high, but the results suggest that the macroeconomic stimulus from applying the subsidy to all agricultural labour is only slightly smaller, so this may be a good second best option. Either way, it is important to note that environmental taxes to induce emissions reductions should not be seen inevitably as a withdrawal from the economy, nor should food price rises be seen as an unavoidable consequence. This chapter has shown just some examples for policies which, in combination with emissions reductions, could increase employment, promote food security, and increase growth in the bioeconomy.

7. Conclusions

7.1. Summary

7.1.1. Motivation and objectives

Scientific theory and empirical evidence both lend strong support to the idea that the climate is changing, and that humanity is contributing to this process through the emissions of Greenhouse Gases (GHGs). As noted in the introduction, the Inter-Governmental Panel on Climate Change (IPCC) has listed some of the likely consequences of climate change as freshwater scarcity, river and coastal flooding, species extinction and loss of biodiversity, reduced fish stocks and crop yields with implications for global food production, increasing forest fires and extreme weather events such as heat-waves or extreme precipitation, and increased prevalence of food- and water-borne diseases (IPCC, 2014).

The debate on climate change has largely moved on from the question of *whether* something needs to be done to reduce emissions to discuss *how* it should be done. This study hopes to contribute in some way to those debates by looking at how agriculture in a Southern European country (Spain) can reduce emissions efficiently, and minimise any adverse impacts on output and global competitiveness. The results presented in this study will primarily be of interest to agricultural and environmental policy-makers, for whom some of the lessons of the study are drawn out after this summary in section 7.3., though the analysis of certain key trends in Spanish agriculture may also be of interest to farmers. Indeed, some of the results may be relevant to other industries, particularly those around permit trading, and the implications of alternative approaches to distributing emissions reductions.

7.1.2. Data and Methodology

Chapter 2 presents a survey of the use of Computable General Equilibrium (CGE) models in environmental analysis, noting four advantages of this type of approach. Firstly, their versatility in analysing diverse kinds of scenarios such as baseline projections, the impacts of a given policy, or calculating the degree of action necessary to meet a given target. Secondly, their potential for dynamic analysis, enabling researchers to implement policies at the time they become active, and to track results through the simulation time period. Thirdly, their ability to deal with multiple policy and economic changes – in the case of the current study the macroeconomic effects of the financial crisis, agreed reforms to the Common Agricultural Policy (CAP) and volatile energy prices offer a ‘real-world’ background to the climate change policies which are the focus of the study. Finally, CGE models are able to include mechanisms for endogenous technological change, which are central to the current study in its incorporation of abatement technologies in the agricultural sector.

Chapter 3 describes the data sources used to support the model, and the challenges associated with constructing the database. The most important data sources are Spanish Input-Output (IO) tables, which have been expanded to include data from institutional accounts to form a Social Accounting Matrix (SAM), and data on greenhouse gas emissions from the United Nations Framework Convention on Climate Change (UNFCCC). Chapter 4 describes the 'Orani-ESP-Green' (OEG) model used in the current study: a demand led, recursive dynamic model of a single country (Spain), based on neoclassical foundations. The model includes a detailed treatment of the agricultural sector, including policy mechanisms associated with the CAP. This enables us to investigate the interdependencies of agricultural and environmental policy (the introduction of the Single Farm Payment, for example, may induce changes in the pattern of agricultural activity in Spain which, given heterogeneity of emissions factors between activities, will have implications for aggregate emissions). Another feature of the model is the ability to track emissions from different sources, as well as various policy options for incentivising emissions reduction. These include carbon taxes and 'cap-and-trade' emissions permit schemes, either of which can be applied on any scale from an individual industry or pollutant up to the whole economy. Furthermore, the model is extended to include 'bottom-up' data on abatement options in the agricultural sector in the form of calibrated Marginal Abatement Cost (MAC) curves, which simulate the degree to which farmers respond to policy-induced price rises in emitting inputs by investing in technologies and practices with lower associated emissions factors.

In Chapter 5 the model is used to explore the implications for Spanish agriculture, in the context of the wider economy, of the target of reducing emissions by 10% between 2005 and 2020. The model is first run with and without the added MAC curves in order to isolate their effect. Then, with the MAC-extended model, two policy options are considered for meeting the 10% target: a reduction in aggregate agricultural emissions with the distribution to be determined within the model – analogous to a cap-and-trade scheme (with full auctioning) in agriculture – and a uniform reduction for each specific agricultural industry, each of which adopts a different emissions tax rate depending on what is necessary to provoke the required reductions. Comparing the two scenarios gives a clear picture of which agricultural sectors would find it most costly to reduce their emissions and the implications for the Spanish economy if they are forced to do so.

In Chapter 6 various options for revenue recycling in the agricultural sector are considered. This is a mechanism whereby environmental tax revenues are targeted towards achieving a specific policy goal, in the hope that a 'double dividend' (environmental benefits plus a non-environmental objective) can be achieved. In this case, the policies are motivated by the Spanish government's stated intent to promote rural development through support for regional agriculture (MAGRAMA, 2010b). The options explored are (i) a subsidy on all primary agricultural workers; (ii) a subsidy on unskilled agricultural workers only: (iii) a subsidy on household purchases of food. Each option is judged on its ability to stimulate employment (a particular concern for Spain over the simulation period of 2007-2020) and domestic production.

7.1.3. Results

Chapter 5 finds that the extension of the model to include calibrated MAC curves for agriculture induces a modest reduction in the macroeconomic cost of the emissions restrictions to Spain in terms of both real GDP (1.2% lower than the baseline in 2020 without MAC curves, 0.9% lower with MAC curves), and employment (1.4% lower without MAC curves, 1.0% lower with MAC curves). Data for the MAC curves suggest that comparing across all agricultural activities, there are more low-cost options for abatement in livestock than crops sectors, which has important implications for the model results as it means their inclusion focuses emissions reductions in livestock, giving crops sectors more scope to reduce their emissions by less than average, or even increase them. This is significant because in the pre-MAC version of the model, livestock emissions could only fall through a contraction in output, whilst crop sectors could substitute other factors of production for polluting fertiliser to reduce their emissions. Including the MAC curves thus alters the burden of emissions reduction in agriculture significantly. Despite this, policy-induced price increases and output contractions are reduced fairly evenly across all agricultural sectors, as agricultural emissions still face a uniform (if much lower) tax rate. Thus the fall in output relative to the baseline is around 20% greater in livestock than that in crops, and this is a consistent result with or without the MAC curves. Introducing the MAC curves reduces the direct cost of the emissions reduction policy to farmers (emissions taxes plus abatement costs) by around 70%.

When the emissions reduction is applied as an aggregate target, the concentration of emissions reductions in the livestock sector allows certain key Spanish export commodities (fruit, vegetables and olives) a degree of slack to increase their production. When each specific agricultural industry has to reduce its emissions by 10%, these are the sectors for whom it is most costly. As a result, the aggregate scenario shows the most potential to improve the Spanish trade balance. At the other end of the spectrum, for cattle and sheep farming, which has the largest reduction in emissions of all agricultural sectors under the aggregate target, the 10% reduction target applied specifically is non-binding, meaning the emissions tax in that scenario is 0.

In general the costs of the emissions restrictions in terms of welfare, GDP, employment and, particularly, agricultural output, are smaller in the aggregate scenario (2) than the specific (3), lending support to the idea that there are efficiency gains from using a cap-and-trade scheme to focus emissions reductions where they can be made at the lowest cost. Such a cap-and-trade scheme appears to work in conjunction with the trend in Spanish agriculture of a moderate expansion in certain key crop sectors relative to livestock. These crop sectors – particularly fruit and vegetables – are among the least emissions intensive agricultural products, so their expansion is likely to help Spain to meet its GHG targets more easily – though it may raise other environmental concerns beyond the reach of this study.

7.2. Caveats and areas for further work

7.2.1. Assumptions of the OEG framework

As mentioned above, the OEG model is a neoclassical, recursive-dynamic representation. As a result, this type of model structure imposes some strong assumptions which will be clarified here in order to set the results and policy lessons summarised in the rest of this chapter, in their proper context.

The central neoclassical assumptions on which OEG rests are as follows:

1. Consumers reveal their preferences through utility maximising behaviour;
2. Firms are cost minimisers acting in competitive markets;
3. Equilibrium is reached in all markets such that demand equals supply for each good and factor in every simulation period.

The merits and limitations of these assumptions have been well documented (Biggart, 2008) and would be too much of a digression to repeat here, so discussion will be limited to the consequences relevant to the current study.

Firstly, the lack of product differentiation means the study has nothing to say about the growth in market share of agrifood products which market themselves on their low environmental impact (e.g. organic produce). On the demand side, the purchasing decisions of the representative consumer are determined solely by their income and the prices and expenditure elasticities of various goods. Whilst such decisions will be affected by policy-induced price increases (such as those arising from an emissions tax), they do not allow for a non-price preference for low-emitting goods. Such preferences could be introduced exogenously, but this would depend on empirical estimates of questionable validity. If present, these preferences would reduce the welfare costs to consumers of environmental measures, and may reduce the impacts on firms as they would reduce the price elasticity of demand for more environmentally benign goods. Thus in this sense welfare cost and consumer response results presented here should be seen as high-end estimates.

On the supply side, the assumption behind the marginal abatement cost (MAC) curve approach is that an abatement measure is either taken up by the whole industry or not at all. This is a common critique of MAC analysis (Kesicki and Ekins, 2012), but relaxing the assumption would not fit with the idea of the 'representative firm' on which CGE models are built. An alternative would be to modify the model to include two (or more) representative firms based on varying degrees of inertia/enthusiasm towards abatement technologies, but such an approach would involve a high degree of speculation as to the market shares of each type of firm. In this sense, the abatement behaviour of farmers can be seen as optimising, and the results should be interpreted as 'best case' estimates.

Finally, the treatment of the flexibility of labour markets is an open question. In the OEG model they are not perfectly flexible: there is some cost to workers of moving between agricultural and non-agricultural industries, and different types of labour exhibit different elasticities of supply (Chapter 4). There is no impediment to falling real wages though, except for the upward sloping labour supply curve, implying workers have no bargaining power save that of withdrawing their labour. In spite of recent reforms aimed at increased labour market flexibility, this is still a strong assumption for an economy such as Spain's, where collective wage bargaining has historically been a consistent feature of labour markets. The alternative would be to introduce an aggregate 'wage elasticity' parameter, representing the sensitivity of wages to employment conditions, and exogenously adjust the size of the labour force over the simulation period. Both of these elements would depend upon external estimates, and the merits of such an approach are open for discussion.

The recursive-dynamic nature of the model, as opposed to comparative static or inter-temporal, has significant implications for the results (Dellink, 2000; Chapter 2.2.1). Relative to a comparative static model, these are all advantageous: the ability to apply/adjust specific policies at different points throughout the simulation period, and track the inter-temporal adjustment in agents' behaviour, are both useful advantages in results analysis in a recursive dynamic model relative to a comparative static. When researching environmental policies this is especially true as abatement undertaken early on in the simulation period can lead to a lasting reduction in emissions factors, which leaves firms in a better place to negotiate ever-tighter emissions restrictions as the period progresses – the reverse of course being true if early abatement action is not taken. For a policy implication of this effect on a macro level, see section 7.3 below.

The relative merits of recursive-dynamic and inter-temporal equilibrium models are more ambiguous. The first tends to understate the role of expectations by assuming agents are completely myopic, while the second tends to overstate them by assuming agents have perfect knowledge of the future. Using an inter-temporal equilibrium model usually (though not inevitably) means assuming a time preference rate of zero, meaning consumers do not differentiate between consuming a given good in the current or any future period. In the analysis of environmental policy this tends to 'frontload' consumption in the early years of the simulation period, as consumers are well aware of the extent to which ever-tightening emissions targets will induce an ever greater carbon price in the future, and thus make the rational decision to spend more of their money in the period where it is worth the most, i.e. early in the simulation period. By contrast, in a recursive dynamic model, consumers ignore the prospect of rising prices in the future, and base their decisions in each period solely on the known prices in that period. Of the two, recursive dynamic models (such as OEG) are more likely to understate the degree to which abatement is undertaken by firms early on, as they ignore the forward looking aspect to such decisions. Nevertheless, behavioural economics has consistently shown support for a positive time preference rate amongst consumers, and by including only backwards-looking expectations, recursive dynamic models implicitly assume a high degree of uncertainty about the future. Given the current uncertainty surrounding how costly it will be for countries to meet their emissions reduction targets, this method seems appropriate for the current study.

The OEG framework makes no differentiation between irrigated and non-irrigated land, and contains no water scarcity mechanism. Water is an input which must be purchased like any other, but the dramatic impact that water scarcity could have on yields in the presence of a changing Spanish climate is not accounted for. In a study of Spanish agriculture in the context of climate change, this could be seen as a significant caveat to the current study. However, the relatively short-term (2007-2020) timeframe of the simulation period reduces the likely importance of both water scarcity and the changing climate on the results. In addition, it should be noted that this study aims to analyse the effects of policies to mitigate climate change, not the effects of climate change itself. The lack of environmental feedback mechanisms has already been mentioned. However, as a first step in this direction, one of the more expensive abatement options available to crop farmers in the Marginal Abatement Cost (MAC) curves is 'precision farming'. One aspect of this scientific approach to farming is that seed planting and fertiliser application can be adjusted in response to different soil conditions (Bongiovanni and Lowenberg-DeBoer, 2004). Thus as the land gets hotter and/or drier, input use may change accordingly. A fuller simulation of such advances in economic models may become increasingly important if such practises become widespread.

7.2.2. Policy instruments

The results are heavily influenced by the choice of policy instruments used in model simulations, and how they are implemented. In some respects, the author has tried to keep scenario design true to current EU environmental and agricultural policy. However, there are deviations from this approach, some by choice, and some by necessity. No environmental indicators other than greenhouse gas emissions are considered, nor are policies to improve them included in the scenarios. Extending the model to include emissions of air pollutants, or some accounting for water scarcity, for example, may be straightforward, given appropriate data, but neither was the focus of this study, so each has been left out for the time being. Comparing the aggregate target for agricultural emissions to a 'cap-and-trade' scheme for agriculture should be seen as purely hypothetical, as there is no evidence such a scheme would be implemented, and certainly not before 2020. In simulating the actual EU Emissions Trading Scheme (ETS), which covers CO2 emissions from heavy industry and the energy sector, note that there are assumed to be no administration or transaction costs associated with the scheme. Note also that there is a high degree of uncertainty over the future path of ETS permit prices, which may affect the macroeconomic results of the study but are unlikely to have a dramatic impact on agricultural results.

In a study such as this, which compares different policies with regard to their distance from an economic 'optimum', it is important to note that the analysis takes place in a 'second-best' framework (Atkinson and Stiglitz, 1980) given the presence of pre-existing taxes and subsidies in the model (Chapter 2.3.4). However, the degree to which a 'carbon' (emissions) tax should be seen as a 'distortion' depends on what may at times be normative views on the concept of social cost (Pearce, 2003). If the social cost of carbon to the global economy is taken seriously, it has significant implications for economic analysis, as a zero tax on carbon, or a tax of any value less than the social cost, is an implicit subsidy on emissions, while a tax equal to the social cost removes this distortion. Of course any tax greater than the social cost would still be seen as a distorting tax within this framework.

7.3. Lessons for policy

As mentioned above (7.2.1.), one advantage to using a dynamic model in environmental policy analysis, is the ability to track how early abatement action (of the lack thereof) affects emissions factors going forward, which then have implications for the costs of adjustment to increasingly tight emissions restrictions towards the end of the simulation period. Indeed, with current proposed EU emissions cuts of 40% by 2030, and 80-95% by 2050, this has implications beyond the current period. On a macroeconomic level this is particularly relevant to the current Spanish context. Between 2007 and 2012, real GDP in Spain fell by 4.7% (IMF, 2014). Results from the current study suggest that over this period, GHG emissions would have fallen by around 10% in the absence of any policy to reduce them, or any change in specific abatement factors. This reduction in the carbon intensity of the Spanish economy (around 5%) is purely driven by the changing structure of a contracting economy. Purchases of essential items like food hold up relatively well, while capital investment in construction and heavy industry – both heavily polluting sectors, suffer disproportionate falls in output. The average euro's worth of Spanish output (at constant prices) has lower emissions attached to it. In reality, Spanish emissions have fallen by 22.7% between 2007 and 2012 (UNFCCC, 2015), suggesting a combination of this effect and some abatement measures undertaken by firms and households. The share of each of these is important, because while abatement measures make a lasting impact on emissions, the pure effect of economic contraction does not, such that the emissions reductions coming from the latter will be reversed when the economy returns to growth. By including endogenous emissions factors, and by its dynamic nature, the OEG model allows us to separate these two effects, and to explore the extent to which the financial crisis could actually be harming Spain's long-term ability to meet its later emissions reduction targets, by inducing short-term emissions reductions, which will be quickly reversed, but which will reduce incentives to invest in abatement.

The results from Chapter 5 suggest there may be macroeconomic benefits to using cap-and-trade schemes as opposed to industry-specific targets if such an approach were to prove administratively feasible, a finding supported by Perez and Holm-Muller (2007). In any case, the evidence suggests a gradual movement towards less emissions intensive activities is underway in Spanish agriculture, and policy could work complement this trend if it allows such sectors some flexibility to increase emissions, and makes an effort to focus abatement where it is cheaper. It should be noted that the focus of the this study has been the current phase of emissions reductions, which ends in 2020. As further cuts are likely to be required over the long-term (Chapter 1), there will, at some point, need to be some degree of abatement investment in all agricultural activities and, as has been suggested here and in other studies, reducing emissions factors early on is likely to make future targets easier to meet. In the current period, however, as it emerges from a six year economic slowdown, the Spanish economy, or certain key industries therein, may need further policies to make emissions restrictions more politically palatable.

The results from Chapter 6 suggest that recycling the revenue from agricultural emissions taxes as a subsidy for low-skilled labour would be the most beneficial policy option for improving employment and the trade balance. There are questions about the desirability of incentivising 'low-skilled' jobs however, and the impact this may have on human capital formation. If the political or administrative costs of such an approach were deemed to be prohibitively high, a subsidy on all agricultural labour would be a good second-best option for ameliorating the costs of agreed emissions reductions. In reality, of course, such a 'subsidy' would be implemented as a cut in payroll taxes, which would ease the administrative burden considerably.

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Tables

Table 3.1. The 28 primary agricultural activities included in the OEG model.

Aggregate	Detailed description
Wheat	Hard wheat and durum wheat
Barley	Barley
Maize	Grain maize
Rice	Rice
Other cereals	Rye and meslin, oats, millets, sorghum, other cereals n.e.c.
Potatoes	Potatoes and sweet potatoes
Sugar	Sugar beet and cane.
Oilseeds	Soya beans, groundnuts, castor beans, linseed, mustard seed, niger seed, rapeseed, safflower seed, sesame seed, sunflower seed, other oilseeds n.e.c.
Textile crops	Cotton, jute, kenaf and other textile fibre crops, flax and hemp, sisal, abaca, ramie and other vegetable fibres.
Other ind. crops	hops, peppers, other industrial crops
Feed crops	Cereals, leguminous, root and tuber feed crops, other feed crops.
Grapes wine	Grapes for wine production
Olives for oil	Olives for crushing
Vegetables	Artichokes, asparagus, cabbages, cauliflower and broccoli, lettuce and chicory spinach, other leafy or stem vegetables, cucumbers, gherkins, aubergines (eggplants), tomatoes, watermelons, cantaloupes, other melons and fruit bearing vegetables, carrots, turnips, garlic, onions, leeks, and other leeks, other root, bulb or tuberous vegetable (excl. Sugar beet and potatoes)
Flowers	Growing of flowers and ornamental plants, production of cut flowers and flower buds, growing of flower seeds.
Table olives	Olives for direct consumption.
Dry fruit	Almonds, cashew nuts, chestnuts, hazelnuts, pistachios, walnuts, other nuts.
Grapes	Grapes for direct consumption.
Other fruit	Apples, apricots, cherries and tree and bush berries, peaches and nectarines, pears and quinces, plums and sloes, other pome and stone fruits
Citrus fruit	Grapefruits, lemons, oranges, tangerines, mandarins, clementine, other citrus fruits
Tropical fruit	Avocados, bananas, dates, figs, mangoes, papayas, pineapples, other tropical fruits.
Other crops	Protein crops (beans, broad beans, lentils, lupines, chick peas, cow peas, pigeon peas), coffee, tea, maté, cocoa, other beverage crops, pepper, chillies, nutmeg, ,ace and cardamons, anise, badian, fennel, cinnamon, ginger, vanilla, other spices and aromatic crops
Cattle	Raising and breeding of cattle, production of bovine semen.
Pigs	Raising and breeding of pigs
Sheep & goats	Raising and breeding of sheep & goats, production of raw wool, production of raw sheep/goat milk.
Poultry & eggs	Raising and breeding of chickens, turkeys, ducks, geese and guinea fowls, production of eggs from poultry
Raw milk	Production and raising of dairy cattle, raw milk production

Other animals	Raising and breeding of horses, asses, mules, hinnies (not including race horses), other birds (except poultry), insects (e.g., bees), worms and silk worms, snails, rabbits and other fur animals, production of skins, pets (i.e., cats, dogs, hamsters etc).

Source: Philippidis and Sanjuan, 2009a.

Table 3.2. The 11 processed food activities included in the OEG model

Aggregate	Description
Beef	slaughtering dressing and packing of meat, preparation of burgers etc, fresh meat dishes
Pork	slaughtering dressing and packing of meat, preparation of burgers etc, fresh meat dishes
Sheep and Goat	slaughtering dressing and packing of meat, preparation of burgers etc, fresh meat dishes
Poultry	slaughtering dressing and packing of meat, preparation of burgers etc, fresh meat dishes
Other meat	production of hides and skins, 'rendering' of lard and other edible animal fats of animal origin; production of wool; processing of animal offal; production of feathers and down; slaughtering and preparation of rabbit, horse and other meats of the like
Dairy	Fresh milk, milk based drinks, cream, butter, cheeses, yoghurts, ice cream, sorbet, casein, lactose etc.
Oils & Fats	Vegetable oils, olive oils, soya oils, palm oils, sunflower seed oils, cotton seed oil, rape oil etc..
Sugar Processing	Refining of sugar from cane and beet, manufacture of sugar syrups, molasses, cocoa powders, chocolate and sugar confectionary
Processed animal feed	Prepared feeds for pets, for farm animals, unmixed feeds for farm animals, slaughter waste to produce animal feeds (ISIC Rev. Code 1533 - not the same as other animal products)
Other food processing	Fish products, fruit and vegetable products, milling, bakery products, pastas, rices, soups, sauces, spices, condiments, vacuum packed and canned foods, coffee, tea, baby foods etc..
Drinks industry	Wines, malt liquors (i.e., beers), spirits, soft drinks, juices, bottled water etc.

Source: Philippidis and Sanjuan, 2009a.

Table 3.3. Concordance between UNFCCC and OEG data

UNFCCC Code	Source Description	Model Data
1	**Energy**	
1A	Fuel Combustion Activities	
1A1	**Energy Industries**	
1A1a	Public Electricity and Heat Production	Coal, refined fuel, gas use - electricity and gas distribution industries
1A1b	Petroleum refining	Crude gas, refined fuel, gas use - crude oil and refined fuels industries
1A1c	Manufacture of Solid Fuels	Refined fuel, gas distribution use - coal industry
1A2	**Manufacturing Industries and Construction**	
1A2a	Iron and Steel	Coal, refined fuel, gas use - metallurgy industry
1A2b	Non-ferrous Metals	Coal, refined fuel, gas use - metallurgy industry
1A2c	Chemicals	Coal, crude oil, refined fuel, gas use - chemical industries
1A2d	Pulp, Paper and Print	Refined fuel, gas use - paper and publishing industries
1A2e	Food Processing, Beverages and Tobacco	Refined fuel, gas use - food processing industries
1A2f	Other	Coal, crude oil, refined fuel, gas use - manufacturing not specificied above
1A3	**Transport**	
1A3a	Aviation	Refined fuel, gas use - air transport industry
1A3b	Road Transportation	Refined fuel, gas use - land transport industry
1A3c	Railways	Refined fuel, gas use - rail transport industry
1A3d	Navigation	Refined fuel, gas use - sea transport industry
1A4	**Other sectors**	
1A4b	Residential	Coal, biofuels, refined fuel, gas use – households
1A4c	Agriculture / Forestry / Fishing	Coal, refined fuel, gas use - agriculture, forestry, fishing industries
1A5	Other (not elsewhere specified)	Coal, refined fuel, gas use - all industries not specified above
1B	Fugitive Emissions from Fuels	
1B1	Fugitive Emissions from Solid Fuels	Output - coal industry
1B2	Oil and natural gas	Output - crude oil, gas, refined fuel industries
2	**Industrial processes**	
2A	Mineral Products	
2A1	Cement Production	Output - cement industry
2A2	Lime Production	Output - cement industry
2A3	Limestone and Dolomite Use	Output - cement industry
2A4	Soda Ash Production and use	Output - cement industry
2A7	Other (to be specified)	Output - glass, ceramics, non-metallic minerals industries
2B	Chemical Industry	Output - chemicals industry
2C	Metal Production	Output - metallurgy industry
2E	Production of Halocarbons and SF6	Output - electricity industry

2F	Halocarbons use	Output - electrical machinery and chemicals industries
3	**Solvent and other product use**	Output - chemicals industry
4	**Agriculture**	
4A	Enteric Fermentation	Output - livestock industries
4B	Manure Management	Output - livestock industries
4C	Rice Cultivation	Land use - rice industry
4D	Agricultural Soils	Agro-chemicals use - crop industries
4E	Prescribed Burning of Savannas	Output - crop industries
4F	Field Burning of Agricultural Wastes	Output - crop industries
6	**Waste**	Output - market and non-market sanitation industries

Source: UNFCCC and own work

Table 3.4. A Summary of Spanish GHG emissions in 2007, measured in Giga grams (Gg)

	CO2	CH4	N2O	HFCs	PFCs	SF6
	CO2 Gg	**CH4 Gg**	**N2O Gg**	**Co2e Gg**	**Co2e Gg**	**Co2e Gg**
1. Energy	336507	140	9	0	0	0
A. Fuel Combustion	334027	74	9	0	0	0
Energy industries	*122281*	*6*	*2*	*0*	*0*	*0*
Manufacturing and construction	*68509*	*27*	*2*	*0*	*0*	*0*
Transport	*106156*	*7*	*3*	*0*	*0*	*0*
Other	*37081*	*35*	*1*	*0*	*0*	*0*
B. Fugitive Emissions	2479	66	0	0	0	0
2. Industrial processes	26179	3	3	0	0	0.02
3. Solvent and other prods	1112	0	2.5	0	0	0
4. Agriculture	0	929	70	0	0	0
5. LULUCF	-29689	2	0	0	0	0
6. Waste	15	540	4	0	0	0
Emissions excl. LULUCF	363813	1617	88	6284	298	0.02
Emissions incl. LULUCF	334124	1615	88	6284	298	0.02
Emissions all measured in CO2 equivalent tonnes (CO2e):						
Emissions excl. LULUCF	**363813**	**33951**	**27376**	**6284**	**298**	**0.02**
Emissions incl. LULUCF	**334124**	**33909**	**27376**	**6284**	**298**	**0.02**

Source: UNFCCC and own calculations

Table 3.5. Assignment of fuel combustion emissions in energy activities

	Coal mining	Oil extraction	Petrol refining	Electricity generation	Gas distribution
Coal	E	zero usage	T	E	T
Crude oil	zero usage	zero usage	T	zero usage	zero usage
Crude gas	zero usage	E	E	zero usage	T
Petrol	E	E	E	E	E
Electricity	NE	NE	NE	NE	NE
Gas distribution	E	E	E	E	E

Source: own work

Table 3.6. Elasticities in the OEG model

Variable name	Description	Source	Value
SIGMA1T	CES between value-added and intermediate inputs: agricultural	Keeney and Hertel, 2005	0.9
SIGMA1T	CES between value-added and intermediate inputs: non-agricultural	Various	0
SIGMA1PRIM	CES between value-added inputs	Narayanan et al., 2012	from 0.2 to 1.45
SIGMA1LAB	CES between different labour types	Double SIGMA1PRIM	from 0.4 to 2.9
SIGMA1KE	CES between capital and energy	Birur et al., 2008	0.5
SIGMA1EGY	CES between electricity and coal as intermediate inputs	Birur et al., 2008	0.5
SIGMA2EGY	CES between other intermediate energy inputs	Birur et al., 2008	0.25
SIGENE	CES between household energy sources	Birur et al., 2008	0.1
SIGMA1	Armington elasticity between domestic and imported intermediate inputs	Narayanan et al., 2012	from 0.005 to 9
SIGMA2	Armington elasticity between domestic and imported investment goods	Narayanan et al., 2012	from 0 to 9
SIGMA3	Armington elasticity between domestic and imported household purchases	Narayanan et al., 2012	from 0 to 9
CETLND	CET for land moving between different uses	Own estimates	from 0.25 to 1
None	Supply elasticities for different labour types	Fernandez-Val, 2003	from 0.5 for 10
ETRAE	CET for labour and capital moving between agric and non-agric uses	Keeney and Hertel, 2005	0.5
SIGMA1OUT	CET for multi-commodity output	Horridge, 2000	0.5
EPS	Household expenditure elasticity: agrifood products	Moro and Sckokai, 2000	from 0.25 to 0.62
EPS	Household expenditure elasticity: non-agrifood products	Narayanan et al., 2012	from 0.55 to 1.95
FRISCH	Frisch parameter	Dixon and Lluch, 1977	from 1.03 to 2.85

Source: various

Table 5.1. Coverage of the European Union's Emissions Trading Scheme (EU ETS)

Time period	Included in Emissions Trading Scheme (ETS)	
Throughout simulation period	Combustion emissions of CO2 from:	Coal, oil, gas, electricity, petrol, metal, cement and lime, glass, paper, ceramic industries.
	Process emissions of CO2 from:	Oil, glass, petrol, metal, cement and lime, glass, ceramic industries
2012 onwards	Combustion emissions of CO2 from:	Aviation
2013 onwards	Combustion and process emissions of CO2 and N2O from:	Chemical industries
	Process emissions of PFCs from:	Metal industries

Source: European Parliament 2003 and 2009b

Table 5.2 Industry aggregation used in these simulations

Aggregate	Disaggregated OEG industries
Wheat	Wheat
Barley	Barley
Maize	Maize
Rice	Rice
Other cereals	Other cereals
Potatoes	Potatoes
Sugar	Sugar
Oilseeds	Oilseeds
Textile crops	Textile crops
Feed crops	Feed crops
Vegetables	Vegetables
Grapes	Grapes for wine, grapes
Citrus	Citrus
Other fruit	Dry fruit, tropical fruit, other fruit
Olives	Olives for oil, olives
Other crops 1	Other crops
Other crops 2	Other industrial crops, flowers
Cattle	Cattle
Pigs	Pigs
Sheep & goats	Sheep and goats
Poultry & eggs	Poultry & eggs
Raw milk	Raw milk
Other animals	Other animals
Coal	Coal
Oil	Oil
Gas	Gas
Biodiesel	Biodiesel
Bioethanol	Bioethanol 1, bioethanol 2
Petrol	Refined fuels
Electricity	Electricity
Red meat	Beef, lamb & goat
White meat	Pork, poultry
Dairy	Dairy
Processed sugar	Processed sugar
Animal feed	Animal feed
Other food	Other meat, oils and fats, other food, beverages
Tobacco	Tobacco
Chemicals	Chemical
Metals	Metallic minerals, metallurgic industry, metal products,
Cement & lime	Cement & lime
Glass	Glass
Paper	Paper
Ceramics	Ceramics
Transport	Rail transport, land transport, sea transport, auxiliary transport
Buildings	Construction, real estate
Waste	Market industrial cleaning, public sanitation

Aviation	Air transport
Electrical machinery	Electrical machinery, electrical equipment
Manufacturing n.e.c.	Forestry, fishing, non-metallic minerals, water, textiles, clothing, leather, wood, publishing, rubber & plastic, Other non-metallic mineral products, machine equipment, office and computing equipment, precision instruments, car assembly, other transport products, furniture, motor maintenance
Services	Recycling, wholesale trade, retail trade, hotels, restaurants, travel agents, postal service, financial intermediaries, insurance & pensions, financial auxiliary, machine rentals, IT, R&D, other business services, public administration, market education, non-market education, market health & social care, public health & social care, non-profit health & social care, market associations & activities, non-market associations & activities, public recreational activities, non-profit recreational activities, personal services, domestic services

Source: own work

Table 5.3 Commodity aggregation used in these simulations

Aggregate	Disaggregated OEG commodities
Wheat	Wheat
Barley	Barley
Maize	Maize
Rice	Rice
Other cereals	Other cereals
Potatoes	Potatoes
Sugar	Sugar
Oilseeds	Oilseeds
Textile crops	Textile crops
Feed crops	Feed crops
Vegetables	Vegetables
Grapes	Grapes for wine, grapes
Citrus	Citrus
Other fruit	Dry fruit, tropical fruit, other fruit
Olives	Olives for oil, olives
Other crops	Other industrial crops, flowers, tobacco, other crops
Cattle	Cattle
Pigs	Pigs
Sheep & goats	Sheep and goats
Poultry & eggs	Poultry & eggs
Raw milk	Raw milk
Other animals	Other animals
Coal	Coal
Oil	Oil
Crude gas	Crude gas
Biodiesel	Biodiesel
Bioethanol	Bioethanol 1, bioethanol 2
Petrol	Refined fuels
Electricity	Electricity
Gas	Gas distribution
Beef	Beef
Pork	Pork
Lamb	Lamb & goat
Poultry	Poultry
Dairy	Dairy
Processed sugar	Processed sugar
Animal feed	Animal feed
Other food	Other meat, oils and fats, other food, non-alcoholic beverages
Alcohol	Alcohol
Agricultural chemicals	Agricultural chemicals
Other chemicals	Basic chemical products, pharmaceutical products, other chemicals
Metals	Iron minerals, Metallic minerals, metallurgic products, metal products,
Cement & lime	Cement & lime
Glass	Glass
Paper	Paper

Ceramics	Ceramics
Transport	Non-market rail transport, non-market other land transport, other transport services, other non-market transport services
Buildings	Residential construction, other construction, real estate, non-market real estate
Waste	Market sanitary services, non-market sanitary services, market industrial cleaning, non-market industrial cleaning,
Aviation	Air transport
Electrical machinery	Electrical machinery, electrical equipment
Manufacturing n.e.c.	Forestry, fishing, non-metallic minerals, water, textiles, clothing, leather, leather products, wood, paper and card products, publishing and graphic art, rubber products, plastic products, Other non-metallic mineral products, agricultural machinery, domestic appliances, other machinery, office and computing equipment, audio visual production, other electronic materials, precision instruments, car assembly, train products, aerospace and aircraft products, other transport products, furniture, motor maintenance, other manufacturing articles
Services	Agricultural services, Recycling, civil engineering, rental of construction equipment, hotels, restaurants, travel agents, non-market travel agents, postal service, telecommunication, financial intermediaries, insurance & pensions, financial auxiliary, car rental, furniture rental, IT, market R&D, non-market R&D, market law and accounting, non-market law and accounting, architectural and engineering, publicity, security, other business services, public administration, market education, non-market education, market veterinary care, market social services, non-market social services, market associations & activities, non-market associations & activities, market news, drama & art, non-market news, drama & art, cultural and sporting activities, other recreational activities, personal services, domestic services
Margins	Margins

Source: own work

Table 5.4. Emissions intensities of various agricultural activities in 2007

Industry	Total emissions (MmtCO2e)	Size of industry (€ millions)	kgCO2e/€
Cereals	10.24	5966	1.72
Fruit	4.62	6139	0.59
Vegetables	0.99	7039	0.14
Olives	6.07	1606	3.78
Cattle and sheep	19.03	7824	2.43
Pigs, poultry and other animals	9.89	8729	1.13
Agriculture	53.22	42644	1.25
Spanish industrial total	358.53	2071404	0.17

Source: own calculations

Table 5.5. Scenario descriptions

Scenario	ETS emissions	Non-agric diffuse emissions	Agricultural emissions	End-of-pipe abatement in agriculture?
Baseline	Zero ETS price	Unrestricted	Unrestricted	No
Scenario 1	Exogenous non-zero ETS price	Reduced by 10% for each industry	Aggregate emissions reduced by 10% - single carbon price	No
Scenario 2	Exogenous non-zero ETS price	Reduced by 10% for each industry	Aggregate emissions reduced by 10% - single carbon price	Yes
Scenario 3	Exogenous non-zero ETS price	Reduced by 10% for each industry	Emissions of each specific agric industry reduced by 10% - multiple carbon prices	Yes

Source: own work

Table 5.6. Agricultural subgroups in scenario 3

Agricultural subgroup	Composed of:
Cereals	Wheat, barley, maize, rice, other cereals
Fruit	Grapes, citrus, other fruit
Vegetables	Vegetables
Olives	Olives
Other crops	Potatoes, sugar, oilseeds, textile crops, feed crops, other crops
Cattle and sheep	Cattle, sheep
Pigs	Raw milk
Raw milk	Pigs
Poultry	Poultry and eggs
Other agric	Other animals

Source: own work

Table 5.7. Macroeconomic results

Cumulative results in 2020	Baseline	Scenario 1	Scenario 2	Scenario 3
	% change 2007-2020	% relative to baseline		
Real GDP	1.8	-1.2	-0.9	-1.0
Real private consumption	-3.0	-0.8	-0.7	-0.7
Real investment	-39.8	-2.8	-2.5	-2.4
Real government spending	5.8	0.2	0.1	0.2
Real exports	64.3	-1.1	-0.7	-0.9
Real imports	-0.3	-0.5	-0.7	-0.6
Consumer price index	-0.9	2.0	1.5	1.6

Source: model results

Table 5.8. Percentage change in emissions factors 2007-2020

Industry	Scenario 2 relative to baseline/scenario 1	Scenario 3 relative to baseline/scenario 1
Cereals	-2.6	-5.4
Fruit	-2.6	-21.9
Vegetables	-2.6	-22
Olives	-2.6	-19.5
Other crops	-2.6	-15.8
Cattle and sheep	-21.7	0.0
Raw milk	-23.5	-28.1
Pigs	-21.6	-11.4
Poultry	-22.1	-7.1

Source: model results

Table 5.9. Emissions reductions from scenario 2 and taxes from scenario 3

Industry	Scenario 2 cumulative emissions change (%)	Scenario 3 emissions tax in 2020 (€/tCO2e)
Cereals	-6.3	30.9
Fruit	20.2	91.2
Vegetables	34.6	259.3
Olives	14.6	63.6
Other crops	4.6	52.4
Cattle and sheep	-31.5	0.0
Raw milk	-5.7	11.1
Pigs	-18.1	7.8
Poultry	-1.7	412.3

Source: model results

Table 5.10. Total direct cost of each scenario

€ millions	1	2	3
Cereals	2464	762	1060
Fruit	1057	311	956
Vegetables	323	91	608
Olives	1743	520	1706
Other crops	896	273	684
Cattle and sheep	3827	1021	0
Raw milk	1052	270	230
Pigs	2427	642	358
Poultry	153	42	594
Agriculture	14064	3964	6246

Source: model results

Table 5.11. Percentage change in baseline price and output 2007-2020

Industry	Output	Price
Wheat	-15	30.6
Barley	10.9	25.2
Maize	-22.4	24.9
Rice	-22.3	36.3
Sugar	-71.9	5.9
Feedcrops	21.5	27.2
Vegetables	10.8	41.6
Grapes	6.9	52.3
Citrus	16.9	54.5
Othfruit	12.1	35.1
Olives	10.4	36.6
Cattle	-16.3	64.2
Pigs	1	28.3
Sheepgoats	-13.3	75.7
Poulteggs	-2.2	60.3
Rawmilk	-2.2	22.1

Source: model results

Table 5.12. Factor prices in 2020 relative to the baseline

2020 relative to baseline	Land: Scenario			Labour: Scenario			Capital: Scenario			Energy: Scenario			Fertiliser: Scenario		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Wheat	-15.1	-5.2	5.5	1.3	1.1	1.1	-21.1	-8	-9	53.1	14.8	19.4	58.9	16.4	20.8
Barley	-5.8	-2	-1.3	1.3	1.1	1.1	11.2	4.5	4.5	53.1	14.8	19.4	66.9	18.6	23.7
Maize	-11.2	-4.1	-4.1	1.3	1.1	1.1	-18.6	-7.1	-8.6	53.1	14.8	19.4	27.8	7.8	9.8
Rice	-0.2	-2	-4.3	1.3	1.1	1.1	-41.7	-14.2	-4	53.3	14.8	19.4	13.6	3.9	4.8
Sugar	-10.2	-3.7	-5.6	1.3	1.1	1.1	-21.2	-8.1	-14.3	53.1	14.8	32.8	29.5	8.2	15.5
Feedcrops	-2	-0.8	0.9	1.3	1.1	1.1	5.9	4.4	5.4	53.1	14.8	32.8	62.3	17.2	32.7
Vegetables	-2.1	-1	-1.5	1.3	1.1	1.1	-0.7	-0.6	-0.1	53.3	14.8	153.3	9.2	2.7	21.3
Grapes	-6.1	-2.1	-5	1.3	1.1	1.1	-1.8	-0.7	-1.8	53	14.8	56.2	38.2	10.6	32
Citrus	-1.9	-0.8	-1.2	1.3	1.1	1.1	0	-0.2	-0.2	53.2	14.8	56.4	10.1	2.9	8.5
Other fruit	-3.3	-1.3	-2.5	1.3	1.1	1.1	-0.4	-1.4	-1.1	53	14.8	56.1	36.9	10.2	30.9
Olives	20.9	7.6	15.6	1.3	1.1	1.1	36.2	13.3	23.5	53.2	14.8	39.7	120.5	33.2	73.3
Cattle	-10.6	-3.2	-0.9	1.3	1.1	1.1	-11.5	-3.2	0.5	51.8	14.4	-0.5	0.1	0.2	0.1
Pigs	-5.6	-1.8	-1.1	1.3	1.1	1.1	-5.3	-1.7	-1.2	52.1	14.5	4.5	0.2	0.2	0.2
Sheep	-9.9	-3	-1.1	1.3	1.1	1.1	-11.7	-3.3	0.2	52.1	14.5	-0.5	0.2	0.2	0.2
Poultry	-3.1	-1.2	-1.8	1.3	1.1	1.1	-3.2	-1.2	-2	52.2	14.5	233.8	0.3	0.2	0.7
Rawmilk	-7.3	-2.5	-1.9	1.3	1.1	1.1	-5	-1.8	-1.6	51.9	14.4	6.6	0.1	0.2	0.1

Source: model results

Table 5.13. Factor demands in 2020 relative to the baseline

2020 relative to baseline	Land: Scenario			Labour: Scenario			Capital: Scenario			Energy: Scenario			Fertiliser: Scenario		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Wheat	-8.5	-2.6	-3.9	-14.7	-5	-6.4	-1.2	0.1	-0.6	-29.1	-10.4	-13.2	-30.4	-11	-13.7
Barley	5.8	1.9	1.9	2.8	0.7	0.9	1.3	0	0.5	-13.7	-4.6	-6	-17.3	-6.1	-7.6
Maize	-7.6	-2.7	-3.8	-12.3	-4.7	-5.8	-1	-0.3	-0.6	-27.8	-10.3	-13	-21	-7.5	-9.3
Rice	-26.6	-7.9	-1.1	-27	-9	-3.3	-2.6	-0.9	-0.2	-39.9	-14.4	-10.5	-30.2	-10	-4.5
Sugar	-9.8	-3.4	-6.9	-14	-5.3	-9.3	-0.2	-0.1	-0.2	-28.4	-10.6	-19.8	-22.1	-7.9	-14
Feedcrops	1.5	0.4	1.5	0.2	-0.3	1.4	0.6	-1	1	-16.3	-5.6	-10	-18.7	-6.6	-10
Vegetables	0.2	0	-0.1	-1.1	-0.8	-1.2	-0.1	0	-0.1	-19.5	-7	-37.2	-4.7	-1.6	-9.3
Grapes	-0.8	-0.3	-1.1	-3.8	-1.5	-3.5	0	0	0	-19.9	-7	-20.7	-15.7	-5.3	-13.7
Citrus	0.2	0.1	-0.1	-1	-0.7	-1	0	0	-0.1	-19.2	-6.8	-20.2	-4.7	-1.5	-4.1
Other fruit	-0.1	0	-0.4	-1.9	-1	-1.9	-0.1	0.4	0	-19.4	-6.9	-20.3	-14.8	-5	-13
Olives	4.6	1.8	3.2	12.3	4.4	8.9	2.3	0.4	0	-3.5	-0.2	-3.7	-19.6	-7.3	-13.6
Cattle	-1.4	-0.3	0.6	-6.2	-2	-0.2	-0.7	-0.2	-1.8	-24.2	-8.2	0.5	-6.6	-1.9	0.2
Pigs	-0.9	-0.3	-0.2	-3.6	-1.4	-1.1	-0.6	-0.1	0.1	-21.5	-7.5	-2.8	-3.3	-1.1	-0.8
Sheep	-1	-0.2	0.5	-5.5	-1.8	-0.4	-0.2	-0.1	0	-23.9	-8.2	0.3	-6.3	-1.8	0
Poultry	-0.2	-0.1	-0.4	-2	-1	-1.5	-0.1	-0.1	-0.1	-20.3	-7.2	-46	-1.9	-0.8	-1.4
Rawmilk	0.4	0.1	0.1	-3.1	-1.3	-1.1	-0.4	-0.1	0	-21.3	-7.5	-3.9	-3	-1.2	-0.9

Source: model results

Table 5.14. Percentage change in real factor prices and factor demands relative to the baseline in 2020

	1	2	3
Real land price	-4.1	-2.3	-2.0
Real wage	-1.0	-0.7	-0.8
Real rate of return to capital	-2.9	-2.3	-2.4
Land use	0.0	0.0	0.0
Employment	-1.4	-1.0	-1.1
Capital use	-0.1	-0.1	-0.1

Source: model results

Table 5.15. Benchmark capital use and abatement expenditure in millions of euros

	Benchmark capital use	Scenario 2 abatement expenditure 2008-2020	Scenario 3 abatement expenditure 2008-2020
Wheat	265.1	0.9	4.1
Barley	396.6	2.2	9.1
Maize	140.5	0.2	0.9
Rice	18.4	0	0.2
Sugar	22.7	0	0.4
Feedcrops	114.7	0.7	16.1
Vegetables	1302.7	0.5	49.1
Grapes	90.8	0.5	20
Citrus	308.2	0.2	11.7
Othfruit	584.0	0.9	38.6
Olives	224.0	3.3	110
Cattle	503.0	45.8	0
Pigs	779.6	47.1	11.9
Sheepgoats	402.6	33	0
Poulteggs	715.3	0.2	1.5
Rawmilk	476.5	21.9	23.8
Agriculture	6079.6	156.5	293.3

Source: model results

Table 5.16. Percentage change in household food prices relative to the baseline in 2020

	1	2	3
Olives	28	8.9	18.7
Lamb	10	3.1	1.4
Beef	5.9	1.9	0.9
Poultry	4.3	1.7	2.2
Potatoes	4.2	1.8	2.8
Pork	4	1.5	1.8
Alcohol	4	1.7	2.9
Other fruit	3.9	1.5	3.5
Dairy	2.5	1	1.1
Other food	2.5	1.2	1.9
Citrus	2.3	1.1	2.2
Other crops	2.3	1.2	1.7
Vegetables	1.6	0.9	3.1
Sugar	0.7	0.6	0.7
Food index	6.1	2	3.2

Source: model results

Table 5.17. Percentage change in household food demands relative to the baseline in 2020

	1	2	3
Olives	-21.9	-8.1	-15.7
Lamb	-8.8	-2.9	-1.3
Beef	-4.5	-1.5	-0.7
Potatoes	-4.1	-1.7	-2.6
Poultry	-3.9	-1.6	-2
Pork	-3.6	-1.4	-1.6
Othfruit	-2.9	-1.1	-2.6
Ocrops	-2.6	-1.2	-1.7
Dairy	-1.8	-0.7	-0.8
Other food	-1.8	-0.9	-1.3
Citrus	-1.6	-0.8	-1.5
Vegetables	-1.4	-0.8	-2.7
Alcohol	-0.7	-0.3	-0.5
Sugar	-0.1	-0.1	-0.1
Food index	-4.1	-1.5	-2.1

Source: model results

Table 5.18. Estimated price elasticities of demand of food products

	1	2	3
Olives	-0.78	-0.91	-0.84
Lamb	-0.88	-0.94	-0.93
Beef	-0.76	-0.79	-0.78
Poultry	-0.91	-0.94	-0.91
Potatoes	-0.98	-0.94	-0.93
Pork	-0.90	-0.93	-0.89
Alcohol	-0.18	-0.18	-0.17
Other fruit	-0.74	-0.73	-0.74
Dairy	-0.72	-0.70	-0.73
Other food	-0.72	-0.75	-0.68
Citrus	-0.70	-0.73	-0.68
Other crops	-1.13	-1.00	-1.00
Vegetables	-0.88	-0.89	-0.87
Sugar	-0.14	-0.17	-0.14

Source: model results

Table 5.19. Percentage change in utility in 2020 relative to the baseline

	Scenario		
	1	2	3
Utility	-1.2	-1	-1.1
Food utility	-0.9	-0.4	-0.5
Non-food utility	-1.4	-1.2	-1.2

Source: model results

Table 6.1. Description of the scenarios in Chapter 6

	'No RR'	'All'	'Low-skilled'	'Food subsidy'
Reduction in aggregate agricultural emissions 2005-2010	10%	10%	10%	10%
Calibrated MAC curves included in the model?	No	No	No	No
Revenue to be recycled	None	Agricultural emissions taxes	Agricultural emissions taxes	Agricultural emissions taxes
Policy for revenue recycling	None	Subsidy on all agricultural labour	Subsidy on low-skilled agricultural labour	Subsidy on private household purchases of domestic food

Source: own work

Table 6.2. Elasticities of substitution between labour types, and price elasticity of demand for labour, selected industries

Industry	Elasticity of substitution	Price elasticity of demand
Cereals	0.24	-0.45
Potatoes	0.33	-0.57
Sugar	0.33	-0.57
Vegetables	0.45	-0.76
Grapes	0.40	-0.70
Citrus	0.46	-0.75
Other fruit	0.45	-0.73
Olives	0.47	-0.77
Cattle	0.32	-0.57
Pigs	0.07	-0.30
Sheep	0.41	-0.66
Poultry	0.30	-0.51
Raw milk	0.31	-0.56
Red meat	14.26	-12.68
White meat	16.73	-15.20
Dairy	15.59	-14.18
Electricity	28.11	-26.70
Manufacturing	9.94	-8.23
Services	5.82	-4.04

Source: Narayanan et al., 2012 and own calculations

Table 6.3. Household Armington elasticities and imports as a % of household purchases, selected food commodities

Food commodity	Armington elasticity	Imports as % of household purchases
Dairy	3.65	24.3%
Pork	4.40	4.6%
Beef	3.85	13.9%
Poultry	4.40	5.1%
Vegetables	2.50	17.1%
Lamb	3.85	1.9%
Sugar	9.00	21.0%
Other fruit	2.86	41.8%
Animal feed	2.50	10.8%
Alcohol	2.50	83.0%
Agrifood total	NA	26.2%

Source: Narayanan et al., 2012 and INE, 2011

Table 6.4. % change in components of aggregate demand in 2020 relative to baseline

	'No RR'	'All'	'Low-skilled'	'Food subsidy'
Real GDP	-1.0	-0.4	-0.3	-0.7
Real private consumption	-0.7	-0.5	-0.5	-0.5
Real investment	-2.7	-1.9	-1.6	-2.4
Real government spending	0.1	0.2	0.2	-0.2
Real exports	-0.8	-0.2	0.1	-0.7
Real imports	-0.6	-0.9	-1.0	-0.9

Source: model results

Table 6.5. % change in labour quantity in 2020 relative to the baseline

	'No RR'	'All'	'Low-skilled'	'Food subsidy'
High skilled				
Agricultural	-1.2	5.1	0.6	-0.5
Non-agricultural	-0.6	-0.5	-0.5	-0.3
Aggregate	-0.6	-0.4	-0.5	-0.3
Skilled				
Agricultural	-1.5	5.3	0.6	-0.8
Non-agricultural	-1.0	-0.7	-0.8	-0.6
Aggregate	-1.0	-0.5	-0.8	-0.6
Low skilled				
Agricultural	-2.6	6.3	10.8	-1.4
Non-agricultural	-2.7	0.7	2.4	-1.6
Aggregate	-2.7	1.6	3.6	-1.5
Overall				
Agricultural	-2.1	5.9	7.0	-1.1
Non-agricultural	-1.1	-0.4	-0.2	-0.7
Aggregate	-1.2	-0.1	0.1	-0.7

Source: model results

Table 6.6. % change in nominal labour prices at agents' and market prices in 2020 relative to baseline

	'No RR'	'All'	'Low-skilled'	'Food subsidy'
<u>High skilled</u>				
Market price: agricultural	-0.8	11.8	2.4	-0.1
Market price: non-agricultural	0.5	0.3	0.2	0.2
Market price: aggregate	0.5	0.4	0.2	0.2
Agents' price: agricultural	-0.8	-8.8	2.4	-0.1
Agents' price: non-agricultural	0.5	0.3	0.2	0.2
Agents' price: aggregate	0.5	0.2	0.2	0.2
<u>Skilled</u>				
Market price: agricultural	-0.5	12.7	3.2	-0.1
Market price: non-agricultural	0.6	0.3	0.3	0.3
Market price: aggregate	0.6	0.8	0.4	0.3
Agents' price: agricultural	-0.5	-7.4	3.2	-0.1
Agents' price: non-agricultural	0.6	0.3	0.3	0.3
Agents' price: aggregate	0.6	0.1	0.4	0.3
<u>Low skilled</u>				
Market price: agricultural	1.6	11.1	16.0	1.0
Market price: non-agricultural	1.3	-0.3	-1.0	0.7
Market price: aggregate	1.4	1.4	1.5	0.7
Agents' price: agricultural	1.6	-10.3	-19.6	1.0
Agents' price: non-agricultural	1.3	-0.3	-1.0	0.7
Agents' price: aggregate	1.4	-1.4	-3.1	0.7
<u>Overall</u>				
Market price: agricultural	0.7	11.7	10.4	0.6
Market price: non-agricultural	0.7	0.2	0.0	0.3
Market price: aggregate	0.7	0.7	0.5	0.3
Agents' price: agricultural	0.7	-9.4	-9.2	0.6
Agents' price: non-agricultural	0.7	0.2	0.0	0.3
Agents' price: aggregate	0.7	-0.1	-0.3	0.3

Source: model results

Table 6.7. Consumer tax rates with and without food subsidy

Food commodity	Tax rate: no subsidy	Tax rate: subsidy
Dairy	5.5%	-0.1%
Pork	5.4%	-0.2%
Beef	5.4%	-0.1%
Poultry	5.3%	-0.3%
Vegetables	2.3%	-3.1%
Lamb	5.6%	0.1%
Sugar	4.2%	-1.2%
Other fruit	2.2%	-3.2%
Animal feed	3.7%	-1.7%
Alcohol	50.0%	41.9%
Agrifood total	5.6%	0.0%

Source: model results

Table 6.8. % change in consumer prices changes relative to baseline in 2020

Food commodity	'No RR'	'All'	'Low-skilled'	'Food subsidy'
Dairy	1.4	-0.3	-0.4	-1.6
Pork	2.8	1.2	1.1	-1.8
Beef	3.6	2.7	2.6	0.6
Poultry	3.0	1.0	0.9	-1.1
Vegetables	0.8	-3.7	-3.9	-3.5
Lamb	7.4	5.4	5.3	2.6
Sugar	0.1	0.1	0.1	-0.9
Other fruit	1.5	-1.4	-1.6	-2.0
Animal feed	1.3	0.8	0.8	-3.4
Alcohol	0.4	0.2	0.2	-0.7
Agro-food total	2.0	0.6	0.5	-1.5
Consumer price index	1.6	1.2	1.1	0.9

Source: model results

Table 6.9. % change in household food consumption relative to baseline in 2020

Food product	Total			
	'No RR'	'All'	'Low-skilled'	'Food subsidy'
Dairy	-0.2	0.1	0.1	0.3
Pork	-0.5	-0.2	-0.2	0.3
Beef	-0.7	-0.5	-0.5	-0.5
Poultry	-0.5	-0.1	-0.2	0.2
Vegetables	-0.2	0.8	0.9	0.9
Lamb	-1.2	-0.8	-0.8	-0.5
Sugar	0.0	0.0	0.0	0.2
Other fruit	-0.4	0.3	0.4	0.5
Animal feed	-0.2	-0.1	-0.1	0.5
Alcohol	-0.1	-0.1	0.0	0.2
Agro-food total	-0.3	-0.1	-0.1	0.2

Source: model results

Table 6.10. % change in domestic and imported food consumption relative to baseline in 2020

Food product	Domestic				Imported			
	'No RR'	'All'	'Low-skilled'	'Food subsidy'	'No RR'	'All'	'Low-skilled'	'Food subsidy'
Dairy	-2.1	0.4	0.6	2.5	4.8	-2.6	-1.3	-5.5
Pork	-1.5	-0.6	-0.6	0.9	12.3	5.2	4.7	-7.4
Beef	-4.1	-2.9	-2.9	-0.6	13.9	10.1	9.8	2.1
Poultry	-1.6	-0.5	-0.5	0.6	13.2	4.3	3.7	-4.5
Vegetables	-0.4	2.0	2.1	2.1	1.4	-8.2	-8.6	-8.2
Lamb	-2.5	-1.7	-1.6	-0.9	30.1	21.3	20.8	9.7
Sugar	-4.8	-3.4	-2.8	37.4	1.0	0.7	0.6	-7.6
Other fruit	-1.5	2.1	2.2	3.4	2.4	-3.5	-3.9	-6.1
Animal feed	-0.4	-0.2	-0.2	1.1	3.2	2.0	1.8	-7.8
Alcohol	-4.6	-2.2	-1.9	8.0	0.8	0.4	0.3	-1.4

Source: model results

Table 6.11. Trade as a proportion of total purchases by value: 2007

Commodity	Imports	Exports	Sum
Wheat	31.0%	6.0%	37.0%
Barley	2.1%	6.0%	8.1%
Maize	59.8%	1.8%	61.6%
Sugar	21.5%	0.6%	22.1%
Vegetables	11.6%	39.8%	51.5%
Grapes	7.4%	20.1%	27.5%
Citrus	7.6%	85.1%	92.7%
Othfruit	26.5%	41.4%	67.9%
Olives	0.1%	0.8%	0.8%
Cattle	8.4%	1.2%	9.6%
Pigs	2.0%	3.3%	5.3%
Sheepgoats	1.3%	1.3%	2.6%
Poulteggs	1.9%	4.1%	6.0%
Rawmilk	0.0%	0.0%	0.0%
Crops total	23.8%	23.0%	46.8%
Livestock total	3.6%	3.3%	6.9%
Agric total	18.0%	17.4%	35.4%

Source: INE, 2011

Table 6.12. Changes in terms of trade, and trade balance

	'No RR'	'All'	'Low-skilled'	'Food subsidy'
change in terms of trade 2007-2020	-2.4%	-2.9%	-3.0%	-2.4%
Agrifood trade balance 2007 (€ million)	1,294	1,294	1,294	1,294
Agrifood trade balance 2020 (€ million)	2,693	3,453	3,505	3,575
Total trade balance 2007 (€ million)	-112,395	-112,395	-112,395	-112,395
Total trade balance 2020 (€ million)	6,963	7,795	8,040	7,894

Source: model results

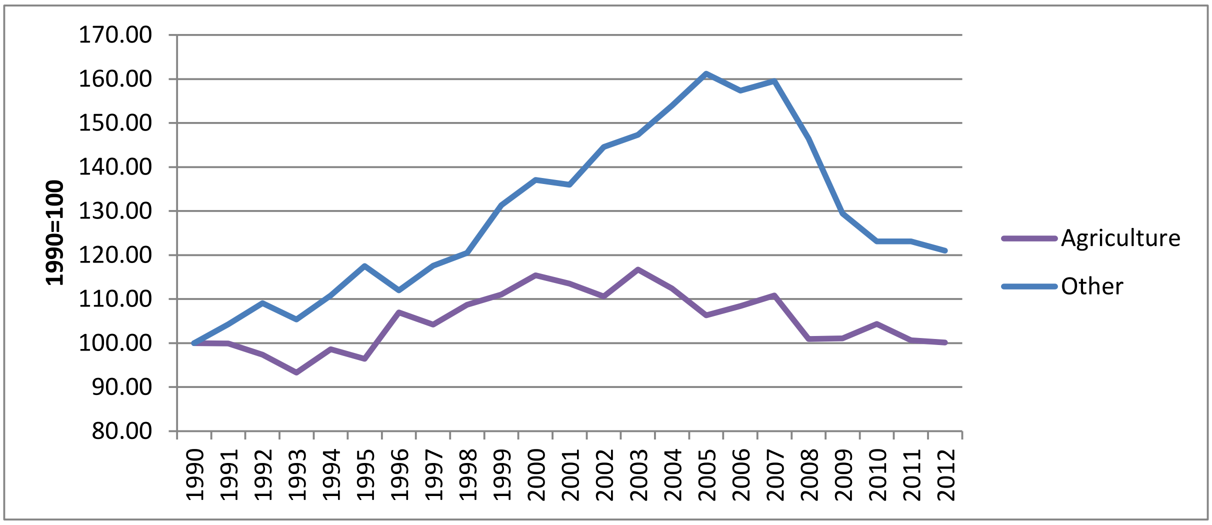
Table 6.13. % change in real exports relative to the baseline in 2020, selected food commodities

	'No RR'	'All'	'Low-skilled'	'Food subsidy'
Vegetables	-0.6	6.5	6.7	-1
Alcohol	-1.2	-0.5	-0.5	-0.9
Other fruit	-1.9	3.5	3.7	-2.4
Citrus	-1	4.4	4.6	-1.2
Pork	-5.7	-2.5	-2.2	-6.5
Dairy	-2.8	0.3	0.5	-4.4
Beef	-7.8	-5.7	-5.6	-10.2
Animal feed	-1.6	-0.8	-0.7	-1.9
Barley	-5.1	-3.7	-3.6	-6
Wheat	-12.8	-8.5	-8.3	-14.8

Source: model results

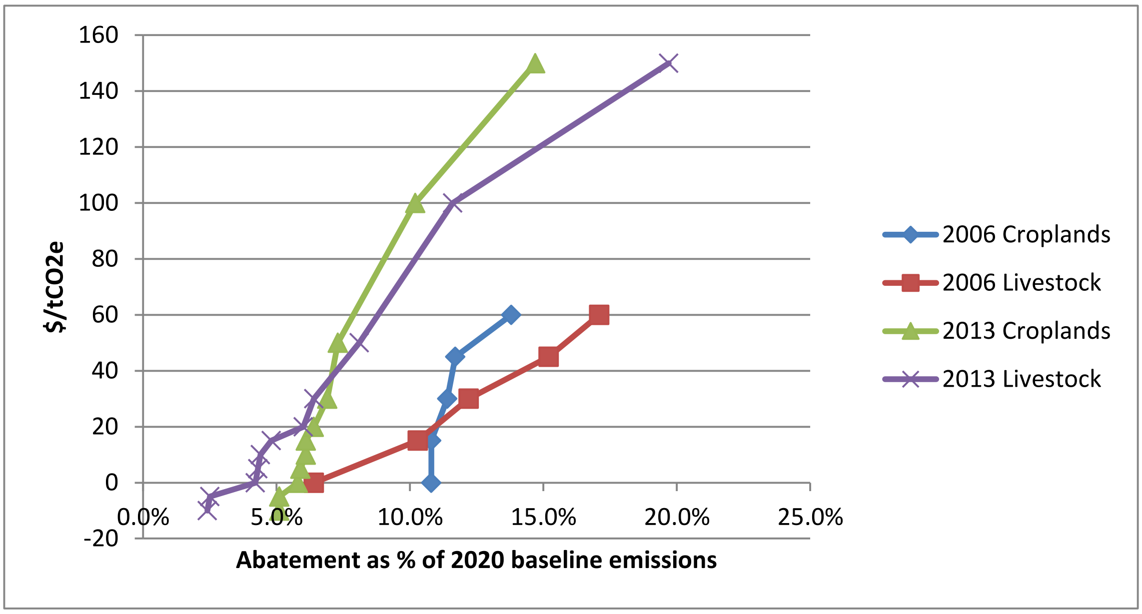
Figures

Figure 1.1. Index of agricultural and other emissions 1990-2012



Source: UNFCCC, 2015

Figure 2.1. MAC curves, initial and updated



Source: EPA, 2006 and 2013

Figure 3.1. The standard ORANI-G absorption, make and tariff matrices

		Absorption Matrix					
		1	2	3	4	5	6
		Producers	Investors	Household	Export	Government	Change in Inventories
	Size	I	I	1	1	1	1
Basic Flows	CxS	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V6BAS
Margins	CxSxM	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	n/a
Taxes	CxS	V1TAX	V2TAX	V3TAX	V4TAX	V5TAX	n/a
Labour	O	V1LAB					
Capital	1	V1CAP					
Land	1	V1LND					
Production Tax	1	V1PTX					
Other Costs	1	V1OCT					

C = Number of Commodities
I = Number of Industries
S = 2: Domestic,Imported,
O = Number of Occupation Types
M = Number of Commodities used as Margins

	Joint Production Matrix
Size	I
C	MAKE

	Import Duty
Size	1
C	V0TAR

Source: Philippidis and Sanjuan, 2009a.

Figure 3.2. Illustrative use tables and make matrix

Total USE table	**Intermediate demands**			**Final demands**					
	Agric	**Manu**	**Servs**	**Priv**	**Govt**	**Invest**	**Stocks**	**Export**	**Total**
Agric	7	2	1	5	0	1	-2	3	**17**
Manu	2	14	9	46	21	8	-3	28	**125**
Servs	1	15	9	62	18	2	0	0	**107**
Margin	2	9	18	26	12	3	0	5	**75**
Indirect Tax	-2	7	0	12	8	3	0	-2	**26**
Op Surplus	4	34	31	-	-	-	-	-	**69**
Lab	5	42	19	-	-	-	-	-	**66**
Prod Tax	-2	5	7	-	-	-	-	-	**10**
Total	**17**	**128**	**94**	**151**	**59**	**17**	**-5**	**34**	**495**

Domestic USE table	**Intermediate demands**			**Final demands**					
	Agric	**Manu**	**Servs**	**Priv**	**Govt**	**Invest**	**Stocks**	**Export**	**Total**
Agric	6	2	1	3	0	1	-2	3	**14**
Manu	1	11	4	38	18	6	-3	28	**103**
Servs	1	8	5	32	9	1	0	0	**56**
Margin	2	8	18	20	10	3	0	5	**66**
Indirect Tax	-2	6	0	8	5	2	0	-2	**17**
Op Surplus	4	34	31	-	-	-	-	-	**69**
Lab	5	42	19	-	-	-	-	-	**66**
Prod Tax	-2	5	7	-	-	-	-	-	**10**
Total	**15**	**116**	**85**	**101**	**42**	**13**	**-5**	**34**	**401**

Import USE table	**Intermediate demands**			**Final demands**					
	Agric	**Manu**	**Servs**	**Priv**	**Govt**	**Invest**	**Stocks**	**Export**	**Total**
Agric	1	0	0	2	0	0	0	0	**3**
Manu	1	3	5	8	3	2	0	0	**22**
Servs	0	7	4	30	9	1	0	0	**51**
Margin	0	1	0	6	2	0	0	0	**9**
Indirect Tax	0	1	0	4	3	1	0	0	**9**
Op Surplus	0	0	0	-	-	-	-	-	**0**
Lab	0	0	0	-	-	-	-	-	**0**
Prod Tax	0	0	0	-	-	-	-	-	**0**
Total	**2**	**12**	**9**	**50**	**17**	**4**	**0**	**0**	**94**

MAKE MATRIX	**Agric**	**Manu**	**Servs**	**Total**
Agric	13	1	0	**14**
Manu	3	100	0	**103**
Servs	1	2	53	**56**
Margin	0	25	41	**66**
Total	**17**	**128**	**94**	

Source: Philippidis and Sanjuan, 2009a.

Figure 3.3a. Conceptual Social Accounting Matrix (SAM)

	I	II			III	IV	V	VI
	PROD	**FAC**	**HH**	**STOCK**	**NGOs**	**GOVT**	**INVEST/SAVE**	**ROW**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Production activities								
	V1BAS("dom")		V3BAS("dom")	V6BAS("dom")	V8BAS("dom")	V5BAS("dom")	V2BAS("dom")	V4BAS
	V1MAR		V3MAR	V6MAR	V8MAR	V5MAR	V2MAR	V4MAR
2. Factors								
Capital	V1CAP							
Labour	V1LAB							
Land	V1LND							
Quota Rent	RENT							
3. Households								
Capital rent income		V1CAP						
Labour (gross) income		V1LAB						
Land rent income		V1LND						
Quota rent income		RENT						
Social lending (D62)						SOCSEC("expend")		
Social transfers (D63p)						SOCSEC("expend")		
Other current transfers (D7)						OTHERS("expend")		
Capital transfers (D9)						V2TOT_G		
Non-productive acquisitions (K2)						V2TOT_G		
4. Inventories								
5. NGOs								
6. Government								
Net indirect taxes (less subsidies)	V1TAX		V3TAX	V6TAX	V8TAX	V5TAX	V2TAX	
Net production taxes (less subsidies)	V1PTX							
Land taxes (V1LND-V1LNDM)	LNDTAX							
Capital taxes (V1CAP-1CAPM)	CAPTAX							
Income and estate taxes (D5)			INCTAX					
Social security (D61)			SOCSEC("recp")					
Property taxes (D4)			PROPTAX					
Inheritance taxes (D9)			HERTAX					
P11/P12+P131+D7			OTHERS("recp")					
7. Investment								

HH SAVE			Gross HH save (HHSAVE)		Net ISLFSH save			
REST SAVE			Other institut save		Depreciation			
Government investment						V2TOT_G		
Fiscal deficit (-ve)/surplus (+ve)						Budget (T-G)		
Balance of payments (M-X)								
8. ROW	V1BAS("imp")		V3BAS("imp")	V6BAS("imp")	V8BAS("imp")	V5BAS("imp")	V2BAS("imp")	-
TOTAL expenditures								

Source: own work

Figure 3.3b. 2007 Social Accounting Matrix for Spain

		I	II			III	IV	V	VI			
		PROD	**FAC**	**HH**	**STOCK**	**NGOs**	**GOVT**	**INVEST/SAVE**	**ROW**			
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**		**Total receipts**	
I	**1. Production activities**											
		825961.2		419508.4	2854.6	9359.6	183541.5	249225.4	214572.3	1905023.0		
		50169.0		90049.1	0.0	0.0	2025.2	8523.9	15648.1	166415.3	**2071438.3**	**I**
II	**2. Factors**											
	Capital (V1CAP)	425294.2								425294.2		
	Labour (V1LAB)	514581.6								514581.6		
	Land (V1LND)	4249.4								4249.4		
	Quota Rent (RENT)	623.0								623.0	**944748.2**	**II**
	3. Households											
	Capital rent income		425294.2							425294.2		
	Labour (gross) income		514581.6							514581.6		
	Land rent income		4249.4							4249.4		
	Quota rent income		623.0							623.0		
	Social loans (D62)						122486.0			122486.0		
	Social transfers (D63p)						25882.0			25882.0		
	Other current transfers (D7)						15401.0			15401.0		
	Capital transfers (D9)						14201.0			14201.0		
	Non-productive acquisitions (K2)						394.0			394.0		
	No subsidy expenditure									0.0		-11315
	4. Inventories									0.0		
III	**5. NGOs**									0.0	**1123112.2**	**III**
IV	**6. Government**											
	Net indirect taxes (incl. subsidies)	23445.3		60494.6	0.0	0.0	534.3	24265.0	2546.3	111285.5		
	Net production taxes (incl subsidies)	4578.8								4578.8		
	Land taxes	-4446.1								-4446.1		
	Capital taxes	-767.6								-767.6	110650.6	
	Income and estate taxes (D5)			135783.0						135783.0		
	Social security (D61)			136752.0						136752.0		
	Property taxes (D4)			10394.0						10394.0		
	Inheritance taxes (D9)			4935.0						4935.0		

	P11/P12+P131+D7			21452.0						21452.0		
	Residual			1526.4						1526.4	**421493.0**	**IV**
V	**7. Investment/Saving**											
										0.0		
	HH SAVE			71184.6						71184.6		
	REST SAVE			93390.1						93390.1		**42587**
	Government investment						34707.9			34707.9		
	Fiscal deficit (-ve)/surplus (+ve)						20057.0			20057.0		
	Balance of payments (M-X)								112428.1	112428.1	**331767.7**	**V**
VI	**8. ROW**	227749.7		65276.8	152.0	0.0	2263.1	49753.4	0.0	345195.0	**345195.0**	**VI**
	subtotals	2071438.5	944748.2	1110746.0	3006.6	9359.6	421493.0	331767.7	345194.8			
	TOTAL expenditures	**2071438.5**	**944748.2**			**1123112.2**	**421493.0**	**331767.7**	**345194.8**			
		I	**II**			**III**	**IV**	**V**	**VI**			
									5237754.4			

Source: own work

Figure 3.4: MAC data from the GAINS model

MAC curves for methane emissions

Industries: Cattle (dairy and non-dairy) and pig farming

Sources of emissions: Enteric fermentation and manure management

Mitigation options for enteric fermentation: Feed changes

Mitigation options for manure management: Anaerobic digestion plants at community, farm-scale, or household level.

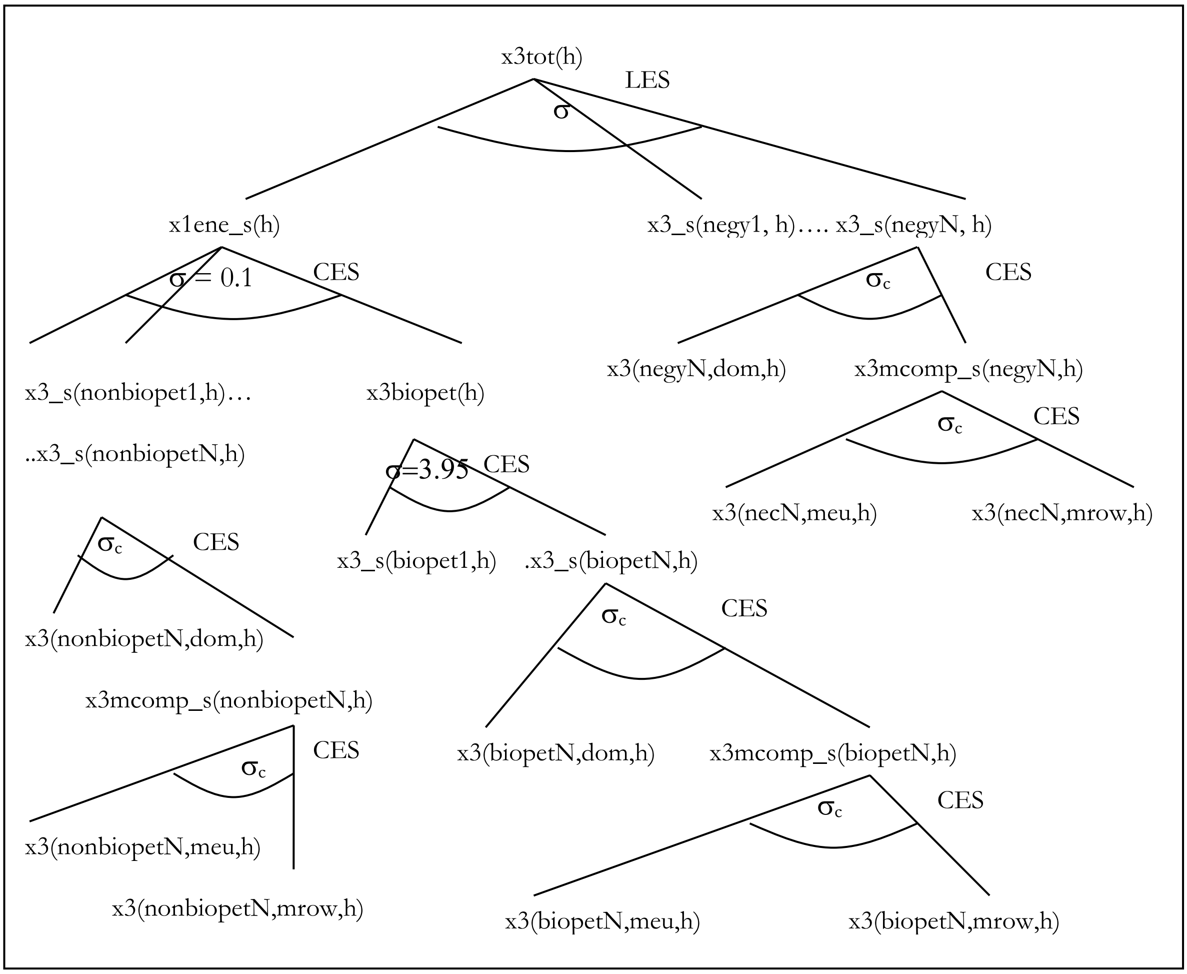
MAC curves for nitrous oxide emissions

Industries: Crop growing

Sources of emissions: Application of nitrogen-based fertiliser

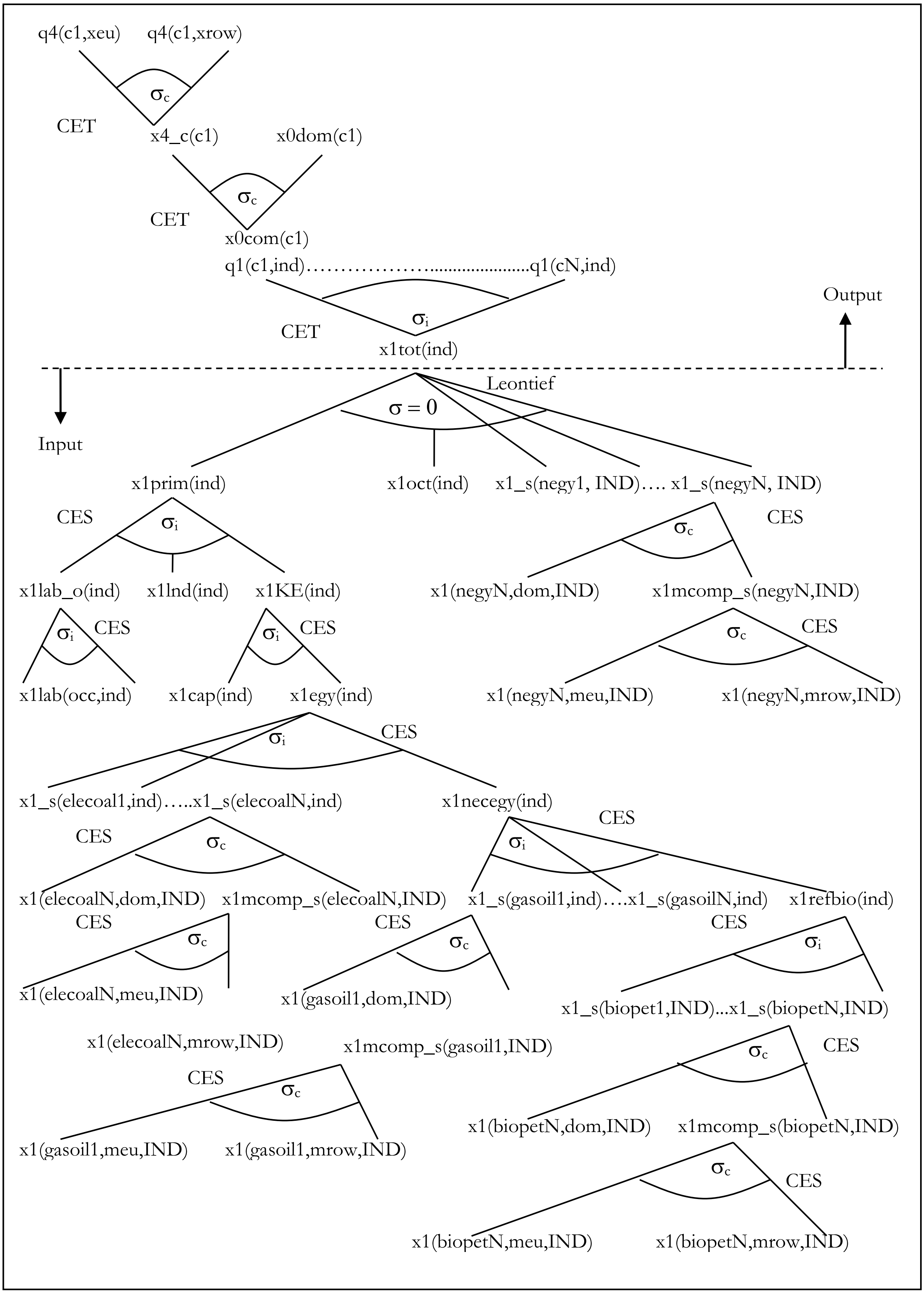
Mitigation options: Reduced fertilizer application, improved timing of fertiliser application, nitrification inhibitors, precision farming techniques.

Figure 4.1: Nested consumption function for private households



Source: Philippidis and Sanjuan, 2009b.

Figure 4.2: Nested Constant Elasticity of Substitution (CES) function for non-agricultural industries in the OEG model



Source: Philippidis and Sanjuan, 2009b.

Figure 4.3: MAC data from the GAINS model

MAC curves for methane emissions

Industries: Cattle (dairy and non-dairy) and pig farming

Sources of emissions: Enteric fermentation and manure management

Mitigation options for enteric fermentation: Feed changes

Mitigation options for manure management: Anaerobic digestion plants at community, farm-scale, or household level.

MAC curves for nitrous oxide emissions

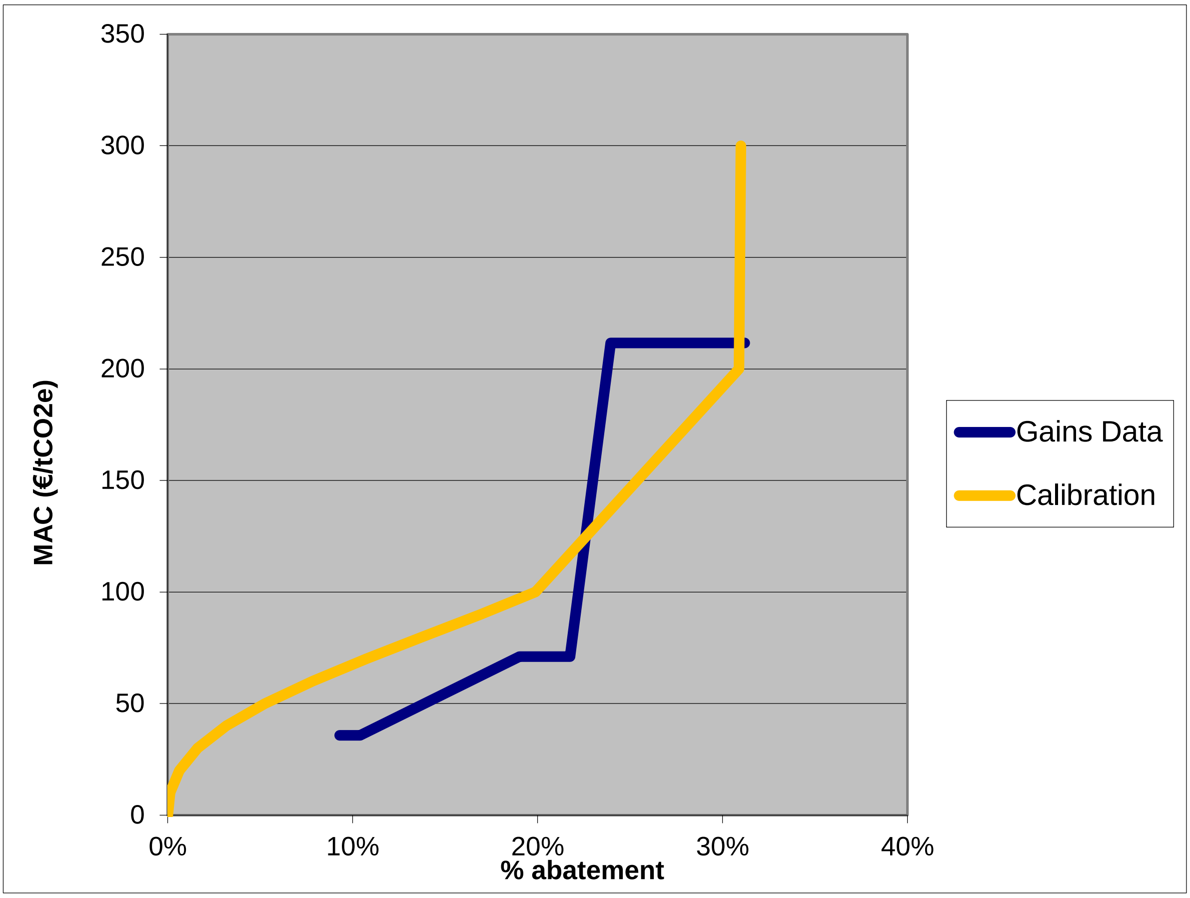
Industries: Crop growing

Sources of emissions: Application of nitrogen-based fertiliser

Mitigation options: Reduced fertilizer application, improved timing of fertiliser application, nitrification inhibitors, precision farming techniques.

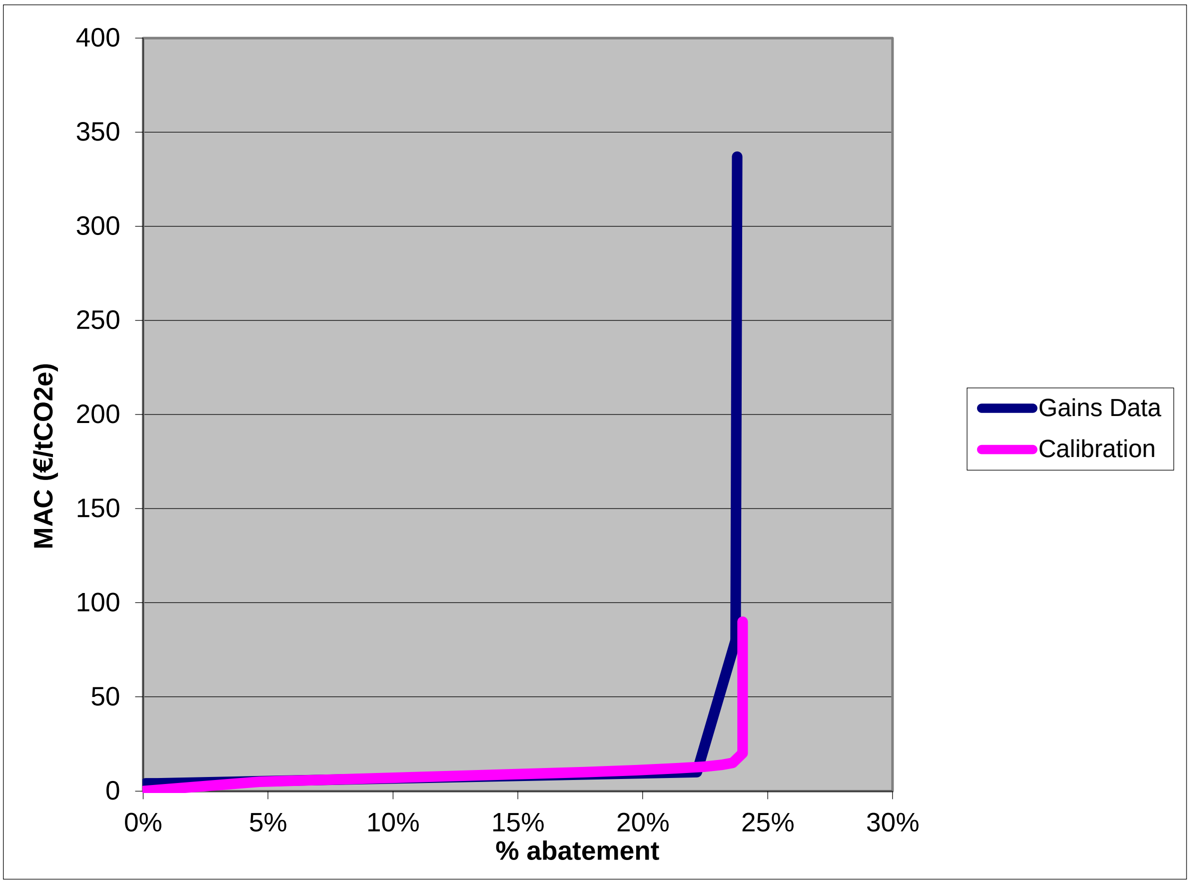
Source: IIASA, 2015

Figure 4.4: Calibrated MAC curve for N2O emissions from crops sectors



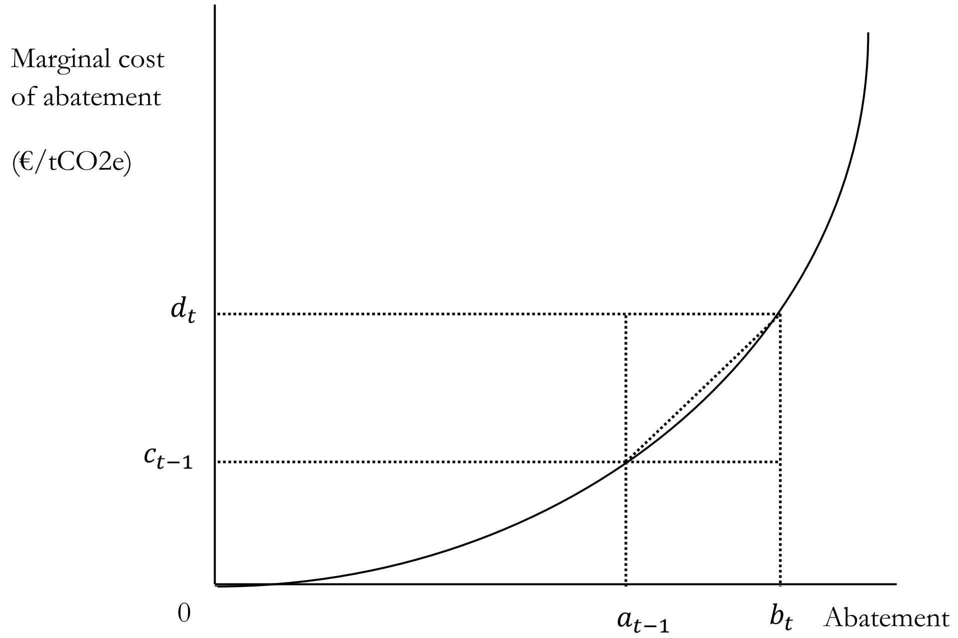
Source: IIASA, 2015 and own work

Figure 4.5: Calibrated MAC curve for CH4 emissions from livestock sectors



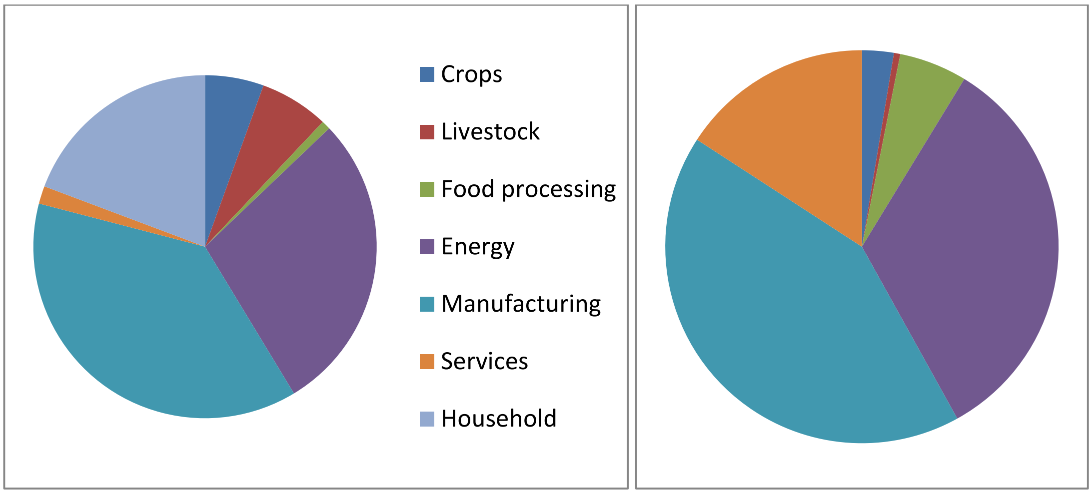
Source: IIASA, 2015 and own work

Figure 4.6. Illustrative MAC curve for abatement expenditure calculations



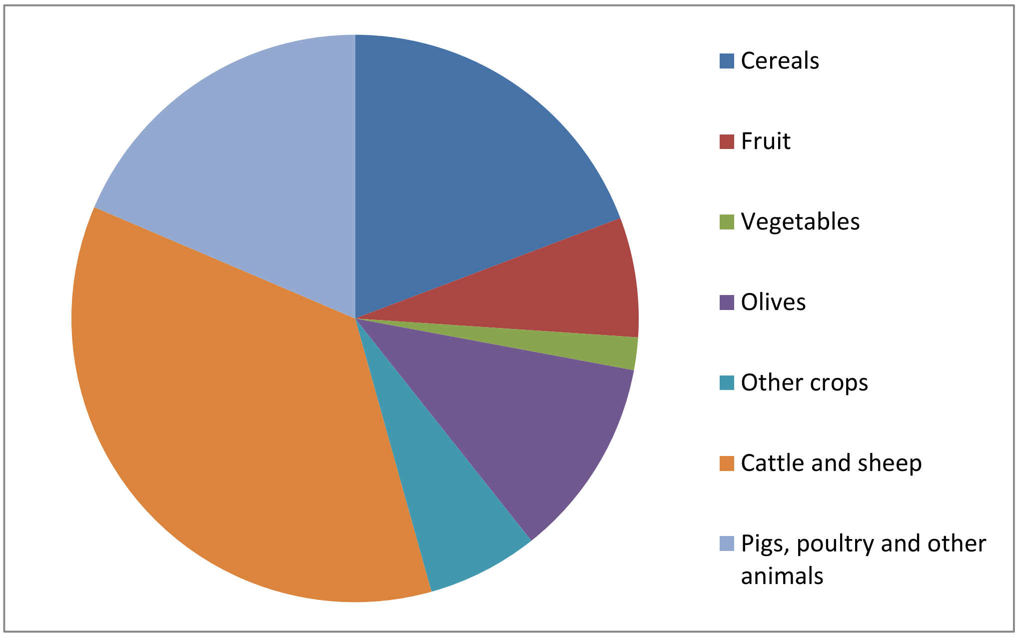
Source: own work

Figure 5.1. Emissions allocated by industry (5.1a) and final demand commodity (5.1b)



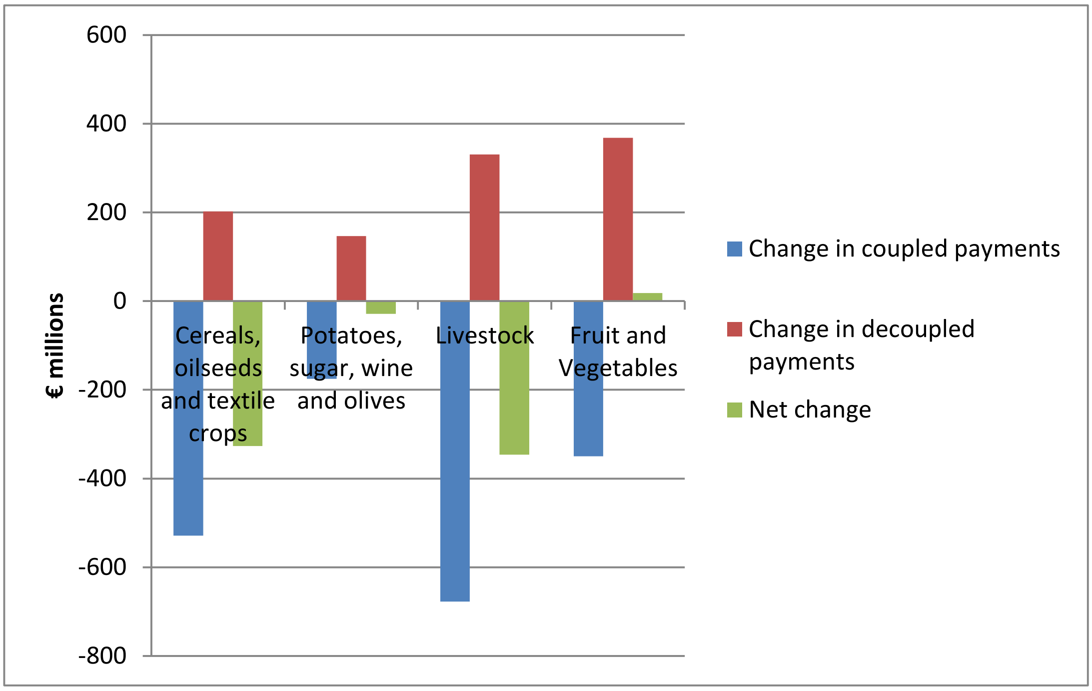
Source: UNFCCC, 2015 and own calculations

Figure 5.2. Breakdown of agricultural emissions in 2007



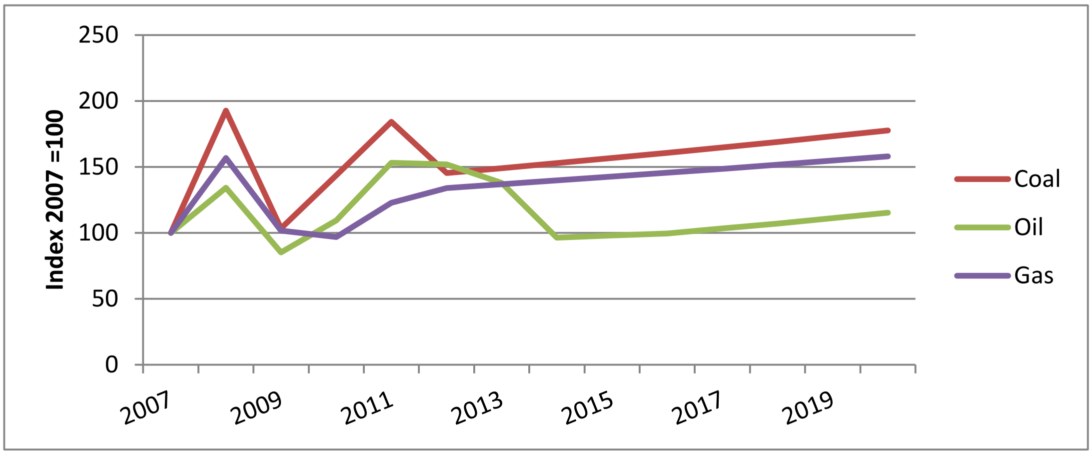
Source: UNFCCC, 2015 and own work

Figure 5.3. Cumulative changes in CAP payments 2007-2020



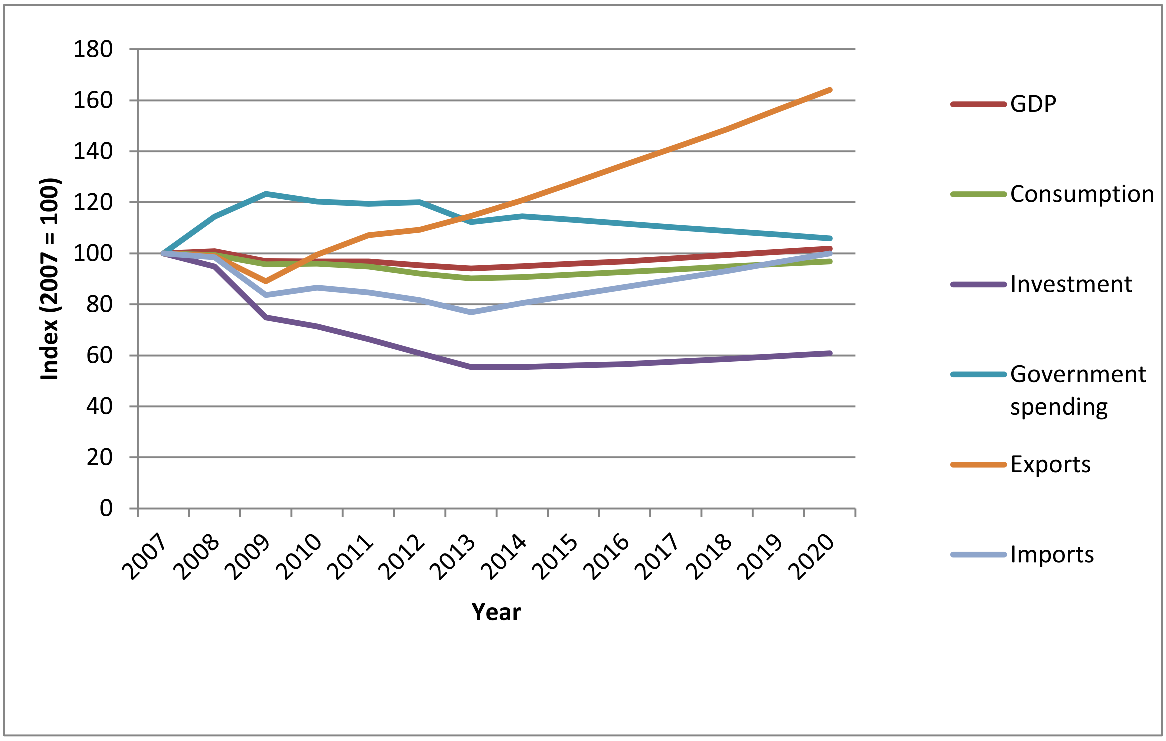
Source: FEGA, 2010 and own work

Figure 5.4. Evolution of world fossil fuel prices in all scenarios, 2007=100



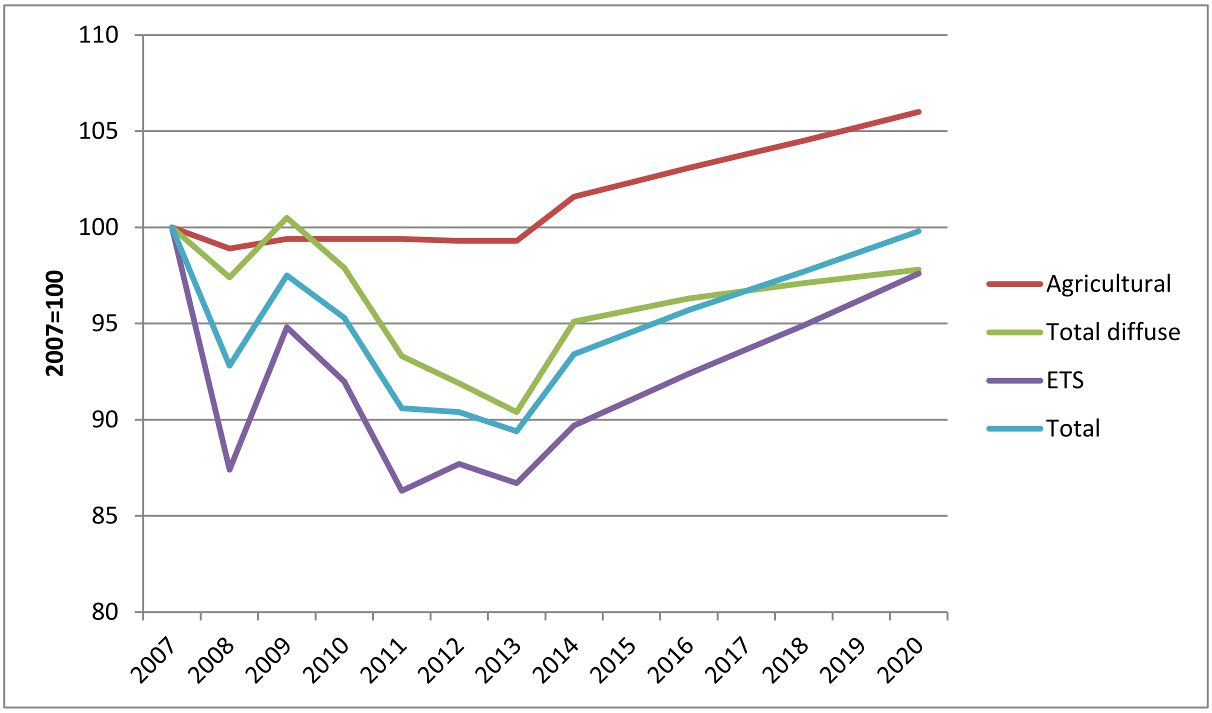
Source: IEA, 2015

Figure 5.5. Evolution of macroeconomic indicators in the baseline 2007=100



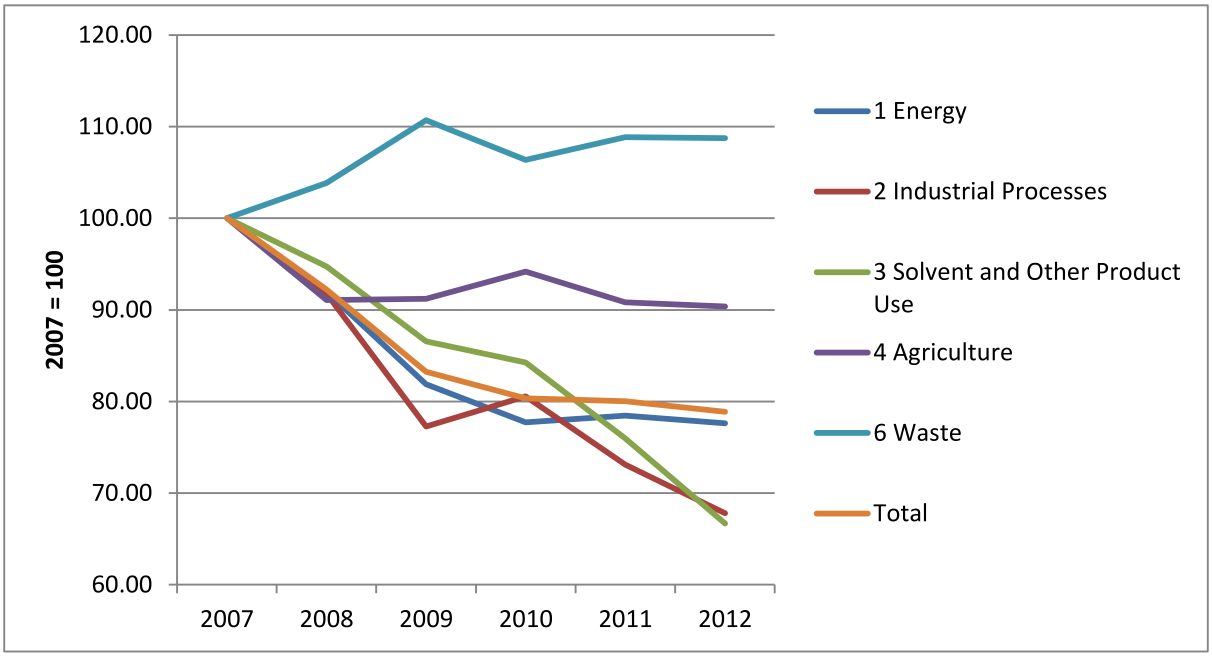
Source: IMF, 2014

Figure 5.6. Index of baseline emissions 2007=100



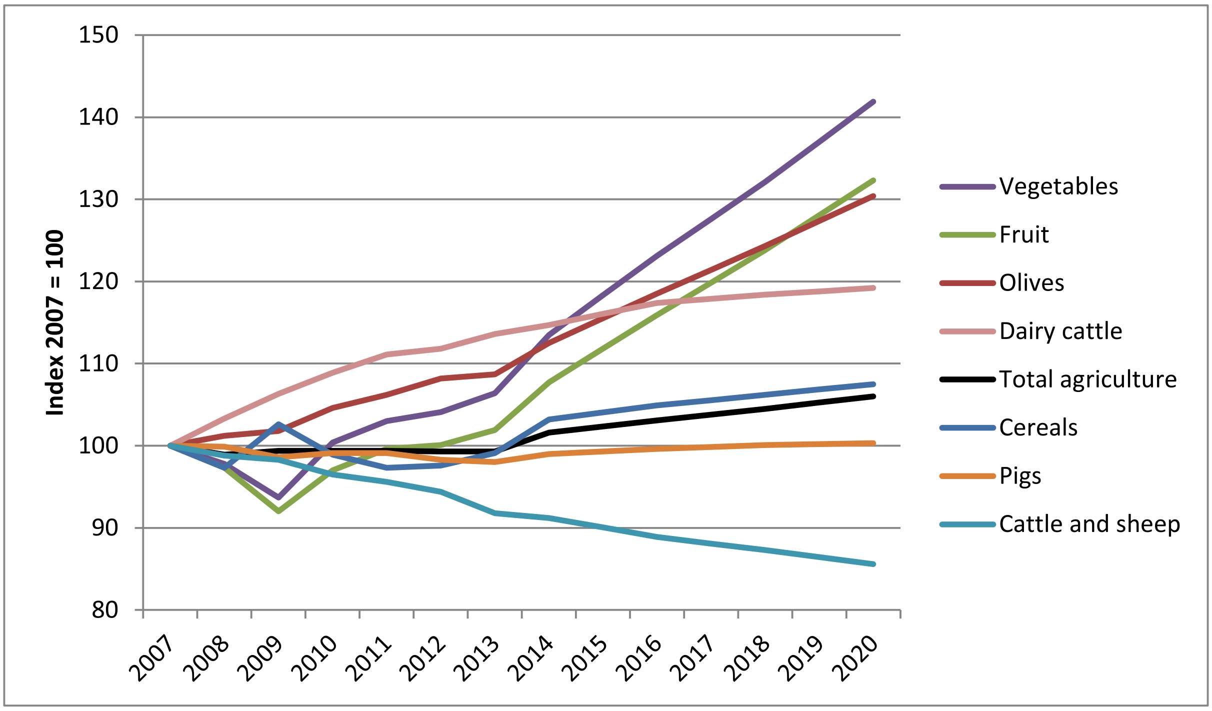
Source: model results

Figure 5.7. Index of actual emissions 2007=100



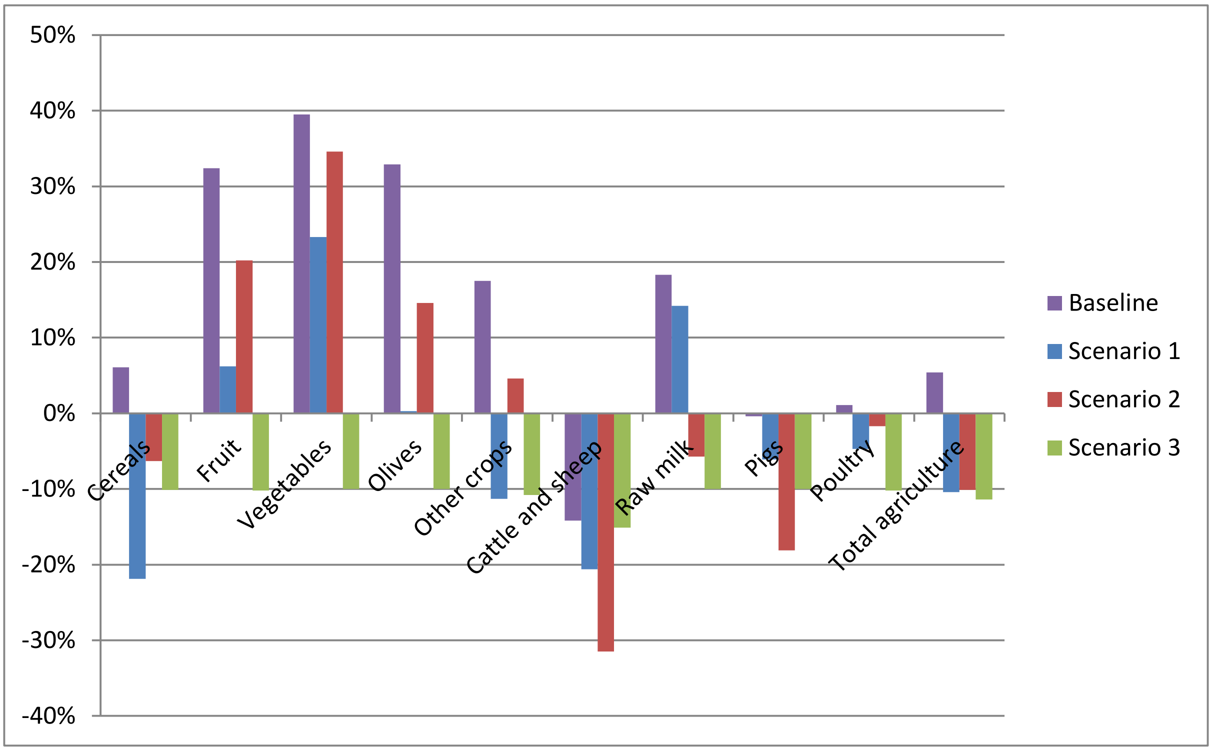
Source: UNFCCC, 2015

Figure 5.8. Index of agricultural baseline emissions 2007=100



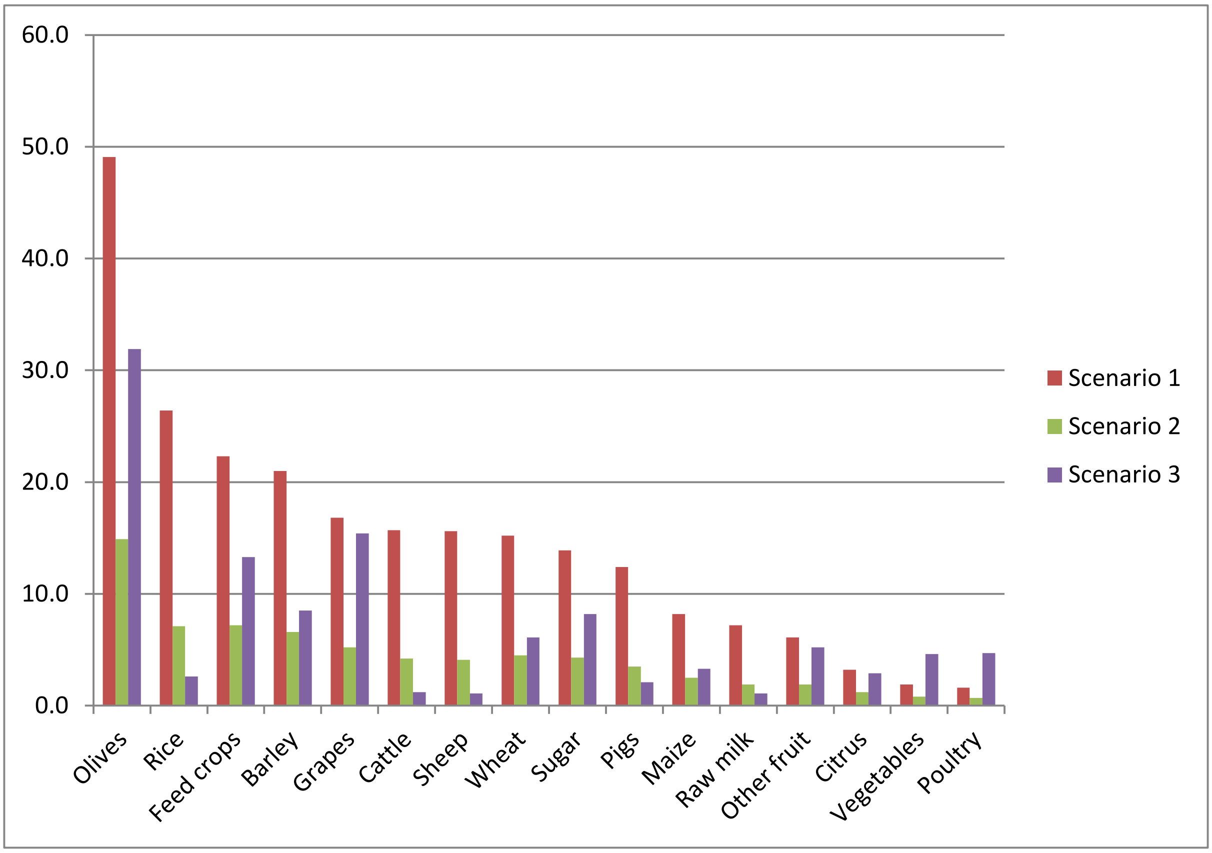
Source: model results

Figure 5.9. Cumulative changes in emissions 2007-2020, baseline and scenarios 1-3



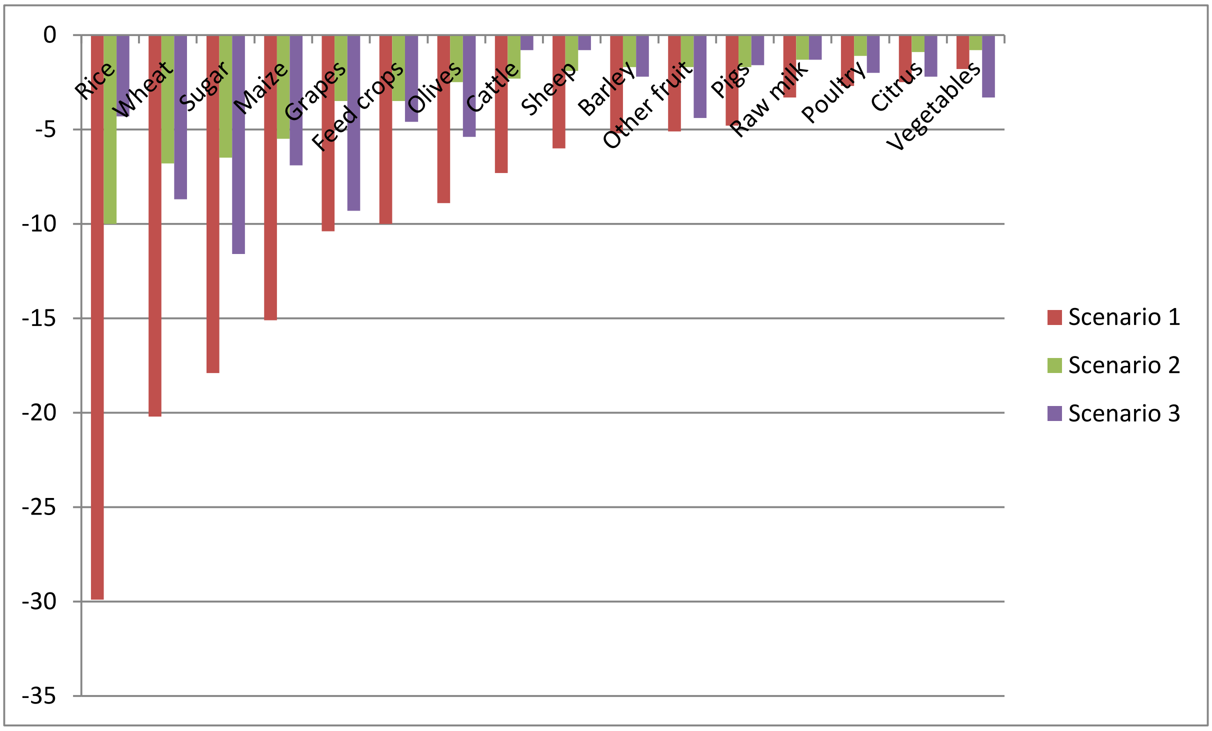
Source: model results

Figure 5.10. Price changes relative to the baseline



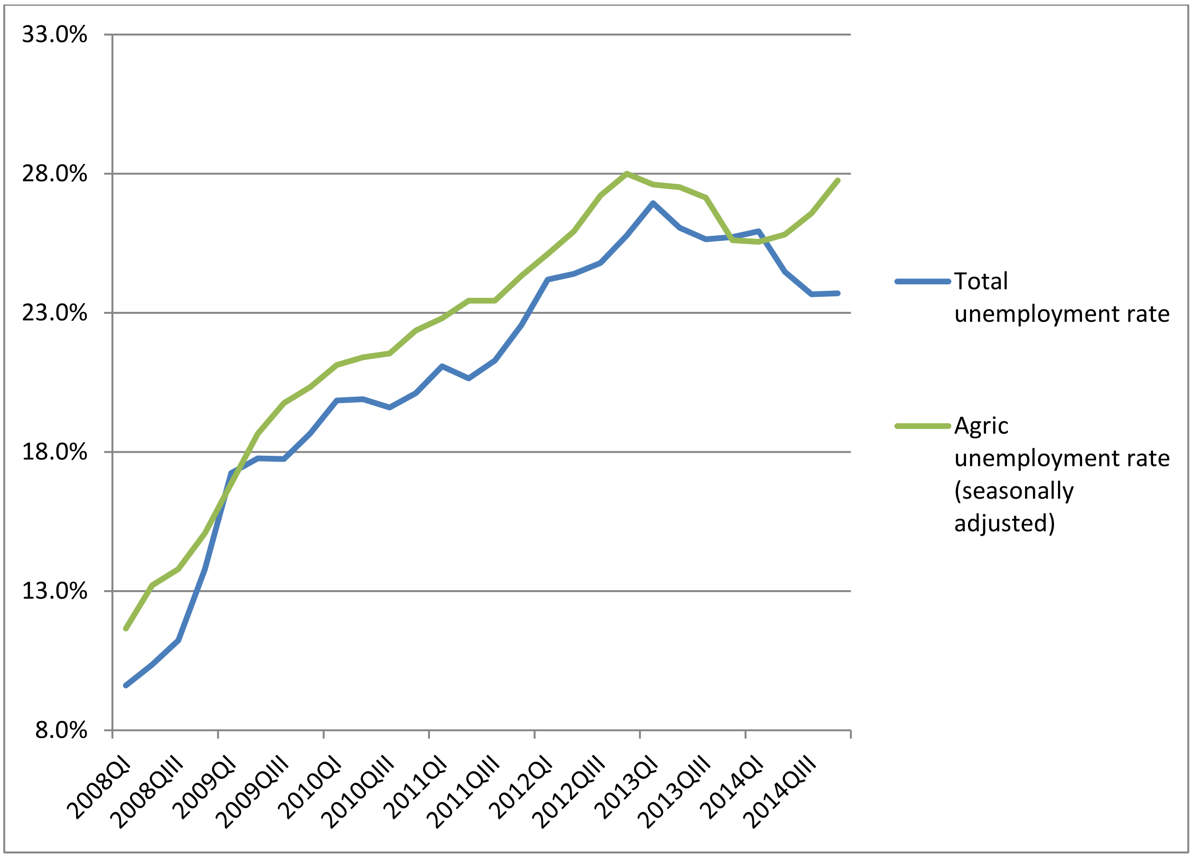
Source: model results

Figure 5.11. Output changes relative to the baseline



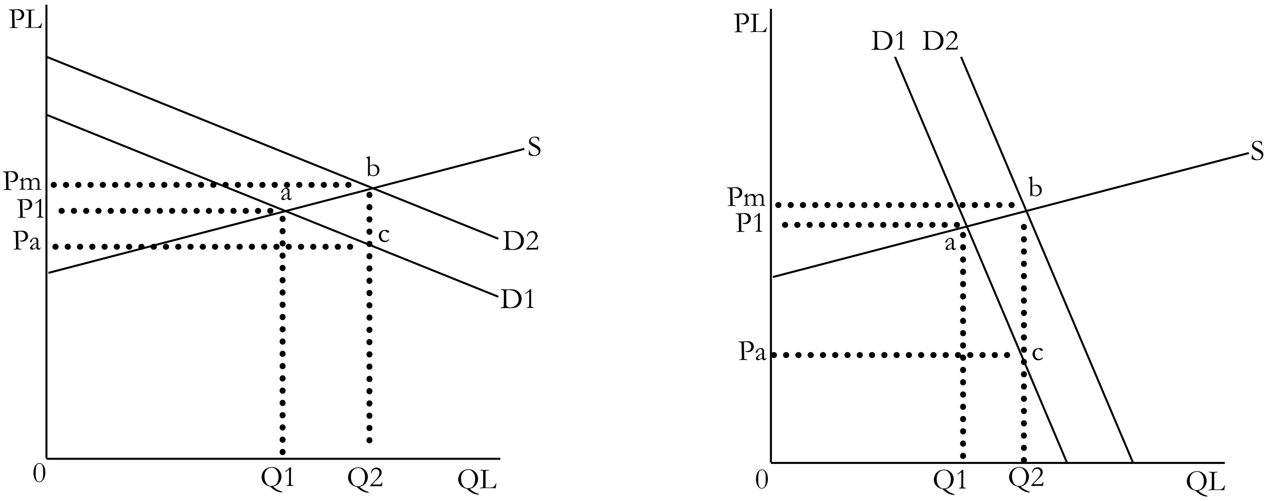
Source: model results

Figure 6.1. Agricultural and total unemployment rate

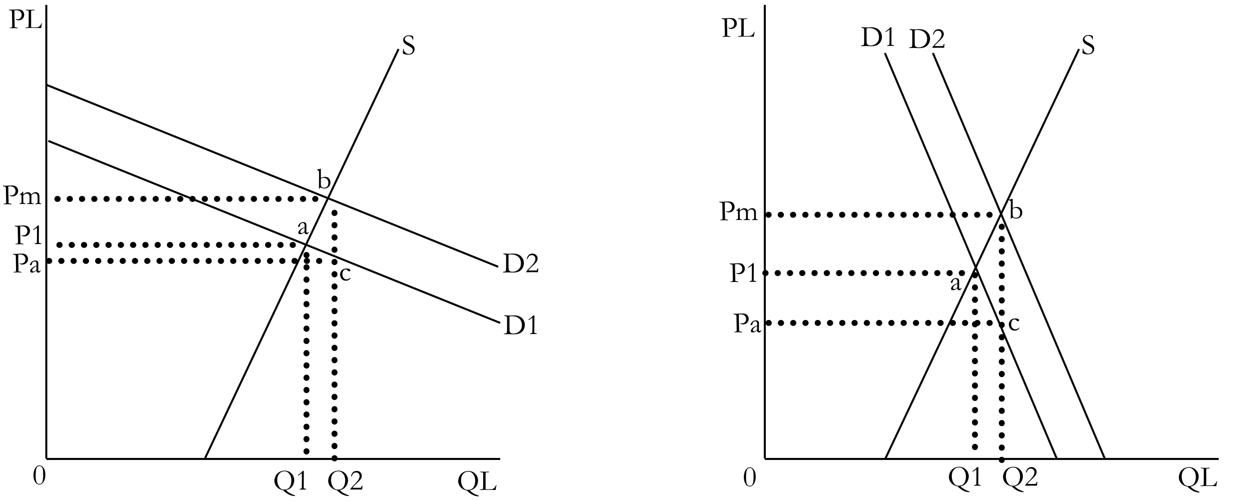


Source: INE, 2015

Figure 6.2. Possible effects of a subsidy on the labour market


a: Elastic demand and supply

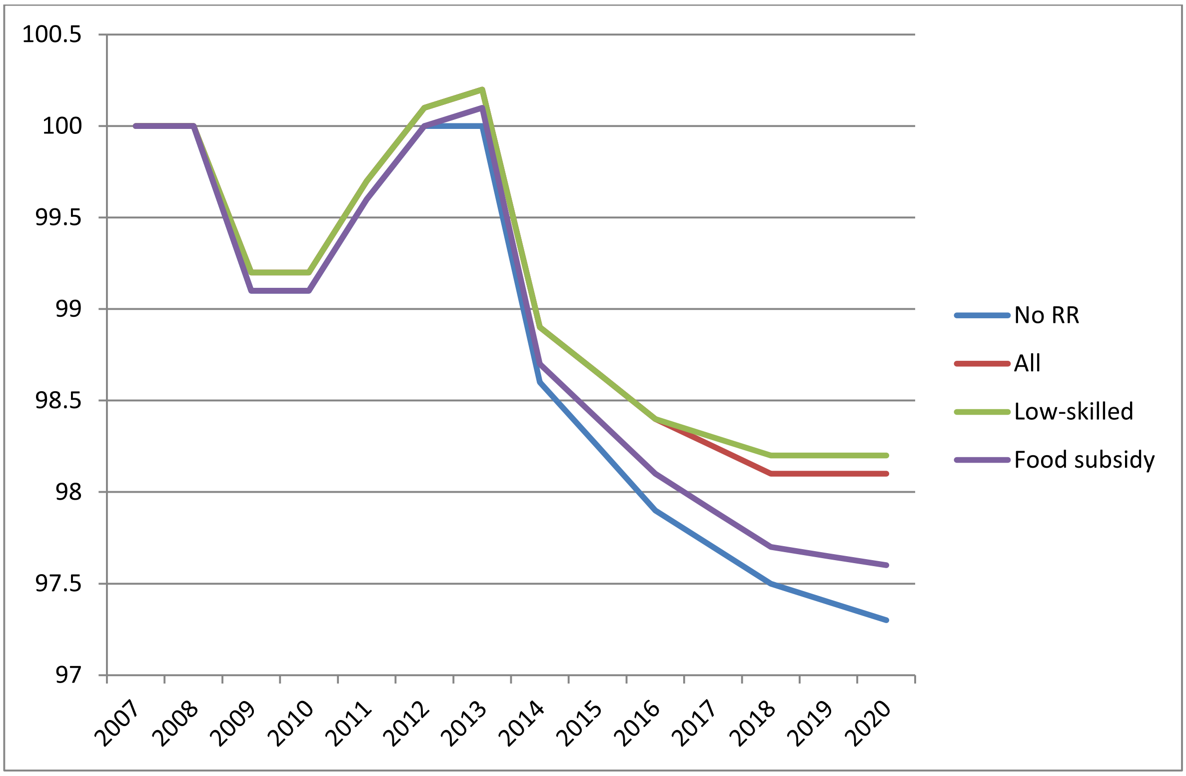
b: Inelastic demand and supply


c: Elastic demand, inelastic supply

d: Inelastic demand and supply

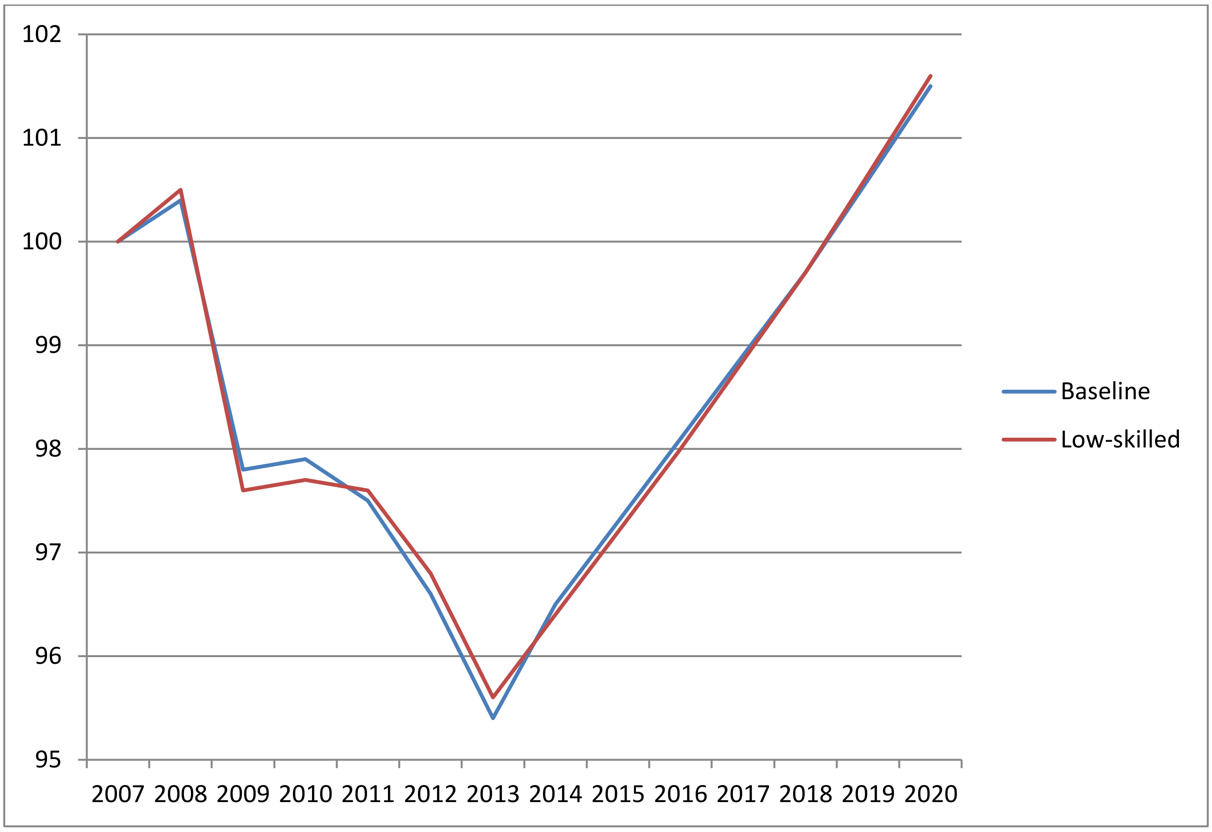
Source: own work

Figure 6.3. Index of investment over time relative to the baseline 2007=100



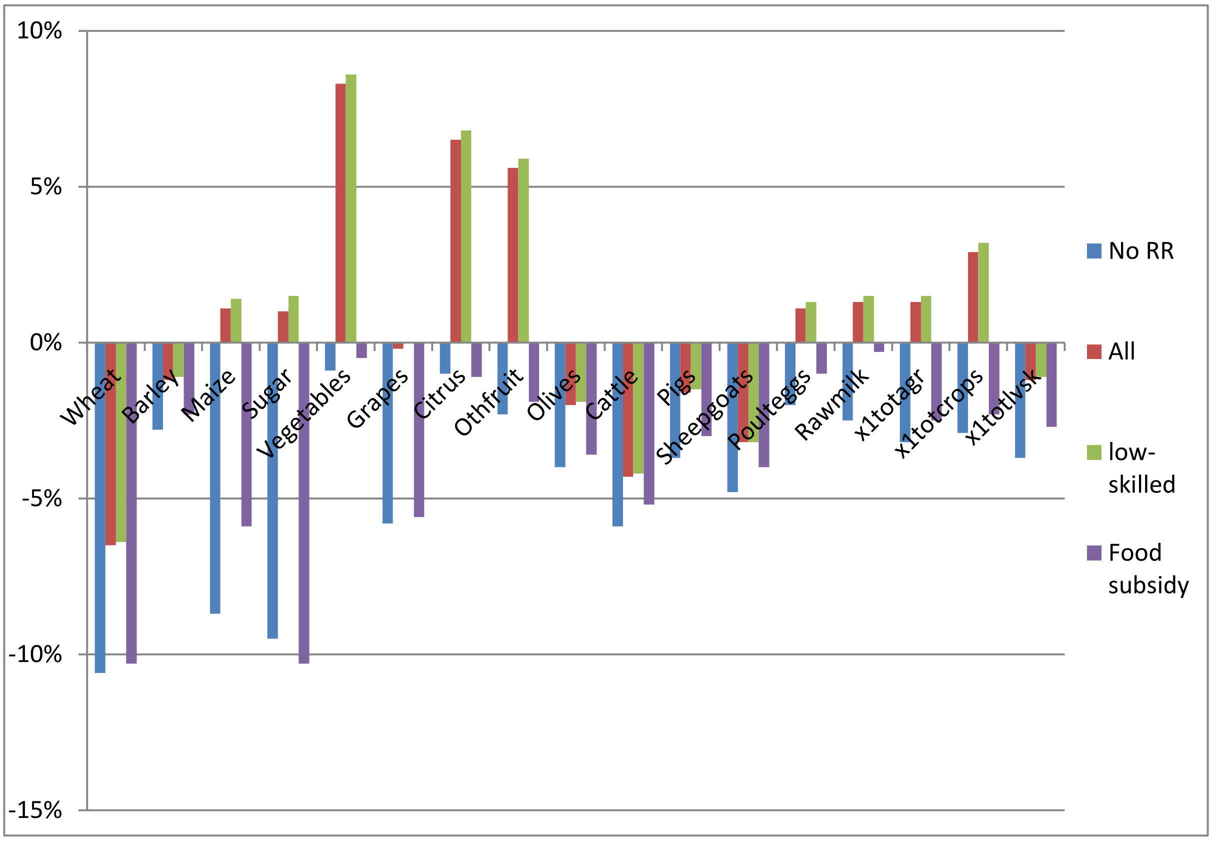
Source: model results

Figure 6.4. Index of employment over time in the baseline and low-skilled scenarios, 2007=100



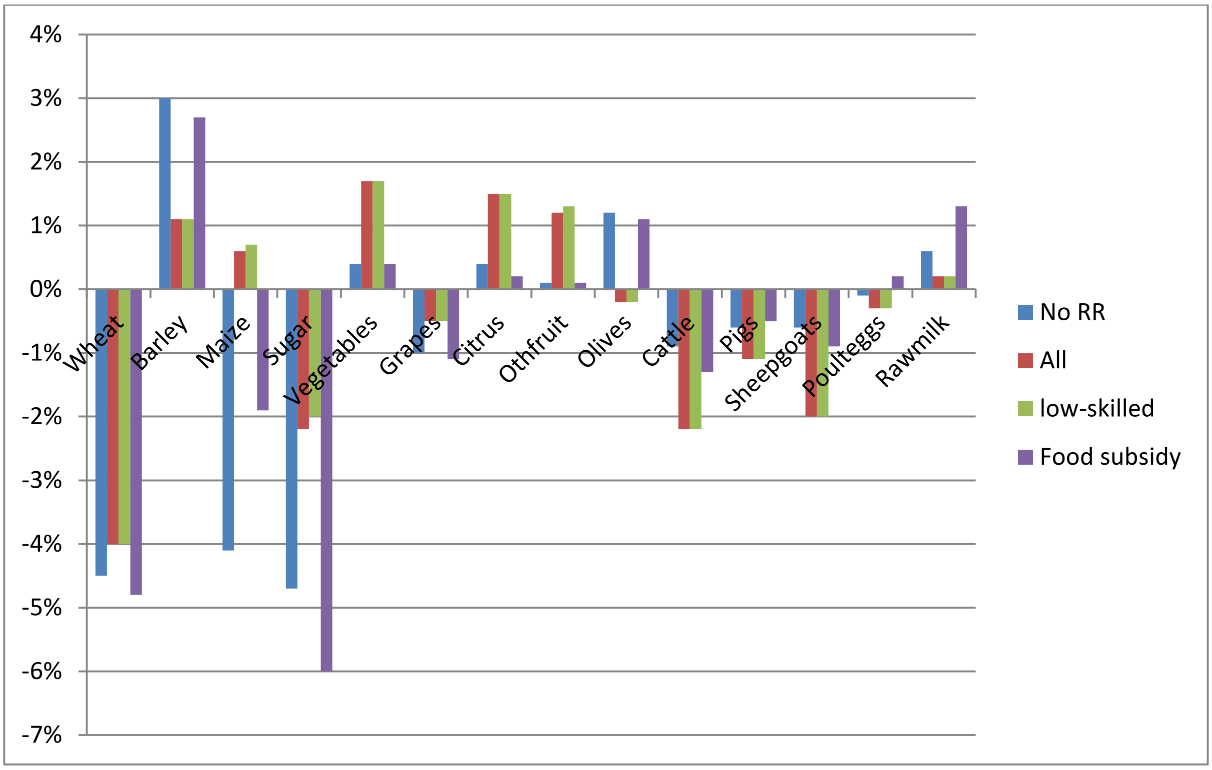
Source: model results

Figure 6.5. Production of selected agricultural industries relative to the baseline



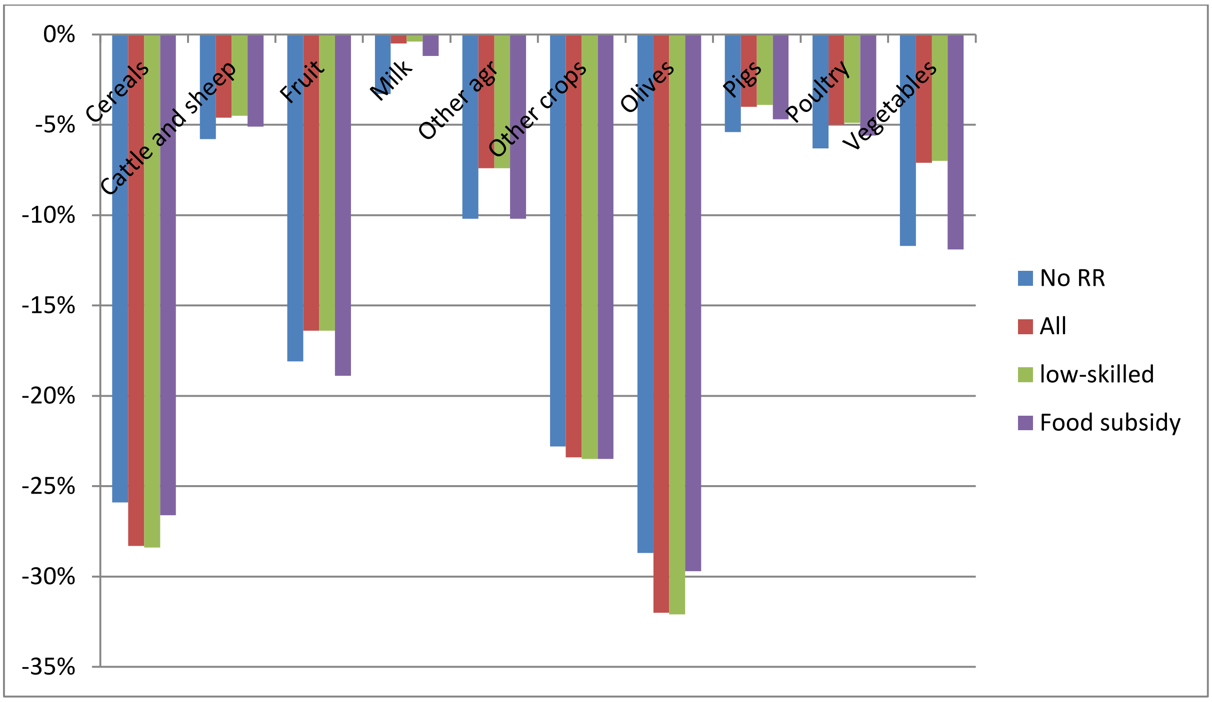
Source: model results

Figure 6.6. Land use relative to the baseline



Source: model results

Figure 6.7. Emissions in 2020 relative to the baseline



Source: model results