# Reducing Greenhouse Gas Emissions from Irish Agriculture: A market-based approach

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***Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.***

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## Abstract

To date within Europe, a regulatory approach has been favoured when trying to curtail emissions from agriculture, the Nitrates Directive being a recent example. Economic theory indicates that market based solutions such as tradable emissions permits are the least cost means of achieving desired reductions in emissions. This paper compares the impact on farm incomes of a regulatory approach to emissions abatement with an emissions trading approach. A farm-level linear programming model for the Irish agriculture sector is constructed. A 20 percent reduction in Greenhouse Gas (GHG) emissions is introduced and the impact on farm incomes is measured. The linear programming model is then used to determine each farmer's shadow value for an emissions permit. These shadow values are then weighted to estimate supply and demand curves and used to simulate a market for emissions permits and the farm incomes are re-estimated. Finally, the implications for farm incomes of both abatement strategies are compared with a scenario where no constraint is placed on GHG emissions.

**Keywords:** Farm-level modelling, greenhouse gas emissions, tradable emissions permits

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## Introduction

The European Union (EU) as a signatory to the Kyoto Protocol and one of its main advocates, stated that "In deciding the next steps in our climate change policy, the European Council should take decisions which will enhance the conditions for reaching a new global agreement to follow on from the Kyoto Protocol's first commitments after 2012" (European Commission 2007). This led to a commitment by the EU to reduce EU Greenhouse Gas (GHG) emissions by 20 percent by 2020 compared to 1990 levels. Furthermore, if a "comprehensive international climate change agreement" is reached, the 20 percent reduction target would be increased to 30 percent (European Commission 2008).

The 20 percent reduction in EU emissions is to be achieved by reducing emissions from both the Emissions Trading Scheme (ETS)[1] sector and the non-ETS[2] sector. In the case of the ETS sector, an EU-wide cap on emissions from the sector will be introduced with emissions being reduced year-on-year to a level of 21 percent below the 2005 level by 2020. For the non-ETS sector, a 10 percent reduction target from 2005 levels by 2020 is proposed. The 10 percent reduction target is to be achieved through the introduction of individual emissions reduction targets for each member state (MS). These national reduction targets vary across MS and as a result, the burden placed on some countries is far greater than on other countries. For example,

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[1] The ETS sector is comprised of heavy industry sectors such as power plants, cement works, steel works etc.

[2] The Non-ETS sector is comprised of sectors that are not included in the ETS, such as transport, households, services, smaller industrial installations, agriculture and waste.

Romania and Bulgaria will be required to limit their growth in emissions from their non-ETS sectors to 19 and 20 percent above their 2005 levels, respectively. On the other extreme, Ireland, Denmark and Luxembourg must achieve a 20 percent reduction in non-ETS emissions by 2020. The allocation of the emissions reduction target across an individual MS's non-ETS sectors is at the discretion of the individual MS. Given the variability that exists between MSs in terms of the contribution of individual sectors to non-ETS emissions, each MS is likely to be faced with its own unique challenge to allocate its emissions reduction target. The initial allocation of emissions reduction targets across sectors is likely to be driven by economic, environmental and political motivations.

As a result, the burden faced by the agricultural sector across MSs is likely to vary considerably, not only as a result of differences in MS emissions reduction targets, but also as a result of the variability in the contribution of agriculture to each MS's non-ETS emissions. Within the EU, Irish agriculture represents the most extreme case where agriculture accounts for approximately 40 percent of non-ETS emissions compared with 15 percent for the whole EU. Thus far, no decision has been made on the share of the emissions reduction target for individual sectors within Ireland. However, given agricultures share of non-ETS emissions coupled with the 20 percent reduction target for non-ETS emissions, Irish agriculture could potentially face serious challenges both in terms of an emissions reduction target and the cost of achieving such a target.

Policymakers in MSs are likely to consider several criteria when designing GHG emissions abatement policies, including equity, minimizing the cost to those who must reduce their emissions, minimizing the administrative cost and political acceptability. Many alternative emissions abatement policies or mechanisms are available for consideration including emissions standards, emissions taxes and tradable emissions permits. For example, an emissions standard levied on all emissions sources are equitable, but tradable emissions permits are a least-cost policy for achieving a given level of emissions reduction (Prato, 1995).

This paper examines the potential impact on Irish agriculture of introducing a 20 percent emissions reduction target by 2020. Two possible emissions abatement instruments (emissions standard and tradable emissions permits) are examined and the impact of a 20 percent emissions reduction target on farm profitability is examined under both of these instruments relative to a baseline of no emissions reduction.

## Background

There are three broad approaches to reducing future GHG emissions from agriculture: (1) technological abatement strategies (e.g. changes in farm management practices and abatement technologies) (2) structural changes or changes in the enterprise mix from enterprises that produce high levels of GHG emissions to enterprises that produce low levels of emissions (Wassmann and Pathak 2007); and (3) a reduction in production levels. To date, research in Ireland has focussed largely on the potential of technological abatement strategies to reduce GHG emissions[3]. Within this group the costs and the potential abatement varies considerably, some of the farm management practices can reduce GHG emissions while increasing farm profitability. In contrast some of the abatement technologies have been shown to be quite costly. Lovett et al.

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[3] See O'Mara et al. (2007) for a more detailed review of research about GHG emissions abatement technologies for Irish agriculture.

(2006) argued that in order for farmers to reduce GHG emission levels, it is necessary to show that either the change in production system will not only reduce GHG emissions, but also increase farm profitability or, alternatively, some form of technology subsidy is required. However, technology subsidies are just one of a number of policy-based instruments that governments can use to reduce farm-level GHG emissions. These instruments can be grouped into three broad categories: (1) decentralized, such as environmental liability; (2) command-and-control, such as emissions standards; and (3) market-based, including tradable emissions permits, emission taxes and emissions subsidies (Common and Stagl 2005).

Emissions standards are relatively simple in their design and in the past, the EU and many of its MSs have shown a preference for this type of command-and-control approach to environmental policy within agriculture. For example, the EU Nitrates Directive (91/676/EEC) was implemented as a command-and-control policy with limits on the allowable level of nitrate emissions per hectare.  If an emissions standard is enforced, it provides the desired reduction in emissions. However, as numerous sources (e.g. Prato 1995, Common and Stagl 2005 and Tietenberg 2006b) have noted, it is not a cost minimizing approach and does not consider the variation in the marginal cost of emissions abatement across emissions sources. While Dietz and Heijnes (1995) argued that these policies in EU MSs are neither effective nor efficient.

In contrast, tradable emissions permits have been advocated as a cost minimizing abatement solution. The origins of tradable emissions permits are traced back to the work of Coase (1960). As Tietenberg (2006a) noted prior to Coase's (1960) article, there were two accepted mechanisms to reduce emissions: (1) a Pigouvian tax; and (2) a command-and-control mechanism that could take a variety of forms including an emissions standard, regulating the location of an emissions source or regulating technology. Alternatively, Coase (1960) proposed that we think of factors of production, including the right to create emissions, as property rights. If these property rights are explicit and transferable, we can then use the market mechanism to place a value on the rights in order to solve the externality problem. This concept was further developed by Crocker (1966) and Dales (1968). Finally, as Baumol and Oates (1988) noted, the creation of a market for tradable emissions permits leads to a market clearing price which will signal to polluters the 'opportunity cost of waste emissions.'

Tradable emissions permits have a number of limitations, most notably the transaction costs incurred in participating in the market. Tietenberg (2006a) described transaction costs as those costs other than the permit price, which are incurred and include market research costs, negotiation costs and legal costs. Jaraite et al. (2009) defined transaction costs as including both trading and administrative costs. Stavins (1995) concluded that transaction costs can lead to higher total costs of emission control because they lead to a reduction in the volume of emissions trading that takes place, as well as an increase in the total costs of control.

Given the range of alternative policy-based mechanisms that exist and the complexities that are associated with each mechanism, careful consideration should be given to the impacts of the policy on both GHG emissions and farms. For example, Helm and Pearce (1991) issued a stark warning when they argued that "the pursuit of single instrument solutions is naïve and possibly even dangerous." Instead, policies must be examined using a case-by-case approach because market and government failures vary on a case-by-case basis. Pezzey (2003) argued that in order to identify the best policy instrument, it is necessary to consider the full range of instruments that are available, as well as the full range of costs that would be incurred. Similarly, Hahn (1989) argued that most emissions problems cannot be solved by a single solution but require the use of multiple instruments. De Cara et al. (2005) used a combination of mixed integer and linear programming to model the emissions of methane and nitrous oxide from regionally representative EU farms. They found that there was a wide variability in GHG emissions abatement costs within EU agriculture and concluded that there was potential for a market-based mechanism such as emissions trading to reduce the cost of emissions abatement in EU agriculture. Similarly Kampas and White (2003) argued heterogeneous abatement costs were the main requirement for farmers to start trading emissions permits.

Springer (2003) grouped emission trading models into five categories: (1) integrated assessment models that capture both the physical and social aspects over a long period of time; (2) computable general equilibrium models; (3) Neo-Keynesian macroeconomic models; (4) emissions trading models; and (5) systems or bottom-up models. Perez Dominguez et al. (2009), Carlier et al. (2005) and Bakam and Matthews (2009) are three examples of systems or bottom-up models that have been developed to model the impact of using an emissions standard and a system of tradable emissions permits to reduce agricultural emissions. Using simulation models of the Flemish pig sector Carlier et al. (2005) compared the performance of tradable emission permits and a command-and-control approach in the context of the EU Nitrates Directive. They concluded that significant cost savings could be achieved by using a market-based abatement strategy instead of a command-and-control approach to reduce nitrate emissions. Perez Dominguez et al. (2009) used a comparative-static agricultural sector model to measure the regional impact of an 8 percent reduction in EU GHG emissions. A number of emissions standard and emissions trading scenarios were examined relative to a baseline scenario of no reduction in GHG emissions. They concluded that under an assumption of zero transaction costs, market-based abatement strategies were superior to emissions standards however this superiority is less clear-cut when transaction costs are considered.

Bakam and Matthews (2009) used an agent-based model to examine the potential of using tradable emissions permits to reduce the cost of GHG emissions abatement. They valued the minimum price a seller would be willing to receive for one unit of carbon as the average additional gross margin that would be earned if that unit of carbon were not sold, but instead used on the farm to increase their production activities. Similarly, the maximum price a buyer would be willing to pay for a unit is the additional average gross margin earned from increasing their farming activities. They found that the price for carbon was highly sensitive to changes in emissions reduction targets and changes in assumptions regarding the adoption of abatement technologies. Bakam and Matthews (2009) concluded that while emissions trading is cost minimizing in theory, careful consideration needs to be given to the design of the trading scheme in light of farmers' acceptance of the policy and compliance with the targets.

The following section provides a description of the data and methods used in the analysis. Results from three policy scenarios are compared with a baseline scenario of no emissions reduction target. Finally, a discussion of the results and the implications for policymakers are presented along with potential areas of future research.

## Data and Methods

The modelling approach used in this paper is similar to Perez Dominguez et al. (2009) in that a bottom-up model of Irish agriculture is constructed to estimate farmers' shadow prices for an emissions permit which are then used to simulate an emissions trading market. Springer (2003) argued that "bottom-up" models, such as those employed in this study, allow for a detailed analysis of the sector and are effective in examining the cost of achieving a given emissions reduction target. Springer (2003) also offered a note of caution when using bottom-up models, as typically the demand for and price of commodities is exogenous in bottom-up models and as a result, the analysis lacks a price effect. However, Ireland is a small country exporting more than 80 percent of its dairy and beef output. Therefore, Irish commodity prices are largely determined by changes in international supply and demand rather than domestic supply.

A farm-level linear programming model[4] was constructed based on data from the Teagasc National Farm Survey[5] (Connolly et al. 2007). Linear programming is a normative modelling approach and therefore is well suited to modelling behaviour under conditions which are outside the range of past experience and cannot be modelled by more positive techniques such as econometric models. The model simulates the future behaviour of Irish farmers under an emissions standard scenario

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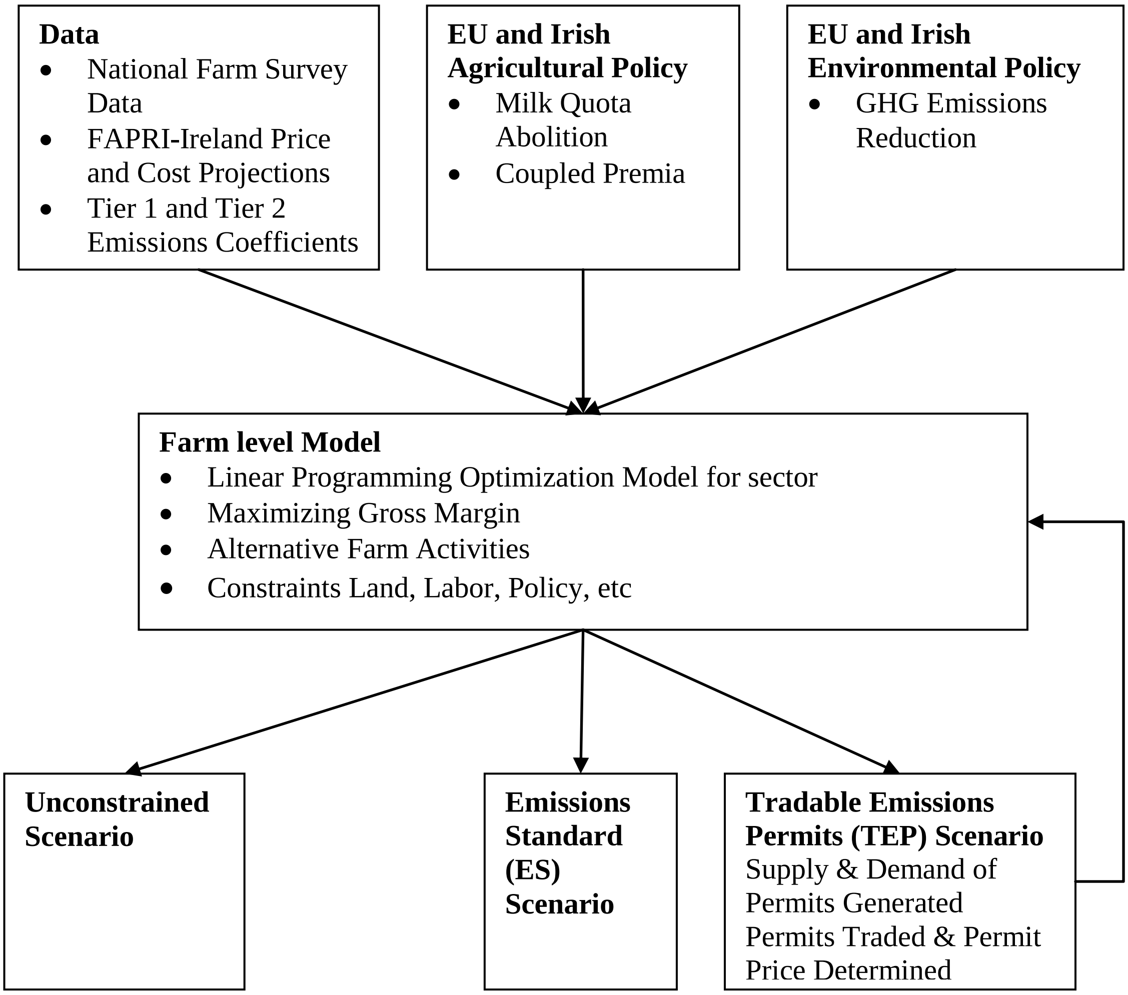
[4] The model is solved using "What's Best!" a specialist solver that operates as an Excel add-on and solves both linear and nonlinear optimization problems.

[5] The NFS is a member of FADN, the Farm Accountancy Data Network of Europe. It surveys approximately 1,200 farms nationally that are weighted to represent the total population of over 100,000 farms.

and two tradable GHG emission permit scenarios; one without transaction costs and one with transaction costs. Simulation results are then compared with a baseline scenario in which there is no restriction on GHG emissions in order to compare the impact of alternative emissions abatement strategies. Figure 1 provides an overview of the modelling system, data and key outputs.

**Figure 1: Modelling Framework for Greenhouse Gas Emissions Farm level Model**



The farm-level linear programming model is represented by the central box in figure 1. The objective function of the model is to maximise overall sectoral gross margin Π.

$$\underset{x_{ijt}}{Max}\,\Pi = \sum_{i=1}^{N} \sum_{j=1}^{J} \sum_{t=0}^{T} \left[c_{ijt}\, x_{ijt}\right] \tag{1}$$

$i \in \{1,\ldots,N\};\ j \in \{1,\ldots,J\};t \in \{1,\ldots,T\};$

where:

$\Pi$ is farm gross margin

$i$ is an index for the set of farms of dimension N

$j$ is an index for the set of decision variables (activities) of dimension J

$t$ is an index for the set of time periods (years) of dimension T

The input-output coefficients for the different activities are for the base year and are assumed to remain largely fixed through time despite policy changes; in other words, for any given production process only one combination of the factors of production is assumed. The exceptions are the abatement technology activities, which are also based on 2006 NFS data, but assume alternative levels of output and/or one or more inputs. For example, the artificial fertilizer application is lower under the dairy with clover activity than under the conventional dairy activity. As the adoption of clover as an abatement technology works on the principle that clover fixes nitrogen from the atmosphere, therefore requiring a lower rate of application of artificial nitrogen fertilizer and as a result produces less GHG emissions.

The individual farmer’s production decisions are constrained by farm specific resource constraints including the availability of land, labour, milk quota etc.

$$\sum_{j=1}^{J} a_{kijt}\, x_{ijt} \le b_{kit} \tag{2}$$

Farmers’ decisions may also be constrained by agricultural and environmental policy from the EU and Ireland, and these are represented by the upper right and upper central boxes of figure 1. There are also a number of sectoral constraints within the model which provide a biological consistency, for example the number of calves born cannot exceed the number of cows

$$\sum_{j=1}^{J} g_{sijt} x_{ijt} \leq s_{st} \tag{3}$$

$$x_{ijt} \geq 0 \tag{4}$$

$k \in \{1,\ldots,K\}; s \in \{1,\ldots,S\}$

where:

*k* is an index for the set of farm-level resource constraints of dimension K

*s* is an index for the set of sector-level constraints of dimension S

A number of farm activities are specified for each farmer based on their existing activities and other possible activities. However, non-dairy farmers are restricted from entering milk production because they currently do not possess milk quota[6]. The gross margin of each of these activities is estimated and projected commodity prices and input costs from the FAPRI-Ireland aggregate level model[7] (Binfield et al. 2007) as represented by the box in the top left-hand corner of figure 1 are used in calculating the gross margin across a multi-period planning horizon. This allows the simulation of farmer behaviour across a multi-period time horizon and the impact of policy changes on GHG emissions to be examined.

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[6] With the abolition of the EU milk quota regime in 2015, non-dairy farmers will no longer be required to own a milk quota in order to enter milk production and some expansion in milk production on non-dairy farms is likely. However, other barriers to entry are likely to remain. The conversion of existing non-dairy farms to dairy production will be dependent on a number of factors including resource constraints such as farm size, land quality and capital for investment in new facilities and farmer-specific characteristics including age, management ability and risk preferences. Given the complexity surrounding this issue, it is assumed in this analysis that there is no growth in milk production on non-dairy farms.

[7] The FAPRI-Ireland model is comprised of a set of individual econometrically estimated commodity models that are linked and solved simultaneously.

Total GHG emissions per farm in the base year of 2006 are calculated by multiplying the number of animals, crops produced and amount of artificial nitrogen fertilizer used by their respective Tier 1 and Tier 2 emissions factors. This provides a historical reference level of emissions against which the emissions reduction targets are measured. This approach is consistent with the Irish National Inventory Report (EPA 2010). The model solution provides projected gross margin and GHG emissions over a 10 year period from 2011 to 2020. These annual emissions projections for each farm are calculated based on the activity levels from the models primal solution and the appropriate Tier 1 or Tier 2 emissions factors for that activity.

Four scenarios are evaluated. Initially, as shown by the box in the lower left corner of figure 3, a baseline scenario is run that imposes no constraints on GHG emissions generated by an individual farmer (unconstrained scenario). The potential impact on farm income of achieving a reduction in GHG emissions through either an emissions standard (ES) (second scenario) or tradable emissions permits (TEP) (third scenario) is compared to the "unconstrained" scenario. In both the ES and TEP scenarios, an emissions reduction target of 20 percent is imposed as an additional constraint on each individual farmer's production activities. Under the ES scenario, each farmer has to reduce their emissions in 2020 by 20 percent relative to their emissions level in the base year. This reduction is to be achieved in 2 percent annual increments beginning in 2011. Under the TEP scenario, farmers are issued a number of tradable emissions permits; one emission permit equals one tonne of $CO_2$ equivalents. The tradable emissions permits are "grandfathered," or issued based on the historical level of emissions produced on the farm in 2006. The number of permits issued is reduced in 2 percent increments annually. Individual farmers have the option to purchase additional permits from other farmers to offset emissions or they can reduce their emissions further and sell the surplus permits to other farmers.

The fourth or TC scenario assumes a market for tradable emissions permits and non-zero transaction costs. This scenario follows the approach used by Perez Dominguez et al. (2009), and assumes a transaction cost of €5 per permit, which covers brokerage fees and is incurred by the purchasers of permits.

The dual value or shadow price of a tonne of $CO_2$ equivalents is estimated for each of the 1,159 individual farmers within the NFS. This is in effect, the marginal value product of a given resource and indicates the cost or value to the objective function of an additional unit of resource in this case an additional unit of GHG emissions (Hazell and Norton 1986). These marginal values are weighted[8] up using individual population weights for each farm in the sample to estimate the supply and demand curve for permits for Irish farmers in each year. The estimated supply and demand curves are then used to simulate the market for emissions permits in each year. This market is modelled as a closed market with trade limited to Irish farmers who trade permits expressed in terms of $CO_2$ equivalents among themselves. The market determines the quantity of permits traded and the equilibrium price for a permit. The outcome of the simulated market is then fed back into the farm-level model (denoted by the backward arrow in figure 1) and each farmer's GHG emissions constraint is adjusted by the annual quantity of permits bought or sold. The linear programming model is then resolved and a new optimum solution is determined that maximizes

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[8] Each farm within the NFS is assigned a population weight which allows the sample of farms within the NFS to be weighted up to be representative of the national farming population. The population weights used are provided by the Central Statistics Office.

sectoral gross margin subject to the new emissions constraints. The approach taken in both the TEP and TC scenarios is the same, except that the TC scenario includes transaction costs.

## Results

The results section is divided into two parts. In the first part, the potential for abatement technologies to reduce GHG emissions is not considered. The second part allows for the inclusion of a number of abatement technologies in all four emissions scenarios. This is similar to the approach used in Bakam and Matthews (2009), which allowed farmers to either purchase credits to offset emissions or adopt one or more farm management abatement strategies such as reducing their stocking rate and reducing nitrogen fertilizer use. The Unconstrained, ES, TEP and TC scenarios are examined under both the “with” and “without” technologies options. The impact of all four scenarios on farmer gross margin per hectare is presented for dairy and specialist cattle farms along with the equilibrium price for permits.

### *Without Technologies*

Figures 2 and 3 below illustrate the estimated supply and demand curves for tradable emissions permits in 2012 and 2020, respectively. The estimated supply and demand curves are used to simulate an annual market for tradable emissions permits. From this simulated market, we can ascertain a market clearing price for the permits and determine the number of permits that would be bought or sold each year at this price between 2011 and 2020. In 2012, 1.7 million permits would be traded at a market clearing price of €14.10 per permit. The annual increase in the emissions reduction target leads to an increase in both the number of permits being traded and the market clearing price of these permits over time. By 2020, the number of permits traded increases to 2.17 million and the market clearing price increases to €55.

**Figure 2: Simulated Market for Tradable Greenhouse Gas Emissions Permits, 2012 TEP scenario, without Abatement Technologies**

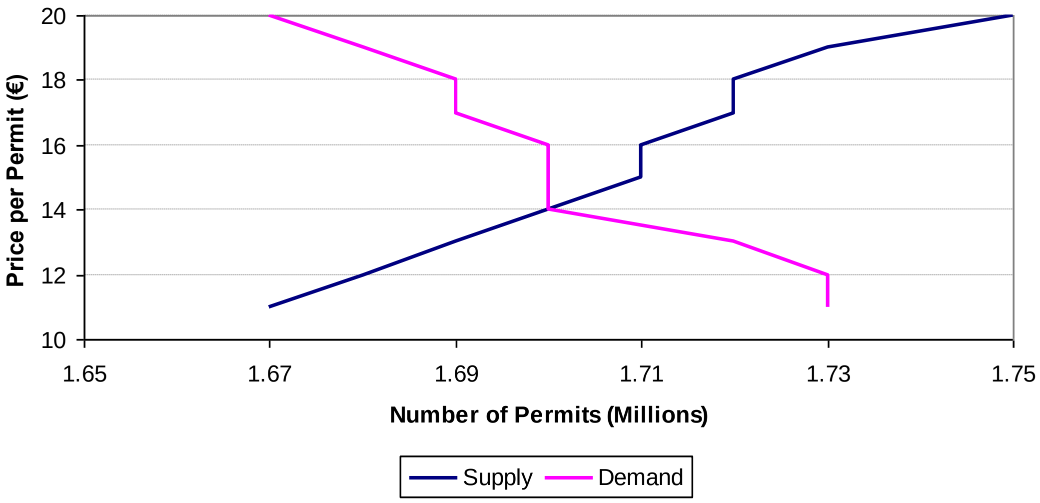


**Figure 3: Simulated Market for Tradable Greenhouse Gas Emissions Permits, 2020 TEP scenario, without Abatement Technologies**

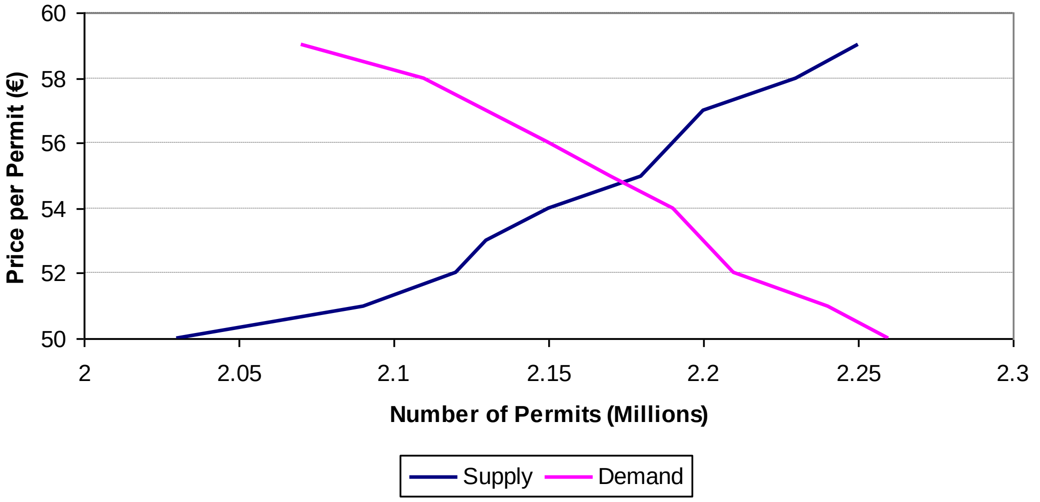
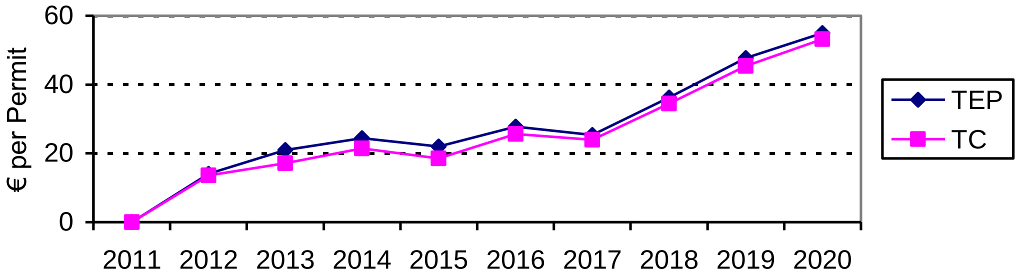


Figure 4 illustrates the change in the market-clearing price of permits over time. In 2011, the number of permits supplied exceeds the number of permits demanded under both scenarios and as a result, the market clearing price is zero. This is due to a significant proportion of farmers not utilizing their full allowance of emissions permits in 2011 and a small number of farmers who do not utilize any emissions permits because they have no profitable enterprise on their farms. However, as the emissions target becomes more binding over time, fewer farms have surplus permits to trade in the market. Furthermore, the projected increase in production from the dairy sector increases dairy farmers' demand for permits. As a result, in each of the subsequent years, there is a positive market clearing price for tradable emissions permits. In the TEP scenario, the market clearing price increases from €14.10 per tonne of $CO_2$ equivalents in 2011 to €55 per tonne of $CO_2$ equivalents in 2018. It is assumed that the transaction costs are levied on the purchasers of permits, therefore reducing the price that farmers are willing to pay for permits and lowering the market clearing price for permits. As a result, the projected annual market clearing prices in the TC scenario are slightly lower. In 2020, the permit price is €53.20 under the TC scenario compared with €55 under the TEP scenario.

Perez Dominguez et al. (2009) estimated a permit price of €56 per tonne of $CO_2$ equivalents for Ireland in 2013 under the assumptions of a smaller emissions reduction target of 8 percent and with trade restricted to a national level. In this study the estimated market clearing price for an 8 percent reduction is €24.4 per tonne of $CO_2$ equivalents. While De Cara and Jayet (2011) concluded that the emissions tax necessary for Irish agriculture to meet cost effective abatement rates of 8.4 percent and 9.1 percent was between €95.9 and €81.8 per tonne of $CO_2$ equivalents. There are a number of key differences between this study and the other two studies, which would contribute to different results. Firstly, this paper exclusively models GHG emissions from Irish farms, while both De Cara and Jayet (2011) and Perez Dominguez et al. (2009) use models representing farms across the whole of Europe. By using a larger number of farms for Ireland, it is likely that this analysis reflects more accurately the range of marginal abatement costs that exist across farms and the potential for trade amongst farms, particularly in the context of the substantial number of farms with no profitable enterprise. Assuming these farmers are profit maximizers, then they would cease production and supply all of their permits to the market, which would drive down the market-clearing price. Secondly, the iterative solution approach within the CAPRI modelling system[9] means that a reduction target of 8 percent across all EU member states is likely to result in some positive price effect for agricultural commodities, which in turn, may lead to an increase in the permit price (Vermont and De Cara 2010). However, Vermont and De Cara (2010) also argue that counterbalancing this effect is a greater degree of flexibility in the allocation of resources within partial equilibrium models which can lead to lower marginal abatement costs.

**Figure 4: Market Clearing Price for Tradable Emissions Permits 2011-2020**



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[9] The CAPRI Modelling System or Common Agricultural Policy Regionalised Impact Modelling System is an agricultural sector model covering the whole of the EU27 as well as Norway and Western Balkans at a regional level as well as global agricultural markets at country or country block level.

Figure 5 compares the impact of the three scenarios on dairy farm gross margin. The average gross margin per hectare for dairy farms under the unconstrained scenario is projected to increase from €989 per hectare in 2011 to €1,108 per hectare by 2020. The main drivers of this increase are an assumed increase in milk yield per cow of 1 percent per annum[10] and an assumed increase in milk production per farm of up to 15 percent by 2020 after abolition of the milk quota.[11] The introduction of an emissions standard leads to a reduction in average gross margin of €86 per hectare in 2020 or 8 percent. Most Irish dairy farmers have one or more non-dairy enterprises with a lower marginal abatement cost; therefore, when faced with an emissions standard of 20 percent, the less profitable non-dairy enterprise would be reduced first. As a result, the percentage change in average gross margin per hectare is substantially lower than 20 percent. However, while the reduction in average gross margin for all dairy farms is only €86 per hectare, the loss on some farms is considerably higher. For example, on those more specialized dairy farms on which more than 80 percent of the livestock units are dairy cows, the average gross margin in 2020 is €197 per hectare lower under the ES scenario than under the Unconstrained scenario.

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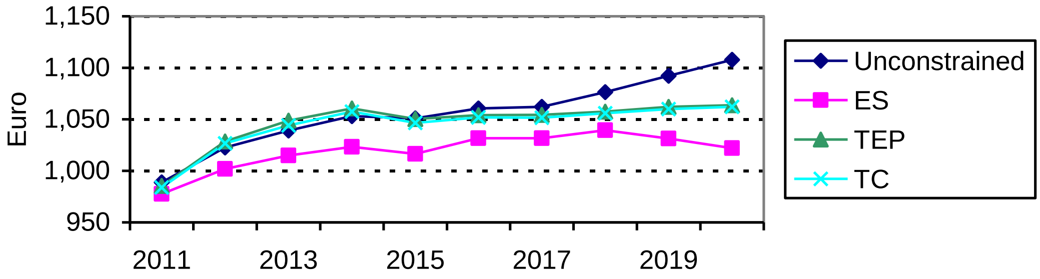
[10] Ireland uses Tier 2 methane emissions factors for dairy cows, which increase over time on the assumption that milk yields increase at a rate of approximately 1 percent annually.

[11] There has been much debate as to the potential growth in Irish dairy production post 2015. For example, the Food Harvest 2020 report (Department of Agriculture, Fisheries and Food) set a target for a 50 percent increase in the volume of milk production by 2020. While some farmers would have the ability to expand their milk production by 50 percent or more with limited investment required, other dairy farmers are likely to require significant capital investment including the expansion of milking facilities, building extra dairy cow housing and the acquisition of land. Because these considerations are beyond the scope of this study, a more modest milk production expansion plan of 15 percent was assumed in the period to 2020.

**Figure 5: Projected Average Dairy Farm Gross Margin per Hectare**

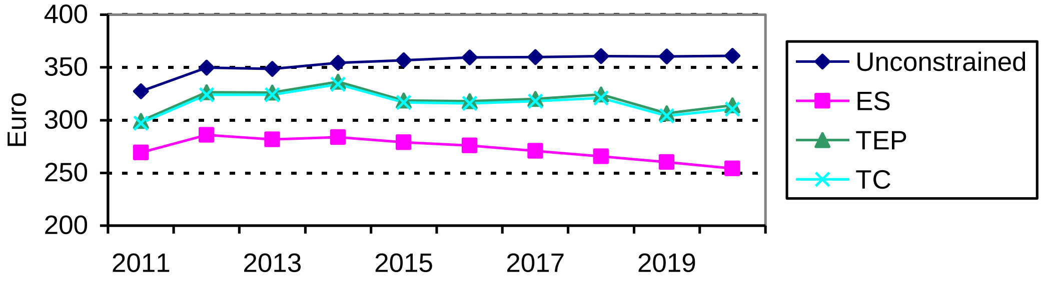


Under the TEP scenario, the reduction in average gross margin for all dairy farms is substantially smaller at only €44 per hectare in 2020 or 4 percent. The inclusion of a €5 transaction cost has a limited impact on the average gross margin per hectare in the TC scenario. In each of the 10 years modelled, the reduction in average gross margin per hectare in the TC scenario compared with the TEP scenario was less than €5 per hectare. By 2020, the average gross margin per hectare under the TC scenario is €1,062 compared with €1,064 per hectare under the TEP scenario.

Over the period 2011 to 2014, the average gross margin per hectare for dairy farms is slightly higher under the TEP scenario than under the Unconstrained scenario. This is because over the period 2011 to 2014, the revenue earned by dairy farmers selling permits is greater than the combined cost incurred by those dairy farmers who are purchasing permits and the loss in income incurred by those farmers who must reduce their production levels. However, as the emissions constraint becomes more binding, the revenue earned by those farmers who sell emissions permits is no longer large enough to offset the combined loss in dairy farmers' gross margin from the emissions reduction and the cost incurred by those farmers who purchase permits.

The average gross margin per hectare for specialist cattle farms under the Unconstrained scenario is projected to increase from €328 per hectare to €361 per hectare over the period 2011 to 2020 (see figure 6). This is largely due to a moderate increase in beef prices projected under the FAPRI-Ireland aggregate level scenario being only partially offset by an increase in direct costs of production. The introduction of an emissions standard leads to a reduction in suckler cow numbers and their progeny and an eventual reduction in the average gross margin per hectare of €107 by 2020. This constitutes a reduction in average gross margin of 30 percent. Whereas most dairy farmers have substantial capacity to reduce emissions at a relatively low cost through a reduction in less profitable non-dairy enterprises, most cattle farmers have a limited capacity to reduce emissions. Although some cattle farmers have less profitable non-cattle activities on the farm, emissions from these activities are likely to be small relative to the emissions from the cattle enterprise. Consequently, the capacity of cattle farmers to reduce emissions at low cost is limited. As in the previous graph, the presence of a market for tradable emissions permits gives rise to a higher projected average gross margin per hectare on cattle farms than under the ES scenario. The dramatic increase in the average gross margin per hectare under the TEP scenario compared to the "ES" scenario can be largely attributed to non-profitable and low profitability cattle farmers earning substantially more through the permit market than they would have earned from the market place under the emissions standard scenario. Once again, the inclusion of a €5 transaction cost per permit traded has only a minor impact on gross margin, which accounts for the minor differences in gross margins between the TEP and TC scenarios.

**Figure 6: Projected Average Gross Margin per Hectare for Cattle Farms**



Under the Unconstrained and ES scenarios, there were almost 5,000 farmers with a zero gross margin. These farms have no profitable farm enterprise and therefore, their optimal solution is to cease production while retaining their land in order to draw down their Single Farm Payment[12]. By doing this, the only income to these non-productive farms would be payments and subsidies, such as the Single Farm Payment. However, under the TEP scenario, these farmers are able to trade permits based on their historical production and, as a result, have an additional source of income. Figure 7 below projects the increase in income and income per hectare earned by these non-productive farms from 2011 to 2020. In 2011, the average income earned is €0 because the market clearing price is zero. However, as the emissions reduction target increases, it becomes more binding on farmers and as a result, the market-clearing price for permits increases. This gives rise to an increase in the income earned by the non-productive farms from the sale of tradable emissions permits. By 2020, these farms earn €112 per hectare or €2,734 per farm on average by selling tradable emissions permits. This appears to be consistent with the findings of Butt and McCarl (2004), who concluded that as environmental legislation becomes more binding, the ability of US farmers and forest producers to earn revenue from the carbon market increases.

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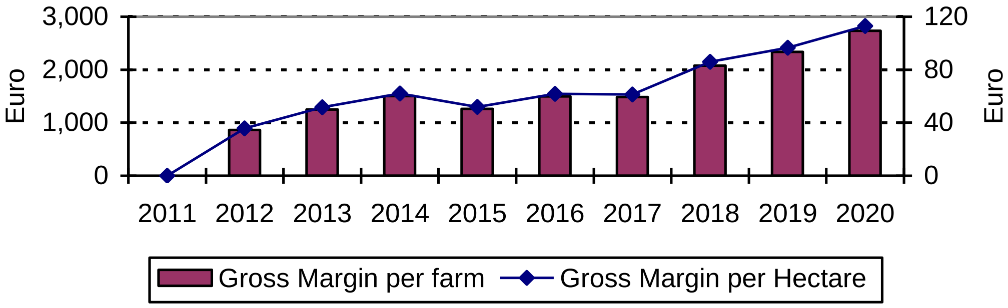
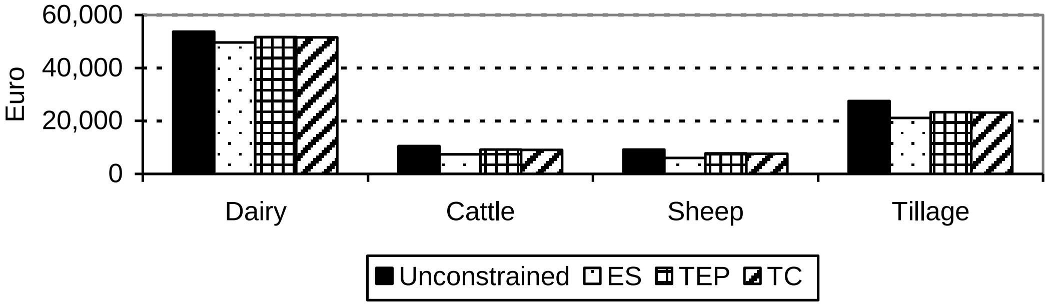
[12] The Single Farm Payment is a decoupled income support payment to farmers paid by the EU.

**Figure 7: Annual Increases in the Gross Margin of Non-productive Farms from Tradable Emissions Permits under the TEP scenario**



As illustrated in figure 8, the average gross margin for all four types of farms in 2020 is highest under the Unconstrained scenario. The specialist tillage farms experience the largest decrease in average gross margin under the 20 percent emission reduction scenario. This occurs because this farm type experiences the largest loss in gross margin per hectare and also specialist tillage farms are on average the largest farm type in Ireland. This result is consistent with De Cara and Jayet (2000), who concluded that if French farmers were faced with a large emissions reduction target, crop farms would incur the greatest cost. The average loss in gross margin is lower on drystock farms (€3,117 for cattle farms and €3,123 for sheep farms). However, because of the relatively low returns on these farms under the Unconstrained scenario, this loss in gross margin is equivalent to a 30 percent reduction in gross margin on cattle farms and a 34 percent reduction in gross margin on sheep farms.

**Figure 8: Average Gross Margin by Farm Type (2020)**



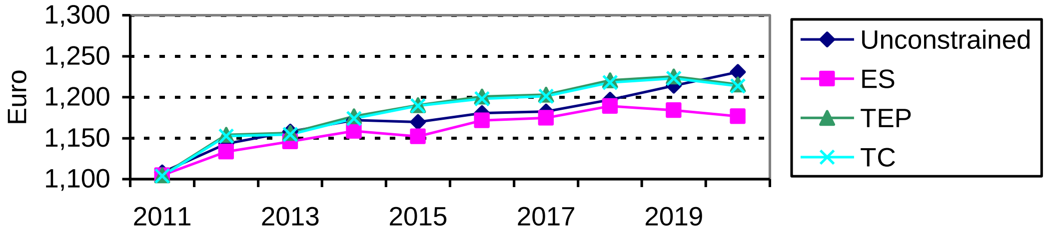
As expected, the average gross margin for each of the four farm types is higher with the TEP scenario than with the ES scenario. The higher gross margin with the TEP scenario for dairy farms is largely due to the purchasing of emissions permits, which allows those farms to achieve the GHG emissions target with less reduction in agricultural production. In contrast, the increase in the revenue earned from the sale of emissions permits explains much of the increase in average gross margin on sheep farms. Average gross margins under the TC scenario are only marginally lower than under the TEP scenario.

*With Technologies*

The loss in gross margin incurred with a 20 percent emissions standard is significantly lower when abatement technologies are considered. If abatement technologies are adopted by all farms where applicable, the loss in average dairy farm gross margin falls to €54 per hectare compared with €86 per hectare per farm without technologies.

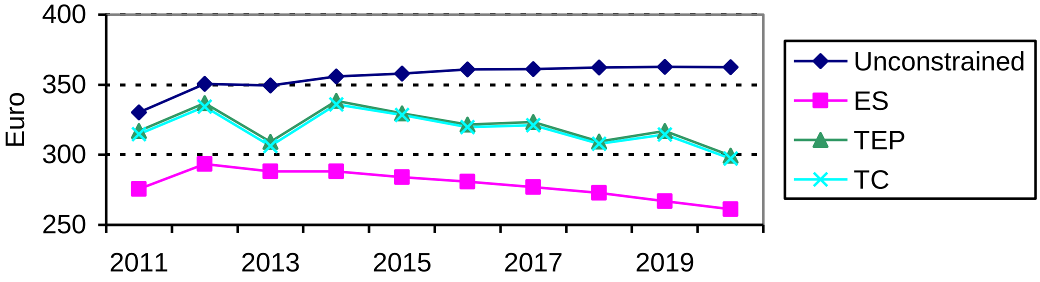
Under the TEP and TC scenarios, the combination of the full implementation of abatement technologies and the gains from the trade in emissions permits causes the loss in average gross margin to be minimal. In fact, in a number of years, the average gross margin per hectare is higher under the TEP and TC scenarios than under the Unconstrained scenario. In a market for tradable emissions permits, the adoption of abatement technologies can allow some farmers to reduce GHG emissions without having a negative impact on their production levels. In this instance, this will allow farmers to trade surplus emissions permits within the permit market and further increase farm profitability.

**Figure 9: Projected Average Gross Margin per Hectare for Dairy Farms**



The average gross margin per hectare for cattle farms under the unconstrained and ES scenarios is almost identical with technologies (figure 10) as without technologies (figure 6). This is due to the lack of suitable abatement technologies for the cattle enterprise. However, the average gross margin under the TEP scenario is lower with technologies than without technologies. By 2020, the estimated average gross margin is €7 per hectare lower with technologies than without technologies, which is largely due to a lower permit price as a result of the adoption of abatement technologies. In 2020, the estimated price for a tradable emissions permit with technologies is €51.1 per tonne compared with €55 per tonne without technologies. This is consistent with Bakam and Matthews (2009) who found that as the adoption of abatement technologies increases, the price of permits decreases.

**Figure 10: Projected Average Gross Margin per Hectare for Cattle Farms**



## Conclusions

The above analysis describes the potential impacts of reducing GHG emissions from agriculture. If a 20 percent reduction in GHG emissions relative to their historical base emissions is enforced at the farm level, tillage and dairy farmers experience the greatest reduction in average gross margin. This result is due, in part, to the fact that both tillage and dairy farms are on average significantly larger than drystock farms. Secondly, the average gross margin earned from dairy and tillage production is higher. As a result, the marginal cost of abatement per tonne of $CO_2$ equivalents from these enterprises is higher and therefore the cost of achieving even a modest reduction in GHG emissions on highly specialized dairy farms is high in the absence of abatement technologies. The loss in average gross margin is lower in absolute terms for drystock farms than for dairy farms. However, due to their low income levels, the loss incurred by drystock farms accounts for a substantially larger proportion of the overall gross margin.

The results suggest that permit trading can lower the cost of reducing GHG emissions from Irish agriculture. For all four farm types, the average gross margin is higher when farmers are allowed to use tradable emission permits. The most significant gain occurs on cattle farms where the average gross margin per hectare in 2020 is €60 higher under the TEP scenario than under the ES scenario. A number of emissions abatement technologies have been described as “win-win” technologies because they allow farmers to not only reduce emissions but also increase farm profitability. In a market for tradable emissions permits that recognizes the emissions reductions achieved by these technologies, there is a third potential gain from technology adoption for farmers, namely, the permits saved from the technology adoption could potentially be traded within the market thus increasing overall farm revenue.

As expected, the number of permits traded and the price at which they are traded increases over time as the emissions reduction target increases. The other significant gain from allowing farmers to trade permits is made by those farms with a negative market gross margin under the Unconstrained scenario. The average income on these farms would be more than €2,700 higher in 2020 if they are allowed to supply permits to a GHG emissions market.

It has been argued that if the transaction costs associated with participating in a market for tradable emissions permits are high, then the cost of participation may offset any efficiency gains from trading. This analysis shows that a transaction cost of €5 per permit has a minimal impact on gross margins when compared with the TEP scenario, which assumes no transaction cost. The Irish Department of Agriculture, Fisheries and Food currently administers a market for milk quota and the transaction costs incurred by farmers from market participation are minimal. There may well be just cause for the Department to administer a similar market for tradable emissions permits. All farmers within Ireland are currently obliged to report their livestock numbers to the Irish Department of Agriculture, Fisheries and Food. This information along with the Tier 1 and Tier 2 emissions factors could be used to track emissions at the individual farm level. This information could in turn be used to administer and monitor a market for emissions permits at a reasonable cost. However, establishing a market that accounts for the potential emissions savings from the types of abatement technologies discussed here would require a significant level of monitoring and enforcement, the cost of which might exceed the savings achieved by the market.

The finding that tradable emissions permits have the potential to reduce the cost associated with achieving a given emissions reduction target is based on the assumption that farmers are profit maximizers and, therefore, choose to buy or sell permits when it is profitable to do so. Anecdotal evidence suggests that farmer’s behaviour is motivated by not only profit maximization, but also lifestyle choices or by a desire to maximize utility. Several socioeconomic characteristics of farmers, such as age, education level, tradition, availability of off-farm employment and risk aversion, are likely to influence the behaviour of farmers with respect to permit trading. However, while the concept of farmers ceasing production and supplying permits to a market for GHG may seem farfetched, there are past precedents that suggest such behaviour is plausible. For example, many farmers in Ireland and the EU have in the past opted to take land out of cereal production or reduce stocking rates because schemes, such as voluntary set-aside, livestock extensification premia and the Rural Environmental Protection Scheme, offered a higher economic return than conventional agriculture. Therefore, it is plausible that less profitable farmers would be willing to reduce their stocking rate and trade permits rather than continue farming.

The results indicate that tradable emissions permits can reduce the cost of achieving a given emissions reduction target when compared with an emissions standard. This result holds with or without farmer adoption of abatement technologies. In fact, a market for tradable emissions permits could provide an additional incentive for the adoption of abatement technologies. This paper highlights the potential for market-based mechanisms to minimize the cost of achieving a given GHG emissions reduction target. If an emissions reduction target is established for Irish agriculture, policymakers need to look beyond traditional command-and-control policies by considering the potential of market-based mechanisms to deliver emissions reductions in a cost effective manner.

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