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Climate policy, interconnection and carbon leakage: the effect of unilateral UK policy on electricity and GHG emissions in Ireland

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Abstract:

This paper examines the effect of the UK's unilateral policy to implement a carbon price floor in Great Britain for fossil-fuel based electricity generation on the adjoining electricity market in Ireland. We find that, subject to efficient use of interconnectors between the two markets and constant imports from France and the Netherlands, a carbon price floor will lead to carbon leakage, with associated emissions in the Republic of Ireland increasing by 8% and electricity prices increasing by 2.4%. However, across the combined Irish and British electricity markets total emissions decline: high carbon prices drive decarbonisation in electricity generation. The UK's now implemented policy, which is a mechanism to directly manage carbon prices, substantially differs with the yet to be agreed EU policy response to postpone auctions of Emissions Trading Scheme allowances with the intention of indirectly increasing the price of carbon. The analysis suggests that the EU proposal will have only negligible additional effect on emissions from the combined Irish and UK electricity sectors.

Keywords: carbon leakage, carbon price floor, electricity markets, interconnection

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1. Introduction

The European Union's energy policy envisages open and competitive energy markets in electricity and gas, maintaining secure energy supplies at the lowest possible cost (CEC (2011)). Efficient, integrated, and fluid energy markets in Europe are also integral to making the transition to a low-carbon economy (CEC (2012c)). Among the actions being implemented to achieve these goals is the EU third energy package, adopted in 2009, which comprises regulations on access to electricity and gas networks and directives concerning common rules for the internal markets in gas and electricity. The mechanisms implementing these new internal energy markets are, for the most part, to be completed by 2014. But the European Commission fears that that deadline will not be met, as Member States are slow in adjusting their national legislation and in some instances are engaging in inward-looking or nationally inspired policies (CEC (2012b)). One member state policy that could be considered inward looking is Great Britain's carbon price floor (HM Treasury (2010)). While the policy is nominally consistent with EU aspirations for a low carbon economy, it overrides the EU's own proposals to support the price of carbon within the EU Emissions Trading Scheme (EU ETS) and additionally it disregards the potential for carbon leakage to adjacent countries. While this paper this paper focuses on the impact of Great Britain's unilateral climate policy on interconnected electricity markets, more widely Glachant and Ruester (2014) suggest that there is a serious risk of fragmentation in the European electricity market due to uncoordinated national policies affecting the electricity sector.

The paper contributes to the existing literature on CO_2 leakage by illustrating that unilateral climate policies have the potential to cause perverse outcomes through carbon leakage. The literature has focused primarily on leakage between trading blocs due to differing carbon policies whereas the analysis here focuses on leakage between countries within the same trading bloc. Specifically, we use a model of the electricity markets in Ireland and Great Britain (GB) to show that GB's carbon price floor (CPF) will increase both electricity prices and greenhouse gas emissions in Ireland. We also contrast GB's CPF with the EU Commission's proposal to support ETS allowance prices through the postponement of auctions of ETS allowances planned for 2013-2015 (CEC (2012f)). Not surprisingly given the high level of the CPF, we find that the CPF can be very effective in decarbonising electricity generation in the GB and Ireland but total emissions within the EU ETS will remain unchanged.

As far as we know, this is the first work in which the effects of the CPF imposed by UK are simulated. Increasingly simulation techniques are being used determine the effects of policy measures in electricity markets, including, carbon pricing (Denny and O'Malley (2009); Wagner *et al.* (2013)), wave and tidal energy(Deane *et al.* (2012); Denny (2009)).

The outline of the paper is as follows. Section 2 describes the policy environment within which electricity markets operate. The analysis focuses on the electricity markets in Ireland and Great Britain, which are described in section 3. Section 4 describes the policy scenarios. Section 5 presents scenario results and discussion. Section 6 presents some conclusions.

2. The Policy Context

A major pillar of the European Union's (EU) climate policy is the EU Emissions Trading Scheme (ETS). Market trading in emissions allowances establishes a price for carbon dioxide, the price of which is intended as an incentive to reduce greenhouse gas emissions and decarbonise the economy. A high price for carbon is widely considered as necessary to drive investment in energy efficiency and renewable energy (Clarke et al. (2009); Edenhofer et al. (2009)). For most of the history of the ETS, allowances have traded at prices significantly below the levels envisaged prior to the implementation of the EU ETS and during 2013 allowances traded at levels below €4 per allowance.

A surplus of almost 1 billion allowances has accumulated in the ETS. There are several causes of the accumulation of the allowances. A large part is attributable to recession but the over-estimation by EU governments of the reserve for new entrants to the ETS is also significant, as is financial support for renewable generation in member states, which resulted in a significant expansion in low-carbon generation. The over supply of allowances put downward pressure on the ETS price, as noted by CEC (2012d).[1] The European Commission has proposed a number of options to underpin allowance prices, including postponing auctions of allowances planned for 2014-2016, as well as reforms of the ETS to address the growing structural supply-demand imbalance (CEC (2012e); CEC (2013c)). In January 2014 the European Parliament's Environment Committee, following earlier approval by both the parliament and Council, approved an amendment to the ETS Directive to enable postponement of auctions of allowances but there remains considerable uncertainty surrounding how that will affect allowance prices and the ultimate impact on emissions.

[1] More on the surplus of allowances can be found here: http://europeanclimatepolicy.eu/?p=27

The UK Government has unilaterally instituted a much more significant market support for climate policy objectives. Commencing 1st April 2013 a carbon price floor (CPF) for fossil-fuel based electricity generation was introduced in Great Britain at a rate of Stg£16/t CO_2 in 2013 rising to approximately £30/t CO_2 in 2020, and to £70/t CO_2 in 2030 (HM Treasury (2011); HM Treasury (2012)). The CPF is complementary to the EU ETS and affects the power sector only. The objective of the CPF is to provide an incentive to invest in low-carbon power generation by providing greater support and certainty regarding the price of carbon in Great Britain's electricity generation sector.[2] The CPF will significantly reduce the uncertainty associated with pricing under the ETS. As the CPF is likely to be significantly higher than ETS allowance price, the CPF will provide an incentive to invest in low-carbon generation in the GB electricity market, to invest in interconnection capacity and to increase electricity generation outside of GB for export into the GB market (i.e. carbon leakage).

Both the EU ETS and the UK's climate policies affect the electricity market on the island of Ireland due to the nature of the electricity market. The Single Electricity Market (SEM) is the wholesale electricity market operating in the Republic of Ireland (ROI) and Northern Ireland (NI). Fossil fuel based electricity generators in both jurisdictions are regulated under the EU ETS. The CPF will affect electricity generation, emissions, and prices within both ROI and NI, as the SEM is interconnected with the GB electricity market, British Electricity Transmission and Trading Arrangements (BETTA). In general, we find that with a higher price for carbon in BETTA compared to the ETS, generation plants in the electricity market interconnected with GB will increase their exports into the BETTA market, subject to interconnection constraints.

Carbon leakage is often defined as a gross outflow usually arising when competitive advantage is lost compared with foreign countries and production occurs in the foreign countries satisfying domestic demand. Computable General Equilibrium (CGE) models such as Elliott *et al.* (2010), which studied the effect of carbon taxation outcomes in the USA and other country blocs suggest that as much as one quarter of all emissions abatement is offset by leakage, whereas Bernard and Vielle (2009), also using a CGE model to study the effects of Europe's transition to a low carbon economy, conclude that leakage will be small with a magnitude of at

[2] On the motivations behind the carbon price floor see here: http://www.nera.com/nera-files/EVT_UK_Carbon_Price_Floor_0511.pdf. On the relation between the CPF and the risk reduction for investors see here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/81283/consult_carbon_price_support_responses_s.pdf (from pg. 14).

most a few percent of GHG abatement.[3] What is more, in electricity markets, the threat of leakage is quite acute because electricity is easily traded via interconnectors but the magnitude of leakage between electricity markets has not been examined in the literature. For certain, the extent of potential leakage in the electricity sector depends to a large extent on the level of interconnection between markets.

3. SEM and BETTA Electricity Markets

This section briefly describes the SEM and its rules, a detailed description of which can be found in SEMO (2012). The SEM is a centralized market with all electricity sold through a pool via a market clearing mechanism. Generators receive the System Marginal Price (SMP) for their scheduled dispatch quantities, capacity payments for their actual availability, and constraint payments for changes in the market schedule due to system constraints. The SMP is the price calculated by the market software for every half hour trading period. The SMP is made up of a shadow price component and an uplift component. The shadow price forms the basis of the SMP calculation and reflects the cost of supplying an incremental change in demand. Fixed costs are remunerated through the uplift component of SMP. Wind is currently modelled as a price taker in the SEM. A price taker cannot set the SMP, it merely receives the SMP during the trading period.

The electricity market in Great Britain, British Electricity Transmission and Trading Arrangements (BETTA), is designed to encourage bilateral trading between generators and suppliers. As described by Steggals *et al.* (2011), most of the transactions take place within vertically integrated firms, with the system operator (SO) in charge of the balancing market. In BETTA's wholesale market electricity generators and retail suppliers contract directly between one another; electricity is then sold in the retail market between the suppliers and the final consumers. Final consumers may switch between electricity suppliers incentivising price competition between suppliers. The market operates on the basis of rolling half hourly slots. Generators are required to contract with suppliers at the latest one hour ahead of actual supply ('gate-closure') and to declare their final settlement to the SO. The SO penalises companies that default on their contracts.

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[3] The results are sensitive to and proportional to the degree of competition in world markets, the well-known Armington elasticity (Armington, 1969)

Given the nature of a bilateral market, the BETTA market is particularly difficult to model and simulate. We assume that the bilateral contracts between generators and suppliers lead to the same price that emerges from a centrally dispatched market. We also assume that the incentives provided by the consumers to the suppliers are strong enough to generate an electricity price that minimizes the system costs. We impose in our model that the import flows from France and the Netherlands to BETTA are equal to the average of the historical flows from 2008 to 2011. The imports are subtracted from UK final demand and are not considered in the generation process between BETTA and SEM.

4. Policy Scenarios

We use the PLEXOS model to investigate policy questions relevant to the electricity sector on the island of Ireland in relation to proposals to support the price of carbon both within the EU ETS and unilaterally by the UK through a carbon price floor.

PLEXOS[4] is a widely used modelling tool used for electricity market modelling and planning (e.g. Gil (2012); Tomšic and Pašicko (2010); William E. *et al.* (2012)). The Commission for Energy Regulation in the Republic of Ireland and the Utility Regulator in Northern Ireland have validated a PLEXOS model for use in simulating system marginal prices and other market outcomes in the SEM (SEMO (2011b)).[5] Without a demand model for electricity demand in either Northern Ireland or Great Britain we have assumed that electricity demand remains constant in both jurisdictions.

Specifically we attempt to answer the following questions:

- What is the effect of the CPF on electricity prices, electricity demand, emissions and carbon leakage?
- Given GB's CPF what is the effect of the EU's proposal to 'back load' the auctioning of ETS allowances?
- Should ROI consider implementing a CPF in response to the GB CPF?

To make the analysis tractable we make a number of assumptions to enable the analysis to focus on the effects of climate policies on the electricity sector. The first simplifying assumption is that our analysis is for just one year, which abstracts from the effects of changes

[4] PLEXOS is available from Energy Exemplar (http://energyexemplar.com/). A PLEXOS academic license was used for this research. The solver used for this research was Xpress MP available from FICO (fico.com) also under an academic license partnership.
[5] See Appendix for more details on the PLEXOS model.

over time in the mix of generation capacity between fuels and renewable generation and allows us to assume as fixed the amount of interconnection capacity between ROI, NI and BETTA. We use 2016 as our year of analysis, as it is covered in network capacity statements in both the SEM and BETTA markets (National Grid (2012); SONI & EirGrid (2011)). It is also the first year in which the Large Combustion Plant Directive (2001/80/EC) becomes effective for existing generation plants, which will have a significant effect in reducing coal-fired generation capacity in the BETTA market. Directly as a result of the Large Combustion Plant Directive we assume that coal power plants in BETTA are constrained at 38% of capacity. We use a constant set of assumptions on fossil fuel prices and sterling-euro exchange rates across the scenarios we run. For fuel prices we use E3M-Lab (2012) projections for 2020, which are based on a stochastic world energy model, and we interpolate values for 2016, as show in Table 1. The cost of gas is higher in SEM than in BETTA, as Ireland pays the transport costs to supply the gas from Great Britain but gas power plants are more efficient in SEM than BETTA.[6] Coal is cheaper in SEM, as this fuel is imported directly to the deep water port at the main coal power plant (Moneypoint) but coal power plants are more efficient in BETTA, as they are newer than the Irish power plants. It is arguable that these price projections will be overtaken by developments in international energy markets, particularly related to shale gas, which is generally much cheaper than the natural gas and could revolutionise the global gas market. For the purpose of this analysis these prices are sufficient to demonstrate the scale of the effects climate policies can have on electricity costs and emissions.

We develop four scenario analyses to investigate the policy questions posed, which are summarised in Table 2. Scenario 1, 'Pre Q2 2013' describes the policy situation in spring 2013 when the only price for carbon in electricity generation in ROI, NI and BETTA was that which prevailed under the EU-ETS. Point Carbon (2012c) project an ETS price increasing to €5 in 2016 under an assumption of no policy change in the EU-ETS. Beginning 1st April 2013 a CPF was implemented in BETTA for the electricity sector, which we model in scenario 2, 'CPF in BETTA', where the price of carbon dioxide in the BETTA market in 2016 will be approximately €27 (stg£21) HM Treasury (2011). A potential policy response in ROI would be to match the CPF in BETTA. Scenario 3, 'CPF in SEM & BETTA', examines the impact of introducing a CPF within both jurisdictions of the SEM at a rate equivalent to the BETTA CPF. Scenario 4, 'EU Back-loading' investigates the impact of one variant of the EU Commission's

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[6] In BETTA the power plant conversion efficiency are equal to 0.54 for gas and to 0.38 for coal, whereas comparable conversion efficiencies for SEM are equal to 0.56 and 0.35.

proposal to postpone auctions for ETS allowances. Under the EU proposal allowances will be held back from auction in the years 2014-2016 when demand for allowances is expected to remain very low (CEC (2012a); CEC (2013b)). Point Carbon (2012b) have projected ETS allowance prices under a number of 'back-loading' variants. Under such a scenario their projections for ETS allowance prices is €12 in 2016.

5. Results and Discussion

A summary of scenario results on the SEM's load, wholesale electricity price, total system cost, and emissions for each of the scenarios are presented in Table 3.[7] These results are conditional on the assumptions about fuel prices, generating plant efficiencies and electricity demand.

What is the effect of the CPF on electricity prices, electricity demand, emissions and carbon leakage?

With a carbon price floor equivalent to €27 in BETTA in 2016 compared to €5 throughout the ETS, equivalent generation technologies are cheaper within the SEM and will export into the BETTA market subject to interconnector constraints. As generation within the SEM increases to supply additional exports to the BETTA market, the marginal dispatching plant during any trading period will change, which directly affects the system marginal price. On an annual basis the effect of BETTA's CPF is to increase the SEM's system marginal price in 2016 from a projected €76.9/MWh to €78.7/MWh, as per scenarios 1 and 2 in Table 3 and this represents a projected 2.4% increase in price. Table 4 shows the projected percentage change in interconnection flows between the SEM and BETTA and also within the SEM between ROI and NI. The introduction of the CPF makes BETTA generators less competitive compared to the SEM and net exports of electricity from the SEM to the BETTA market increase by 154%. While this is a very large increase in projected exports to the BETTA market, it is constrained by interconnection capacity between the markets.

Electricity demand within Ireland will remain practically unchanged due to the relatively low price elasticity of demand but with prices 2.4% higher, expenditure on electricity by Irish consumers will increase by a similar amount. Another major effect of the CPF is the redistribution of emissions. Greenhouse gas emissions in 2016 are projected to increase by 6.9% in the SEM with respect to the no policy change scenario, and by slightly more within the

[7] The calculated wholesale electricity price is an annual load-weighted average.

ROI. This projected outcome is contrary to HM Revenue & Customs (2013), which contend that “carbon emissions in Northern Ireland and the Republic of Ireland do not increase as a result of the introduction of the CPF”. Model projections are that BETTA’s emissions will decline by 2.8% due to the displacement of carbon intensive generation with imports from the SEM, which outweighs the increase in emissions in SEM. However, it should be noted that emissions within the EU-ETS will not decline so there is no beneficial improvement in global emissions.

The reduction in electricity generation in BETTA is compensated by a rise in generation within the SEM subject to interconnection constraints. The magnitude of these changes in generation may vary depending on the level of interconnection between BETTA and other markets. Our model just considers the interconnection between SEM and BETTA and assumed constant imports between GB and Europe, as we do not model European electricity markets. However, if other markets are included in the analysis, such as France or the Netherlands, carbon leakage from BETTA to these markets is also likely.

Without a demand model for BETTA’s electricity demand we have assumed that electricity demand in BETTA remains constant across all scenarios. As anticipated a BETTA CPF results in a carbon leakage from the BETTA into the SEM market. This measure is an upper bound estimate of the real effect of the CPF in GB, as interconnection flows between GB, France and the Netherlands are fixed in our model. An outcome that was not anticipated is that the CPF results in an overall reduction in emissions from the combined SEM and BETTA markets of 1.2%. Emissions intensity (carbon dioxide (CO_2) equivalents per GWh generated) improves in both SEM and BETTA. The improvement within the SEM is attributable to an economy of scale, with a larger system load due to increased exports; generation plant is capable of operating at optimum efficiency for longer periods with less ramping cycles necessary.

Under the CPF in BETTA scenario the carbon leakage rate between GB and SEM, calculated as the ratio of the change in SEM emissions to the change in BETTA emissions, is 52%. The CPF policy is projected to reduce emissions from the GB electricity sector by 3% but half of those savings are realised by increased emissions within the SEM.

The model’s projected interconnection flows are affected by fuel and plant efficiency assumptions. Gas is frequently the marginal fuel both in SEM and BETTA. The low efficiency of GB gas power plants leads to higher shadow prices in BETTA than in SEM. In PLEXOS the interconnection flows are driven by the shadow price and as result, in our model SEM is a net exporter. This is not confirmed by historical data, as shown by Deane *et al.* (2013), which finds that wholesale electricity prices in BETTA are substantially lower than SEM prices for the period 2008-2011. Rules on the operation and access to the interconnectors between SEM and

BETTA are quite complex (SEMO (2011a)). Transmissions capacity auctions are persistently undersubscribed, and transmissions rights acquired are not fully used (McInerney and Bunn (2013b)). This occurs even though there are significant price differentials between the SEM and BETTA markets, as noted by Deane *et al.* (2013). There are also significant power flows on the SEM-BETTA interconnectors against the efficient price spread direction, which McInerney and Bunn (2013c) attribute to factors such as intermittent wind and strategic behaviour by dominant firms. We have modelled interconnection flows as if there was free access subject to physical constraints, and assumed fixed interconnector flows between GB, France and Netherlands. Consequently the model projections on interconnector flows are an upper bound estimate of potential trade (and carbon leakage) between markets.

Abstracting from the management of interconnectors it is nonetheless interesting to analyse carbon emissions and exports based on the assumption of unhindered and free access to the interconnectors. In our analysis the high price of carbon in BETTA relative to SEM drives the price integration between the two markets. As shown in Table 4, in scenario 2 carbon is priced at €27 in BETTA versus €5 in SEM and the electricity price differential narrows. Exports from SEM to BETTA increase. When carbon is priced equally in SEM and BETTA (scenarios 1 and 4) the differential in electricity prices rises and exports from SEM to BETTA decline.

Given GB's CPF, what is the effect of the EU's proposal to 'back load' the auctioning of ETS allowances?

The European Parliament is currently discussing a proposal to postpone (i.e. back load) or potentially cancel ETS allowances as a measure to support allowance prices (CEC (2013d); ENVI (2013)). A major uncertainty surrounding the back-loading proposal is its effect on the ETS price. The back-loading scenario here assumes that the ETS price will rise to €12 in 2016. This price is based on projections undertaken by Point Carbon (2012a) on the basis of 700-900,000 ETS allowances held back from auction in the years 2013-2015 but subsequently cancelled in 2019-2020. We limit our analysis of the effect of back-loading to the SEM and BETTA markets. Given that the CPF has already been implemented in BETTA the effect of subsequently introducing a back-loading mechanism that increases the ETS price to €12 can be examined through the difference between the 'CPF in BETTA' and 'EU Back-loading' scenarios. With the ETS price increasing from €5 to €12 the cost of electricity in the SEM increases by 1.2% and demand for electricity within the SEM slightly declines. As the gap between the ETS price and the CPF narrows, electricity in the SEM is less price competitive compared to BETTA and interconnection flows to the BETTA market are less than under the 'CPF in BETTA' scenario. Overall, net exports decline by 11%, though exports are still significantly above pre-CPF levels at +125%. The effect on emissions varies between jurisdictions. Combined SEM and BETTA emissions are practically unchanged compared to the ‘CPF in BETTA’ scenario. Emissions and emissions intensity decline in the SEM, while the reverse is the case in BETTA. With total emissions from the SEM and BETTA combined unchanged compared to the ‘CPF in BETTA’ scenario one conclusion is that there is no additional climate benefit within SEM or BETTA from implementing the back-loading proposal. But that is a narrow interpretation as back-loading will reduce emissions throughout the EU, whereas GB’s CPF results in carbon leakage to adjoining electricity markets.

Should ROI consider implementing a CPF in response to the BETTA CPF?

As carbon leakage from BETTA to ROI will decrease Ireland’s efforts to move to a low carbon economy, ROI authorities may consider implementing its own CPF. The relative simplicity and the effectiveness of a CPF at reducing emissions compared to the EU-ETS are also potential benefits of a CPF. Introducing a CPF similar to that in BETTA in both jurisdictions of the SEM is projected to increase SEM’s wholesale electricity prices by 17.5%. Such a large price increase would affect export competitiveness and consequently might not be a realistic policy option. However, as a climate policy a CPF in the SEM would be quite effective with electricity sector emissions within the SEM projected to fall by 15.9%, and by 17.3% in the ROI. A CPF would also generate significant tax revenues. If a CPF is implemented in the SEM, taxes on emissions in NI will be remitted to the UK Treasury and taxes on emissions in ROI will be remitted to the Irish Treasury. Because the SEM is a wholesale pool market with a single price, customers in both jurisdictions will effectively be paying the taxes to both treasuries. In proportion to their relative share of total SEM demand ROI customers will remit €204 million in carbon floor payments to the Irish Treasury and a further €76 million to the UK Treasury. Had electricity generators in NI not been exempt from the CPF (i.e. scenario ‘CPF in NI & BETTA’), customers from the ROI would pay approximately €65 million to the UK Treasury in 2016. In the absence of the NI exemption this unilateral climate policy by the UK government had the potential to generate significant tax revenue from ROI and given the difficult state of Irish public finances would have posed an important justification for consideration of implementing a similar CPF in ROI. However, a counter argument would have been the impact of significantly higher electricity prices on competitiveness.

Welfare Implications

A detailed analysis of the welfare implications associated with increasing electricity prices is beyond the scope of this paper but it is worth noting that there is likely to be a significant redistribution of welfare between electricity producers and consumers. The case of a carbon tax is directly comparable. A carbon tax is paid to government and there is a potential welfare loss if the tax revenue is not redistributed, as firms will face higher fuel prices and consumers will pay higher utility bills.[8] However, depending on how the tax revenue is used, for example for additional spending or to offset existing taxation, the welfare impacts will differ. Conefrey *et al.* (2012b) and Di Cosmo and Hyland (2013b) examine the effect of a carbon tax on the ROI economy and find that when the tax revenue is recycled through lower income taxes a double dividend is possible, yielding both a reduction in emissions and an improvement in economic performance. But if, for example, the tax revenue is recycled as lump-sum transfers to households, the double dividend is unlikely to materialise and negative welfare impacts may be substantial. Callan *et al.* (2008) and Verde and Tol (2009) have shown that carbon based taxes are regressive and unless supporting compensatory measures are instituted poorer households will be significantly impacted by the measure.

If the CPF is only implemented in the BETTA market, electricity generators within the SEM are the beneficiaries of the increased electricity prices. In that situation there is no additional tax revenue available to be recycled and policy responses, such as those discussed in Conefrey *et al.* (2012a) and Di Cosmo and Hyland (2013a), to offset negative welfare impacts will not be feasible. The scale of the welfare losses are difficult to quantify. However, it is plausible that with carbon prices equal to €27, the industrial sectors in Ireland and UK will lose competitiveness with respect to their European partners.

6. Conclusions

In April 2013 the UK implemented a unilateral climate policy that sets a floor for the price of carbon in the BETTA market, and which overrides the EU's price mechanism for pricing carbon within Europe – the EU-ETS. Northern Ireland was exempt from the CPF in recognition of energy security issues and implausibly to ensure that "carbon emissions in Northern Ireland and the Republic of Ireland do not increase as a result of the introduction of the CPF" (HM

[8] A carbon tax already exists in Ireland but is not applied in the EU ETS sector, which includes the power sector. Thus, any increase in the electricity price that may be induced by the CPF is unrelated to the carbon tax.

Revenue & Customs (2013)). Using a simulation model of the SEM and BETTA electricity markets we investigated the effect of the CPF, finding that BETTA's CPF has the potential to have significant spill-over into the SEM due to the interconnection between the SEM and the BETTA markets.

Our simulation projections for 2016 are that GB's CPF will result in the SEM electricity price increasing by 2.4% and emissions increasing in both NI and ROI by 4.2% and 7.8% respectively, given our model assumptions. The increase in SEM emissions is directly attributable to carbon leakage from the BETTA market. A carbon price floor in the BETTA market leads to a reduction of 2.3% in GB emissions, which contributes to the UK government's ambition to move to a low carbon economy. The UK's unilateral carbon policy has a clear and significant impact on adjoining energy markets. Policy ambitions within the ROI to decarbonise the electricity sector will become more difficult. There is also a negative welfare impact with Irish electricity consumers paying more for electricity. In the SEM market the marginal dispatching generation plant sets the marginal price, which in the case of a CPF will be a more expensive generation plant that is dispatched to supply exports to GB. On the contrary generation companies within the SEM will benefit through higher electricity prices. The UK's unilateral climate policy has negative impacts on neighbouring countries both in terms of prices and carbon leakage. An EU-wide rather than unilateral approach may be less distorting.

An unanticipated result of the analysis is that emissions from the SEM and BETTA markets combined declined by 1.2%. This result is attributable to more efficient electricity generation across the two markets, rather than directly attributable to the UK's policy choice. However, in the wider context of the EU-ETS the GB's CPF will not affect the number of ETS allowances. Any reduction in emissions in the SEM or BETTA markets has the potential to be offset by increased emissions elsewhere in Europe. The UK's unilateral policy has no global impact on emissions. If the policy objective is to reduce emissions, any measures to increase the price of carbon must be integrated with the EU-ETS scheme.

When the CPF was initially proposed the CPF was intended for the entire UK including NI. Had the CPF been actually implemented in NI, dispatching generation plant in NI would increasingly set the SEM's marginal price and simulations suggest that Irish electricity prices would increase by 20% (The SEM price is common to both ROI and NI). A CPF within the SEM is still a policy option and as a carbon abatement policy option would be quite attractive. A ROI CPF would reduce emissions from the electricity sector by 17.3% and raise tax revenues for the Irish Treasury of some €260 million, which is not insignificant in the context of austerity budgets. However, a CPF would significantly reduce business competitiveness and household welfare, with electricity prices rising by roughly 17%. The analysis here is based on the assumption that interconnection capacity between the SEM and BETTA markets is used optimally and that the interconnection flows between GB, France and the Netherlands are kept constant and equal to their historical levels. However, empirical evidence indicates that interconnector transmissions capacity auctions are persistently undersubscribed, and transmissions rights acquired are not fully used, and also that there are significant power flows against the efficient price spread direction (McInerney and Bunn (2013a)). While some of those issues can be attributed to factors such as intermittent wind, strategic behaviour by dominant firms is also suspected. The implication for the analysis here is that the model projections on interconnector flows are upper bound estimates of potential trade and carbon leakage between markets. Market rules that hinder trade on the interconnectors are a barrier to carbon leakage.

The EU is currently discussing a proposal to postpone (i.e. 'back-load') or potentially cancel ETS allowances as a measure to support allowance prices and thereby reduce emissions (CEC (2013a); ENVI (2013)). Because of the relatively high floor price in the GB CPF compared to the expectation of ETS allowance prices under the EU proposal (Point Carbon (2012d)) our analysis suggests that back-loading will have only minimal additional effect on the electricity sector in the UK or ROI. But the GB's CPF will not reduce aggregate emissions either in the EU or globally, as it will not have any effect on the total allocation of emission allowances in the EU-ETS. The policy may improve the carbon intensity of the electricity generation sector in the UK but total emissions within the EU-ETS will not be reduced.

Table 1: Fuel Price Assumptions, €/GJ, 2016

		BETTA	SEM
Gas	Winter	10.45	10.52
	Summer	8.56	8.63
Oil		15.05	15.08
Coal		4.17	3.83

Table 2: Scenarios for carbon pricing under a carbon price floor (CPF) and in the EU Trading Scheme (ETS)

Scenario		ROI/NI transmission constraint	ROI	NI	BETTA
1	Pre Q2 2013	Yes	ETS=€5	ETS=€5	ETS=€5
2	CPF in BETTA	Yes	ETS=€5	ETS=€5	CPF=€27 (£21)
3	CPF in SEM & BETTA	Yes	CPF=€27 (£21)	CPF=€27 (£21)	CPF=€27 (£21)
4	EU Back-loading	Yes	ETS=€12	ETS=€12	CPF=€27 (£21)

Table 3: Scenarios for carbon pricing under a carbon price floor (CPF) and in the EU Trading Scheme (ETS)

Scenario		SEM System Margin Price, SMP €/MWh	SEM load, million TWh	SEM system total cost, €million	ROI CO_2, million tonnes	NI CO_2, million tonnes	SEM (ROI + NI) CO2, million tonnes	BETTA CO_2, million tonnes	SEM + BETTA CO_2, million tonnes
1	Pre Q1 2013	76.9	41.40	1808	13.6	4.9	18.5	91.7	110.3
2	CPF in BETTA	78.7	41.40	2004	14.7	5.1	19.8	89.2	109.0
3	CPF in SEM & BETTA	92.5	40.75	2199	12.2	4.5	16.7	90.8	107.4
4	EU Back-loading	79.7	41.30	2051	14.1	5.2	19.4	89.6	108.9

Table 4: SEM and BETTA prices and projected flows on the interconnectors

Scenario		SEM price (€/MWh)	BETTA price (€/MWh)	Δ in price (€/MWh)	Net Exports (Scenario 1 = 100)		
					SEM to BETTA	ROI to BETTA	NI to BETTA
1	Pre Q2 2013	76.9	70.9	6.0	100	100	100
2	CPF in BETTA	78.7	81.0	-2.3	254	254	253
3	CPF in SEM & BETTA	92.5	80.4	12.1	96	94	98
4	EU Back-loading	79.7	80.5	-0.9	225	224	226

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Appendix: PLEXOS model

PLEXOS is a flexible platform allowing user defined constraints. Importantly from a research perspective PLEXOS is a transparent model, which allows users to browse and verify the equations of the problem via a diagnostic tool. PLEXOS co-optimises hydro, thermal, renewable, and reserve classes; and no heuristic or sequential approach is taken. Modelling is carried out using mixed integer linear programming that aims to minimize an objective function subject to the expected cost of electricity dispatch and a number of constraints. The objective function of the model includes operational costs, consisting of fuel costs and carbon costs; start-up costs, consisting of a fuel off-take and a start cost; penalty costs for un-served energy and for failing to meet reserve requirements. System level constraints consist of an energy balance equation ensuring supply (net pumping demand) meets regional demand at each period. Water balance equations ensure water flow within pumped storage units is conserved and tracked. Constraints on unit operation include minimum and maximum generation, maximum and minimum up and down time and ramp up and down rates.

PLEXOS solves for each period and maintains consistency across the full problem horizon. Our scenarios use a model run with an optimisation length of one hour and period of one day with a horizon of one year, which entails 365 individual daily optimisations at a resolution of one hour each. To avoid issues with inter-temporal constraints (i.e. unit commitment of large units and storage end levels) at the simulation step boundaries the optimiser solves for the full simulation period and an additional look ahead period. However, only results for the simulation period are retained. Pumped storage units are also optimized in the model. Within the model, maintenance schedules for generation units are fixed exogenously if a known maintenance schedule is available, otherwise the model can determine an optimal maintenance schedule based on the annual maintenance rate and mean time to repair for each unit. The objective function of the maintenance scheduling formulation is to equalize the capacity reserves across all peak periods. Random outages for units are calculated based on Monte Carlo simulations. Outages occur at random times throughout the year with frequency and severity defined by forced outage rate, mean time to repair and repair time distribution. At simulation run time PLEXOS dynamically constructs the linear equations for the problem using AMMO[9] software and a solver to solve the equations.

The PLEXOS model solves for an exogenously given electricity demand. We use energy demand equations from the ISus model to project electricity demand in the Republic of Ireland. The ISus model is an environmental emissions simulation model (Lyons and Tol (2010)) and the energy demand equations are described in detail in di Cosmo and Hyland (2012).[10] PLEXOS and ISus scenarios are iterated until electricity price and demand reach equilibrium.

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[9] AMMO performs a similar role in PLEXOS as other mathematical languages such as AIMMS, AMPL, or GAMS but is written exclusively for PLEXOS

[10] Price elasticities of demand for electricity in the residential, industrial, service and agricultural sectors are -0.03, -0.12, -0.03, -0.3. While the residential price elasticity estimate is low by comparison to other countries, elasticities for the other sectors are of similar magnitude. See Taylor et al. (2005) for example.

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