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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 on Ireland's Single Electricity Market (SEM) of the UK's unilateral policy to implement a carbon price floor for electricity generation based on fossil-fuel. We simulate electricity markets and find that, subject to efficient use of the interconnectors between the two markets, a carbon price floor will lead to carbon leakage, with associated emissions in the Republic of Ireland increasing by 8% and SEM's electricity prices increasing by 2.4%. As the carbon price floor does not affect the number of ETS allowances no change is anticipated in aggregate European emissions. We also find that the EU's proposal to postpone ETS allowance auctions will reduce Irish emissions somewhat but that the trade opportunities associated with the UK carbon price floor means that emissions reductions in Ireland will be lower than might have been otherwise. A carbon price floor will result in substantial tax revenues and had the carbon price floor been implemented in Northern Ireland the larger share of taxes remitted would be paid by Republic of Ireland customers within the SEM. A carbon price floor in the Republic of Ireland is a potential policy option that would generate revenues in excess of €250 million but associated electricity prices increases in excess of 17% would have significant negative welfare and competitiveness effects.

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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 (2012a)]. Among the actions being implemented to achieve these goals is the EU third energy package, 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 (2012a)]. 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. This paper uses Great Britain's carbon price floor (CPF) and its impact on the Single Electricity Market (SEM) for the island of Ireland to demonstrate the impact of unilateral energy policy on interconnected markets, discussing the intertwined issues of carbon pricing, electricity interconnection capacity, and carbon leakage.

The price of carbon is the market signal that will drive investment in renewable energy and help in the transition to a low carbon economy. However, the current low price for carbon, in the absence of alternative subsidies, is not supportive of investment in renewable energy and hence the policy efforts within the EU, Great Britain and elsewhere to support the price of carbon. Interconnection between electricity markets facilitates greater penetration of intermittent generation on the electricity network but interconnection also enables carbon leakage, particularly if policies relating to the price of carbon are misaligned across countries. Under Great Britain's CPF carbon will be more expensive than in adjoining member states making electricity generation more competitive outside of Great Britain.

One of the objectives of this paper is to illustrate that unilateral climate policies have the potential to cause perverse outcomes through carbon leakage. Specifically, we use a model of the electricity markets in Ireland and Great Britain (GB) to show that GB's 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 (2012b)]. Not surprisingly given the high level of the CPF, we find that the CPF can be very effective in decarbonising electricity generation in the UK and Ireland but total emissions within the EU ETS will remain unchanged. The EU's proposals to postpone allowance auctions may reduce emissions initially but over the total period to 2020 total emissions will remain unchanged. Given the SEM's interconnection with the GB electricity market, the decision by the UK government to introduce the CPF poses a dilemma for policy makers in the Republic of Ireland (ROI). We briefly review some of the issues faced by the ROI had it considered implementing a CPF in response to the GB's CPF.

The outline of the rest 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 outlines the modelling approach. Section 5 describes the policy scenarios. Section 6 presents scenario results and discussion. Section 7 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). The ETS operates a cap on total greenhouse gas emissions from in excess of 11,000 factories, power stations, and other installations across all 27 EU member states plus Croatia, Iceland, Norway, and Liechtenstein. 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. 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 in early 2013 allowances traded at levels below €4 per allowance (equivalent to one tonne). 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)]. A surplus of almost 1 billion allowances has accumulated in the ETS, partly attributable to the recession but which is putting downward pressure on price [CEC (2012b)]. The European Commission has proposed a number of options to underpin allowance prices, including postponing auctions of allowances planned for 2013-2015, as well as reforms of the ETS to address the growing structural supply-demand imbalance [CEC (2012b)]. While it is likely that the allowance auctions will be postponed, there is considerable uncertainty surrounding how that will affect allowance prices and the ultimate impact on emissions. Point Carbon (2012) have projected that ETS allowance prices could double in a scenario in which allowance auctions are postponed until the end of the decade.

The UK Government has unilaterally instituted a much more significant market support for climate policy objectives. Commencing 1st April 2013 the UK will operate a carbon price floor (CPF) for fossil-fuel based electricity generation at a rate of approximately Stg£16/tCO2 in 2013 rising to £30/tCO2 in 2020, and to £70/tCO2 in 2030 [HM Treasury (2011)]. The CPF is complementary to the EU ETS and affects the generation sector only. Subject to European Commission approval, the UK government intends to exempt electricity generators in Northern Ireland (NI) and as such the CPF with only apply in the Great Britain electricity market [HM Treasury (2012)]. 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. But two prices for carbon within Europe will distort markets. A GB carbon price floor that is likely to be significantly higher than ETS allowance prices will provide an incentive to invest in low-carbon generation in the GB electricity market; investment in interconnection capacity; and increased electricity generation outside of GB for export into the GB market (i.e. carbon leakage). In the short run within existing interconnection constraints the UK's unilateral policy will provide an incentive for carbon leakage into adjacent markets.

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. SEM is the wholesale electricity market operating in the Republic of Ireland and Northern Ireland. Fossil fuel based electricity generators in both jurisdictions are regulated under the EU ETS. Regardless of the NI exemption, 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). Considering the particular case of the Irish and Great Britain electricity markets only (i.e. ignoring other markets), with a higher price for carbon in the BETTA market compared to the SEM, generation plant in ROI and NI will be dispatched more; consequently there will be more electricity exported into the BETTA market, subject to interconnection constraints. Because the wholesale electricity price in the SEM is determined as a pool price rather than through bilateral contracts, the extra demand for electricity from the BETTA will result in more expensive plant being dispatched within the SEM, which in turn affects the average price. Accordingly, the UK's unilateral domestic climate policy will affect electricity price, generation and greenhouse gas emissions in both the Republic and Northern Ireland.

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. The threat of leakage in electricity markets is quite acute because electricity is easily traded via interconnectors. Computable general equilibrium models such as Elliott *et al.* (2010) suggest that as much as one quarter of emissions abatement is offset by leakage. The concept of negative leakage has also been advocated where the taxed sector substitutes away from carbon into capital (e.g. from fossil fuels into wind turbines) causing a potential overall net reduction in carbon emissions [Elliott and Fullerton (2013); Fullerton *et al.* (2011)]. Given the long lead times in energy infrastructure the potential for negative leakage in the short term is likely to be low.

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). Since November 2007, Ireland and Northern Ireland are combined in the All Island Single Electricity Market. All electricity generated in Ireland with a capacity greater than 10 MW must be sold within the SEM. The SEM is a centralized or gross pool market with 48 trading periods per day (24 hours) with the first period at 06:00. Electricity is bought and sold through the pool under 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 that will cover the cost of meeting the cost of a unit increase in demand in the SEM. Electricity retailers purchasing energy from the pool pay the SMP for each trading period, capacity costs, and system charges. The SEM is designed around a single unconstrained marginal pricing structure, i.e. the wholesale price determined within the market ignores transmission and reserve constraints but respects generator physical abilities. The system (wholesale) marginal price is made up of a shadow price component and an uplift component. Shadow prices form the basis of the SMP calculation for each half hour trading period. The shadow price only reflects the cost of supplying an incremental change in demand. Payment of shadow prices only will mean that generator units will not recover the full costs of production, as the shadow price does not reflect start up, capital and zero load costs. 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.

Given the nature of a bilateral market, the BETTA market is particularly difficult to model and simulate. In this paper, 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. In this paper, we model only the BETTA and the SEM markets and exclude from the analysis interconnection flows between BETTA and both France or the Netherlands.

4. Modelling Electricity Markets

We employ the modelling software, PLEXOS, to solve unit commitment and dispatch optimisation within the SEM and BETTA electricity markets. PLEXOS 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)]. 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. Start-up/shutdown profiles and times are enforced via run-up rates, however for simplicity these are ignored in these market simulations.

In chronological mode, 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, a 'look ahead' period is used. 'Look ahead' means that the optimiser is given information about what happens ahead of the period of optimisation, and then solves for this full period (i.e. simulation period + 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 can be 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[1] software and a solver to solve the equations. Within the PLEXOS modelling tool, wind and other renewables are essentially treated as 'free' generation (i.e. the marginal cost is zero).

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). PLEXOS and ISus scenarios are iterated until electricity price and demand reach equilibrium. 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 [National Grid (2012); SONI & EirGrid (2011)].

5. 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. Specifically we attempt to answer the following questions:

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

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

- 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?
- How much do electricity transmission constraints add to emissions and costs?

There is no single answer to these questions, as there are many compounding factors including: weather conditions, renewable energy generating capacity, fossil fuel mix in generation capacity, fuel prices, interconnection capacity, exchange rate volatility, and electricity demand. To make the analysis tractable we make assumptions surrounding these issues, which 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. In doing this it allows us to abstract from the effects of changes over time in the mix of generation capacity between fuels and renewable generation in both electricity markets. It also allows us to assume as fixed the amount of interconnection capacity between ROI, NI and BETTA. We picked 2016 as our year of analysis, as it is sufficiently close in the future that there are reasonable estimates of what generating capacity will exist in both the SEM and BETTA markets [National Grid (2012); SONI & EirGrid (2011)]. 2016 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. We also assume that coal power plants in BETTA are constrained at 38% of capacity as a consequence of the Large Combustion Plant Directive. Power plant efficiencies also vary between SEM and BETTA. Gas power plants are more efficient in SEM, whereas coal power plants are more efficient in BETTA, as shown by Table 1. 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 2. The cost of gas is higher in SEM than in BETTA, as Ireland pays the transport costs to supply the gas from Great Britain. Coal is cheaper in SEM, as this fuel is imported directly to the deep water port at the main coal power plant (Moneypoint). It is arguable that these price projections will be overtaken by developments in international energy markets, particularly related to shale gas, but 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 six scenario analyses to help answer these questions, which are summarised in Table 3. 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. The ETS allowance price fluctuated around €4 in spring 2013. Point Carbon (2012) project an ETS price increasing to €5 in 2016 under an assumption of no policy change in the EU-ETS. Beginning 1st April 2013 the CPF was implemented in BETTA for the electricity sector, with NI exempt. We model this 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). Scenario 2 is essentially the status quo in a policy context, with a carbon price floor applicable in BETTA and carbon priced through the ETS in the Republic and Northern Ireland.

Scenario 3, ‘CPF in NI & BETTA’ is used to examine the implications if the carbon price floor were to be extended to include Northern Ireland. Through the design of the SEM a CPF in NI would directly increase electricity prices in ROI. An implication of higher electricity prices in the SEM due to a CPF in NI is that electricity customers in ROI will be indirectly paying taxes to the UK Treasury. A potential policy response in ROI would be to match the CPF in NI and BETTA. Scenario 4, ‘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 5, ‘EU Back-loading’ investigates the impact of one variant of the EU Commission’s proposal to postpone auctions for ETS allowances. Under the EU proposal allowances will be held back from auction in the years 2013-2015 when demand for allowances is expected to remain very low. Point Carbon (2012) have projected ETS allowance prices under a number of ‘back-loading’ variants, the most radical of which assumes that the back-loaded allowances will be cancelled in 2019-2020. Under such a scenario their projections for ETS allowance prices is €12 in 2016. The SEM is effectively two interconnected transmission networks in the Republic and Northern Ireland, which has transmission constraints. Scenarios 1-5 all incorporate those transmission constraints. Scenario 2unc, ‘Unconstrained’, relaxes these transmission constraints and allows us to examine the additional costs and emissions associated with the constrained North-South tie line.

6. 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 4.[2] Prior to discussing individual scenarios it should be noted that the results are conditional on the assumptions about fuel prices, generating plant efficiencies and electricity demand. The analysis also assumes a low price elasticity of demand, and even though the system marginal price varies substantially across the scenarios the variation in load demand is relatively muted. For example, the household sector’s price elasticity for electricity in ROI is estimated at -0.06 [di Cosmo and Hyland (2012)]. We compare differences in results across the scenario runs to help answer the policy questions posed earlier.

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 4. This represents a projected 2.4% increase in price, as shown in Table 5. Table 6 shows the projected percentage change in interconnection flows between the SEM and BETTA and also within the

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

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 represents a very large increase in projected exports to the BETTA market, the level of exports are constrained by the capacity of interconnection between the markets.

The higher costs associated with the introduction of the carbon floor are only partially mitigated by the savings from the REFIT scheme.[3] Under this scheme, wind plants are guaranteed a minimum price for each unit of electricity they generate. As described above, the introduction of the CPF will lead to higher prices and more exports from SEM to BETTA. This in turn will impact on the Irish wind generators in two ways. (i) *price effect*: the compensation payments paid to wind generators are linked to the system marginal price. The wind generators receive the compensation payment every period the system marginal price is lower than the guaranteed price. The introduction of the CPF raises the system marginal price in SEM and consequently payments to the wind generators will be not higher than in the scenario without the carbon floor. (ii) *curtailment effect*: the introduction of the CPF in BETTA makes the exports from SEM to the UK market higher than in the pre Q2 2013 scenario; with higher demand, wind in SEM will be curtailed less frequently, as the electricity generated by the wind power plants will be exported to BETTA. The calculated savings in REFIT payments associated with the adoption of the CPF in BETTA is 0.36% of total costs of €1808 million conditional on model assumptions.[4] Under the 'CPF in BETTA' total SEM costs increase to €2004 million, an increase of 10.9%, therefore the savings associated with reduced REFIT payments to wind generators are more than offset by the rise in total costs.

Electricity demand within Ireland remains practically unchanged due to the 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 Republic of Ireland. This projected outcome is contrary to HM Revenue & Customs (2013), which contend that the NI exemption would ensure that emissions in NI and ROI will not increase due to the CPF. Emissions from the BETTA market are projected to decline by 2.8%. In absolute terms the increase in emissions in the SEM is 50% of the change in emissions in BETTA. The decline in BETTA emissions is due to the displacement of carbon intensive generation with imports from the SEM. But aggregate emissions within the EU-ETS will not decline so there is no beneficial improvement in global emissions.

In our model, the reduction 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. As our model just considers the interconnection between SEM and BETTA, the increase in the carbon emissions in SEM should be taken as an upper bound

[3] The Renewable Energy Feed in Tariff (REFIT) is the primary means through which electricity from renewable sources is supported in Ireland.

[4] In this scenario the reduction in REFIT payments entirely due to price effects with no reduction in payments due to curtailment effects.

estimate of the potential effects of the implementation of the UK CPF. However, if other markets are included in the analysis, carbon leakage from BETTA will be extended across Europe, and consequently impact on emission targets.[5]

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. 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%. Table 7 reports emissions of carbon dioxide (CO_2) equivalents per GWh generated (excluding transmissions losses), which shows that emissions intensity improves in all jurisdictions following the introduction of the CPF in BETTA in scenario 2. While emissions intensity may improve there is no net reduction in EU or global emissions. 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.

The model's interconnection flows are determined 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 BETTA prices are substantially lower than SEM prices for the period 2008-2011. Consequently the analysis here should be taken as an upper bound estimate of the potential effects on the interconnection flows. It is difficult to model interconnector flows between the SEM and BETTA markets, as the rules on the operation and access to the interconnectors are quite complex [SEMO (2011a)]. Transmissions capacity auctions are persistently undersubscribed, and transmissions rights acquired are not fully used [McInerney and Bunn (2013)]. 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 (2013) attribute to factors such as intermittent wind and strategic behaviour by dominant firms.

Abstracting from the existing management of the interconnectors it is nonetheless interesting to analyse carbon emissions and exports based on the assumption of unhindered and free access to the interconnectors. Research by Malaguzzi Valeri (2009) on the SEM and BETTA markets in 2005 concluded that price integration between the two markets required a high level of interconnection but that the amount of interconnection necessary for integration decreases for high costs of carbon. With a high price of carbon in the BETTA market less interconnector capacity may be required to move towards price integration. In Table 8 we

[5] Our model has assumed no interconnection between GB and Europe, as we do not model European electricity markets. To check the robustness of this assumption we incorporated a European node in the model based on past interconnector flows between BETTA and other European markets. This analysis suggested that excluding interconnection between GB and Europe does not significantly alter model results and conclusions.

report SEM and BETTA prices and changes in the interconnection with respect to the Pre Q1 2013 scenario. The implementation of the CPF in BETTA increases the electricity price in the BETTA market by roughly €10/MWh reaching €81/MWh. The flow on the market interconnectors increases by 154% and the gap between the BETTA and SEM price falls from €6/MWh to €2.3/MWh. In several of the scenarios carbon is priced differently in the two markets but in the 'Pre Q2 2013' and 'CPF in SEM & GB' scenarios it is the same, €5 in the former and €27 in the latter. The largest price difference between the two markets occurs under the 'CPF in SEM & GB' scenario. In this scenario the CPF is applied both to BETTA and SEM, so the gap between the wholesale prices in these two markets is almost the same as under the 'no policy change' scenario.

What is the effect of the EU's proposal to 'back load' the auctioning of ETS allowances?

The European Parliament is currently discussing the 'back loading' proposal as a support measure for the ETS's allowance price [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 (2012) 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 from implementing the back-loading proposal. This would be a narrow interpretation as back-loading will affect electricity prices and emissions throughout the EU. Specifically within the SEM the back-loading proposal reduces emissions by 2.3% in 2016 compared to the 'CPF in BETTA' scenario. Under the back-loading proposal the allowances will be auctioned in 2019-2020 so the initial reduction in emissions will not be permanent.

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 in both jurisdictions of the SEM could lead to an increase of 17.5% in the price of electricity in the SEM, which would result in a significant loss in competitiveness for firms exporting to continental Europe and further afield. However, as a climate policy a CPF in the SEM would be quite effective with emissions projected to fall by 15.9%, and by 17.3% in the ROI (but would have no effect on aggregate EU emissions). It should be noted that the reduction in emissions in the SEM may be over-estimated in our model, as we do not consider interconnection between BETTA and the other EU electricity markets. A CPF would also generate significant tax revenues. Table 9 presents estimates of tax revenues associated with emissions arising in ROI and NI, which are conditional on the ETS price assumption as well as net export flows on the interconnectors to the BETTA market. 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 tax payments to the Irish Treasury and a further €76 million to the UK Treasury. The remittance by Irish customers to the UK Treasury is almost offset by remittances by Northern Ireland customers to the Irish 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. A counter argument would have been the impact of significantly higher electricity prices on competitiveness.

How much do electricity transmission constraints add to emissions and costs?

Several studies recognize the importance of the construction of a second North-South tie line between NI and ROI, including CER (2012) and FitzGerald (2004). EirGrid is currently developing a second line to enhance the integrity of the systems, which will be operative from 2017 [see SONI & EirGrid (2011)]. This will both ensure the security of supply in NI and allow the SEM generation system to dispatch efficiently.

Because NI and ROI are two interconnected electricity systems both entirely in the same market they are an ideal case study for illustrating the benefits of developing sufficient interconnection capacity between markets. We use the comparison between scenarios 'CPF in BETTA' and 'Unconstrained' to highlight the potential gains of greater transmission between NI and ROI. The 'CPF in BETTA' scenario reflects actual transmission constraints between ROI and NI, whereas in the 'Unconstrained' scenario the second North-South tie line is assumed built and there is sufficient transmission capacity between NI and ROI.

Investment in removing transmission constraints between NI and ROI has the potential to reduce the SEM's total system cost by 1.5% and reduce NI emissions by 2.6%, as shown in the final row of Table 5. There is a small reduction in emissions in the ROI. With a transmission constraint in place NI generation plants, which are generally older and less efficient than ROI plants, are prioritised in the merit order to ensure that system demand within the NI network is met. When the transmission constraints are relaxed more efficient power plants in the ROI can generate electricity for the whole SEM system. With more efficient ROI plants displacing

NI plants in the merit order, the SEM's system marginal price, determined by the marginal dispatching plant, will be lower. The reduction in SEM's costs totals €30 million, which results in a reduction of 0.9% in electricity price.

The capital cost of an overhead second North-South tie line is roughly €81 million, which when compared to the reduced costs and emissions avoided that will recur on an annual basis means that the strengthening of transmission between NI and ROI is a worthwhile financial investment.[6] Strengthening transmission within the SEM is a simple case-study of the benefits of market interconnection. Interconnection is often discussed as a means to increase wind generation capacity on electricity networks [e.g. Denny et al. (2010)] but this analysis shows that there can be both financial benefits and reduced emissions independent of the level of wind generation capacity, which was held constant in this scenario analysis.

Welfare Implications

In the previous section we have analysed how emissions, prices, and costs change under different scenarios. As expected, the scenario with the highest carbon prices (i.e. scenario 4 'CPF in SEM & BETTA') has the greatest impact on emission reductions, with total emissions from SEM and BETTA combined falling by 1.4% to 107.4 million tonnes. This was also the scenario under which the carbon intensity of electricity generation was lowest for the SEM and for the SEM and BETTA combined, as shown in Table 7. A detailed analysis of the welfare implications driven by the rise of the 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.

In the case of a carbon tax or CPF, the 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. 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.* (2012) 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.* (2012) and di Cosmo and Hyland (2011), 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] We assume here that the N-S line is constructed overground.

7. 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 (NI) was exempt from the CPF in recognition of energy security issues and to ensure that emissions in NI and ROI do not increase as a result of the introduction of the CPF [HM Revenue & Customs (2013)]. Using a simulation model of the SEM and BETTA electricity markets we investigated the effect of the CPF on electricity prices, interconnection, emissions and carbon leakage. We find that the 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 the 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, under the assumption of no interconnection between the GB and other European electricity markets. An unanticipated result 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 and excludes the demand impact of higher cost electricity in the BETTA market. As the CPF does not affect the number of ETS allowances, any reduction in emissions in the SEM or BETTA markets will be offset by increased emissions elsewhere in Europe such that there is unlikely to be any change in aggregate European emissions.

While the SEM market is not insulated from the impact of the CPF, we find that the decision to exempt NI from the CPF averts a peculiar situation where ROI electricity customers would, via NI electricity generators, remit approximately €65 million in CPF payments to the UK Treasury. While the NI exemption precludes that situation arising, ROI electricity customers still face higher prices than would occur otherwise. Electricity generators within the SEM, rather than government treasuries, are the beneficiaries of the higher prices. Had the CPF been implemented in NI, projected emissions in ROI would have been even higher. A potential policy response by ROI to the CPF was to implement its own CPF to prevent further carbon leakage and maintain ROI efforts to decarbonise the economy. An ROI CPF similar to that in BETTA would raise tax revenues for the Irish Treasury of some €260 million, subject to scenario assumptions, which is not insignificant in the context of austerity budgets. However, A CPF in ROI would significantly reduce business competitiveness and household welfare with electricity prices rising by roughly 17%.

Security of electricity supply in NI is a significant issue [CER (2012)]. A second transmission line is currently being developed to enhance the integrity of NI and ROI systems, to ensure security of supply in NI, and allow the SEM generation system to dispatch more efficiently. The strengthening of transmission within the SEM is a simple case-study of the benefits of market interconnection. The analysis shows that there can be both financial and environmental benefits from developing sufficient interconnection capacity, independent of any requirements to expand wind generation capacity on networks.

Analysis of the welfare implications of climate policies was beyond the scope of this paper but it is important to note that policies, which have the potential to be quite effective from a climate perspective, such as the CPF, are also likely to have significant welfare impacts. A number of studies have suggested how the negative welfare impact can be minimised [Callan *et al.* (2008); Conefrey *et al.* (2012); Verde and Tol (2009)].

Table 1: Power plant conversion efficiency, SEM and BETTA

	BETTA	SEM
Gas	0.54	0.56
Coal	0.38	0.35

Table 2: 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 3: 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)
2unc	Unconstrained	No	ETS=€5	ETS=€5	CPF=€27 (£21)
3	CPF in NI & BETTA	Yes	ETS=€5	CPF=€27 (£21)	CPF=€27 (£21)
4	CPF in SEM & BETTA	Yes	CPF=€27 (£21)	CPF=€27 (£21)	CPF=€27 (£21)
5	EU Back-loading	Yes	ETS=€12	ETS=€12	CPF=€27 (£21)

Table 4: 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 CO2, million tonnes	NI CO2 million tonnes	SEM (ROI + NI) CO2 million tonnes	BETTA CO2, million tonnes	SEM + BETTA CO2, 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
2unc	Unconstrained	78.0	41.45	1974	14.6	5.0	19.6	89.5	109.1
3	CPF in NI & BETTA	80.6	41.27	2086	15.2	3.9	19.0	89.7	108.7
4	CPF in SEM & BETTA	92.5	40.75	2199	12.2	4.5	16.7	90.8	107.4
5	EU Back-loading	79.7	41.30	2051	14.1	5.2	19.4	89.6	108.9

Table 5: Percentage Change in price, load, cost and emissions

Moving From scenario x to y	SEM System Margin Price	SEM load	SEM system total cost	ROI emissions	NI emissions	SEM (ROI + NI) emissions	BETTA emissions	SEM+BETTA emissions
1 to 2	2.4	0.0	10.9	7.8	4.2	6.9	-2.8	-1.2
2 to 3	2.4	-0.3	4.1	3.1	-24.3	-3.9	0.6	-0.3
1 to 5	3.6	-0.2	13.4	3.6	6.7	4.4	-2.3	-1.2
2 to 5	1.2	-0.2	2.3	-4.0	2.4	-2.3	0.5	0.0
3 to 4	14.7	-1.2	5.4	-19.8	16.4	-12.5	1.2	-1.2
2 to 4	17.5	-1.6	9.7	-17.3	-11.8	-15.9	1.8	-1.4
2 to 2unc	-0.9	0.1	-1.5	-0.4	-2.6	-0.9	0.4	0.1

Table 6: Percentage Change in interconnection flows between ROI, NI and BETTA markets

Scenario	ROI to GB	ROI to NI	NI to GB	AI (ROI+NI) to GB
1 vs 2	154	-538	153	154
2 vs 3	-9	-449	-9	-9
1 vs 5	124	-929	126	125
2 vs 5	-12	89	-11	-11
3 vs 4	-59	-95	-58	-59
2 vs 4	-63	-117	-61	-62
2 to 2unc	9	290	7	8

Table 7: Tonnes CO2 per GWh generated

Scenario		ROI	NI	SEM	BETTA	SEM+BETTA
1	Pre Q2 2013	409	481	426	284	301
2	CPF in BETTA	406	478	423	279	297
2unc	Unconstrained	406	479	422	280	298
3	CPF in NI & BETTA	405	438	412	280	297
4	CPF in SEM & BETTA	371	447	389	281	294
5	EU Back-loading	402	475	420	280	297

Table 8: 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
2unc	Unconstrained	78.0	81.0	-3.0	235	234	236
3	CPF in NI & BETTA	80.6	80.5	0.1	231	231	231
4	CPF in SEM & BETTA	92.5	80.4	12.1	96	94	98
5	EU Back-loading	79.7	80.5	-0.9	225	224	226

Table 9: Carbon Price Floor tax remittances, € million

Scenario		To Irish Treasury		To UK Treasury	
		ROI	NI	ROI	NI
3	CPF in NI & BETTA			65	20
4	CPF in SEM & BETTA	204	63	76	23

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