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Controlling greenhouse gas emissions in Spain: what are the costs for agricultural sectors?

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Abstract

Employing a recursive dynamic computable general equilibrium (CGE) model of the Spanish economy, this study explicitly aims to characterise the potential impact of Kyoto and European Union environmental policy targets on specific agricultural activities up to 2020. The model code is modified to characterise the emissions trading scheme (ETS), emissions quotas and carbon taxes, whilst emissions reductions are applied to all six registered greenhouse gases (GHGs). Compared to a 'business-as-usual' baseline scenario, by 2020, GDP and employment fall 2.1% and 2.4%, respectively, whilst the retail price index rises 3.4%. In agriculture, the indices of output (4.3% fall), and supply price (7.7% rise) perform relatively worse, whilst there is a concomitant cumulative fall in aggregate farm incomes of €1,510 million by 2020. The more notable impact in agriculture is attributed to its relatively higher emissions intensity. Consequently, we record an agricultural marginal abatement cost estimate of €86 ton^{-1} of CO_2 equivalent by 2020, which is consistent with other estimates in the literature. In addition, we find that the optimal mix of emissions reductions across specific agricultural sectors is a function of the degree of substitutability of their emitting activities. In light of estimated income losses within the strategically important farm sector, a final simulation contemplates an 'agricultural cost-neutral' emissions reduction policy akin to a cross compliance payment between 2013 and 2020. This is found to reduce food price rises, whilst altering the optimum mix of agricultural emissions reductions across specific agricultural activities.

Additional key words: agriculture; computable general equilibrium; European Union Climate & Energy Package; Kyoto protocol.

Resumen

El control de las emisiones de gases de efecto invernadero en España: costes para los sectores agrarios

Empleando un modelo dinámico recursivo de equilibrio general computable (EGC) de la economía española, este estudio analiza el impacto de las políticas medioambientales de Kioto y de la Unión Europea (el acuerdo '20/20/20'), sobre distintas actividades agrarias hasta 2020. En comparación con el escenario de referencia, se pronostican caídas en el PIB y el empleo de un 2,1% y 2,4%, respectivamente, en 2020, mientras que el índice de precios al consumo sube un 3,4%. En agricultura, el índice de producción (que cae un 4,3%) y el de precios (aumenta un 7,7%), empeoran y además los ingresos acumulados de los agricultores bajan 1.510 millones de euros en 2020. El impacto más acusado en el sector agrario se atribuye a la mayor intensidad de sus emisiones donde se estima un coste marginal de reducción de 86 € t^{-1} de CO_2 equivalente para 2020, lo cual es consistente con las estimaciones existentes en la bibliografía. Además se observa que la combinación óptima de reducción de emisiones en los diferentes sectores agrarios depende del grado de sustitución de las actividades emisoras. A la vista de las pérdidas de ingresos observadas en el sector agrario, se contempla un escenario de mitigación de coste-cero para los agricultores, semejante a un pago de condicionalidad, entre 2013 y 2020. Los resultados señalan una mitigación en el incremento de los precios de los alimentos y una redistribución en la combinación óptima de las emisiones en los sectores agrarios.

Palabras clave adicionales: agricultura; modelo de equilibrio general computable; paquete de energía y cambio climático; protocolo de Kioto sobre el cambio climático.

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Introduction

The necessity for international cooperation in conceiving a global strategy to both mitigate and adapt to climate change, coupled with the absence of a sovereign international authority, bestowed upon individual governing bodies world-wide a sense of collective responsibility to engender binding and effectual policy measures. Against this background, the United Nations Framework Convention on Climate Change (UNFCCC) was created, which in turn oversaw the ratification of the Kyoto Protocol. This international accord set a detailed roadmap for curbing both carbon dioxide (CO_2) emissions, as well as a collective basket of non-CO_2 'greenhouse gas' (GHG) emissions.[1] More recently, the European Union (EU) has taken the lead in fighting climate change, by agreeing a series of further unilateral emissions cuts over the 2013-2020 period under the auspices of its Climate and Energy Package (CEP).

Amid discussions on the best way to achieve these goals, the EU Emissions Trading Scheme (ETS) emerged for a test period in 2005-2007 and thereafter for different commitment phases from 2008-2028. The ETS created an internal trading market for CO_2 emissions permits, initially allocated across a select grouping of sectors (excluding agriculture), with the intention that abatement be incentivised via charges for exceeding (gradually contracting) domestic emissions limits or revenues to more efficient firms from the sale of excess permit allocations. Individual member states distribute emissions permits subject to both the approval of the European Commission and those limits stipulated within the National Allocation Plan (NAP). When Kyoto expires, the ETS will continue to operate to extend CO_2 emission reductions to 2020 (see Table 1).

For non-ETS GHG emissions, parallel EU-wide emissions reductions are implemented up to 2012, although under a 'burden sharing agreement' Spain has been granted a softer emissions reduction target (see Table 1). Notwithstanding, in light of Spain's impressive growth between 1990-2007, some commentators estimate that its economy still faces relatively steep emissions reductions in order to meet its Kyoto commitment (Labandeira & Rodríguez, 2010; González-Eguino, 2011).[2] In the post-Kyoto period an independent 'diffuse' sector (includes agriculture) emissions target is in place up to 2020 (see Table 1).[3] A cursory examination of Spanish emissions data reveals that diffuse emissions make up 55% of all Spanish GHG emissions, of which the transport sector produces the largest proportion (accounting for more than 40% of total energy consumed in Spain) followed by the agriculture sector which itself accounts for 14% of total Spanish GHG emissions. A closer look at Spain's agricultural emissions reveals that methane emissions from livestock activities constitute the largest proportion of total agricultural emissions (38%), followed by nitrous oxide from fertiliser application (34%), and carbon dioxide from petroleum usage (16%). The remaining emissions are largely nitrous oxide from manure, and small amounts of methane released during field burning in the cereals sectors.

The adaptability of computable general equilibrium (CGE) modelling has led to a range of climate change studies with varying focal points and objectives. These 'top-down' representations can be employed to quantify the direct and indirect impacts (*i.e.,* prices, outputs, costs) of climate change policies because of their unique ability to assess the interactions between many different agents and sectors across the whole economy. This key strength is particularly pertinent when examining the integrated nature of energy production and usage across industries and consumers, as well as macroeconomic impacts of policy controlled emissions targets. Notwithstanding, as a caveat, comparing with bottoms-up 'engineering' representations, top-down

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Abbreviations used: CAP (common agricultural policy); CEP (climate & energy package); CGE (computable general equilibrium); CO2e (carbon dioxide equivalent); ETS (emissions trading scheme); EU (European Union); GDP (gross domestic product); GHG (greenhouse gas); GWP (global warming potential); IO (input-output); LULUCF (land use, land-use change and forestry); MAC (marginal abatement cost); NAP (National Allocation Plan); tCO2e (tonnes of carbon dioxide equivalent); UNFCC (United Nation Framework Convention on Climate Change).

[1] The non-CO_2 gases within the remit of Kyoto are: methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Importantly, these gases have a considerably higher Global Warming Potential (GWP) than CO_2.

[2] Spain has been permitted an emissions target of 15% above 1990 levels, rising to a projected 37% when heavy usage of Kyoto approved 'flexibility mechanisms' (20%) and carbon sinks (2%) are accounted for.

[3] In the case of agricultural practice, a proportion of its pollution is classified as point source (*i.e.,* emitted from a single discharge point such as a pipe). However, a large proportion is non-point source (difficult to determine an emitting source), which implies a more 'diffuse' nature to its emissions.

Table 1. Emissions reduction schemes and their coverage

Scheme and targets	Industrial coverage	Gas coverage[1]
— European Union (EU) Emissions Trading Scheme (ETS): domestic permit EU wide ETS emissions reduction of 8% on 1990/1995 levels by 2012 (Kyoto 2007-2012). Different base years are employed for different greenhouse gases. Burden sharing allows Spanish reduction to 15% above 1990 levels. Under the CEP, ETS emissions reduction of 21% on 2005 levels by 2020.	2007-2020: coal, oil, gas, petrol, electricity, metals, paper, glass, ceramics, cement and lime	CO_2 (plus PFCs from metals from 2013 onwards)
	2012-2020: Aviation	CO_2
	2013-2020: Chemicals	CO_2, N_2O
— (Up to 2012) Non-ETS: Kyoto stipulates the same percentage targets as the ETS to 2012.	Non-ETS industries non-CO_2, other manufacturing (including food processing), transport, chemicals (up to 2011), agriculture, waste, aviation (up to 2012).	CO_2, CH_4, N_2O, HFCs, PFCs, SF6
— (2013-2020) Diffuse sectors: EU emissions down by 10% on 2005 levels by 2020. Spanish target identical to the EU average (*i.e.,* –10%).	Transport, buildings, agriculture, waste	CO_2, CH_4, N_2O, HFCs, PFCs, SF6
— (2013-2020) Non-ETS, non-diffuse sectors: Maintain Kyoto emissions limits to 2020.	Food processing, services and manufacturing not elsewhere classified.	CO_2, CH_4, N_2O, HFCs, PFCs, SF6

[1] PFCs: perfluorcarbons. HFCs: hydrofluorcarbons.

models have less detail on specific technology options, which may compromise the accuracy of sectoral abatement cost estimates.

In surveying the existing literature we observe multi-region studies (*e.g.* Böhringer & Rutherford, 2010), whilst differences in the decomposition of emissions gases in specific member countries has given rise to sectorally more detailed single region CGE studies (*e.g.* Dellink *et al.,* 2004). As expected, the general consensus is that meeting emissions reduction targets entails a short to medium term cost, but the differences in contexts and policies modelled render direct comparison of results difficult, or of little value. A cursory review of the relevant Spanish literature (Labandeira *et al.,* 2004, 2009a; Labandeira & Rodríguez, 2010; González-Eguino, 2011) suggests that gross domestic product (GDP) falls of between 0.1% and 1% by 2012 may result from emissions restrictions.

A key issue for this study is how the agriculture sector is impacted directly from facing its own emissions reduction targets, and indirectly from facing higher energy prices under the auspices of the ETS scheme. Given the diffuse nature of agricultural emissions, how reductions targets are to be achieved is left as an internal matter in each member state (European Parliament, 2009a) and is beyond the focus of this research. Some CGE applications (Labandeira & Rodríguez, 2006; Van Heerden *et al.,* 2006; Labandeira *et al.,* 2009b) report limited impacts on agriculture, but only account for emissions controls on combustion, whilst not accounting for agriculture's diffuse emissions. One exception is a study assessing the Dutch economy by Dellink *et al.* (2004). The authors estimate relatively sharper falls in agricultural production (–4.8%) compared with the wider economy (–2.7%) by 2050, citing the relatively higher emissions intensity in agriculture (*i.e.,* including non-CO_2 gases).

Given a general paucity of antecedents within the quantitative literature, there exists an additional need to assess the economic impacts of emissions targets on a selection of specific livestock and cropping practises. Our focus on Spain is also justified by its strong growth record (pre-crisis) and the consequent sharp adjustment process it will need to follow in order to adhere to its emissions targets, which is likely to have important implications on the agricultural sectors. Furthermore, with few exceptions (González-Eguino, 2011) existing CGE Spanish studies have either analysed only the impact of meeting the Kyoto 2012 targets or other hypothetical short term policy targets. In addition to Kyoto, this research includes a detailed treatment of the EU CEP package, whilst a detailed baseline of annual macroeconomic projections to 2020 which accounts for the impact of the crisis on investment and capital accumulation, favours the usage of a recursive dynamic CGE treatment. A further important characteristic of this study is that we account for all six GHGs given the relative importance of non-CO_2 gases in agriculture, whilst we combine environmental policy targets with an explicit representation of common agricultural policy (CAP) mechanisms.[4] In a further experiment, we contemplate the mitigating impacts of a hypothetical support mechanism (akin to a 'cross-compliance' Pillar I transfer payment) post-2013, which reimburses the agriculture sector for any costs incurred in meeting environmental targets.

The objective of this research is to explore the effects on Spanish agriculture of the emissions reduction targets proscribed by the Kyoto Protocol and the Clean Energy Package, employing a dynamic CGE framework.

Methodology

Model database

To support our construction of the accompanying CGE Spanish database, the latest available Input-Output (IO) tables (year 2007) published by the Instituto Nacional de Estadística (INE, 2010) are a principle source of secondary data. Importantly, the conditions imposed by the IO table underlie the fundamental accounting conventions of the CGE model framework. For the purposes of this study, our aggregation focuses principally on agricultural activities, whilst remaining sectors are those identified within the EU ETS, the non-agricultural 'diffuse sectors' (see Table 1), and 'residual' manufacturing and services activities. The model has three broad factors (capital, labour and agricultural land), of which labour is further subdivided into 'highly skilled', 'skilled' and 'unskilled'. Household Survey Data (INE, 2009) permit a disaggregation of private household purchases for up to eight distinct disposable income groupings. In addition, trade is disaggregated by 'intra-' and 'extra-EU' routes.

UNFCCC (2011) Spanish submissions data on emissions are separated into fuel combustion; fugitive emissions; industrial processes; solvent and other product usage; land use, land use change and forestry (LULUCF); waste emissions; and agricultural emissions. The data set includes concordance by industry activity, although in some cases further disaggregation is required to map to the model sectors. For combustion emissions, UNFCCC data is combined with energy usage data from the International Energy Agency (IEA, 2011), and intermediate input data from the Spanish IO database (INE, 2010), to map emissions by fuel type, industry and source (*i.e.*, domestic/imported). Fugitive and industrial process emissions are assigned to specific IO industries following Rose & Lee (2009), whilst solvent and other product emissions all originate from the chemical industry. Waste emissions are apportioned between the IO sectors of market and non-market sanitation services, whilst LULUCF emissions are excluded from the current analysis.[5] Spanish agricultural emissions by activity are, in general, clearly disaggregated into specific agricultural activities within the UNFCCC database, although nitrogen run-off from agricultural soils is assigned employing additional data on land usage (MARM, 2008) and nitrogen uptake for specific crops (MARM, 2010). As a final step, non-CO_2 emissions by each sector are converted into CO_2 equivalents (CO2e) employing global warming potential (GWP) conversion ratios.

Model framework

The standard CGE framework is a 'demand' led model, based on a system of neoclassical final, intermediate and primary demand functions. Under the assumption of weak homothetic separability, a multi-stage optimisation procedure allows demand decisions to be broken into 'nests' to provide greater flexibility through the incorporation of differing elasticities of substitution. Moreover, accounting identities and market clearing equations ensure a general equilibrium solution for each year that the model is run. After appropriate elasticity values are chosen to allow model calibration to the database, and an appropriate split of

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[4] Given that the CAP introduces supply rigidities into agricultural markets, whilst maintaining relatively inefficient farmers in production, it implies that the necessary rise in agricultural MAC to comply with emission reductions targets is higher (compared with a hypothetical reality where the CAP did not exist).

[5] Whilst the UNFCCC data provide a figure for the total sequestration of land, due to data limitations, we were unable to disaggregate this sequestration potential between agricultural land types and forestry land. Moreover, due to the difficulty in valuing forestry land, the model does not have a land factor in the forestry sector.

[6] In order to ensure a general equilibrium solution, the number of endogenous variables and model equations must be equal.

endogenous-exogenous variables is selected (closure)[6], specific exogenous macroeconomic or sector specific 'shocks' can be imposed to key variables (*e.g.,* tax/subsidy rates, primary factor supplies, technical change variables, or real growth in GDP and/or its components). The model responds with the interaction of economic agents within each market, where an outcome is characterised by a 'counterfactual' set of equilibrium conditions. For the interested reader, key equations are reproduced in Suppl. Table 1 (pdf).

To improve our estimates of the supply responsiveness of agricultural activities to emissions targets in the context of supply rigidities and support policies, additional code is implemented to support the representation of the CAP. This follows previous CGE agricultural studies and is described in Table 2. As an important driver of (carbon dioxide) emissions, modifications are also made to the intermediate and final demands energy nests (Burniaux & Troung, 2002). Energy demands are now separated from non-energy demands, where in the production nest they are treated as part of value added (rather than intermediate inputs) owing to the important relationship between (energy using) capital and energy. Furthermore, electrical and non-electrical (*i.e.,* coal, gas, oil, bio-fuels) demands are in separate nests. For producers, this implies that primary energy (unlike electricity) can also be used as a 'feedstock' input into other industries (*i.e.,* fertilizer, refining of raw energies) rather than directly consumed as an energy source.

Changes in GHG emissions are assumed to be directly proportional to five driving mechanisms in the model (Rose & Lee, 2009): output, land use[7], fertiliser use (in the crop sectors), fossil fuel use by firms and households.[8] Furthermore, sectors are granted some flexibility to mitigate their emissions by reducing their fertiliser use (*e.g.,* crop sectors), or substituting toward cleaner energy sources or less energy intensive capital, while output related emissions can only be reduced by a contraction in the scale of operation[9]. Additional tax wedges between pre- and post-emission cost prices, measured in Euros per metric tonne of CO2e, are inserted into the model code on each of these five transaction flows to characterise endogenous changes in marginal abatement costs (MAC) for sectors outside the ETS scheme and the exogenous permit price for ETS sectors, respectively.

Kyoto emissions reductions to 2012 are modelled by (exogenous) annual linear reductions in both the number of domestic permits issued for the ETS sectors and the relevant emissions quota for non-ETS sectors. It should be noted that since Spain is assumed to be a 'price taker' within the ETS (*i.e.,* small country assumption), the permit price is held exogenous in all years. Then, in line with Labandeira & Rodriguez (2010), Spanish industries are able to endogenously import additional permits from other EU Member States subject to domestic demand conditions (determined by the macroeconomic projections), gradual reductions in the exogenous supply of domestic permits, and year-on-year exogenous changes in the permit price. The purchase/sale of permits from/to other EU members is subsequently recorded as an additional import/export in the national accounts, adjusting the trade balance, and subsequently Spanish GDP.

In keeping with the EU's decision to initially allocate the majority of permits for free (employing a 'historical' emissions criterion), ETS permit allocation up to 2012 is via a 'grandfathering' method, whilst in the subsequent period (2013-2020), an increasing proportion of permits are auctioned at different rates (depending on the sector). Permit allocation is modelled by refunding the proportion of the cost incurred by firms in 'buying' grandfathered permits via a lump-sum subsidy payment, as set out in Edwards & Hutton (1999) and Parry (2002). Thus, in a given year, if 40% of a sector's permits are auctioned, only 60% of the cost is refunded. Revenue raised from the auctioning of permits is paid, along with taxes on non-ETS sector emissions, to the government as tax revenue.[10] For the non-ETS sectors, emissions totals are subject to ceiling limits governed by inequality constraint equations. These equations directly determine an endogenous MAC per tonne of CO2e associated with meeting the specified reduction.

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[7] Methane released from rice-growing

[8] For example, vegetable sector emissions from combustion of petrol are in direct proportion to the percentage change in the quantity demanded of petrol; output emissions vary in direct proportion to percentage changes in output.

[9] The authors recognise the potential for emissions reductions from adaptations in production processes as an area for further research. See Hertel *et al.* (2008).

[10] There are various hypothetical options for revenue recycling of environmental tax revenues ('double dividend') which lie beyond the scope of this study.

Table 2. Common Agricultural Policy (CAP) Modelling and Baseline Policy Shocks

A. Modelling

In the model data, coupled support payments to the agricultural sector are characterised as subsidies on land (*e.g.,* set-aside and area payments) capital (*e.g.,* headage premia on livestock, investment aids), production (*e.g.,* production aids, stock purchases) and intermediate input subsidies (seed payments, irrigation aids, distribution and marketing payments, etc.). Given the policy evolution of the CAP, sector specific payments are gradually decoupled year on year and reconstituted as a Single Farm Payment (SFP), which is introduced as a uniform subsidy rate on the land factor (Frandsen *et al.,* 2003). Intervention prices are modelled as changes to trade protection whilst pillar I modulation payments are implemented year on year as a direct payment to the 'agricultural farm household', which collects all agricultural policy payments and returns on agricultural value added. Employing inequality constraint step functions (Elbehri & Pearson, 2005), production quotas are modelled for raw sugar and milk (Lips & Rieder, 2005), as well as Uruguay Round constraints on export quantities and subsidy expenditure. In agricultural factor markets, the movement of heterogeneous land types between agricultural sectors is governed by a three nested elasticity of transformation function (OECD, 2003), whilst a land supply curve is incorporated within the model code based on an econometric specification (Renwick *et al.,* 2007).

B. Policy shocks

- Introduction of the SFP — year on year shocks (2008-2015) taken from historical data (FEGA, 2010). Complete decoupling of agricultural payments by 2015.
- Modulation implemented based on historical data (FEGA, 2010). Modulation projections assumed to rise to 3% by 2015. Given the structure of the agricultural industry in Spain and the small farms exemption, historical data reveals that Spain's modulation rate is below the EU policy prescribed rate (1% a year from 4% in 2006 to 10% in 2012) (FEGA, 2010). Consequently, we assume that the modulation rate rises to 3% by 2015. Pillar II Modulation payments transferred to farm household income function.
- Dairy (2008) and sugar (2008-2010) intervention price reductions.
- Export subsidy changes based on historical data (2008-2009) (FEGA, 2010).
- 2% increase in EU wide milk quota sanctioned by the EU (April 2008). Year on year 1% increases (2009-2014). Abolition 2015.

Given the lack of relevant Spanish data sources, calibration is facilitated through usage of substitution and expenditure elasticities from the standard GTAP version 7.1 data base (Narayanan & Walmsley, 2008). In the energy module, substitution elasticities from GTAP-E (Burniaux & Troung, 2002) for developed countries are employed. Following Dixon & Rimmer (2002), export demand elasticities are calibrated to upper level GTAP Armington elasticities, whilst the transformation elasticities for land (between uses) and agricultural industry substitution elasticities between (i) intermediate inputs and value added and (ii) individual intermediate inputs are taken from Keeney & Hertel (2005). Central tendency estimates of labour supply elasticities for Spain are taken from Fernándes-Val (2003) whilst for agro-food products, private household expenditure elasticities are taken from a study by Moro & Sckokai (2000) on Italian households stratified by wealth.

Closure and scenario design

The study implements sequential shocks for three alternative realities during the period 2007-2020. In our *business as usual* 'baseline' scenario (*i.e.,* no emissions restrictions), a projection of the Spanish economy is plotted by exogenising and shocking real GDP, consumption, investment, government expenditure and aggregate exports (see Table 3). Aggregate imports (and by implication the trade balance) adjust endogenously as a residual component of the aggregate demand function, whilst the (numeraire) exchange rate is fixed. Shocks to aggregate investment and public expenditure simulate the fallout from the recent financial crisis, the fiscal stimulus that took place in the crisis years and the 'austerity measures' that followed. Further shocks simulate exogenous world fuel price changes, total factor productivity changes for all sectors, consumer taste changes toward white meats (see Table 3) and reforms to the CAP (see Table 2). For the duration of the *baseline* scenario, emissions in all sectors are free to rise or fall in line with the endogenously determined behaviour of their drivers.

Scenario *EPol* contemplates the impact of EU environmental policy as prescribed by current Kyoto targets and a number of EU policy initiatives. A fully detailed description of this scenario is provided in Table 1. To gauge the macroeconomic impacts on Spain's economy,

Table 3. Baseline projections shocks (%) between 2007-2020 in Spain

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2016**	**2018**	**2020**
Real GDP	0.9	–3.7	–0.2	0.8	1.6	1.8	1.9	3.6	3.6	3.6
Real Consumption (C)	–0.6	–5.0	1.2	0.9	1.4	1.6	1.9	3.8	3.8	3.8
Real Investment (I)	–4.4	–15.7	–7.6	–1.3	2.7	3.7	4.5	9.2	9.2	9.2
Real Public Expenditure (G)	5.5	5.2	–0.7	–1.3	–0.8	–0.6	–0.6	–1.2	–1.2	–1.2
Real Exports (X)	–1.1	–11.6	10.3	6.7	4.6	4.7	4.9	10.4	10.5	10.5
Population (P)	1.8	1.2	0.4	0.2	0.3	0.2	0.2	0.5	0.5	0.5
Bioethanol world prices (WP)	13.2	–5.5	32.5	10.6	–1.0	–0.4	0.7	3.4	2.2	–1.8
Biodiesel world prices (WP)	44.0	–25.7	6.0	19.9	0.4	–0.5	1.2	–1.0	0.4	–0.3
Coal world price (WP)	14.3	3.2	–6.7	–0.5	0.5	0.5	0.0	0.0	0.0	–0.5
Oil world price (WP)	37.3	–41.6	18.7	3.9	8.7	8.0	6.0	8.1	6.3	3.7
Crude gas world price (WP)	23.0	–58.7	21.6	27.4	8.6	–0.6	–0.7	4.7	1.1	3.2
Preferences for white meat	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.8	1.8	1.8
Preferences for red meat	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.7	–0.7	–0.7
Productivity changes:										
Crops	1.5	1.5	1.5	1.1	1.1	1.1	1.1	2.3	2.3	2.3
Ruminants	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.6	0.6	0.6
Non ruminants	0.8	0.8	0.8	0.7	0.7	0.7	0.7	1.4	1.4	1.4
Food	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.8	0.8	0.8
Energy industries	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0
Manufacturing	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	4.0	4.0
Others	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0

Sources: GDP, X, P up to 2016 (IMF, 2011) then project constant rate forward; C, I, G up to 2014 (EC, 2011) then project constant rate forward; WP Biofuels (OECD/FAO, 2011); WP Others (US EIA, 2010).

appropriate macroeconomic 'shifter' variables are exogenised to allow each component of aggregate demand (*i.e.,* real GDP, consumption, investment, etc.) to become endogenous. These shifter variables assume their exact same values as recorded in the baseline, where any additional impacts on GDP, consumption, investment etc. are attributed to the incremental impacts of emissions targets.

As noted previously (section 'Model Framework'), the ETS permit price is exogenous (small country assumption), which allows for endogenous changes in pan-European imports/exports of permits at the given price. Thus, shocks to ETS permit prices follow historical trends up to 2011 (www.sendeco2.com), whilst from 2012 the price is projected forward linearly in order to meet a final price of €50 ton^{-1} of CO_2.[11] Domestic ETS permits, which are controlled exogenously, are grandfathered until 2012. Full auctioning then becomes the rule for the electricity sector from 2013, whilst the remaining ETS sectors linearly increase the proportion of permits to be auctioned towards a 70% target by 2020 (European Parliament, 2009b). In the non-ETS sectors, with the enforcing of emissions limits in scenario *EPol*, the MAC assumes a positive value in those cases where limits become binding and therefore abatement is necessary.

Agriculture is initially required to meet the 2012 Kyoto target, and subsequently the 2020 diffuse sector target, whilst they are expected to remain outside the ETS for the whole period (Ancev, 2011).[12] Since there remain non-diffuse sector emission flows outside the scope of the ETS that are not explicitly covered by emissions policy beyond the 2012 Kyoto target (see Table 1), Kyoto ceiling limits are maintained from 2013-2020. In scenario *EPol* the model closure is modified so that Spanish intra-EU commodity import prices rise (relative to the baseline) in direct proportion to environmental policy driven (Spanish) commodity export

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[11] In an assessment by Capros *et al.* (2008), which was employed by the European Commission in preparation of the Climate and Energy Package, it was estimated that the permit price required to meet the emissions reductions for the ETS industries by 2020 was €47 ton^{-1} of CO_2.

[12] This article provides an informative discussion on the issues surrounding the extension of the ETS to agriculture.

price rises.[13] This assumption implies that EU trade will be at a competitive disadvantage to non-EU trade since (i) EU emissions reductions are stricter over the time horizon of our experiment (in the absence of a 'Kyoto II' agreement) and (ii) two large non-EU (agricultural) traders, the USA and Canada, are not are not signatory members of the Kyoto Protocol.

Scenario *EPolComp* is identical to *EPol*, except that it ensures that post-Kyoto (2013-2020) environmental policies are cost neutral for all the Spanish agricultural sectors. In other words, all revenue accrued from agricultural environmental taxes is returned via a lump sum payment to each agricultural sector. Given that the budget allocations are already agreed up to 2013, it is not envisaged that further farm payments will be made prior to this date. Of particular interest here are the effects, relative to scenario 2, on food prices, agricultural employment and farm household incomes.

Results

Unless otherwise stated, results are presented in comparison with the baseline scenario. Consequently, the results are not absolute changes but deviations from a 'baseline' path. Further sensitivity analyses can be found in Suppl. Table 2 (pdf).

Overview

As expected, the Spanish economy faces a short to medium-run economic cost with the implementation of the Kyoto and EU environmental targets, as evidenced by reductions in all real macro indicators and rises in general price indices (Table 4). In meeting Kyoto targets by 2012, Spanish GDP falls 0.7% in the *EPol* scenario with concurrent general price rises of 1.6% (Table 4). By 2020, GDP and general price changes are exacerbated further (–2.1% and 3.4%, respectively). Spain's relative macroeconomic contraction depresses both employment (–2.4%) and real wages (–1.9%), with supply-elastic 'unskilled' labour (used heavily by the agricultural sector) suffering more from the employment fall (–5.5%), whilst inelastic 'high-skilled' labour witnesses a real wage drop of 2.5%. In terms of economic welfare (real incomes), by 2020 household utility falls, though slightly more so for the lowest income grouping (–3.1%) compared with the highest income grouping (–2.2%), indicating the potential regressivity of the environmental policy. This is because lower income households spend a larger share of their incomes on energy, where household energy costs have risen cumulatively by 48% (not shown) by 2020 compared with the baseline.

Since the effect of the emissions quota reductions is to raise the cost of GHG emitting energy inputs and outputs, the primary energy sectors perform badly, in line with expectations. Among those industries which witness the most notable output declines by 2020 (results not shown) are coal (26.5%), gas (14.7%), oil (13.3%), and petrol industries (8.4%).

In Figure 1, the annual evolution of (endogenous) emissions between 2007 and 2020 is estimated. Emissions under the ETS increase slightly in 2009 despite the recession due to the dramatic fall in permit price (see Fig. 2), whilst ETS emissions surge in 2011-2012, and again in 2012-2013, due to the accession of aviation and chemicals industries, respectively. From 2013 onwards, ETS emissions continually rise in spite of a steadily rising (exogenous) permit price and a decreasing domestic allocation of permits, as pan-EU permit trading (*i.e.,* imports) plays an increasingly pivotal role in accommodating downwardly ratcheted domestic emissions targets for those sectors within the ETS (Table 1). Indeed, we estimate that Spain increases its imports of emissions permits from 24 million allowances in 2007 to 50 million in 2020. In the case of agriculture, emissions reductions are frontloaded based on the commitments mandated under Kyoto, whilst the same is true for the remaining diffuse sectors which have already met their 2020 target by 2012, so in the period 2013-2020, these ceiling limits are maintained in the face of expansionary pressure from the recovering economy.

Figure 2 compares the MAC in agriculture with the exogenously projected permit price. The average MAC across agricultural sectors reaches €51 ton^{-1} of CO2e (tCO2e) by 2012 (Kyoto target), whilst with economic recovery over the 2013-2020 period this estimate increases to €86/tCO2e by 2020.

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[13] We make the simple assumption in our single country CGE model that environmental policy driven cost rises in Spain are, on average, representative for the rest of the EU.

Table 4. Aggregate impacts (%) from emissions reductions targets in Spain *vs.* the baseline

	2012	2020	
		Scenario 'EPol'	**Scenario 'EPolComp'**
Factor markets			
Aggregate employment			
Low skilled	–2.4	–5.5	–5.2
Skilled	–0.9	–2.1	–2.1
High skilled	–0.5	–1.2	–1.2
Overall	–1.0	–2.4	–2.3
Aggregate real wages			
Low skilled	–0.3	–0.6	–0.6
Skilled	–0.9	–2.2	–2.1
High skilled	–1.1	–2.5	–2.4
Overall	–0.8	–1.9	–1.9
Aggregate capital usage	–0,1	–0.3	–0.3
Aggregate real capital price	–2,5	–6.0	–5.9
Agricultural factor markets			
Average usage			
Capital	0.5	0.8	1.6
Labour	–0.7	–1.7	–0.9
Land	0.0	0.0	0.0
Real returns			
Capital	–1.4	–3.9	–2.1
Labour	–0.3	–0.4	1.1
Land	–2.8	–5.4	–3.5
Macro indicators			
Real GDP	–0.7	–2.1	–2.0
Consumption	–0.6	–1.6	–1.5
Investment	–2.1	–5.4	–5.4
Government spending	0.0	–0.2	–0.2
Exports	–1.3	–2.4	–2.3
Imports	–1.4	–3.1	–3.1
CPI	1.6	3.4	3.3
Food price index	2.9	3.7	3.0
Utility			
Lowest income group	–1.4	–3.1	–3.0
Highest income group	–1.1	–2.2	–2.2

GDP: gross domestic product. CPI: Consumer price index. Source: Authors' own calculations.

Finally, examining the impact of agricultural compensation in scenario *EPolComp* from 2013-2020, the MAC in agriculture pivots upwards (Fig. 2), because (*ceteris paribus*) it encourages those agricultural producers 'at the margin' to remain in production. Consequently, the MAC required in order to discourage additional production (and emissions) rises from €86/tCO2e to €97/tCO2e. In contrast, additional compensation mitigates environmental policy induced increases in the cost of production (assuming zero profits), resulting in a relative fall in food (and general consumer) prices in comparison with scenario *EPol* (Table 4 and discussion below). Since such compensation only applies to a small sector, the macro impacts (Table 4) are negligible. With a cumulative cost of €1,301 million to the government (not shown), the scheme improves GDP by 0.1 percentage points (Table 4).

Agriculture

In 2007, Spanish agriculture constitutes 4.0% of GDP (compared with an EU-27 average of 2.9%) (Eurostat, 2012) and employs 877,000 people (INE, 2010).

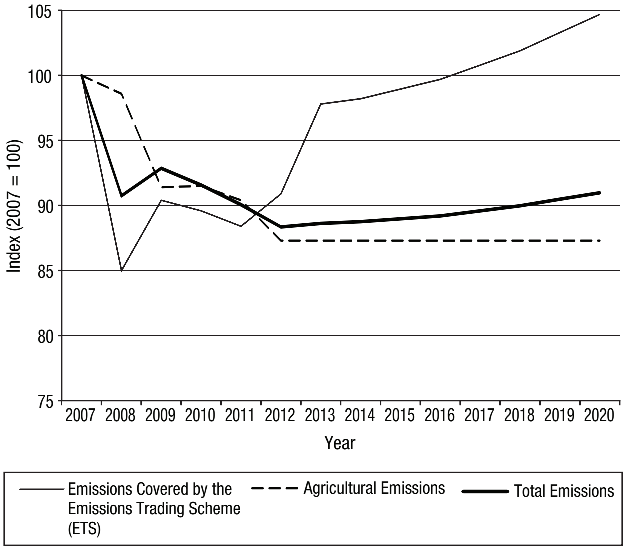

Figure 1. The evolution of Spanish emissions over time. Source: Authors' own calculations.

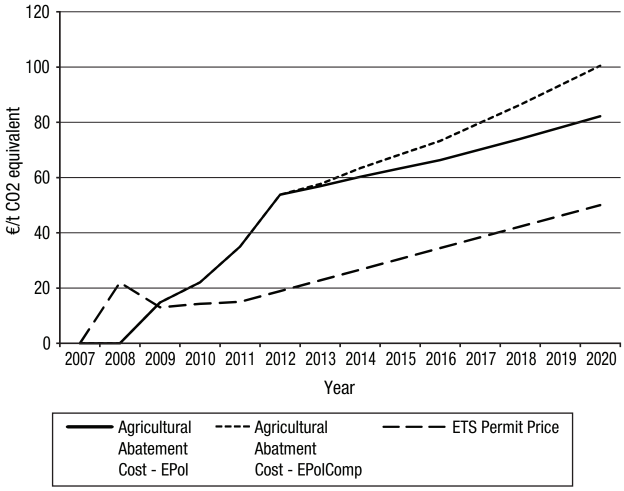

Figure 2. Emissions trading scheme (ETS) permit prices and marginal abatement costs for agriculture. Source: Agricultural abatement costs — Authors' own calculations. ETS permit price up to 2011 from www.sendeco.com, then increased linearly to hit €50 in 2020 (Capros *et al.,* 2008).

Examining the composition of Spanish agriculture, the main arable activities are fruit and vegetables, accounting for 13% and 17% of total agricultural product (Eurostat, 2012). Similarly, the largest livestock activity is pig production, constituting 12% of total agricultural product. Examining the data in Table 5, it is encouraging to note that these three 'large' sectors exhibit relatively lower GHG emissions intensities.

In scenario *EPol*, by 2020 average primary agricultural output falls 4.3% while prices rise 7.7% (Table 5). In the factor markets (Table 4) average agricultural employment falls 1.7% by 2020 compared with 2.4% for the Spanish economy, whilst at 0.4%, the decline in agricultural real wages is smaller than the Spanish average (2.0%). In the land market, rental rates fall by 5.4%, whilst land supply remains unchanged. Agricultural capital usage rises by 0.8% compared to a 0.3% decline for the entire economy. The fact that agricultural factor markets perform better compared to the whole economy, despite relatively greater contractions in output, reflects the changing composition between value added and intermediate inputs in this sector. More specifically, higher prices for fertiliser (in crops sectors) encourage farmers to substitute in favour of labour, land and capital. Consequently, cropping activities become more extensive (less fertiliser usage per hectare) in response to environmental policy.

The reasons why primary agricultural output and prices are disproportionately affected under emissions targets are principally related to the intensity and the substitutability of its emitting activities.[14] Indeed, according to our 2007 data (based on UNFCCC), one tonne of agricultural CO2e emissions corresponds to only €847 of agricultural production (Table 5), compared to €6,709 in the non-agricultural sector. With contractions in agricultural activity, real agricultural income is estimated to fall by 5.9%, leaving Spanish farmers €1,510 million worse off by 2020. This result motivates our exploration of an additional Pillar I type compensatory lump sum transfer to agricultural industries — our *EPolComp* scenario. As expected, this mitigates the negative impact on real agricultural incomes, which by 2020 fall 3.8% (€640 million) relative to the baseline — an improvement of €870 million compared with the scenario *EPol.*

A cursory examination of the bottom of Table 5 shows that the aggregate agricultural sector averages mask a notable divergence in supply and price effects between cereals, livestock, fruit and vegetables activities. These effects are explored in further detail in the following sections.

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[14] In comparing total agricultural activity with the rest of the Spanish economy, González-Eguino (2011) derives the same result as this study.

Table 5. GHG intensivity and performance of agricultural and food industries in 2020 *vs.* the baseline. Bold figures indicate weighted averages

Industry	Emissions (tCO2e)	Production (€/tCO2e)	Scenario 'EPol'			Scenario 'EPolComp'		
			% Change in output	% Change in supply price	% Change in emissions	% Change in output	% Change in supply price	% Change in emissions
Select agricultural sectors								
Wheat	3,296	533	–10.3	10.8	–32.4	–9.3	9.8	–32.8
Barley	5,089	516	–2.8	13.3	–27.5	–1.9	9.3	–28.3
Maize	996	935	–11.9	7.3	–28.2	–11.9	7.4	–29.4
Rice	578	497	–29.5	24.7	–34.9	–29.8	25.3	–36.2
Oilseeds	617	599	–12.7	9.9	–32.2	–10.6	8.3	–31.4
Vegetables	1,016	6,928	–1.9	1.7	–16.2	–1.7	1.5	–17.1
Fruit	2,447	2,296	–3.1	3.7	–24.5	–2.5	3.0	–25.2
Olives	6,254	257	–4.2	23.6	–43.8	–3.2	17.0	–44.4
Cattle	8,632	353	–4.9	14.1	–5.4	–3.7	10.2	–4.3
Pigs	7,853	652	–3.8	10.8	–5.4	–2.8	7.1	–4.6
Sheepgoats	5,110	322	–4.2	12.7	–4.3	–3.2	8.6	–3.3
Poulteggs	563	5,663	–2.1	1.8	–6.2	–1.7	1.6	–6.2
Rawmilk	2,845	1,094	–2.3	6.2	–3.3	–1.9	4.8	–3
Select food sectors								
Red meat	139	47,555	–5.2	8.6	–20.2	–3.9	6.3	–20.2
White meat	246	46,973	–3.0	5.0	–23.4	–2.4	3.7	–23.4
Dairy	610	15,111	–1.7	3.4	–11.7	–1.5	2.9	–11.7
Aggregate sectors								
Cereals	10,417	**573**	**–7.8**	**11.9**	**–29.1**	**–7.1**	**9.7**	**–29.9**
Fruit & Vegetables	3,463	**3,655**	**–2.4**	**2.6**	**–19.9**	**–2.1**	**2.2**	**–20.7**
All cropping activities	24,878	**1,048**	**–4.9**	**6.9**	**–25.1**	**–4.4**	**5.8**	**–25.9**
Livestock	25,474	**650**	**–3.4**	**8.9**	**–5.0**	**–2.6**	**6.2**	**–4.4**
Agriculture	50,352	**847**	**–4.3**	**7.7**	**–17.3**	**–3.7**	**6.1**	**–17.6**
Food	8,193	**24,765**	**–2.6**	**3.7**	**–24.5**	**–2.2**	**3.0**	**–24.6**

Source: Authors' own calculations.

Crops

Crops sectors have a considerably larger proportion of emissions due to energy combustion activities (30%) than livestock (4%). Consequently, there is more flexibility in crop production to substitute away from 'dirtier' energy inputs toward cleaner equivalents and/or less energy intensive capital. Moreover, (nitrogen) fertiliser application in crops is also substitutable, whilst in livestock a large proportion of its emissions are 'output' driven (methane). As a result, there are larger percentage reductions in crop emissions (Table 5) vis-à-vis livestock. In general, cereals and oilseeds sectors fare the worst due to their relatively higher levels of GHG intensity (*i.e,* oilseeds, rice and wheat) and/or due to high dependency on non-EU feed imports of maize and oilseeds in the benchmark data which become relatively cheaper (vis-à-vis EU imports) due to stricter emissions controls within the EU. Barley also exhibits a comparably high GHG intensity compared to other crops, although output falls by less despite suffering a comparable price increase to wheat (Table 5). This is because Spanish wheat is more exposed to competitive external trade,[15] which implies a greater risk of non-EU import substitution.

Elsewhere, vegetable industry output (supply price) falls 1.9% (rises 1.7%) compared with the baseline, whilst for the fruit industry corresponding output (supply price) estimates are –3.1%. (3.7%) (Table 5). Compared with the cereals, oilseeds and olives industries,

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[15] Time series data from DATACOMEX reveals that wheat imports far exceed those for barley, whilst wheat exports are also noticeably larger than barley. Furthermore, the same data source reveals Spain's heavy dependence on extra-EU imports of maize and oilseeds (primarily for animal feed).

these larger agricultural sectors suffer relatively muted output reductions, although emissions reductions in percentage terms are comparable. This is because fruit and vegetable activities emit fewer emissions in relation to the size of the sector. Importantly, it should also be noted that significant exposure to export markets ensures that even limited environmental cost driven price rises lead to responsive output falls in these sectors.[16] In the olive sector, emissions intensity is particularly high (column 1, Table 5) owing to considerable nitrogen emissions from fertiliser usage,[17] resulting in an MAC induced supply price rise of 23.6% compared with the baseline. Notwithstanding, output reductions are relatively small since a large majority of olive demand is intermediate, subject to a (Leontief) inelastic demand curve by the downstream vegetable oils sector.

Livestock

Within extensive livestock systems (*i.e.,* cattle, sheep/goats) there are considerable methane emissions from enteric fermentation. Similarly, intensive livestock production (*i.e.,* pigs), generates significant methane via manure management activities. Consequently, relative to the size of the sector, each of these sectors has high output driven emissions intensity. As a result, cumulative supply price rises in cattle (14.1%), sheep (12.7%) and pigs (10.8%) by 2020 are notable (Table 5). Each of these sectors has limited flexibility in modifying their behaviour to reduce emissions; whilst live animals are predominantly employed as Leontief intermediate inputs in downstream food sectors implying inelastic demand responsiveness for these activities. Consequently, these industries do not fare as badly as their high GHG intensities suggest, with output reductions of 4.9% in cattle, 4.2% in sheep and goats and 3.8% in pig production. As an intensive livestock system, manure management in raw milk contributes a larger source of methane emissions relative to extensive cattle production, although this is outweighed by considerably fewer enteric fermentation methane emissions in raw milk compared with cattle production.[18] Consequently, the GHG intensity in raw milk relative to cattle is lower, resulting in more muted price and output impacts relative to the baseline. In contrast with other livestock activities, poultry and eggs is far less GHG intensive in relative terms with an output reduction of only 2.1% compared with the baseline. Examining downstream sector meat prices (Table 5), the price of white meat falls relative to red meat (5.0% compared to 8.6%). In part, this is because of the mitigating impact of the poultry and eggs sector, whilst the higher price rise of red meat products is fuelled by larger price increases in ruminant livestock products (cattle; sheep and goats). The dairy industry witnesses a smaller price increase owing to relatively muted price rises in the upstream raw milk sector.

Compensation scenario

The addition of a 'cross-compliance' lump sum compensation payment in *EPolComp* does not imply a uniform impact across the livestock and crop sectors (Table 5). Assuming perfect competition, a lump sum transfer payment would reduce (marginal cost) prices and encourage greater participation of farmers at the margin (and therefore greater production). On the other hand, to adhere to stipulated emissions reductions, even higher MACs are now required in light of increased farmer participation (and production). Given greater substitutability, the higher MAC encourages larger reductions in the usage of energy, fertiliser and land use driven emissions, thereby granting greater leeway to those sectors characterised by output driven emissions. Consequently, the compensation scheme alters the optimal 'emissions reduction mix' among competing agricultural activities.

Examining Table 5, for most agricultural sectors the rise in costs provoked by relative MAC increases is more than offset by the compensation payment, such that prices fall and demand driven output rises compared with *EPol* (Table 5). In the livestock sectors

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[16] Fruit faces a larger price rise because it is more emissions intensive. Moreover, nitrous oxide emissions in fruit (UNFCCC, 2011) are almost three times the size as vegetables (despite the latters' larger size).

[17] Olive production has a relatively high nitrogen necessity per hectare, whilst in relation to the size of the sector, considerable land is devoted to this permanent crop. Consequently, GHG emissions are 'relatively' high.

[18] Dairy cattle have a higher energy intake per head than non dairy cattle and consequently generate more kilos of methane a year (per head) via enteric fermentation than non dairy cattle. Notwithstanding, the size of the dairy herd is far smaller than the non dairy herd in Spain, such that aggregate methane emissions from enteric fermentation are much smaller.

(particularly 'cattle', 'sheep and goats', and 'pigs') with a larger proportion of non substitutable output driven emissions, aggregate livestock output and emissions *rise* (0.8 and 0.6 percentage points, respectively) compared with *EPol*. Consequently, compensatory emissions reductions are required from crop activities (particularly cereals, fruit and vegetables), which have greater flexibility in reducing emissions at a reduced cost in terms of lost output. Interestingly, for some crops sectors (*e.g.* maize and rice, see Table 5) this unintended consequence of the compensation scheme in further focussing emissions reductions where they can be most easily made, is stronger than the mitigative effect of the compensation scheme, and output (price) falls (rises) slightly more than in the no compensation scenario.

Discussion

This study represents an important first step in addressing the economic costs of emissions reduction targets for Spanish agriculture (whilst also estimating some of the wider economy impacts) in the context of the complex structure of Kyoto and EU environmental policies. We do not examine the possibility of mandating agricultural emissions reductions within the ETS since at this time the possibility appears to be remote, whilst the merits of agriculture's inclusion within such a scheme are largely confined to administrative considerations which are beyond the scope of a deterministic equilibrium model (see Ancev, 2011; De Cara & Vermont, 2011).

Whilst the underlying short to medium term economic message of our study is (typically) pessimistic, these estimates are only partial in the sense that they do not account for the long term (discounted) social and economic gains from a reduced rate of global warming. A comparison with other Spanish studies reveals an array of base years, model assumptions (*e.g.,* comparative static *vs.* dynamic), elasticities and scenario designs. Notwithstanding, our Spanish GDP cost estimate in 2012 (–0.7%) falls within the (upper) range of estimates presented in the introduction.[19] Importantly, our GDP estimate by 2020 (–2.0%) exceeds that of González-Eguino (2011) by 2030 (–0.4%), which may be due to the imposition of more restrictive emissions targets pertaining to the EU's Climate and Energy Package.

Examining the impacts on primary agriculture, we estimate an agricultural marginal abatement cost (MAC) of €86/tCO2e. Our 2020 estimate is broadly consistent with MAC estimates in the existing economics literature. For example, Perez-Domínguez (2005) and Leip *et al.* (2010) derive agricultural MACs of €81/tCO2e and €108/tCO2e, respectively,[20] while Moran *et al.* (2008) state that UK agriculture reaching its feasible potential of 17.3% GHG emissions reduction would come at an MAC of £100/tCO2e by 2022. Similarly, other (principally engineering) studies report MACs in EU agriculture ranging between €50 and €140/tCO2e (De Cara & Jayet, 2006), with a corresponding average agricultural MAC estimate of €69.60/tCO2e (Vermont & De Cara, 2010).[21] Moreover, we conclude that the sector appears to suffer more than the Spanish average due to the higher emissions intensity and type of emitting activities — a conclusion which is supported by Dellink *et al.* (2004) who also incorporate all six GHGs in their study of the Dutch economy. If such a result is true, it opens up the ethical debate on whether it is possible to balance agricultural emissions mitigation with food security concerns (Golub *et al.,* 2011). Moreover, unilaterally mandated tighter EU emissions targets on (*inter alia*) agriculture may unfairly impact on EU farmers whilst also encouraging potential 'carbon leakage' effects arising from food imports from countries outside of any environmental protection legislation (Sturm, 2011). Further disaggregation by specific agricultural industries reveals that cropping activities bear greater emissions reductions than livestock sectors such that aggregate agricultural emissions targets are met. This is because livestock is characterised by a greater proportion of non-substitutable output driven emissions. Given nitrous oxide's considerably higher global warming potential compared with methane, it is to be expected that a more efficient

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[19] We posit that our estimate is more pessimistic due to additional negative capital accumulation effects (*i.e.,* dynamics).

[20] The former refers to the Spanish agricultural MAC associated with a 10% emissions reduction, while the latter refers to the MAC faced by EU livestock associated with an EU wide 20% emissions reduction.

[21] Direct comparisons are difficult because (i) estimates are from different fields of research (some are top-down' economic models and some are 'bottoms-up' engineering type models); (ii) within fields of research the modelling assumptions differ, and (iii) the emissions reductions targets do not refer to the same emissions limits or year end periods.

reduction in agricultural emissions at the margin may be achieved by reductions in fertiliser application. Nevertheless, our modelling assumption for output driven emissions does not account for adaptation strategies in livestock sectors via technological improvements and should, to some extent, be considered as a caveat of the research (see also below).

A further scenario demonstrates how full agricultural compensation (*i.e.,* zero net cost emissions policy) reduces food price inflation, whilst the resulting inflationary impact on the agricultural MAC has implications for the optimal emissions mix across agricultural sectors. Although we have not stipulated how such a payment would be implemented in practise, in concept, it is entirely consistent with the policy evolution of the current CAP toward simplified 'cross-compliance' transfer payments.

Our final thoughts rest on potential avenues for further research. It should be noted that at the current time, there are no published modelling studies for Spain (to our knowledge) which examine the potential for renewable energies in meeting emissions targets. In addition, further research should be directed toward incorporating the implications of changing land usage (particularly forestry land) and its concomitant repercussions on CO_2 sequestration potential in Spain. A final important issue relates to the sensitivity of technological improvements in agriculture to climate change and policy.[22] In this study, our ruminant, non-ruminant and crop total factor productivity (TFP) estimates are taken from Ludena *et al.* (2006) who employ FAOSTAT time series data (1941-2001) for 116 countries to generate forecasts up to 2040. Whilst some deceleration in TFP is included representing an 'implicit' account of climate change on yields, no 'explicit' climate change factors are incorporated into their analysis. Consequently, there is a greater need to link biophysical and economic models of Spain,[23] where additional climate change induced crop and livestock technological change estimates will have further implications for the emissions reductions mix reported in this paper. Continuing with this line of inquiry, it has been noted (EC, 2009) that an abstinence of adaptation and mitigation driven technological change in agriculture will accelerate medium to long run agricultural crop and pasture yield reductions owing to greater temperature rises, where those EU members on the northern basin of the Mediterranean face the highest risks. Although the exact extent of yield falls is not well understood, *status quo* 'baseline' projections (as in this study) may present an optimistic picture of agricultural output, which when compared with an emissions reduction scenario, overstates the potential relative economic costs of environmental policy. The discussion above provokes the question as to why farmers have not employed adaptation technology strategies more readily. McCarl & Schneider (2000) suggest that risk aversion, management requirements and the lumpiness of investment decisions are factors which reduce farmer adoption rates of such technologies, whilst Joskow & Marron (1992) point to the high fixed costs associated with cost effective environmentally friendly technologies. Notwithstanding, technology transfer is likely to receive greater attention in EU policy circles as the ongoing challenges of climate change mitigation and adaptation continue to gather momentum.

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[22] Farm management improvements include improved crop rotation strategies in order to make the best use of available water; the planting of trees and hedgerows around arable land to reduce water run off. Technological advancements may occur via the development of more resistant strains of seed; lower nitrogen emitting fertilisers; higher concentrate feeds in livestock to reduce enteric fermentation.

[23] Clearly, estimates of biophysical models from other regions will not capture the specificity of changes in the Spanish climate and soil.

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