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THE REGIONAL EMPLOYMENT IMPACTS OF RENEWABLE ENERGY EXPENDITURES: THE CASE FOR MODELLING

BY

GRANT ALLAN AND MICHELLE GILMARTIN

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DEPARTMENT OF ECONOMICS
UNIVERSITY OF STRATHCLYDE
GLASGOW

The regional employment impacts of renewable energy expenditures: The case for modelling

Grant Allan[†] and Michelle Gilmartin[†*]
[†] Fraser of Allander Institute, Department of Economics, University of Strathclyde

Abstract

One aspect of the case for policy support for renewable energy developments is the wider economic benefits that are expected to be generated. Within Scotland, as with other regions of the UK, there is a focus on encouraging domestically-based renewable technologies. In this paper, we use a regional computable general equilibrium framework to model the impact on the Scottish economy of expenditures relating to marine energy installations. The results illustrate the potential for (considerable) 'legacy' effects after expenditures cease. In identifying the specific sectoral expenditures with the largest impact on (lifetime) regional employment, this approach offers important policy guidance.

[*] Corresponding author: michelle.gilmartin@strath.ac.uk Tel: 0141 548 3867, Fax: 0141 548 5776

1.   Introduction

The Scottish government (2008) sets out a number of goals of Scottish energy policy, including: the reduction of emissions; increasing the security of energy supply; and boosting regional economic development. While there are clear potential tradeoffs between these objectives, renewables development offers the possibility of movement towards all three energy policy goals. Thus, investing in renewable energy installations could offer a regional policy 'triple dividend'. In this paper, the link between investments in renewable energy capacity and regional economic (particularly employment) change is examined.

Reducing global greenhouse gas emissions to safe and sustainable levels is expected to require expenditures of around 2% of global GDP per year[1]. It is anticipated that these will be offset to some extent (and possibly outweighed by) global economic benefits associated with better energy security, and new employment in 'green' industries. At a regional level in the UK, the Scottish government has placed particular emphasis on the economic development 'dividend' associated with investments in renewables (Scottish Government, 2009). Expenditures on the manufacture, installation and maintenance of renewables devices are expected to have positive local economic impacts, including employment

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[1] The Stern Review (2006) estimates that the annual cost of reducing global greenhouse gas (GHG) emissions by around 25% by 2050 would be, on average over time, around 1% of GDP per annum (equivalent to around £14bn for the UK economy). Subsequently, Lord Stern revised this estimate to 2% of GDP per year, following scientific evidence from the Intergovernmental Panel on Climate Change showing that GHG emissions are causing more damage than was previously thought (Stern, 2008).

creation. Although there are a (limited) number of studies which attempt to quantify such impacts in the UK (and we review these studies in Section 2), there is a significant degree of uncertainty over the estimates. This is reflected in, for example, a lack of consistency and transparency in estimation methodologies, and a wide dispersion of results across studies.

Furthermore, there is an absence of system-wide analyses in the literature. This represents an important omission if crowding out and supply-side adjustments are anticipated effects of demand-side stimuli. As a result of the expenditures it might be expected that an increase in wages would reduce the region's competitiveness and mitigate the positive impacts of the demand increase, potentially crowding out activity in some sectors. Additionally, in-migration of labour supply in response to higher wages could ease labour market pressures, which could further affect the supply side of the regional economy. Where changes in the supply-side do occur, these can generate 'legacy effects': economic impacts beyond the period in which the expenditures occur (Allan *et al.*, 2008). Capturing these could be important for the *ex ante* evaluation of renewable energy investments. Thus analyses which are not economy-wide, or which (implicitly) assume a passive supply side, or focus solely on the period of demand expenditures could misrepresent the actual qualitative and/or quantitative response to regional policy.

In this paper we adopt an economy-wide modelling approach for examining the link between expenditure on renewable energy developments and regional

employment change. We use a multi-sectoral computable general equilibrium (CGE) model of Scotland to quantify the impact on economic activity of expenditure on renewable energy capacity in Scotland. We explicitly compare results from our economy-wide modelling to those of the Scottish government's Marine Energy Group, who also quantify the employment impacts associated with marine energy expenditures, but following a different methodology (which is not economy-wide and which implicitly assumes a passive supply side). In doing so, we aim to demonstrate the potential value-added of our computable general equilibrium approach.

Our approach allows us to consider three key issues which have not yet been explored in the literature, and which make an important contribution to policy-makers' knowledge base. Firstly, we model the mechanisms through which expenditures on renewable energy technologies in Scotland drive employment change at the regional level. Secondly, we examine the impact of the expenditure changes at the sectoral level on economy-wide activity. Thirdly, we assess the response of the supply-side of the regional economy to the expenditures.

A number of Regional Development Agencies in England also focus on the potential economic benefits associated with the renewable energy industry[2]. However, the Scottish case for renewables as a regional development policy is a particularly interesting one for a number of reasons. Firstly, the dispersion of

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[2] For example, see East Midlands Development Agency (2006); Northwest Regional Development Agency (2009); and Regen SW and the South West Regional Development Agency (2008).

renewables resources across the UK suggests that a disproportionately large amount of renewables industry activity will be concentrated in Scotland, particularly for marine energy[3]. Secondly, although energy policy is strictly a reserved power[4], in practice the Scottish government and Parliament have interpreted the devolved aspects of energy policy widely enough to develop a distinctive energy policy influence. This includes the setting of separate targets for renewable energy generation that are more progressive than those of the UK government. The Scottish Government has set a target for at least 30% of Scottish energy demand to be sourced from renewables by 2020, with 100% of electricity consumption to be met by renewables generation in 2020 (Scottish Government, 2011). In contrast, the UK target is for 15% of energy demand to be sourced from renewables (European Parliament, 2009), and the UK Government's Renewables Energy Strategy suggests that by 2020 around 30% or more of UK electricity consumption could come from renewable sources by 2020 (though this has not been announced as an explicit target) (Department for Energy and Climate Change, 2011). Accordingly, there is a well-articulated debate about the role of the renewables industry in Scotland and its potential economic impacts. Lastly, the active discussion among policy makers is accompanied by detailed government and private sector information on, for

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[3] For example, in Scotland the Pentland Firth area alone contains around 50% of the UK tidal resource and around 25% of the European resource (Department for Business Enterprise and Regulatory Reform, 2008).

[4] Energy policy, and the key policy instruments that can influence the energy industry (i.e. taxation and regulation) remain reserved powers for the UK government. Within energy policy, the Scottish government has responsibility only for the promotion of renewable energy and energy efficiency, and the Scottish Parliament currently has no power to vary taxes, other than the ability to vary the standard rate of income tax by up to 3p in each pound.

example: resource estimates for Scotland; roadmaps for technology installations over time; and device cost estimates, including the sectoral breakdown of expenditures. This allows for well-informed assumptions to underpin our economic analysis.

In this paper we proceed as follows. In Section 2 we describe the literature on the regional employment impacts of renewable energy expenditures. In particular, we consider the methodology and results presented in the recent Scottish government Marine Energy Group report on the Scottish marine energy supply chain. This government report identifies three marine energy deployment scenarios for Scotland and their associated expenditures, and estimates the employment effect of these expenditures. In Section 3 we argue that linking renewable energy expenditures to economic impacts requires a more comprehensive and transparent modelling approach than that adopted in the current literature, and that a regional CGE model is a particularly useful framework for such an analysis. We also describe the AMOS model of Scotland and present our simulation strategy. In Section 4 we present the results of the analysis, and in Section 5 we discuss the importance of locally retained expenditures to the findings. In Section 6 we offer conclusions and directions for future research.

2.   Renewable energy expenditures and regional employment change

2.1   Literature

The (albeit limited) literature on the employment effects of marine energy developments reports a very wide range of estimates. It is difficult to determine the exact reasons for this dispersion: report methodologies and assumptions are not always clearly reported in publicly available documents, making it difficult to compare and evaluate results. There are uncertainties over important assumptions such as: the nature and extent of policy support; the size of exploitable energy resources; the cost of manufacture and installation of devices; and the availability of investment funds. Additionally, these factors are changing over time: policy support announcements are regularly updated, and estimates of resources and costs evolve frequently. It is likely that the underlying assumptions differ considerably across reports.

Furthermore, there is also uncertainty surrounding how economic impacts are modelled and how expenditures on marine energy developments are translated into employment effects. It is often unclear, for example, whether job impacts are quantified using explicit modelling frameworks or via survey evidence; or whether they incorporate direct, indirect and induced effects. In practice there may be impacts on sectors which are not considered 'green' but which are closely linked to activity in 'green' industries via the supply chain (e.g. steel fabrication), and therefore indirectly affected by investments in renewable technologies. Further, the

existence of labour substitution between sectors means that there may be other-sector or supply-side impacts resulting from investments in renewable technologies, and which are only captured with comprehensive, whole-economy, analysis. Any employment estimates will draw the focus of policy makers, investors, and campaigners for and against marine energy development. Accordingly, robust calculations are ideally required, and it is imperative that such figures are understandable and justifiable.

The Carbon Trust (2011) estimates job creation in wave and tidal energy industries for the UK as a whole, and suggests that by 2050 there could be over 48,000 UK jobs in the wave industry and around 20,000 in the tidal stream industry (according to a 'high' scenario). This is based on an installed capacity of marine technologies of around 27.5 GW by 2050. Underlying these estimates, the authors assume that substantial innovation takes place in marine technologies (though it is not clear whether 'learning effects' are explicitly modelled); that peripheral barriers to marine energy deployment are overcome (such as public acceptance; supply chain constraints; and the development of the UK electricity grid infrastructure to accommodate marine technologies); and also that the growth of the UK marine renewables sector is underpinned by significant export demand for UK-manufactured devices and technologies.

In Scotland, the Forum for Renewable Energy and Development (FREDS) (2004) reports that 1,300MW of marine energy installations in Scotland by 2020

should create 7,000 direct jobs in Scotland. AEA Technology and Poyry Energy

Consulting (2006, 2007) estimate that marine energy capacity in Scotland of 650MW

in 2020 would lead to a 'net' jobs boost of 2,340 in Scotland, while a 330MW scenario

projects 630 jobs net in Scotland. These 'net' jobs figures take account of the support

mechanism for renewables and jobs in other renewables that are reduced as a result

of the development of marine energy. The total gross (i.e. direct, indirect and

induced) impact on jobs in Scotland from marine development (without subtracting

these lost jobs) of the 650MW scenario is 4,660.

The Marine Institute and Sustainable Energy Ireland (2005) considers

scenarios for the development of marine energy in Ireland, and suggests a total

employment impact of 1,900 jobs, based on 200MW capacity. This estimate includes

the impact of employment gains associated with the export of marine technologies

developed in Ireland. At a sub-regional level, a study by Arthur D. Little (2005)

estimates that the 'wave-hub' development in Cornwall in the South West region

could generate 100 direct jobs, based on 20MW of installed capacity. The report

suggests that the indirect job benefit could be significant at 450 jobs, with 20-40% of

these retained in Cornwall, and more in the wider region.

The studies above do not detail the methodological approach which

underlines the employment estimates[5], making it difficult to examine how the

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[5] With the exception of the Arthur D. Little (2005) study, where the authors explain that they calculate a "rule of thumb" employment estimate of 1 job per MW of installed capacity based on questionnaire responses from a selection of UK wave energy developers.

marine energy developments are translated and quantified into economic changes. In the following section we consider in more detail one specific study which has sought to estimate the regional employment effect of marine energy expenditures in Scotland. Later in this paper we adopt the same deployment scenarios of this study, and we demonstrate how standard techniques can be used to more comprehensively evaluate the economic impacts of developments in the renewable energy sector.

2.2   *Sgurr and IPA energy report*

Sgurr Energy and IPA (2009) (hereafter, S&I, 2009), prepared for the Scottish government's Marine Energy Group (MEG), attempts to quantify the potential economic (including employment) effects of renewable energy expenditures. The report considers three scenarios for marine energy capacity in Scotland by 2020, in which a total of 500MW, 1000MW and 2000MW of capacity is installed ('downside', 'base case' and 'stretch' scenarios, respectively), and estimates the total (global) expenditure and employment effects corresponding with these scenarios. The authors make *ad hoc* assumptions in order to estimate the share of expenditure and employment effects that are retained in Scotland.

The expenditures included are those costs prior to the operational and decommissioning phases of the marine device lifecycles. The expenditures are estimated following industry consultation and are based on survey responses from

six wave and tidal energy developers[6]. The cost of each MW declines over time in each scenario, which is consistent with 'learning' reducing capital costs as the technologies mature. Table 1a provides the capacity and total expenditure figures[7] (both annual and cumulative) for each of the three scenarios. Monetary values are assumed to be in 2009 prices.

[Table 1a]

The 'base case' scenario assumes a cumulative capacity of 991MW by 2020, with an associated cumulative expenditure of £2.38 billion between 2010 and 2020. In the 'downside' and 'stretch' scenarios these figures are 479MW (£1.3 billion) and 1982MW (£4.7 billion) respectively. Each scenario differs only in terms of the assumed installed capacity of marine energy in each case – the demand and technology assumptions remain constant over each scenario.

In calculating the expenditures which could be made in Scotland in each scenario, S&I (2009) assume that:

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[6] Respondents were asked to estimate the total capital expenditures associated with the manufacture and installation of *[check this - a 1mw?]* device and to identify a breakdown of expenditures by significant cost items. These responses informed the expenditure estimates in the S&I (2009) report.

[7] The expenditure figures here are *total*, i.e. those which would be made across the world in order to install the devices in Scotland.

$$Ex_t^S = Ex_t^W \alpha \qquad \qquad \text{Equation 1}$$

where Ex^S is the total expenditure in Scotland, Ex^W is the total worldwide expenditure, t is the year and α represents the share of the cost of the marine installations which is spent in the Scottish economy. Parameter α is assumed to be constant over time[8] and across the three scenarios. Based on their consultation responses, S&I (2009) use a value of α = 0.53, which means that a cumulative £1.26 billion of expenditure is retained in Scotland in the 'base case' scenario.

The S&I (2009) report acknowledges that some job creation will occur outside Scotland. To estimate the retained employment impact in Scotland each year (Em_t^S) associated with the manufacture and installation expenditures, S&I (2009) use the following:

$$Em_t^S = c_t \gamma \alpha \qquad \qquad \text{Equation 2}$$

where c_t is the (incremental) capacity (in MW) installed in Scotland in year t, and γ is the number of (worldwide) jobs supported by each MW.

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[8] This implies that the Scottish marine energy industry does not become more competitive in marine installations over time, and that there are no 'home market effects' of the type popularised by Krugman (1980) and which are thought to underlie the success of the Danish export market in wind power technologies (Krohn, 1998; Sovacool, 2009).

The values of c_t are estimated by S&I (2009) from their scenarios. They are given in Table 1a. The method used to estimate the γ parameter is considerably less clear. S&I (2009) assume that each MW of marine energy capacity creates a total of 20 jobs in that year, across the world. This figure is based partly on an average of the consultation responses from marine energy technology developers who were asked to provide job creation estimates, and partly on a review of the existing (scarce) literature. The value of γ =20 is assumed to be fixed for every year between 2010 and 2020. This allows S&I (2009) to calculate the employment effect on Scotland of the investments in marine energy capacity. S&I (2009)'s estimates of Scottish 'retained' expenditure and Scottish employment impacts are given in Table 1b.

[Table 1b]

S&I (2009) calculate that this is the 'direct' effect on Scottish employment, and, they argue, will understate the true number of jobs which arise in Scotland as it does not take into account 'indirect' or 'induced' effects. That said, S&I (2009) do acknowledge that jobs in other sectors might be reduced through support for marine energy diverting spending and jobs from these sectors, and so, any jobs created in Scotland from marine should partially account for those 'lost' jobs in other sectors from marine energy. These 'lost' jobs are not quantified in the report by S&I (2009).

In the following sections, we examine regional economic modelling approaches as a means of formally capturing the link between marine energy expenditures and regional employment change. This is a more compelling approach to assessing likely employment impacts in that it is based on a theory-consistent model that has been calibrated on a comprehensive database for the Scottish economy which incorporates all inter-industry linkages.

3. A modelling approach

3.1 Regional multi-sectoral models

Using appropriate models can shed light on the link between expenditures and regional economic impacts. Two approaches suggest themselves as particularly suitable: conventional demand-driven Input-Output (IO) and Computable General Equilibrium (CGE) modelling. Both are system-wide multi-sectoral frameworks widely applied for regional analysis (Loveridge, 2004). These system-wide models allow for the relationships between all parts of the economic system to be captured, and can coherently link disturbances in one area of the regional economy (i.e. increased demands for the output for some sectors) into impacts across the economy. Multi-sectoral models are especially useful as these reveal the sectoral (as well as aggregate) distribution of changes in activity.

IO modelling is typically configured as a demand-driven system (Miller and Blair, 2009) in which sectoral economic output is determined by a vector of (exogenous) demands for sectoral outputs. Changes in demand for particular sectors cause changes in output through the multipliers given by the Leontief inverse. The aggregate and sectoral effects will depend on the extent to which the sector whose output is stimulated is embedded through its backward linkages to the economy. Type 1 multipliers assume that the marginal effects on regional activity come about solely through the interaction of inter-sectoral links arising from intermediate inputs (as given by the IO table). Alternatively, Type 2 multipliers endogenise household incomes/expenditure to include the additional impact of changes in household consumption on the level of regional economic activity.

Two assumptions are necessary for IO modelling. Firstly, there are no supply constraints, with sectoral outputs able to expand to meet any increased demand for that sectors output. This in essence assumes that there is significant excess capacity and involuntary unemployment, so that the supply side would adjust passively to demand with no upward pressure on wages or prices (Allan *et al*, 2008). Secondly, there are assumed to be fixed technical coefficients between each sector's output and its purchases of inputs, and so constant returns to scale[9]. As such, we might consider IO as a special case of a more general multi-sectoral model with these assumptions imposed.

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[9] This would be consistent with an assumption that the relative prices of inputs remain constant in the event of a demand disturbance (McGregor *et al*, 1996).

With a suitably flexible CGE model, these assumptions can be relaxed. Within a regional application for example, labour and capital can typically be considered scarce resource in the short run, making an assumption of a passive supply-side particularly limiting. A stimulus to demand will be expected to put upward pressure on wages and prices, resulting in some loss of regional competitiveness. Further, changes in relative prices could alter the optimal input mix for sectors. In a regional context, the supply of labour services can vary through the migration of labour across regional boundaries.

3.2   The AMOS CGE model

The model used in this paper is AMOS (Harrigan *et al*, 1991): a CGE modelling framework parameterised, in this application, on data from Scotland[10]. It is calibrated on a Social Accounting Matrix (SAM) for Scotland for 2006. In this application, the AMOS model has twenty five commodities/sectors. The sectors identified include those in which the expenditures associated with the assessment, construction and installation of marine energy devices, as identified by S&I (2009), are likely to be made. The twenty-five sectors are listed in Appendix A. The model has three transactor groups – households, government and corporations – and two exogenous transactors – rest of the UK and rest of the world. Commodity markets

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[10] AMOS is an acronym for *A M*acro-micro Model *Of S*cotland. The model is calibrated using a Social Accounting Matrix based around the 2004 Scottish Input-Output Tables, rolled forward to 2006 (Scottish Government, 2007).

are assumed to be competitive. We do not explicitly model financial flows, but assume that the interest rate is exogenous to the model.

The AMOS framework allows a degree of flexibility in the choice of key parameter values and model closures. A constant feature of the model, however, is that producers are assumed to minimise costs using a nested multi-level production function, generally with a constant elasticity of substitution (CES) at each point, so that there can be input substitution in response to relative price changes. There are four components of final demand: consumption, investment, government consumption and exports. Of these, consumption is a linear function of real disposable income, while government consumption is assumed to be exogenous. Exports (and imports) are determined via an Armington link (Armington, 1969) and are therefore sensitive to relative prices. Investment demand is determined in a manner determined by the treatment of capital in the model, discussed below. Capital along with inputs of labour and materials, constitute the supply side of the model.

We impose a single Scottish labour market with perfect sectoral mobility (i.e. workers can move between employment in different sectors). We also assume that wages are subject to an econometrically parameterised regional bargaining real wage function (Layard *et al*, 1991)[11]. Under this configuration, the regional real

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[11] Other labour market configurations are possible in the AMOS framework, but we do not investigate these in this paper.

consumption wage is directly related to workers' bargaining power and therefore inversely related to the regional unemployment rate. This takes the form:

$$\ln\left(\frac{w}{cpi}\right) = c - 0.113\ln(u) \qquad\qquad \text{Equation 3}$$

where w is the Scottish nominal wage, u is the Scottish unemployment rate, cpi is the Scottish consumer price index and c is a calibrated parameter. This implies that changes in the real wage are driven by changes in the unemployment rate, which also determines the changes in employment.

All simulations are run in a multi-period setting. The periods can be interpreted as years as annual data has been used both for the benchmark SAM dataset and for behavioural relationships. The model is assumed to begin in long-run equilibrium. This implies that with no exogenous shocks, the model will replicate the initial values over all subsequent time periods. Within each period of the simulations, both the total capital stock and its sectoral composition is fixed, and commodity markets clear continuously. However, each sector's capital stock is updated between periods via a simple capital stock adjustment procedure in which investment is equal to necessary depreciation plus some fraction of the gap between actual and desired capital stock for the sector.

The labour force adjusts between periods through inter-regional migration flows. The migration specification is based on the Harris and Todaro (1970) model, as estimated on UK data by Layard *et al* (1991). Net migration to Scotland is positively (negatively) related to the real wage (unemployment rate) differential between Scotland and the rest of the UK. The regional economy is assumed to have zero net migration in the base year (2006) and net migration flows act to re-establish this equilibrium.

3.3   *Simulation strategy*

We run the AMOS model in a period-by-period setting. The expenditures related to marine energy development in Scotland – as given by S&I (2009) – are introduced as exogenous disturbances to output demand for specific sectors. Three scenarios ('base case, 'down side and 'stretch') for the annual expenditures on marine energy developments published by S&I (2009). We use the development paths for marine capacity (in MW) and the assumed cost of each unit of capacity in three scenarios to calculate the expenditure disturbances that are then introduced in the AMOS model.

Calculating the expenditure shocks requires four steps: first, the total expenditures for eleven years (i.e. from 2010 to 2020, inclusive) are deflated from 2009 prices to 2006 prices, to be consistent with the AMOS model; secondly, the total

expenditures in each year are shared across the categories of costs, as detailed in S&I (2009)[12]. The third step involves using the share of spending in each category which is likely to be sourced in Scotland – as given in S&I (2009) – to give the Scottish expenditures by category. The fourth step is to allocate the categories to sectors in the AMOS model and calculate the expenditure injection into each of these sectors. Using this procedure the Scottish component of expenditures from twenty-three categories are each allocated to one of eight sectors of the twenty five sector model (these are one of the first eight sectors in Appendix A).

Several points should be noted about this calculation. Firstly, the costs of each MW of capacity are taken from the S&I (2009) publication. As we have noted earlier, S&I (2009) assume that the cost of each MW of capacity installed in each year in each scenario falls over time (Figure 1), in line with increases in the development of marine energy, and, we assume, reflects cost reductions due to learning and improved knowledge about the production processes involved.

[Figure 1]

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[12] These categories are given in Table 2, along with the share of annual total expenditures in each category, the shares of expenditure in each category assumed to be sourced in Scotland (and outside Scotland), and the sector of the model to which each category of spending is allocated.

Secondly, we assume that the distribution of costs across categories (Table 2) remains constant across all three scenarios for each period. For example, the cost of the structure is 34% of the annual expenditure in each scenario for each year between 2010 and 2020. This, combined with a declining total cost for each MW as described in Figure 1, would be implicitly assuming cost reductions are equal across categories of expenditures. This could be a strong assumption; however in the absence of category specific cost reductions, it is a working assumption for this paper.

Thirdly, we have allocated the spending in each category to the most appropriate sector of the CGE model. In some cases this is relatively straightforward – i.e. expenditures on 'Cables, umbilicals and communications, grid connection' are allocated to the 'Insulated wire and cables' sector (sector 4). In others this is less straightforward. At all times however we have endeavoured to select the most appropriate sector for the cost category.

Fourthly, we assume that the regional sourcing for each cost category remains constant across the years of the simulations. This would ignore the possibility that increased development of marine energy capacity in Scotland could lead to a local supply chain in which a greater share of spending in each category might be sourced within Scotland. In sensitivity analysis later in the paper, we investigate the impact

of increasing the Scottish share of expenditures in each category[13].

To recap, the annual expenditures made in Scotland in three alternative development paths for marine renewables are entered as a series of sector-specific exogenous demand shocks. There are eight shocks in each period and eleven periods of expenditure shocks (i.e. from 2010 to 2020 inclusive) making 88 shocks in total. The counterfactual in each case is that there is no change in the Scottish economy, i.e. the base year (2006) would recreate itself as it is in a long-run equilibrium. All results, therefore, can be attributed solely to the sectoral expenditure shocks. The AMOS model is run in its period-by-period setting for one hundred periods (years) with the transitory expenditures introduced for the first eleven periods. The model is run forward for a further eighty-nine periods with no further shocks to demand.

4.   Results

4.1   Aggregate results: 'base case' scenario

We are particularly interested in the effects of eleven periods of expenditures on regional employment over the simulation period. Figure 2 shows the

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[13] From Table 2 we note that almost half (48.8%) of the total annual expenditure is in the 'Structure' (34.4%) and 'Mechanical plant' (14.4%) cost categories. 'Moorings and foundations' are estimated to compromise a further 10% of total annual costs. The extent to which these three categories are expected to source their inputs from within Scotland varies significantly. Only 'Structure' (of these three categories) is expected to see more than two-thirds of the expenditures sourced in Scotland. Multiplying the share of annual expenditures in each category and the categories' Scottish share to construct a weighted average, we calculate that 52.7% of all expenditures will be sourced in Scotland - this is the source for the estimate of α used in Equations 1 and 2.

employment figures as reported in S&I (2009); the employment figures we obtain using employment-output coefficients ('Direct IO') and the Type 1 and Type 2 employment-output multipliers calcaulted from the IO for Scotland in 2006 for the same sectoral aggregation as the CGE model, and; the results from the CGE analysis with the model setup as described in Section 3.2. This gives five series for employment in Scotland over the simulation period for the 'base case' scenario. The S&I (2009) results only relate to the years 2010 to 2020 – as do the IO figures – as these are the years in which expenditures are made. In Figure 2, the series labels are ordered (from highest to lowest) by the employment impact in year 2020.

[Figure 2]

If we focus first on the CGE results, two distinct phases of the modelled results can be observed: the 'concurrent' phases, during which expenditures occur (i.e. 2010 to 2020 inclusive) and the 'legacy' phase, from 2021 onwards. Only in the CGE case are there employment effects during *and* after the period of expenditures. During the concurrent phase, increased expenditure acts as a pure demand stimulus: the prices of Scottish goods and services are bid up, raising profitability in the direct stimulated sectors (and those indirectly linked to the stimulated sectors)

encouraging sectoral expansion and higher employment. We will examine the sectoral distribution of employment gains (and losses) later in this section.

Comparing the results from the CGE method and those published by S&I (2009) during the 'concurrent' phase, we see that the absolute changes in employment in Scotland is broadly similar. By the end of this phase (i.e. 2020) S&I (2009) predict employment in Scotland will be 2,647 higher. Our CGE results estimated that employment in the same year is 2,981 above its base level. While these figures are broadly similar in terms of their order of magnitude, it is interesting to compare the results over the 'concurrent' phase from the CGE and IO results. Recall that S&I (2009) argued that their employment predictions were for employment directly created by the expenditures. S&I (2009) argued that the additional indirect and induced effects of job changes needed to be taken account – with the implication that their results underestimated the 'true' effect on employment.

We estimate that the CGE employment results are (slightly) below the estimate of the 'direct' jobs created in the sectors experiencing the demand boost (calculated using IO). In aggregate therefore, the results suggest that even an estimate, using IO, of the direct jobs created by these expenditures would overestimate the number of jobs created: although the difference in employment in 2020 is small (3,025 in the 'Direct IO' case against 2,981 from the CGE results). The Type 1 and Type 2 IO employment results considerably overstate the impact of these expenditures on employment in Scotland over the period of expenditures.

[Figure 3 here]

The sectoral distribution of absolute employment changes in 2020, calculated using IO and CGE methods, are shown in Figure 3. Employment impacts by sector were not published by S&I (2009). Figure 3 shows that some sectors in the CGE model see small declines in employment by 2020, with employment in the 'Gases, chemicals and pharmaceuticals', 'Other private business services' and 'Other manufacturing' sector down by 187, 126 and 118 respectively from their base levels. Employment is higher in all eight of the sectors which experience the exogenous expenditure shock. Employment also increases in 'Wholesale, retail, hotels and restaurants' by 143, as well as being higher than base year in 'Other services' (20) and 'Water' (2).

Moving to the 'legacy' phase (Allan *et al*, 2008) we examine the impacts on employment in Scotland after the expenditures cease in 2020. In the IO cases, there will be no further impacts on employment as this is a demand-driven system – and no further demand shocks. Using a CGE model, however, in which regional demand *and supply* interact, we observed (Figure 2) a continuing effect on regional employment. The results below demonstrate both the value of CGE modelling of the impact of demand-side disturbances over models in which the supply-side is assumed passive (such as IO) and what features of the CGE model employed here produce impacts which last beyond the expenditures themselves. From these

simulations we can argue that the impact of transitory demand-shocks on regional employment are overestimated by IO analysis during the period of expenditures, and underestimated when the expenditures cease.

The active supply-side in AMOS involves the treatment of migration and investment flows between the region and the exogenous (unmodelled) economy outside the region. As previously stated, migration is assumed to respond to regional real wage and unemployment differentials between Scotland (which has seen the demand stimulus) and the rest of the UK (which has not). Real wages in Scotland are bid up from their initial levels as demand (and sectoral output) increases, which expands the labour force in Scotland through increases in the participation rate (slightly), and positive migration from the rest of the UK.

Migration is crucial for the response of the Scottish economy in the 'legacy' phase. Legacy effects are observed as the expenditures lead to an increase in factor supplies (of labour and capital) which remain after the expenditures cease. De-migration and disinvestment occurs slowly, so that the initial demand-side shock produces a positive supply-side shock which allows output to increase. The dynamics of the real and nominal wages show this point clearly (Figure 4). The pattern is the same in the other two scenarios.

[Figure 4 here]

Both the real and nominal wages increase in the concurrent phase. Expenditures place upward pressures on wages and prices so that some exports are crowded out by the increase in domestic activity. This explains, partly, the reduction in employment in some sectors seen in Figure 3, as their activity is crowded out by increased expenditures in other sectors. From 2021, the real and nominal wages decline sharply so that both are lower than they were initially. These lower wages following the end of the expenditures – with real wages down -0.048% in 2021 - act as a stimulus to the Scottish economy.

Figure 5 and Figure 6 give the evolution of capital rental rates (i.e. the return on capital) in the 'stimulated' and 'non-stimulated' sectors respectively. The stimulated sectors are those eight sectors which directly experience the increased demand for their output, while 'non-stimulated' sectors are the 17 sectors where demand is not directly increased by the expenditures.

[Figure 5 here]

[Figure 6 here]

The return on capital in the 'stimulated' sectors increases significantly during the concurrent phase – rising by more than 20% in the 'Electric motors and generators' sector in the final period of expenditures (2020). The increase in profitability in these sectors initially means that desired capital stock exceeds actual capital stock, so investment occurs. After the expenditures cease the return on capital in the stimulated sectors falls – these sectors have too large a capital stock for the new (post-expenditure) level of demand. Capital stock is reduced over time through depreciation. The return on capital peaks for the (majority of) non-stimulated sectors in the period immediately after the end of the expenditures (i.e. 2021). Over time, the return on capital declines back to its initial level in all sectors.

Figure 7 and Figure 8 give the evolution of output changes in the 'stimulated' and 'non-stimulated' sectors separately. Prices rise in these sectors during the concurrent phase, increasing output, the return on capital, subsequent investment and therefore capital stock (Allan *et al*, 2008). The non-stimulated sectors will be affected indirectly through links to the stimulated sectors, and so might experience expansions in output, or crowding out effects, especially driven by increases in the wage rates and competition between sectors in a tightening labour market.

[Figure 7 here]

[Figure 8 here]

Comparing Figure 7 and Figure 8, it is clear that the eight sectors directly affected by the expenditures experience the largest percentage deviations from their initial levels. The 'Electric motors and generators' sector, for instance, sees output increase by over 12% in 2020, while there are increases of more than 5% in this year in the 'Insulated wire and cable', 'Electrical equipment' and 'Articles of concrete' sectors. For sectors that are not directly affected by the expenditures the output effects are much more muted – notice the difference in scales between the y-axis in Figure 7 and Figure 8. Figure 8 shows that by 2020 the impact on the output of the majority of the non-stimulated sectors is negative – although there are increases in output in four sectors. Again there is a spike in output in 2020 with a discontinuous adjustment for all sectors as the expenditures end. A few years into the legacy phase – from 2024 onwards - the output of all sectors (stimulated and non-stimulated) is higher than initially, and this continues until the end of our simulation. In the long-run, sectoral output converges back to its initial levels – given the demand shock is transitory.

4.2 Discounting, sectorally disaggregated expenditure-employment effects and impacts of increased local (i.e. Scottish) sourcing

As established in Section 4.1, under a CGE analysis of expenditures, there are significant 'legacy' effects on the Scottish economy. By discounting these, the present value of the employment effects can be obtained. This applies the basic principle that a job today is worth more than a job tomorrow, due to individuals (and society) having a positive rate of time preference. The time-discounting of non-monetary variables is done in areas as diverse as health (de Kok, 2010), diet (Ikeda, 2010) and the environment (e.g. Philbert, 1999). The UK Treasury offers advice on the discounting of impacts in its Green Book (HM Treasury, 2003). As well as discounting the results obtained above, the CGE results can be decomposed to consider how the different sectoral expenditures impact on aggregate employment. Such information provides an important addition to the knowledge base of policymakers, who are keen to support the establishment of a domestic supply chain to marine energy industry.

By discounting the estimated Scottish employment effects and the Scottish expenditures, the impact on employment of each £ spent in the Scottish economy can be calculated. A discount rate of 2.5% is used for both expenditures and employment, in line with HM Treasury (2003). This calculates that the impact on (present value) employment in Scotland of each £1million (present value) expenditure for the 'base case scenario is 24.24. For comparison, the same figures for

the 'downside' and 'stretch' scenarios are 24.33 and 23.64 respectively. These figures suggest that a present value of expenditures worth £4million will increase employment in Scotland (as a present value) by around 100. This figure is directly linked to the retained expenditures and takes account of the employment effects beyond the end of the expenditures.

The CGE model can also be used to show the impact of each of the different sectoral expenditures on regional employment. We would not expect expenditures in different sectors to have the same knock-on effects, since, for example, sectors will have different requirements for intermediate inputs and labour. Other things being equal, a boost to a sector with high employment (and therefore a high employment-output multiplier) should produce a greater change in regional employment than the same shock applied to a sector with low employment (and a low employment-output multiplier). By modelling the eight sectoral expenditure shocks from the 'base case' scenario separately, we can estimate the (aggregate) employment effects of each sectoral expenditure stream. As with the aggregate results reported above, we calculate the present value of the expenditures and employment effects. The results are shown in Figure 9.

[Figure 9 here]

From Figure 9 we can see that there are differences in the extent to which expenditures in each of the eight sectors affect the present value of employment in Scotland. The highest impacts come from spending in 'Insulated wire and cables', where, expressed in present value terms, each £1m of expenditures increases regional employment by 72.18. The lowest value is for 'Construction' (6.73). The effect therefore on aggregate employment can vary by a factor of ten depending on the sector which is directly stimulated. This is an important result as it shows that it is not only important to retain volumes of expenditures, but that the impact on regional employment can be massively affected by the sectors which are directly affected.

A further point can be clarified using the CGE model, the expenditure figures, and cost categories. We can calculate the additional impact on employment in Scotland of changes in the share of expenditures in each category which are retained in Scotland. We used S&I (2009)'s figures in Section 3.3 (and Table 2) which stated that a significant portion (52.7%) of the (worldwide) expenditures necessary establish a marine energy capacity in Scotland would be likely to be made in Scotland. Those elements produced outwith Scotland will not directly contribute to Scottish GDP or support Scottish employment. By S&I (2009)'s calculations, over 47% of the expenditures in each scenario are made outside Scotland. A key issue therefore is to assess the impact on employment of increasing the share of expenditure in each category that is retained in Scotland.

To do this, we recalculate the expenditures input to the model with a 1 percentage point higher share of sourcing of each cost category in Scotland. For instance, for the 'Structure' category, we previously followed S&I (2009) and assumed that 70% of the costs under this category were made in Scotland. A 1% increase leads us to higher expenditures in Scotland for this category as we now assume that 71% of the expenditures in this category are made in Scotland. The other sectoral shocks remain unchanged. Taking the difference between the shocks with the new and old local sourcing assumptions, we calculate the new shocks which are entered into the model. Running the model a further twenty-three times – one for each of the expenditure categories – we can obtain the impact on employment over the 100 periods, compared to the 'base case' scenario. Our results are shown in Figure 10.

[Figure 10 here]

Figure 10 shows that the impact on employment of increasing local sourcing by 1% differs considerably across the categories. Increasing local sourcing by 1% in three categories – 'Control and monitoring systems, 'Onshore equipment' and 'Logistics base (e.g. ports and harbours)' – increases employment over the period by approximately zero. At the other extreme, the largest effect on employment comes in

the 'Structure' category – where employment is increased by 249. Part of this difference can be explained by a categories share of total costs[14]. More interestingly however, is the fact that from our simulations there is a large impact on employment (95) – the second largest across all categories, behind only 'Structure' – from an increased local sourcing of 'Cables, umbilicals and communications' despite this category only seeing 5.3% of total costs in each year. Several other categories have higher shares of total costs, but a lower impact on employment across the simulation period from increased local sourcing. This result can be understood by considering the sector into which the expenditures on 'Cables, umbilicals and communications' are allocated (sector 4: 'Insulated wire and cable'). As Figure 9 showed each unit of expenditure in this sector had the largest impact on employment over the simulation period.

5.   Retained expenditures: available capacity, sectoral knowledge and skills

The retention (in Scotland) of expenditures related to marine energy developments in Scotland will depend upon a number of factors. These will include the existence of knowledge and experience in the appropriate technologies and techniques, the extent of government support, and the distance to the development from existing sources of products and the relevant transportation costs. Further,

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[14] The three categories listed above, for example, are 0.93%, 1.07% and 1.13% of total annual expenditures, respectively, while the 'Structure' category accounts for 34% of total annual expenditures.

existing capacity would be expected to act as a draw for further development of a Scottish supply-chain to expand domestic production. Some aspects of early marine energy developments in the UK have been outsourced: for example, with the SeaGen tidal energy turbine installed in Northern Ireland in April 2008, British engineering firms were contracted to build, test and monitor the turbine, whilst the components were manufactured in various locations in the UK and Europe, and a Belgian firm was contracted at the deployment stage.

Experiences from other renewable energy projects also suggest that major components may be imported: Lewis and Wiser (2007) note that out of the 889MW worth of onshore wind power installed in the UK in 2004, 0% of the turbine component parts were manufactured in the UK. Recent anecdotal evidence for the UK suggests that the wind energy industry remains import-dependent, and is focused on turbine assembly, rather than the production of devices. Thus, there is an argument that the UK missed an opportunity to develop a wind energy industry due to a lack of focused policy support to help establish a domestic supply chain for the industry[15].

The development of the marine energy sector could potentially be quite different with appropriate policy mechanisms. Since the Scottish and UK governments already support the industry, the prospects for the sector appear

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[15] Lewis and Wiser (2007) conduct a cross-country comparison of the policy support mechanisms that have been employed to support wind power industry development. They argue that other countries' policy measures have been more successful at developing large indigenous wind turbine manufacturers compared to the UK.

encouraging. Already, there is a significant marine energy production capacity across the UK, and there are indications that a supply chain is already developing, at least in Scotland (Scottish Renewables Forum, 2007). However, since many marine energy technologies are in the early stage of development and the parts are specialised and not mass produced, there could be constraints in terms of lead times, costs, and the supply of skilled labour (NOF energy, 2008). As such, it is likely that some of the contracts associated with anticipated Scottish marine energy installations will be awarded outside the region. Identifying the potential value of an appropriate supply chain is particularly important for the design of sensible policy, e.g. some aspects of the supply chain will be more useful than others. Where the focus of regional policy makers is on job creation, it is important to determine those sectors in the supply chain which may have the most beneficial expenditure-employment links.

The results obtained from Figure 9 and Figure 10 can be useful for this purpose. Figure 9 shows that transitory expenditures in different sectors have important consequences for aggregate employment. Total impacts on employment of each unit of expenditure can vary by a factor of as much as ten. Figure 10 demonstrates that the specific category of costs in which local sourcing is increased can be critical for the impact of increased sourcing on employment objectives. This need not necessarily be in the category in which the largest share of the costs is

concentrated (although, in this instance, this is where the largest impact on employment is seen).

6.   Conclusions

In this paper we model the link between (transitory) expenditures related to marine energy manufacturing and installations and regional employment change using a CGE framework parameterised on the Scottish economy. A CGE model is a particularly suitable framework since it can consider the multi-sectoral impacts on the region and, since it incorporates a full specification of demand and supply sides, can deal appropriately with crowding-out over competition for regional resources.

Our approach represents a more comprehensive and transparent attempt to estimate the economic impacts of investments in renewable energy capacity than that available in the literature. The analysis is specific to the case of marine energy expenditures in Scotland, but the methodology is replicable and the underlying principles are relevant across regions and technologies. Since expenditures on energy developments are typically large relative to the size of regional economies, they can be an important source of regional economic development. As regional governments look to justify policy support for renewable energy based at least partly on anticipated economic benefits, our findings make a valuable contribution to policy makers' knowledge base.

Our results suggest that using an IO model, rather than a CGE model, would drastically overstate the likely employment effects for Scotland of marine energy expenditures. During the period of expenditures, the estimate of the direct employment effect is comparable to that of the aggregate CGE results for employment. Taking account of the sectoral crowding-out caused by competition for scarce factors of production (and the resulting price increases and reduced competitiveness), some sectors see output and employment fall, while others see economic activity rise. Beyond the period of expenditures themselves, the CGE analysis reveals the extent of 'legacy' effects of temporary demand-side disturbances. These are not captured by conventional demand-side IO analysis for temporary expenditure impacts, but are caused by the responses of an active supply-side – for instance through increased immigration and capital stock adjustments.

Additionally, we examine the link between sectoral expenditures and regional employment. A detailed examination of the aggregate employment effects, and the marginal impact of increasing domestic sourcing for each sector, is vital for sound policy-making. In our analysis we identify those expenditures which could provide the most benefit to the regional economy.

Further research should examine the assumed nature of migration to the region. In this paper, we assume myopic behaviour on the part of migrants. This assumption has important consequences for determining the adjustment path of the economy in response to a transitory demand disturbance (including supply-side

adjustments). Adopting a forward-looking perspective could generate a different adjustment path, and a different set of results. Furthermore, initial evidence supports the view that adopting renewable technologies can have a non-neutral (positive) impact on the costs of providing electricity to industries and households. This increase in the cost of supply could offset some of the economic benefits of marine energy expenditures observed in this paper. Cost benefit analyses, which incorporate a wider assessment of the costs and benefits associated with renewable energy provision, would provide an indication of the net welfare benefits of renewable energy supply and would complement economic analyses of the type provided in this paper.

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Table 1a: Annual and cumulative Scottish capacity (MW) and worldwide expenditures under three scenarios of marine energy development in Scotland

	'Downside'				'Base case'				'Stretch'			
	Annual installation (MW)	Cumulative capacity (MW)	Annual worldwide total expenditures (£m)	Cumulative worldwide total expenditures (£m)	Annual installation (MW)	Cumulative capacity (MW)	Annual worldwide total expenditures (£m)	Cumulative worldwide total expenditures (£m)	Annual installation (MW)	Cumulative capacity (MW)	Annual worldwide total expenditures (£m)	Cumulative worldwide total expenditures (£m)
2010	5	7	26	26	5	7	26	26	10	13	53	53
2011	10	17	45	71	10	17	45	71	20	33	87	140
2012	10	27	40	111	20	37	76	147	40	73	151	291
2013	0	27	0	111	40	77	132	279	80	153	262	553
2014	0	27	0	111	52	129	156	435	104	257	308	861
2015	0	27	0	111	68	197	189	624	135	392	369	1,230
2016	50	77	166	277	87	284	224	848	176	568	446	1,676
2017	65	142	191	468	115	399	277	1,125	228	796	544	2,220
2018	85	227	228	696	148	547	336	1,461	297	1,093	665	2,885
2019	110	336	274	970	193	740	414	1,875	386	1,480	816	3,701
2020	143	479	332	1,302	251	991	508	2,383	502	1,982	1,002	4,703

Source: S&I (2009).

Table 1b: Retained expenditures and employment impacts on Scotland under three scenarios of marine energy development in Scotland

	'Downside'		'Base case'		'Stretch'	
	Cumulative spending in Scotland (£million)	Employment in Scotland	Cumulative spending in Scotland (£million)	Employment in Scotland	Cumulative spending in Scotland (£million)	Employment in Scotland
2010	14	53	14	53	28	105
2011	37	105	37	105	74	211
2012	59	105	77	211	154	422
2013	59	0	147	422	292	844
2014	59	0	230	548	454	1,097
2015	59	0	329	717	648	1,426
2016	146	527	447	917	884	1,853
2017	247	685	593	1,213	1,170	2,409
2018	367	891	770	1,561	1,521	3,132
2019	511	1,158	989	2,035	1,951	4,072
2020	687	1,506	1,257	2,647	2,480	5,293

Source: S&I (2009).

Table 2: Categories of expenditure, share of annual expenditure which falls in each category, share of expenditure by location and sector to which category is assigned

| Category | Share of annual expenditure in this category | Location of expenditure | | Sector in AMOS model |
		Scotland	Outside Scotland	
Conceptual engineering	0.33%	50.0%	50.0%	8
Expert resource	0.28%	45.0%	55.0%	8
Site/resource assessment	0.80%	58.3%	41.7%	8
Detailed engineering	0.77%	43.8%	56.2%	8
Component testing	0.73%	40.0%	60.0%	8
Systems integration testing	0.70%	56.7%	43.3%	8
Verification third party approvals	0.45%	25.0%	75.0%	8
Structure	34.37%	69.6%	30.4%	3
Mechanical plant	14.37%	11.0%	89.0%	2
Electrical plant	5.73%	29.2%	70.8%	3
Control and monitoring systems	1.13%	43.4%	56.6%	5
Cables, umbilicals and communications, grid connection	5.30%	31.4%	68.6%	4
Moorings and foundations	9.18%	51.2%	48.8%	1
Onshore equipment	0.93%	46.7%	53.3%	5
Other	4.66%	86.7%	13.3%	5
Logistics base (e.g. ports/harbours)	1.07%	97.5%	2.5%	7
Installation vessels	6.66%	36.7%	63.3%	6
Support vessels	4.93%	55.0%	45.0%	6
Diving	1.60%	83.3%	16.7%	8
Survey	0.87%	82.5%	17.5%	8
Onshore civil engineering	1.40%	90.0%	10.0%	8
Testing and precommissioning	1.20%	70.0%	30.0%	8
Project management	2.53%	77.5%	22.5%	8

100%

Figure 1: Cost (£million) per MW by year in each of the three scenarios
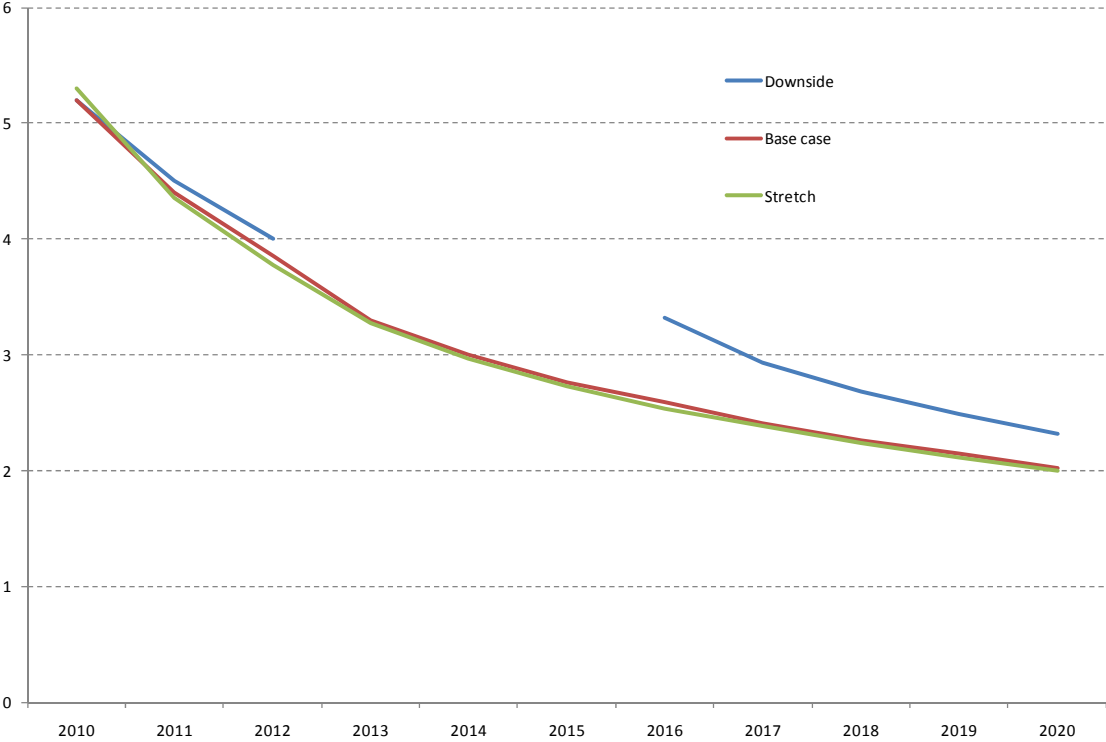
Figure 2: Employment impact of expenditures under S&I (2009) projections, IO analysis and

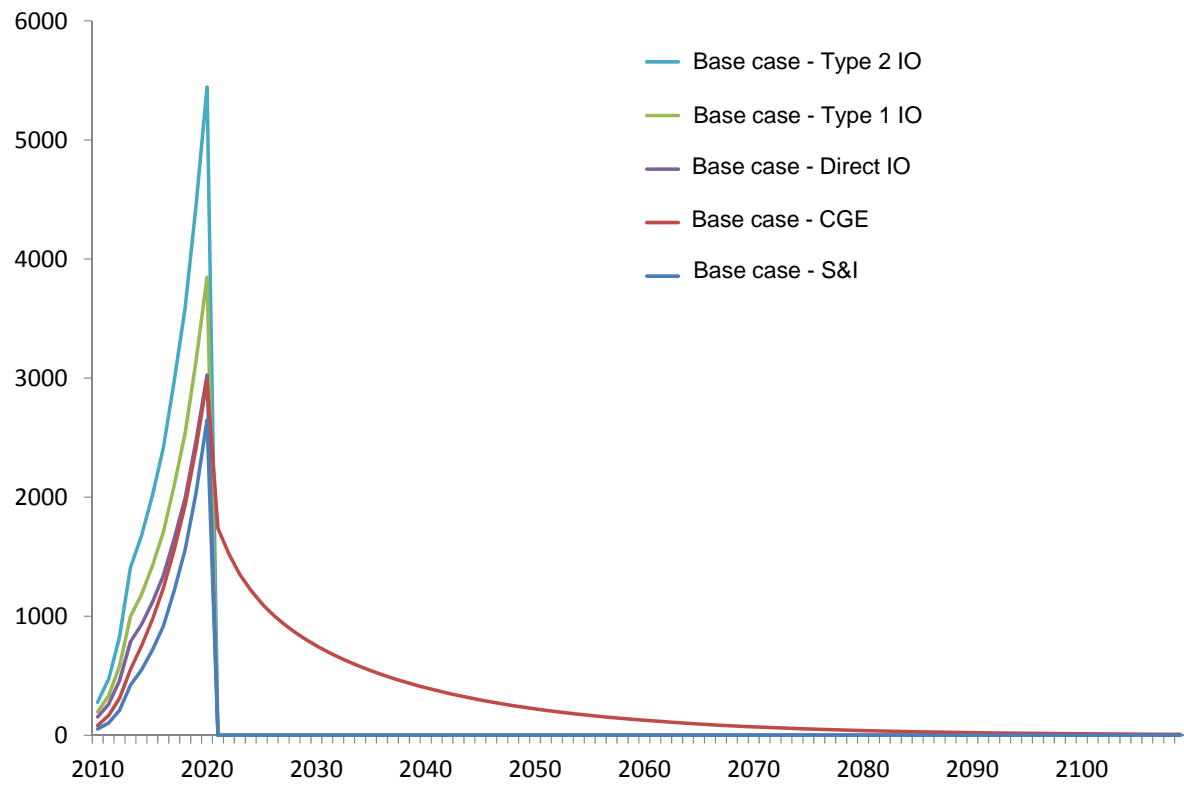*CGE modelling, absolute difference from base year*

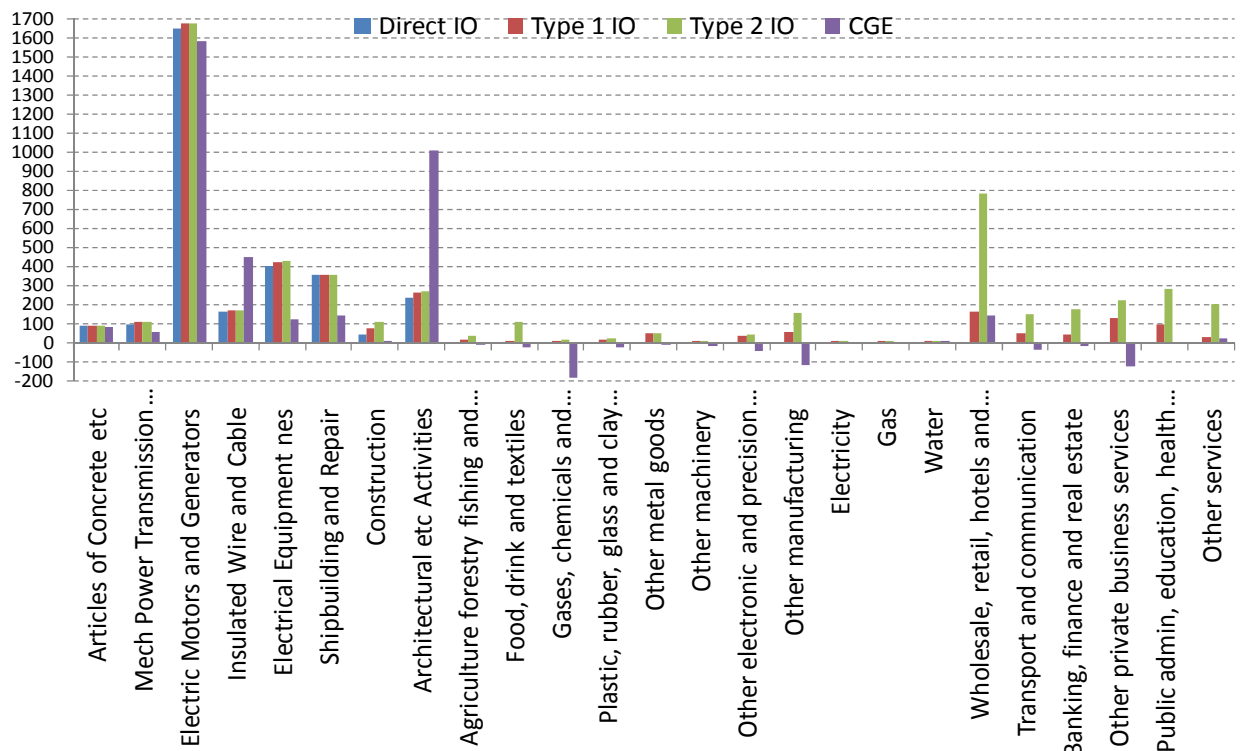*Figure 3: Sectoral employment change in Scotland in 2020, absolute figures by sector compared to base year*

Figure 4: Real and nominal wage values in 'base case' scenario, % changes from base
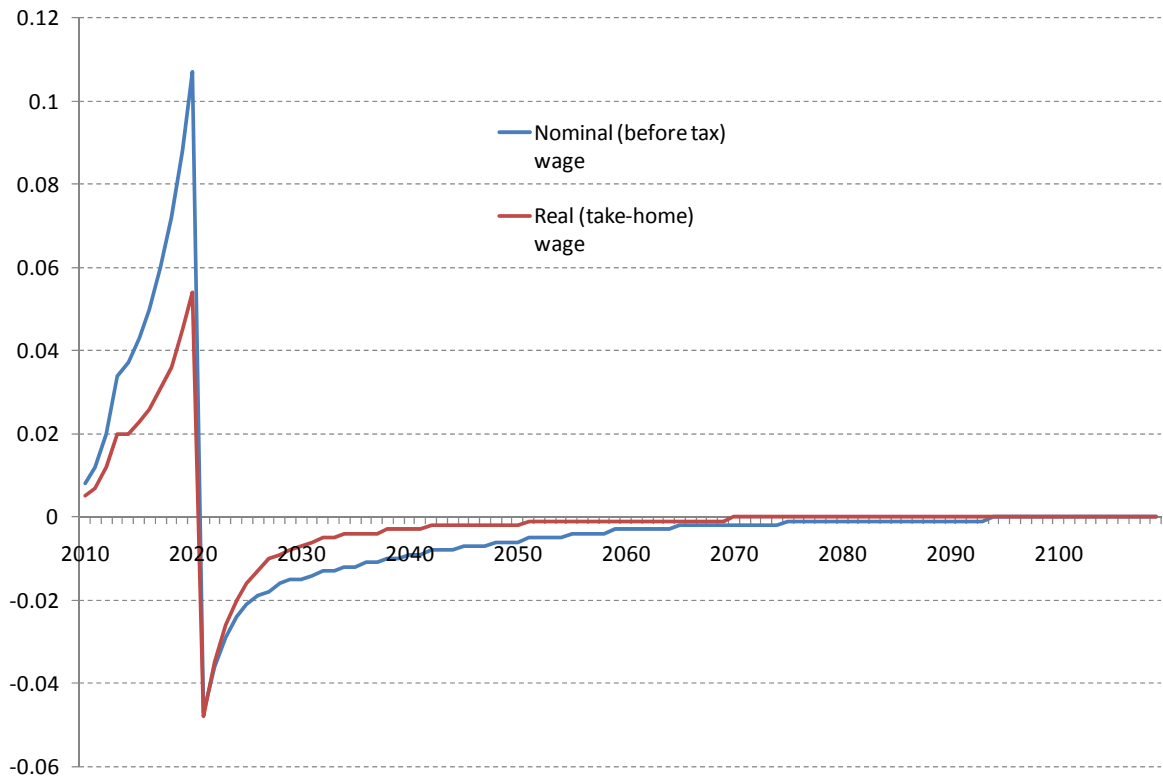
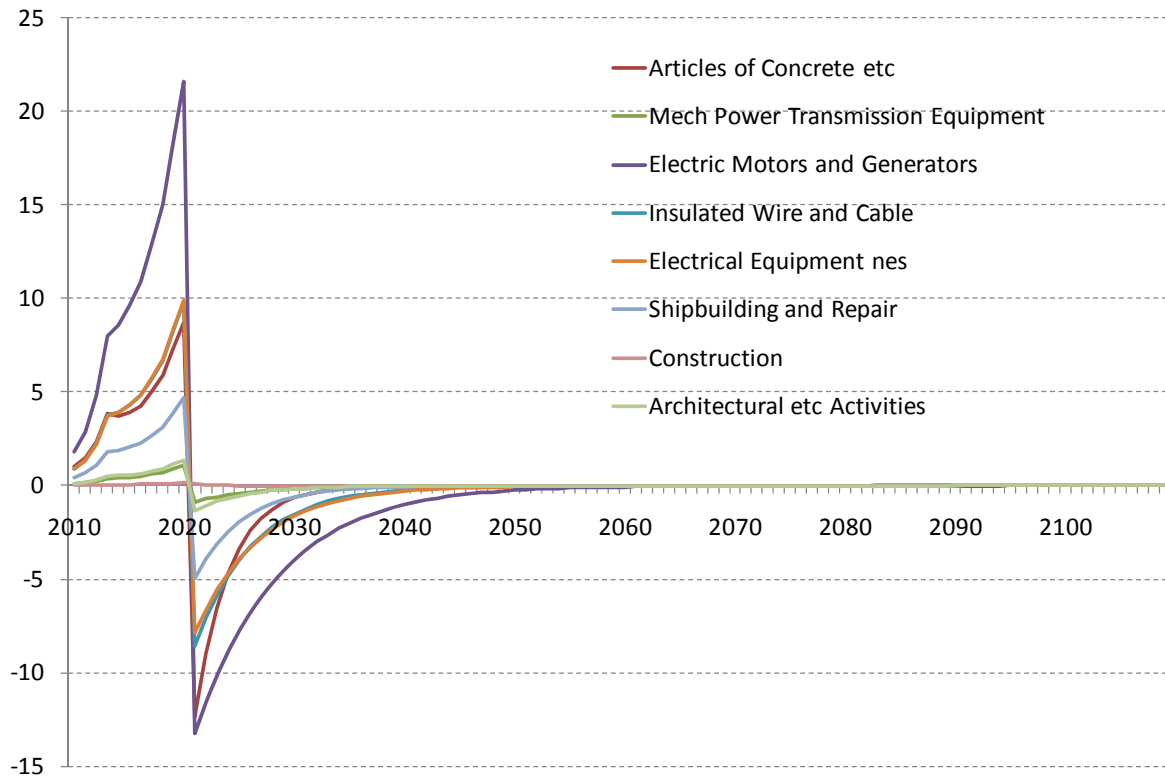*Figure 5: Capital rental rate in 'stimulated' sectors, % change from base*

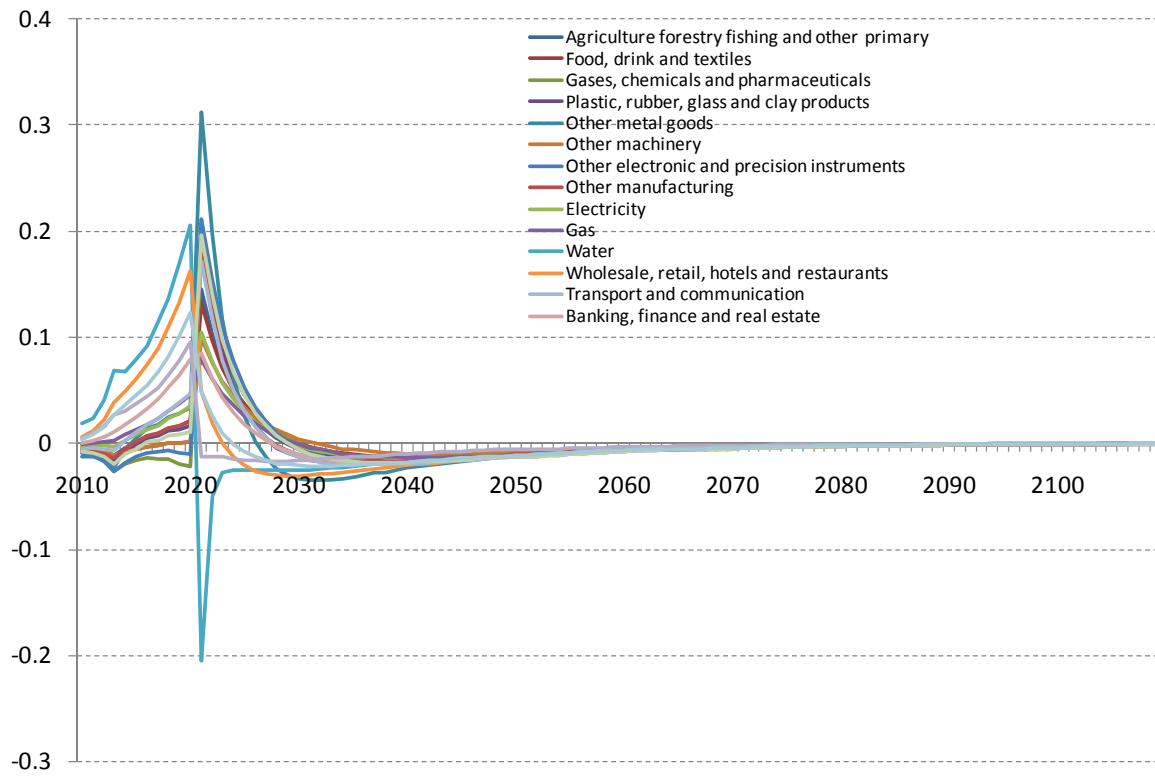*Figure 6: Capital rental rate in 'non-stimulated' sectors, % change from base*

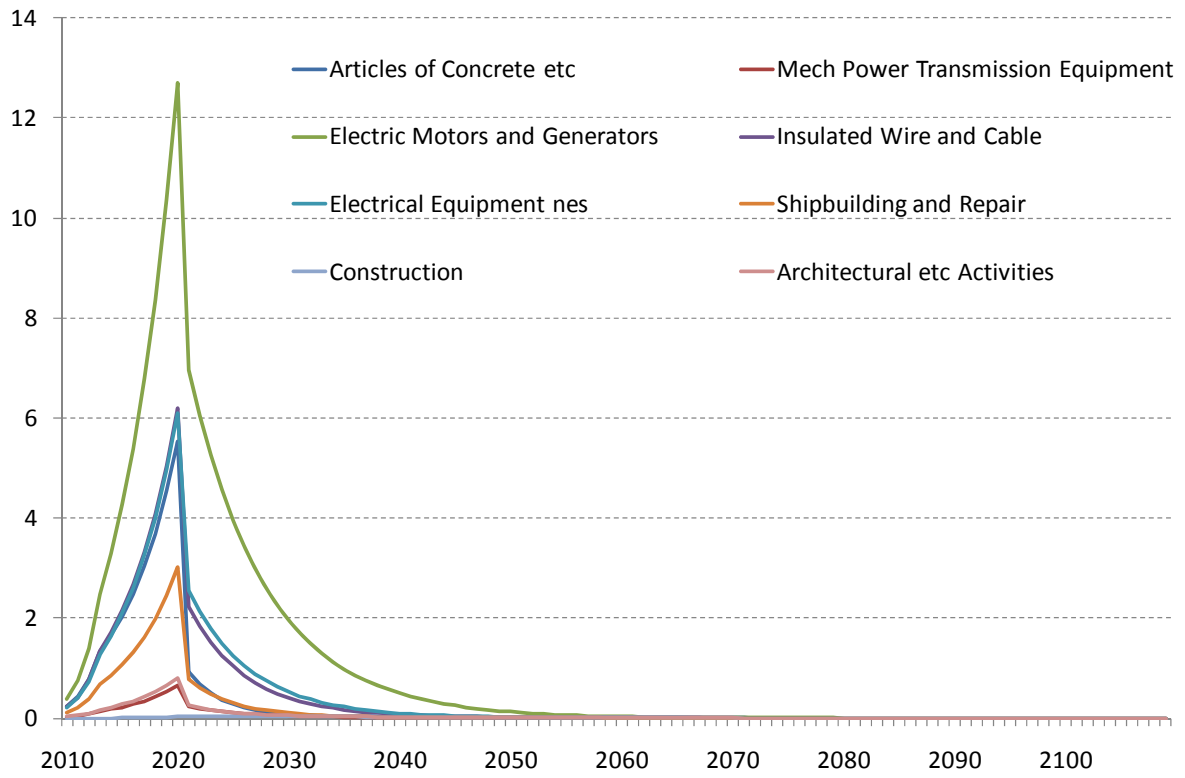*Figure 7: Output in stimulated sectors, % change from base*

Figure 8: Output in non-stimulated sectors, % change from base

Legend:
- Agriculture forestry fishing and other primary
- Food, drink and textiles
- Gases, chemicals and pharmaceuticals
- Plastic, rubber, glass and clay products
- Other metal goods
- Other machinery
- Other electronic and precision instruments
- Other manufacturing
- Electricity
- Gas
- Water
- Wholesale, retail, hotels and restaurants
- Transport and communication
- Banking, finance and real estate
- Other private business services
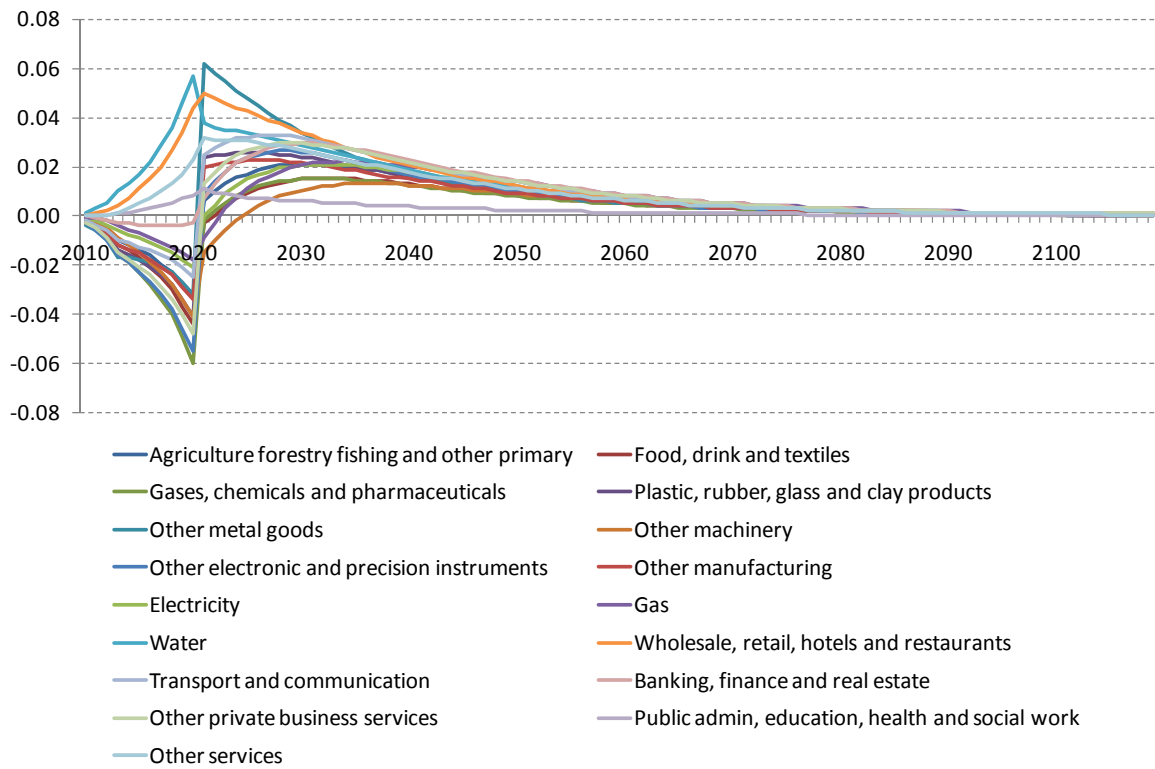- Public admin, education, health and social work
- Other services

Figure 9: Discounted regional employment effects of expenditures in each sector (present value (PV) of aggregate employment divided by PV of sectoral expenditures in sector i)
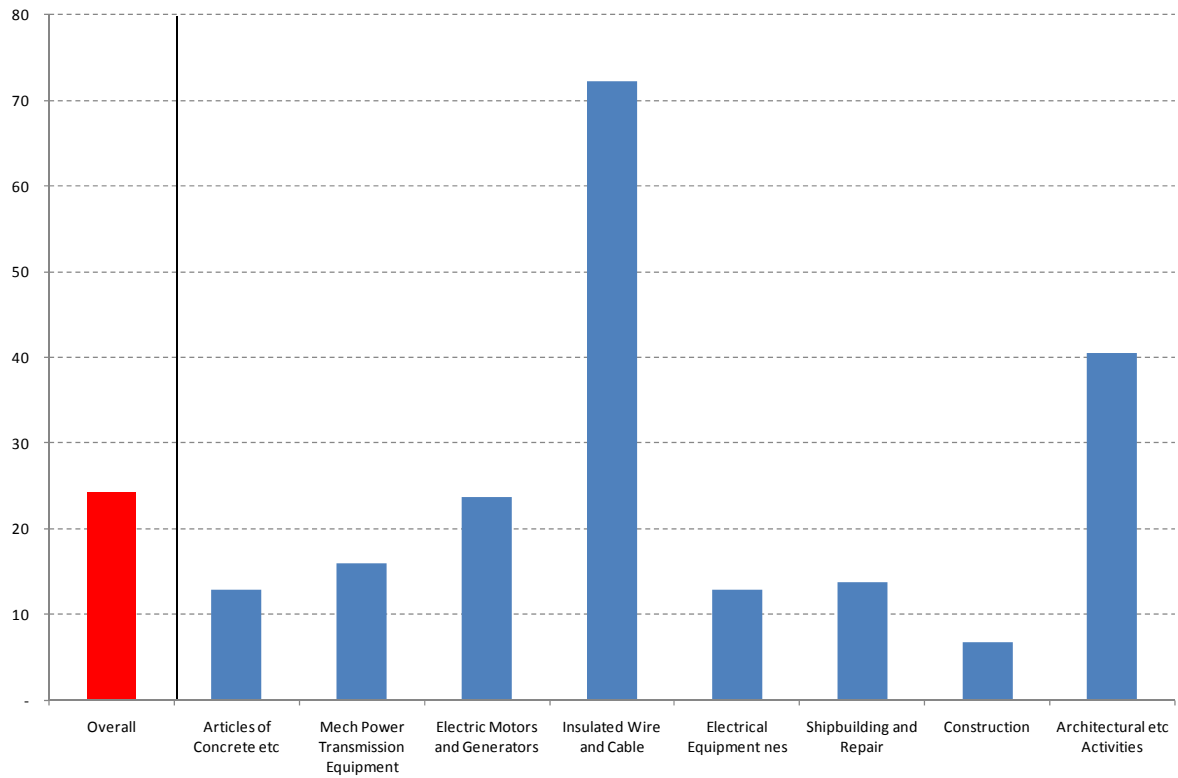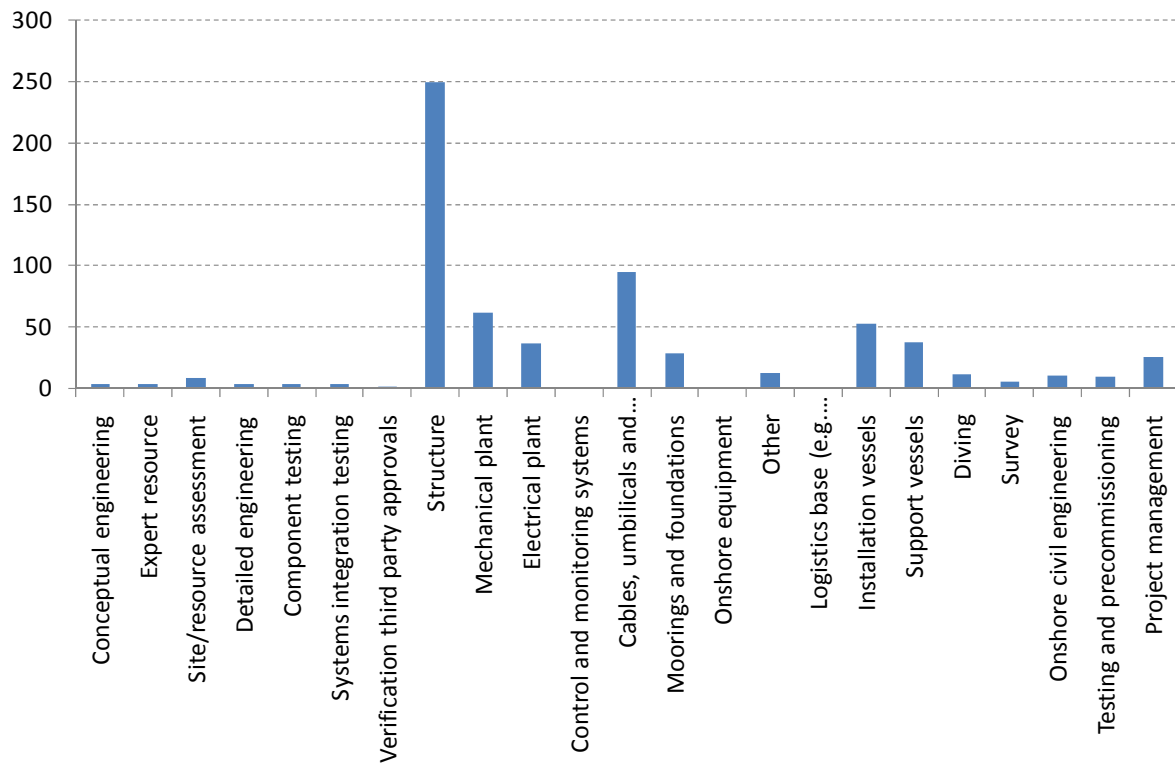
Figure 10: Additional employment for additional 1% sourced in each category in Scotland,

absolute differences from 'base case' scenario

Appendix 1: The sectoral breakdown of the AMOS model

	Sectoral name	*Industrial Order Classification*
1	Articles of Concrete etc	53
2	Mechanical Power Transmission Equipment	62
3	Electric Motors and Generators	70
4	Insulated Wire and Cable	71
5	Electrical Equipment nes	72
6	Shipbuilding and Repair	78
7	Construction	88
8	Architectural etc Activities	112
9	Agriculture, forestry, fishing and other primary	1-7
10	Food, drink and textiles	8-30
11	Gases, chemicals and pharmaceuticals	36-45
12	Plastic, rubber, glass and clay products	46-52
13	Other metal goods	54-61
14	Other machinery	63-69
15	Other electronic and precision instruments	73-76
16	Other manufacturing	31-35, 77, 79-84
17	Electricity	85
18	Gas	86
19	Water	87
20	Wholesale, retail, hotels and restaurants	89-92
21	Transport and communication	93-99
22	Banking, finance and real estate	100-105
23	Other private business services	106-111, 113-114
24	Public admin, education, health and social work	115-118
25	Other services	119-123