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The Potential Economic and Environmental Costs of GHG Mitigation Measures for Cattle Sectors in Northern Ireland

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Abstract: National greenhouse gas (GHG) mitigation strategy can benefit from information on the technical and economic viability of abatement options. The life-cycle-analysis (LCA) and marginal abatement cost curve (MACC) approaches provide a good, although partial, indication for the potential of existing technologies to mitigate GHG emissions. The input-output (IO) approach has advantages in capturing the indirect impacts of technology adoption from shifts in economic structure and linkages between sectors. It is therefore ideal to develop an integrated approach to more accurately assess the overall economic and environmental impacts of climate policy. In this study, we aim to develop such an approach that extends the assessment of viability to include indirect economic and environmental effects of resulting structural shifts in the economy. The new approach is applied to technological GHG mitigation measures in Northern Ireland's cattle sectors. The main findings indicate there is a marked difference (even reversal under some conditions) in the overall impact of technical reductions in emission-intensity on national output and emissions when adjustments in economic structure are taken into account.

Keywords: GHG mitigation; IO analysis, technical cost; Northern Ireland

JEL classification: C67; Q52; Q56; Q58

1. Introduction

An important step towards developing a greenhouse gas (GHG) mitigation strategy is the selection of abatement technologies based on the expected economic and environmental impact of adoption. In most cases, the selection is focused on technologies in emission intensive sectors. As energy production and consumption are the major sources of GHG emissions globally, technologies improving energy efficiency are often referred to as an important component of mitigation efforts. In agricultural sectors, however, non-energy related methane (CH_4) and nitrous oxide (N_2O) are the main forms of the GHG emissions, so focus tends to be on reducing animal and land based emissions. Therefore, the national mitigation strategy for an economy with a relatively large agricultural sector may look quite different from that of a heavily industrialized one because (1) different abatement technologies may be considered viable and (2) technology adoption will interact with the unique economic structure. In order to capture such an interaction, this paper attempts to evaluate the supply of technically viable abatement technology, outlined by life-cycle-analysis (LCA) and marginal abatement cost curve (MACC) approaches, using the demand-based input –output (IO) approach, to provide a better assessment of the indirect, as well as direct, economic and environmental impacts of the technologies to be adopted. The approach provides a more complete assessment of the implications for meeting national mitigation targets.

2. A Structural Approach

2.1. A brief review of the literature

Apart from legal feasibility, technical and economic feasibility are essential to the successful adoption of mitigation measures. The LCA approach is in the family of models that track the material flows and subsequent environmental impact of physical changes in a production system (Bouman, Heijungs et al. 2000). This approach has been widely applied to establish a GHG footprint for different life cycles such as that for renewable energy. It has advantages in avoiding narrow outlook and providing a thorough accounting for direct GHG footprint in all stages of the process. As agricultural production appears to be different from region to region and is very much heterogeneous, regional LCA figures are important for accurately capturing the direct impacts in the region. In Northern Ireland, a LCA analysis for milk production in Northern Ireland (Woods, Ferris et al. 2009) has provided some useful information on the impact of changes in production on the footprint, determining the technical feasibility of an abatement option.

The MACC (McKitrick 1999) approach on the other hand, attempts to asses all three simultaneously. In a MACC analysis, the abatement potential of technology is calculated by multiplying the unit abatement potential and its applicability, with slightly different ways of measuring the environmental and economic potentials. One example in using the MACC approach in the UK agriculture is MacLeod, Moran et al. (MacLeod, Moran et al. 2010). The study has estimated UK MACC by using linear programming (LP) models for different farm-types to determine economic impacts as changes in gross margins (MacLeod, Moran et al. 2010; Moran, Macleod et al. 2011).

A common weakness of the LCA and MACC approaches is that the costs and effects of technology implementation are partial and direct. No linkages between economic sectors are captured. As the indirect impact may work in both positive and negative directions, the overall impact of the technology may be under or over estimated. It is particularly true for those economic sectors with strong links to energy-intensive, and/or emission-intensive sectors in the economy.

There is an argument for taking an emission-intensity approach to mitigation strategies, particularly in the case of agricultural sectors, to avoid the re-location of production to areas with more emission-intensive production technology and resulting ultimately in 'carbon leakage' instead of abatement (Schulte, Lanigan et al. 2011). Under this strategy, new production technology is adopted to reduce the emissions per unit output in targeted sectors. The identification of sectors to target can be achieved by determining the sensitivity of national emissions to the emission-intensity of individual sectors, accounting for the unique structure of the economy. The relevant sectors in an economy are those for which relatively small improvements in emission-intensity yield relatively large national abatement levels when the indirect effects are taken into account (Moran and Gonzalez 2007). These sensitive sectors can be described as having a relatively low *technical cost* of abatement. This implies establishing new technology, or, reviewing the viability of currently available technology in terms of abatement potential and economic impact, is warranted (Minihan and Wu 2011).

2.2. The new approach

This study addresses the indirect impact of technology adoption on national mitigation by accounting for shifts in economic structure. The IO framework is able to account for changes in both economic structure and emission-intensity (Leontief 1970). As abatement technology is adopted in a sector there is a direct impact on (1) the input mix, and (2) emission-intensity. Holding output constant in the sector, there will still be an impact on domestic production and emissions due to changes in demand for intermediate inputs provided locally. Therefore, indirect impacts on national output will be present that, depending on the linkages between relevant sectors, could magnify or dampen the direct impact. The direct and indirect impacts of existing abatement technologies are assessed by combining the corresponding adjustments in the sector's production structure with IO output and emission multipliers.

An isoemission matrix that describes the structural relationship between GHG emission and economic activity in Northern Ireland, indicates that relatively small improvements in emission intensity for these sectors hold promise for mitigating economy-wide emissions (Minihan and Wu 2011). The technologies examined are selected to coincide with those already shown to reduce the emission intensity of milk production for Northern Ireland dairy operations under a LCA framework (Woods, Ferris et al. 2009) and a MACC analysis for the UK (MacLeod, Moran et al. 2010; Moran, Macleod et al. 2011). The first technology (Scenario 1) increases dairy cow longevity and the average number of lactations per cow through genetic improvements. This reduces the number of replacements required to maintain milk production, and thus the animal-related emissions (CH_4) generated in the dairy sector, since the herd size in the dairy sector is reduced. The second technology selected (Scenario 2) is a reduction in nitrogen (N) from chemical fertiliser applied to grass silage and grazing land. This reduces the N_2O emitted from the soils, so the emission intensity of both the dairy and beef sector can be reduced in this manner.

The current NI IO table (2005) was updated from a 2002 table (Wu and Keatley 2009) and includes 10 agricultural sectors, 9 food processing sectors, 9 energy sectors and 4 other sectors. There is a linkage established between the economic accounts and GHG accounts. The vector of emission-coefficients is derived from GHG inventory data for Northern Ireland (Thistlethwaite and Jackson 2009) that is redistributed according to energy, land and animals employed in the production process to reflect the level of disaggregation in the economic model. Land use change emissions and sequestration from cropland and grassland are distributed amongst agricultural sub-sectors and changes in forestland attributed to the forestry sector, the only sector in the model to exhibit negative GWP coefficients.

3. Extending dairy cow longevity

The LCA analysis of Northern Ireland dairy systems found that increasing dairy cow longevity, and thus average number of lactations per cow, reduces the GHG footprint per litre of milk produced by 4.4% of the baseline[1] (Woods, Ferris et al. 2009). This is due to the increased production of milk over each cow's lifetime, spreading the emissions generated during the heifer rearing period over more milk produced, and therefore reducing emission intensity of production in the sector. This paper advances the analysis by (1) addressing the indirect impact on national emissions as well as changes in dairy emission-intensity, and, (2) considering the economic consequences of the technology at the sector and national level. With some modification, the standard IO approach as discussed in Section 2 is used to derive the indirect impacts of the technology.

3.1. Direct impact on the dairy sector

In the satellite emission table, total emissions in the dairy sector include emissions from cows, energy uses and associated land uses. In the IO analysis changes in emission are not directly linked to cow numbers but to total output. Therefore, the first step in the analysis is to adjust the emission intensity of the sector. Holding milk output at a fixed level, extending dairy cow longevity alters animal herd structure and consequently input structure will be changed. The adjustment to emission intensity is equivalent to changes in the dairy herd size and composition. Dairy herd structure depends largely on herd dynamics, the flow of cows in and out of milk production. Dairy cows are those producing milk during lactation. When a cow is not longer capable of milk production she is culled from the herd and a younger cow takes her place. In order to sustain milk production at a given level over a year (*t*), there need to be enough replacement heifers (r) to match the number of culled cows (L).

$$L_t = r_t \qquad (1)$$

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[1] The baseline assumes an average of spring calving, and autumn calving systems for calculating the emission footprint, to reflect that calving is year round in Northern Ireland. The footprint is calculated by taking the sum of emissions from the heifer rearing period, plus the productive lifetime of the cow, and dividing by the milk produced.

As the rearing period takes over two years (between 27 and 30 months), in order to sustain the level of milk production continuously, the replacements for the next year, and a portion of those for the year after are needed. The σ represents the proportion of a year beyond the first two needed to raise a calf to maturity.

$$R = r_t + r_{t+1} + \sigma r_{r+2} \qquad (2)$$

The dairy herd (*H*) can be described in terms of the number of dairy cows at the start of the period (*M*), the number of dairy cows culled (*L*), and the aggregate of current and future replacements for continuous production (*R*).

$$H = M - L + R \qquad (3)$$

Similarly, the culling rate (ϕ) is the ratio of dairy cows (*M*) that are culled, so the number of cows culled can be expressed as

$$\phi = \frac{L_t}{M} \Rightarrow L_t = \phi M \quad . \qquad (4)$$

The parameter γ describes the mortality rate of calves during the rearing process, and allows us to define R in terms of r_t.

$$R = \left[(2+\gamma) + \sigma(1+\gamma)\right] r_t \qquad (5)$$

Replacing L and R in Equation 3 using Equations 1, 4, and 5 allows dairy herd number to be expressed in terms of the culling rate.

$$H = M(1 + \phi(\gamma + \sigma + \sigma\gamma)) \qquad (6)$$

The impact on herd size given a change in culling rate can be determined by taking the partial derivative.

$$\frac{\partial H}{\partial \phi} = M(\gamma + \sigma + \sigma\gamma) > 0 \qquad (7)$$

Therefore herd size is increasing in the culling rate, since we know that both σ and γ are positive. An increase in cow longevity sufficient to increase the average number of lactations and subsequent reduction in the culling rate will decrease the size and composition of the herd (Table 1 shows the figures calculated for Northern Ireland). This in turn will have a direct impact on the costs of production.

The variable cost of maintaining the herd consists of feed costs and other costs. Feed can be divided into two categories: concentrates (c); and hay, silage, forage and grazing (h). Other costs include vet, medicine, and sundries (v). The variable cost of keeping a dairy cow will be different from that for a replacement heifer due to different dietary and veterinary requirements. Therefore, it is useful to represent variable cost for the herd in terms of animal type.

$$VC_H = VC_M + VC_R \tag{8}$$

The variable cost for dairy cows in the herd is the product of the cost per cow-year and number of dairy cows in the herd[2].

$$VC_M = (c^M + h^M + v^M)(M - L + r_t) = M(c^M + h^M + v^M) \tag{9}$$

The variable cost for replacement heifers in the herd is similarly represented by the cost per heifer-year times the number of replacement heifers.

$$VC_R = (c^R + h^R + v^R)(r_{t+1} + \sigma r_{t+2}) = (c^R + h^R + v^R)(1 + \gamma + \sigma + \sigma\gamma)\phi M \tag{10}$$

A change in the culling rate will produce a change in variable herd costs

$$\frac{\partial VC_H}{\partial \phi} = M(c^R + h^R + v^R)(1 + \gamma + \sigma + \sigma\gamma) > 0 \tag{11}$$

The data used to calculate the direct change in variable cost from a change in dairy cow longevity for Northern Ireland appears in Table 2, and the calculations are listed in Table 3. For a 1% reduction in culling rate, variable cost will reduce by £0.88 million holding production constant. The change in herd size is also used to adjust the emission multiplier in the IO table by adjusting the emission intensity of dairy production based on the change in replacement numbers. The emissions assumed to be linked directly to cattle numbers in the dairy sector are listed in Table 4, and indicate emissions reduce under this scenario by 3.92 kt^e. Emission-intensity of production is reduced by 0.04% for each percent reduction in culling rate, compared to the direct impact on emission-intensity found under a LCA approach of 0.6%. The smaller magnitude of the direct impact in the current paper is expected, in that the LCA framework reduces emissions associated with fertiliser and feed manufacture associated with heifer numbers, while our approach only assumes emissions directly linked to the animal numbers are reduced.

3.2. Direct impacts on beef and processing sectors

Although the above analysis indicates reducing the culling rate reduces both costs and emissions associated with milk production, the total economic and emission impact will depend strongly on what happens to the calves no longer retained in the dairy herd. For this study, three potential fates for residual drop calves are explored; exportation by the dairy sector, slaughtering by the meat processing sector, and finishing by the beef sector.

Drop calves (d) are born to instigate lactation in dairy cows, so it is reasonable to assume there are as many as milk producing cows (M). These calves may be retained as replacements (r_t), exported (e_t), slaughtered (s_t), or finished for beef (b_t). Calves not needed for replacement heifers are residual ($c_t = e_t + s_t + b_t$). Expressing the definition of residual calves in terms of the culling rate,

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[2] Here we assume all cows are culled and replaced simultaneously at the beginning of the year.

$$c_t = d_t - r_t = M - L_t = M(1-\phi)\,, \tag{12}$$

and the change in residual calves given a change in culling rate can be determined by taking the derivative

$$\frac{\partial c}{\partial \phi} = -M < 0\ . \tag{13}$$

For the case of Northern Ireland, this means a decrease in the culling rate of 1% results in about 2,871 calves moved from the replacement category to residual (see Table 5 below). How these extra residual calves are distributed amongst exports, slaughter and finishing will determine the impact on the economy and domestically produced emissions. To illustrate the differences, each option is explored in isolation even though the most realistic outcome would be some combination of all three. While the case of additional exports (Scenario 1-A) or immediate slaughter (Scenario 1-B) is fairly straightforward, the third case of transferring the additional calves to the beef sector (Scenario 1-C) is more complicated due to the impact on beef herd size.

In Scenario 1-A, all additional residual calves are allocated to exports. The value of the additional exports, calculated as $p^*\Delta c$ (listed in Table 5), is transferred from gross-fixed-capital-formation to export revenue for the dairy sector. The calves are assumed not to contribute to domestically produced emissions since they are removed from Northern Ireland. It is important to note that depending on the location and uses of the exported calves, there will be a contribution to global emissions, however this is beyond the scope of the current model.

Scenario 1-B assumes all additional residual calves are handed over to the meat processing sector for immediate slaughter. In this case the value ($p^*\Delta c$) is removed from gross-fixed-capital-formation for the dairy sector and allocated to purchases from the meat processing sector. Output and input demands are adjusted for the meat processing sector to reflect the additional production, with the finished product assumed to be exported. The production technology is assumed not to change in the processing sector, so the increase in sector emissions is directly tied to the increased output. However, there are minimal uncertain future global emissions connected to the calves potentially being reared to maturity outside of Northern Ireland.

The direct link to the beef sector in Scenario 1-C requires a more complicated approach. The beef herd size will increase by Δc plus a proportion of that number, since it requires over 1 year for finishing a dairy heifer (Weatherup, Dawson et al. 2010), and we are working with the static structural impact not the transitional impacts. That proportion can be defined as the number of months in the beef herd divided by 12 months (ω). The increase in inputs required to finish the additional calves is assumed to be proportionate to the increase in live animal inputs. There is no change to beef finishing technology, and therefore no change in emission intensity for the beef sector. However, the increase in output for the beef sector will increase national emissions. All additional output created is exported before processing. This scenario may impact global emissions when the exported cattle are processed. The extent of the contribution to global emissions depends on the technology of the recipient economy and is beyond the scope of the current analysis.

The direct impact on output for the wider economy given a 1% reduction in culling rate is -0.78, -0.74, and 1.52 £million for version A, B and C respectively. Emissions for the wider economy face a direct change of -3.97, -3.96, and -3.84 kt^e for every 1% decrease in culling rate.

3.3. Indirect impact on output and emissions

The reduction of inputs demanded by the dairy sector caused by a 5% reduction in culling rate, roughly equivalent to increase dairy cow lactation from 3 to 4 in a cow's lifetime, decreases national output directly by £3.94m and £3.71m for Scenario 1-A (calves are exported) and 1-B (calves are slaughtered then exported) respectively. The direct change in emissions (-19.89 and -19.8 kt^e) is partially attributed to the contraction of the related sectors, but mostly due to the improvement in emission-intensity for the dairy sector. The direct impact for Scenario 1-C (calves are finished then exported) exhibits the opposite result. There is a net increase in input demands due to the additional production by the beef sector and a corresponding increase in national output of £7.61m. Again, the direct impact on emissions is largely due to emission-intensity improvement in the dairy sector, although mitigated somewhat by the additional activity in the animal feed, beef, and other related sectors at -19.24 kt^e.

In both cases A and B, total net change in the output of the wider economy is 1.38 fold the direct change, (i.e. accounting for the indirect impact magnifies the impact by 38%). In the third case (C), when residual calves are finished by the beef sector causing a direct increase in output, the indirect impact is 66% beyond the direct impact on output for the wider economy.

In terms of emissions, the first two scenarios (A and B) exhibit a relatively small indirect impact on national emissions at 5% and 9% beyond the direct abatement. The third scenario (C) shows a greater indirect impact as well as a reversal of sign (-50%), indicating for every 1% reduction in direct emissions, national emissions will *increase* by 1.5%, mainly because animals are moved to more grass based high emission intensity sector.

The ratio of the change in domestic output over the change in domestic emissions from production shows a relative cost of the GHG mitigation measures. For three scenarios examined in this section, Scenario A costs 0.26 £million for each kt abatement, Scenario B a bit less at 0.25, and no abatement is achieved in Scenario C. In terms of the distributional impact, the majority of output lost under Scenarios A and B is divided between the animal feeds sector, and others sector, with much smaller losses experienced by electricity transmission and supply, cereals, and wholesale-retail-hotel-restaurant. For the same two scenarios, the lion's share of abatement (94%) is due to the reduction in emission-intensity in the dairy sector. Over half of the increase in output in Scenario C is from an increase in electricity transmission and supply, with the remaining largely associated with the others sector, electricity generation from gas, and cereals (all relatively emission-intense sectors). Although emissions from the dairy sector are reduced by 19 kt^e, production increases triggered by expanded beef output boosts emissions by 27 kt^e from electricity from fossil fuels alone, and when all indirect impacts are taken into account the net increase in emissions (10 kt^e). Note that in the calculation of the Scenario C, we have only taken account the impact at the stage of beef cattle production, beef slaughtering and later stages are not counted. If the later stages are to be counted, the emission increase is expected to be even more significant.

4. Reducing nitrogen use on grassland

The second change in production technology modelled in this analysis is a reduction of chemical N fertilizer applied to grassland by the dairy and beef sectors. This technology was shown to reduce the GHG footprint of milk production in Northern Ireland by 9 to 11% using the LCA approach (Woods, Ferris et al. 2009). This paper advances from the LCA analysis by (1) addressing the direct economic impact of reducing fertilizer use, and, (2) incorporating indirect impacts on the wider economy. Reducing chemical fertilizer application was shown to exhibit economic costs of 2,045 (£2006/tCO_2e) abatement under the MACC study for the UK[3] (MacLeod, Moran et al. 2010). This paper complements the MACC analysis by capturing the interaction of the technology change with Northern Ireland's unique economic structure. Scenario 2 is run assuming 10%, 20% and 30% reductions in the average N application to silage and grazing land attributed to cattle sectors from the 2005 level.

In recent years, the average chemical N per hectare of farmland in Northern Ireland has declined considerably, as shown in Figure 1 (DARD 2010). However, to estimate the average value of chemical N applied to grassland only, additional data is needed to adjust the average application rate by removing fertiliser used by crops and horticulture. The weighted average of suggested N application according to the Farm Business Data for 2005 is used to obtain an estimate of N used by the cereals, potatoes, horticulture, and 'all other' sectors (including other crops and hay) . This is subtracted from total N purchased (from the SRNIA). The remaining N is divided by grassland area (less hay and rough grazing) to obtain an estimated average of 98.76 kg N/ha. It is assumed that the N supplied from manures and waste does not change, and the reduction is calculated as the percent of average chemical fertiliser N only.

The reduction in N is expected to reduce grassland productivity, however determining an aggregate grass-yield-response curve for all of Northern Ireland is complicated due to the variety of soil type, precipitation and management[4]. In lieu of sufficient data, we adopt the same assumption used in the LCA approach (Woods, Ferris et al. 2010) that each kg N applied to grassland influences dry matter (DM) yield by 12 kg/ha, taken from a data series developed by Teagasc (Dillon, Hennessy et al. 2007). Although the grass response is consistent, there are differences in terms of how managers respond to reduced grass yields. The LCA of Northern Ireland dairy systems assume stocking rates reduce and additional grassland is taken into production to compensate for the deficit (Woods, Ferris et al. 2009; Woods, Ferris et al. 2010) This magnifies the abatement potential since carbon sequestration is increased. However, as our analysis looks at the sector, instead of farm level, and includes the beef sector as well as dairy, grassland available is assumed to be fixed[5], and concentrates are used to supplement reduced grass intake at a rate of 1 kg DM grass to 1 kg FW (fresh weight) concentrates (Saunders 2010). There is some evidence of a negative correlation

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[3] This is the reported central feasible estimate, and is based on a weighted average by farm-type across the whole UK.

[4] Personal communication with Dr R. Laughlin, Agri-Food and Biosciences Institute

[5] In 2005, grassland accounted for 96% of total agricultural and in NI.

between the aggregate purchase of fertiliser and feeds, suggesting substitution of concentrates for chemical fertilisers in the period the Nitrate Directive is applied (Figure 2). A more complicated simulation that accounts for substitution between grassland, fertilizer, and concentrates is left for the next stage of this research.

4.1. Direct impacts on dairy and beef sectors

The direct impact on fertilizer and concentrate costs for the cattle sectors are produced in Table 6. As expected, the substitution of concentrates for fertilizer results in a net increase in production costs, even for the lowest N reduction of 10%, and squeezes dairy and beef profit margins. In this case, dairy and beef sector variable costs increase by £4.61m and £5.19m, respectively, which is equivalent to a 2% increase in variable costs in both sectors in 2005. This is mainly due to the significant difference in costs in using grass DM (in terms of the embedded cost of the fertilizer) and concentrates. The cost saving from reduced fertilizer purchase is £1.46m for dairy and £1.64m for the beef sector. Concentrate feed costs increase £6.07m and £6.83m. This explains the net increase in costs while grass yield is reduced 37,949 and 42,693 DM tonnes. Therefore, each foregone ton of grass DM under these assumptions costs the cattle sectors about £121. At the economy-wide level, this is somewhat counter-acted by the animal feeds sector, that due to the increase in demand from the cattle sectors has a direct increase in final demand valued at £12.9 million. However, it is important to note that only roughly 11% will go to GVA. This means the direct impact of reducing chemical N includes a loss of close to £8.3 million of GVA in the wider economy.

The direct impact on cattle sector emissions appears in Table 7. Emission intensity for the dairy and beef sectors is reduced between 1 and 2%, resulting in a direct reduction in cattle sector emissions of between 23 and 71 kt^e. This means the direct cost to the cattle sectors of reducing emission intensity in is 0.41 £million per kt^e.

4.2. Indirect impact on output and emissions

While fertilizer is imported, animal feeds are largely sourced domestically so there is an indirect impact on the wider economy from an increase in concentrate demand as the animal feeds sector and intermediate sectors expand. Wider economic output is increased indirectly by 25% above the direct impact of £9m, £18m and £27m for each level of N reduction (see Table 9). The emission reduction for the wider economy is 18% less when indirect impacts are taken into account, lowering avoided emissions down to between 19 and 59 kt^e.

This scenario seems preferable at the national level since domestic output increases while emissions decrease, so abatement in this case has negative costs of roughly -0.58 £million per kt^e. However, the distributional impact may be problematic for the cattle sectors, as each kt^e of abatement will cost the dairy sector 0.23 £million of additional production costs and the beef sector 0.26 £million. Therefore, gross value added (GVA) from the cattle sectors is being re-distributed as output for the animal feed sector, only a portion of which will be GVA.

4.3. The combined effects of two technologies

As Scenario 1 targets to reduce CH_4 emissions from cattle, and Scenario 2 reduces N_2O from chemical fertilizer application, the technologies can be combined with minimal interaction effects (although the change in feed composition will likely have an impact on emissions from manures, here we assume such impacts are negligible). However, the next stage of research can incorporate more detailed interactions between feed, cow characteristics, and enteric fermentation emissions based on work carried out in Northern Ireland using respiration chambers (Yan, Mayne et al. 2006).

Table 10 shows the direct and indirect effects of each lactation extension (A-C) combined with a 20% reduction in chemical N applied to grassland. As the reduction in cow numbers in the dairy sector from Scenario 1 counters the direct impact of the reduction in grass from Scenario 2, the direct impact on the dairy sector from combining the technologies is less than for Scenario 2 in isolation.

The indirect impact on output for the wider economy is to increase a further 21 to 37% beyond the direct effect. So, the net impact on output is less variable than Scenario 1 alone (where option C leads to a reversal of sign compared to A and B) and more variable compared to the 25% effect from N application reductions alone when multiple technologies are adopted.

The indirect impact on emissions for Scenarios A and B plus reduced N application is 11% less abatement than the direct impact. When Scenario C is combined with the N reduction, abatement is cut by over half (57%) the direct impact, but is still an improvement over Scenario C alone, which, increases national emissions. These results illustrate that both scenarios are not independent, and interactions between technologies should be considered in the context of the system of production.

5. Conclusions and Discussions

Traditional approaches of estimating economic and environmental impacts of GHG mitigation technologies, such as LCA and MACC, tend to only capture partial and direct impacts. In this study, an IO model based approach is used to avoid possible displacement and carbon leakage problems in partial and direct estimation. In analysing the impacts of two well recommended technologies, i.e. increasing dairy cow lactation and reducing nitrogen use on land, and their combination, we have taken account of animal dynamics, balances of feed (between grasses and concentrates) and fertiliser nutrients (between those from chemical fertiliser and animal wastes) and inter-linkages between economic sectors. The analysis not only provides direct impact estimations but also indirect impact estimations for each single technology and the combined impacts for multiple technologies.

The main conclusion of the analysis is that shifts in economic structure caused by the adoption of abatement technology can greatly influence the overall economic and environmental outcomes. Although an abatement option has been shown to be technically viable for a sector under LCA, such as an increase in cow longevity, when the linkages between sectors are addressed a displacement effect can occur. The abatement gains from reducing emission-intensity in one sector can be eclipsed by increased activity in another to the point of reversing the direct impact. This is clearly displayed in the Scenario 1-C, in which more animals are moved from the dairy sector to grass-based beef production, where direct abatement of -19.24 kt^e is swallowed by the indirect impact for a net emission increase of 10.48 kt^e. Anticipating emission displacement in the economy is particularly relevant for mitigation strategy at the national level, in the case that absolute targets are still in effect.

The analysis also illustrates how abatement technology can intensify the potential for ‘carbon leakage’ to occur. Global emissions may be increased if national policies are not equipped to influence the forward linkages resulting from technology adoption (such as incentives designed to favour the immediate slaughtering of additional residual calves, instead of finishing or live export). In Scenario 1-A national emission may decline due to the export of extra calves, but the 5% reduction in dairy cow culling rate leaves 14,355 calves no longer needed as replacements that will continue to produce CH_4. Therefore, the impact on global emissions depends on the fate of these calves once having left Northern Ireland Many investigations into net national GHG (or at least carbon) emissions, accounting for imported and exported emissions embedded in goods and services, have been carried out using I-O analysis in response to the debate in the policy sphere regarding allocating emissions based on production activities, or consumption activities (Machado, Schaeffer et al. 2001; Wiedmann, Minx et al. 2006; Moran and Gonzalez 2007; Turner, Lenzen et al. 2007; Wiedmann, Lenzen et al. 2007; McGregor, Swales et al. 2008; Moran, Wackernagel et al. 2009; Tukker, Poliakov et al. 2009). In a cooperative two paper effort, (Turner, Lenzen et al. 2007; Wiedmann, Lenzen et al. 2007) it is argued that to effectively capture the environmental impact of trade flows, technical information on the production structure of trading partners needs to be explicitly included, or else the emissions allocated to imports are rudimentary at best. Information on potential carbon leakage from technology adoption could be explored if the regional IO table was linked to the tables of major trading partners, with information on production technology and emission-intensity.

The approach outlined in this paper also provides a framework to explore the distributional issues arising from abatement technology at the national level. Even though the overall impact may help with the abatement objective, the economic burden may be strongly imbalanced. This is evident in the modelling of reducing N applied to grassland, such that cattle sectors experience significant increases in production costs and therefore sacrifice competitiveness on the world market. The distributional feature of the model can be better exploited by expanding the analysis to include additional measures of economic impact such as GVA and employment, and including additional abatement technologies as information becomes available (such as research on substituting fertiliser type to reduce emissions but not yield).

The impact analysis suggests that all GHG measures would have wider impacts / costs than in its own economic sector and that the overall impacts, rather than direct impacts, need to be the basis for the selection of technology. For the two technologies analysed in this study, increasing lactation of dairy cows is likely to increase national emissions when linkages to the beef sector are taken into account. Due to the big squeeze on farm profits, a significant reduction of use of chemical fertiliser is unlikely to be an optimal choice, although the net national emission impact indicates it is worth developing other options, such as switching to different types of fertilizer that can reduce emissions without having much impact on yields.

It is worth noting that the analysis presented in this study is of preliminary nature and the caution is needed in using the results. Apart from a common fixed technical relationships problem in using the IO approach, the analysis is largely constrained by data availability and the aggregation process. For example, in analysing the impact of reducing nitrogen application in grasses, production responses of different soil types to nitrogen and the substitution between grasses and concentrates are crucial for accurate estimation. The traditional way in agricultural economics is to use the flexible form of production function to capture the ‘average’ relationship and this approach however is often subject to data availability. This is the main reason in this analysis we have used many assumptions. The aggregation process is another concern in this type of analysis. Working at the sector as opposed to farm-level, introduces aggregation bias in that the economies of scale are not fully considered for the implications to production processes. This most notably influences the results of the Scenario 2 (i.e. reduction of nitrogen use), since the unique response of grass yield to N on each cattle farm cannot be captured. Another major drawback is that the decision-making process by managers is not endogenous, in that the abatement technology is imposed in command-and-control fashion. The above weaknesses may be improved somewhat by further disaggregation of the cattle sectors based on farm scale and/or location.

Table 1: Direct impact of increasing cow longevity on dairy herd size

Term	Description	Data Source	Value
M	No. of dairy cows needed to meet milk production target	Agricultural Census June 2005	287,094
γ	Calf mortality rate	Farm Business Survey 2005	0.017
σ	Months beyond 2 years until first calving as proportion of a year	Previous NI farm-level study	0.125
	Reduction in herd size given a 1% reduction in culling rate[6]	$M(\gamma+\sigma+\sigma\gamma)*0.01$	3,285

Table 2: Data on variable costs for dairy cows and replacements (£ per head)

	Concentrates	Hay, silage, forage, grazing	Vet and sundries	Total VC
Dairy cow	244	102	72	*418*
Replacement	129	104	34	*267*

Table 3: Calculated change in variable cost given change in dairy herd

	£ million
VC^M	120.01
VC^R	23.24
VC^H	143.25
Change in VC given 1% change in culling rate[7]	**-0.88**
…of which concentrates	-0.42
…of which hay, silage, forage, grazing	-0.34
…of which vet and sundries	-0.11

Table 4: Direct impact of increasing cow longevity on dairy herd emissions

Emissions linked to animal numbers	Kt CO_2 eq.
Dairy cow enteric	632
Other dairy enteric	84
Dairy cow waste	155
Other dairy waste	8
Manure management (all dairy)	61
Total	*940*
Dairy cow emissions	817
Replacement heifer emissions	122
Dairy cow emissions/head/year	0.0028
Replacement heifer emissions/head/year[8]	0.0012
Change in emissions from 1% reduction in culling rate	-3.92

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[6] The partial derivative in Eq. 10 provides the change in herd size given a one unit change in culling rate. However, since culling rate is a percentage, between zero and one, it is not informative to examine a one unit change numerically since this manifests a 100% change in the culling rate.

[7] Ibid.

[8] This figure is very close to enteric and manure emissions for replacement heifers calculated as part of a footprint analysis of Northern Ireland dairy systems by Vanessa B. Woods, Conrad Ferris and Steven Morrison, Agri-Food and Biosciences Institute (AFBI), Agriculture Branch, Hillsborough.

Table 5: Direct impact of dairy cow longevity on the beef herd

Term	**Description**	**Data Source**	**Value**
M	No. of dairy cows needed to meet milk production target	Agricultural Census June 2005	287,094
Δc	Increase in residual calves given 1% reduction in culling rate	$M*0.01$	2,871
ω	No. of months to finishing/12 months	NI Red Meat Task Force Report	1.19
	Increase in beef herd size given 1% decrease in dairy culling rate	$\omega * \Delta c$	3,409
p	Price calves slaughtered or exported 2005 (£)	SRNIA 2009	68

Table 6: Direct impact on fertiliser and concentrate costs

	Reduction in Chemical N Use		
	10%	20%	30%
Change in:			
N (kg/ha)	-9.88	-19.75	-29.63
£/ha	-4.55	-9.11	-13.66
DM (kg/ha)	-118.51	-237.02	-355.53
Dairy			
Grass Yield DM (tonnes)	-37,949	-75,897	-113,846
Fertiliser costs (£m)	-1.46	-2.92	-4.37
Concentrate costs (£m)	6.07	12.14	18.21
Net costs (£m)	4.61	9.22	13.84
Beef			
Grass Yield DM (tonnes)	-42,693	-85,385	-128,078
Fertiliser costs (£m)	-1.64	-3.28	-4.92
Concentrate costs (£m)	6.83	13.66	20.49
Net costs (£m)	5.19	10.38	15.57

Table 7: Direct impact on emissions for cattle sectors

	N2O	e/£	% Δ e/£
10%			
Dairy	-11.17	-0.03	-1%
Beef	-12.56	-0.05	-1%
Total	*-23.73*		
20%			
Dairy	-22.34	-0.06	-1%
Beef	-25.13	-0.09	-1%
Total	*-47.46*		
30%			
Dairy	-33.50	-0.09	-2%
Beef	-37.69	-0.14	-2%
Total	*-71.20*		

Table 8: Indirect impact of extending dairy cow lactation

National Impact	Lactation Extension (A*)	Lactation Extension (B*)	Lactation Extension (C*)
Economic Impact (£million)			
Direct Δ Output	-3.94	-3.71	7.61
Indirect Δ Output	-5.43	-5.11	12.61
Environmental Impact (Kt CO_2 eq.)			
Direct Δ Emissions	-19.89	-19.80	-19.24
Indirect Δ Emissions	-20.93	-20.79	10.48

*In scenario A, residual drop calves are exported immediately as live animals, in B they are slaughtered domestically then exported, and in C, they are reared in the beef sector then exported as live animals

Table 9: Indirect impact of reducing chemical N fertiliser on cattle grassland

National Impact	Chemical N Reduction (10%)	Chemical N Reduction (20%)	Chemical N Reduction (30%)
Economic Impact (£million)			
Direct Δ Output	9.16	18.31	27.47
Indirect Δ Output	11.45	22.90	34.36
Environmental Impact (kt CO_2 eq.)			
Direct Δ Emissions	-24.04	-48.08	-71.20
Indirect Δ Emissions	-19.67	-39.35	-59.02

Table 10: Indirect impact of combining Scenario 1-A, B and C with 20% N reduction

National Impact	A-20%	B-20%	C-20%
Economic Impact (£million)			
Direct Δ Output	14.38	14.60	25.93
Indirect Δ Output	17.47	17.79	35.51
Environmental Impact (kt CO_2 eq.)			
Direct Δ Emissions	-67.97	-67.88	-67.33
Indirect Δ Emissions	-60.28	-60.14	-28.87

Figure 1

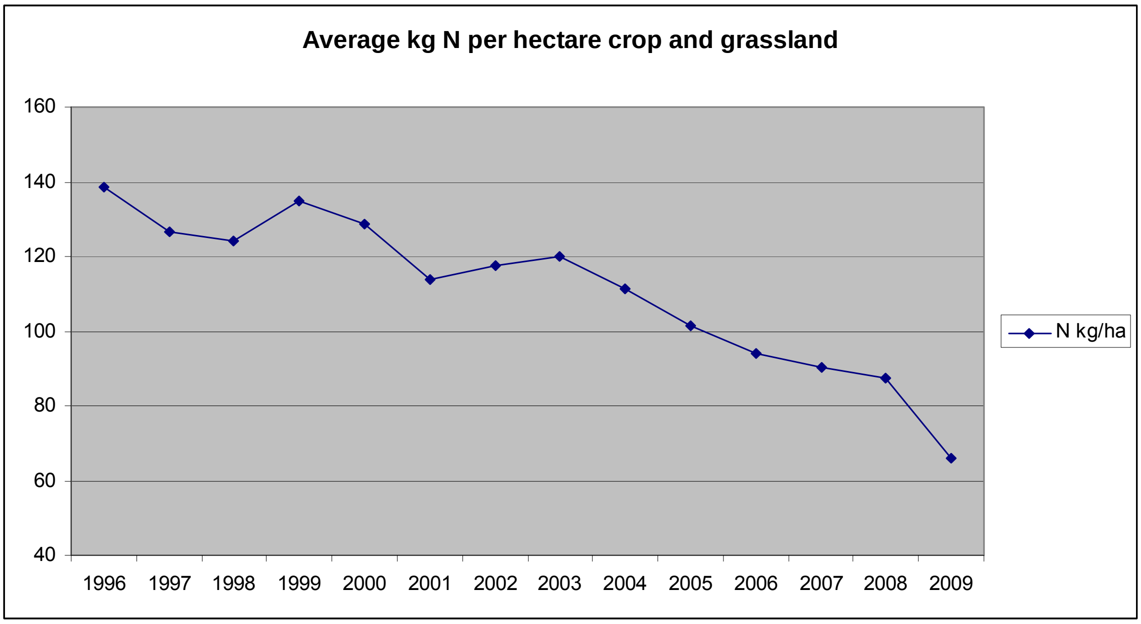
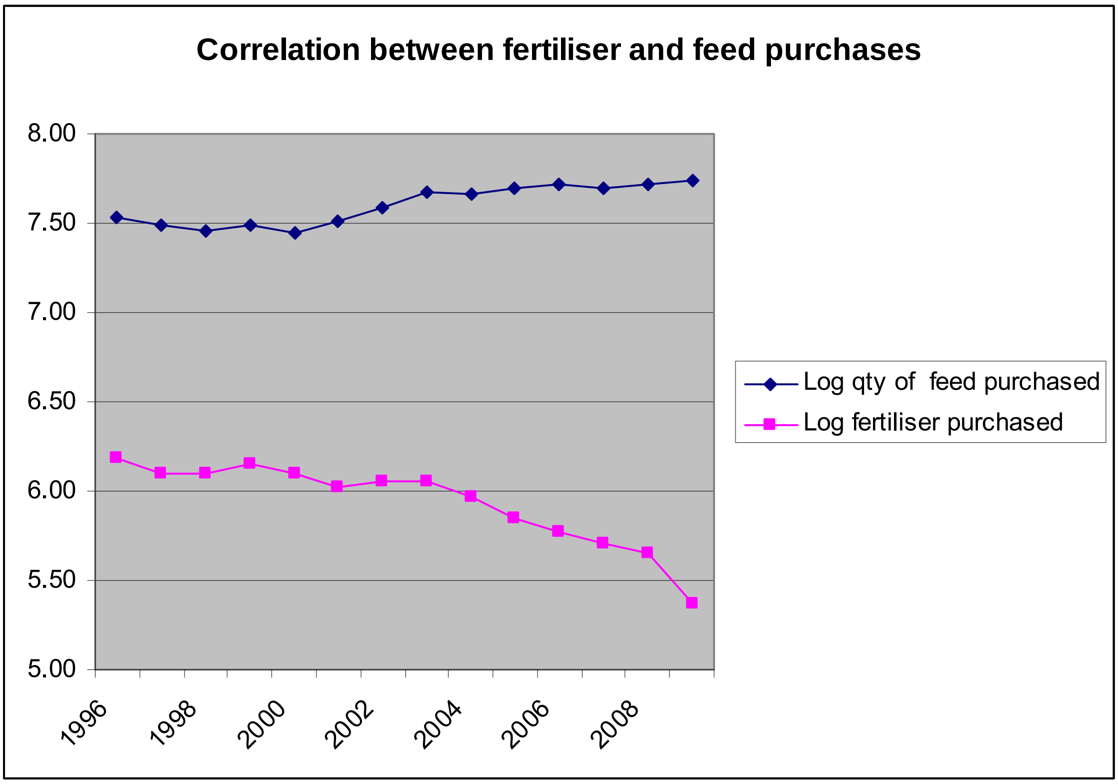


Figure 2



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