Institution: University of Strathclyde

Unit of Assessment: 10

Title of case study: Recovery of cod stocks in the North Sea achieved by a change in EU fisheries policy driven by evidence from mathematical models

1. Summary of the impact (indicative maximum 100 words)

In 2012, cod stocks in the North Sea were assessed as having recovered almost to a level at which their viability is considered to be safe. This recovery followed 3 decades of progressive depletion to only 50% of the safety threshold of abundance. Achieving this recovery required the EU to abandon an earlier 'closed area' policy banning fishing in selected areas of the North Sea, and instead enforce drastic cuts in overall activity on national fishing fleets. The policy change was prompted in part by predictions from mathematical modelling of cod populations by researchers at Strathclyde, showing that the 'closed area' policy was unlikely to be an effective strategy for recovery. The recovery has so far restored £17 million in annual value to the fishery.

2. Underpinning research (indicative maximum 500 words)

Context: Simulating spatial patterns in the demography of mobile species is particularly challenging and a general problem in mathematical ecology. However, validated models of this type are extremely powerful tools since they provide a means of conducting virtual experiments to diagnose the key factors affecting populations. This includes predicting the consequences of climate change and, for commercially exploitable taxa, changes in spatial patterns of harvesting. The research described here provided a significant advance in capability in this area and was used to support a policy change in fisheries management.

Key Research Findings: [*Numbers in parentheses refer to research articles listed in Section 3*]

A numerical technique for modelling spatial populations was developed during two NERC research grants between 2000 and 2006 [1]. The technique was used to simulate the spatial distribution and population dynamics of a marine plankton species (*Calanus finmarchicus*) which is particularly abundant in the North Atlantic Ocean and is an indicator species for impacts of climate change [2]. The life cycle involves spawning, development and dispersal by ocean currents in the surface waters during spring and summer, alternating with a dormant phase at depths of >600 m in the winter. The modelling technique was able to represent these developmental and dispersal processes at a spatial resolution of a few tens of kilometres over the whole North Atlantic, combining data on water currents and temperatures from an ocean circulation model, and on the food of *Calanus* from satellite remote sensing archives [3].

The modelling technique was then used to simulate the spatial population dynamics of cod in the North Sea during a Defra funded research project (2001-2005) [4], building on a body of work on the mathematics of growth in fish [5]. It was fitted to cod distributions derived by statistical analyses of survey data [6] as part of an EU funded project, and explained changes in cod distribution in terms of temperature, migration behaviour, and spatial patterns of fishing. On the basis of this capability, Defra commissioned researchers at Strathclyde to simulate the effects of imposing fishing moratoria in various configurations of spatial regions (marine protected areas) in the North Sea as part of the evidence base for a policy consultation by the EU Commission.

The development of this modelling technique [1], combining mathematical representations of key biological processes with spatial resolution, was a major technical achievement and a significant advance in the field. A key finding of the research on *Calanus* [2] was that sub-regions of high population abundance around the North Atlantic are interconnected by passive transport of *Calanus* life stages. Key findings from the research on cod were that transport of eggs and larvae by water currents, and active migrations of adults to spawning sites were major factors in maintaining the spatial structure of the stock [4]. Displacement of fishing effort from small scale closed areas into the remaining open spaces negated any beneficial effect of the closure as a conservation measure. The models predicted that the most effective action for stock conservation was to reduce the overall regional fishing effort.

The research was published in leading marine science journals, specifically those with top ten

impact factors in the "Fisheries" category such as the *Canadian Journal of Fisheries and Aquatic Science* and *Fisheries Oceanography* or the second top journal in the "Zoology" category, the *Journal of Animal Ecology*. The novel technical aspects of these models have also been published in leading mathematical and statistical journals (*Bulletin of Mathematical Biology*, *Journal of the Royal Statistical Society: Series C*.).

Key researchers at the University of Strathclyde:
The research was originally conceived and led by W.S.C Gurney (Professor in Department of Mathematics in 2000; retired 2011, then part-time contract until 2014) and continues under the leadership of Professor M. Heath, who was involved in the project during previous employment at Marine Scotland Science, joining the University of Strathclyde in 2010.
Dr D. Speirs (postdoctoral researcher) worked on the spatial modelling of Calanus in the North Atlantic during 2000-2006. Dr J. Bridson nee Andrews (postdoctoral researcher 2001-2006) worked on developing the model to represent cod in the North Sea. E. McKenzie (Professor of Mathematics 2001; retired 2011) and Dr R. Hedger (postdoctoral researcher 1999-2002) contributed the statistical analysis of cod data.

Key collaborators at other institutions:
Calanus modelling – University of St Andrews (S. Woods and E. Clarke)
Cod modelling – Centre for Environment, Fisheries and Aquaculture Science, Lowestoft (C. Darby and C. O'Brien); Marine Scotland Science, Aberdeen (M. Heath, now University of Strathclyde member of staff, and P. Wright)

3. References to the research (indicative maximum of six references)

References 1, 2 and 3 best exemplify the quality of the underpinning research

1. *Gurney, W.S.C., Speirs, D.C., Wood, S.N., Clarke, E.D. and* Heath, M.R. (2001). Simulating spatially and physiologically structured populations. *Journal of Animal Ecology 70, 881-894.*
2. *Speirs, D., Gurney, W.S.C., Heath, M.R., Horbelt, W., Wood,* S. and de Cuevas, A. (2006). Ocean-scale modelling of the distribution, abundance, *and seasonal dynamics of the copepod C*alanus finmarchicus. *Marine Ecology Progress Series* 131, 183-192.
3. Clarke, E.D., Speirs, D.C., Heath, M.R., Wood, S.N., Gurney, W.S.G., Holmes, S.J. (2006). Calibrating remote sensed chlorophyll *a* data using penalized regression splines. *Journal of the Royal Statistical Society: Series C (Applied Statistics)* 55(3) 331-353.
4. Andrews, J.M., Gurney, W.S.C., Heath, M.R.,Gallego, A., O'Brien, C.M., Darby C. and *Tyldesley, G. (2006). Modellin*g the spatial demography of cod on the European continental shelf. *Canadian Journal of Fisheries and Aquatic Sciences*, 63, 1027-1048.
5. Gurney W.S.C., Veitch R. (2007). The dynamics of size at age variability. *Bulletin of Mathematical Biology* 69, 861-885. .
6. Hedger, R., McKenzie, E., Heath, M., Wright, P., Scott, B., Gallego,A. and Bridson, J. 2004. Analysis of the spatial distributions of mature cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) abundance in the North Sea (1980-1999) using Generalised Additive Models. *Fisheries Research* 70, 17-25.

Other evidence for quality of research (grants, patents etc.)
The research group at Strathclyde developed and supported its research programme, and continues to do so, on the basis of competitive funding from NERC and Defra. Development of the initial model methodology was supported by two consortium grants (2000-2004, £593k), led by Strathclyde, from the NERC Marine Productivity Thematic Programme. Further development of the models to investigate cod populations was carried out in a Strathclyde led consortium project funded by Defra (2000-2003, £500k). On the basis of this, Defra commissioned the targeted research on closed areas which ultimately yielded the impact on cod stock recovery.
Additional relevant funding has been a stake in an EU project on North Atlantic cod (1998-2001, EU-FAIR-CT98-4122, consortium total award 1.13M Euro), and the research has continued under a NERC consortium grant from the Sustainable Marine Bioresources programme (2009-2012, £114,363 to Strathclyde).

4. Details of the impact (indicative maximum 750 words)

Process from research to impact

In the early 1990's, the International Council for the Exploration of the Sea (ICES) viewed cod stocks in the North Sea to be in a declining state and consistently advised cuts in fishing, to the point of recommending zero Total Allowable Catch (TAC). Nevertheless, the EU Council of Ministers consistently agreed on TAC's in excess of the scientific advice. The problem was that cod were caught in a mixed-species fishery so vessels fishing for other species could not avoid catching cod regardless of whether they were legally allowed to land them. Zero TAC for cod would have effectively closed the North Sea for all demersal fisheries with severe economic consequences. However, in 2000 the Commission was asked to seek additional conservation measures that might protect cod whilst enabling a continuing fishery for other species. The first of these, in 2001, was the emergency establishment of 'closed areas' containing high densities of cod, where fishing for all species was prohibited [Source A]. The Commission then sought scientific advice from member states as to whether the 2001 closed areas were likely to be effective in promoting stock recovery. In the UK, Defra then commissioned the research at Strathclyde into spatial simulation modelling methods for cod in the North Sea, as a means of analysing the effectiveness of the closed area strategy. The resulting advice from Strathclyde was that simply closing selected areas to fishing was unlikely to be effective due to displacement of effort into neighbouring regions. The most effective measure was permanent removal of fishing capacity from the system [Source C]. These results formed part of the UK evidence supplied to the Commission [Source D] and, on the basis of this evidence, the Commission abandoned the closed area policy in 2004 and instead implemented the 'Cod Recovery Plan' [Source B].

Impact on the state of cod stocks, 2008-2012:

Although the Recovery Plan was implemented in 2004 significant impact on cod numbers was not expected to be seen for a number of years, and the aim was to reverse the decline of stocks by 2009. Annual stock assessments showed that the decline was successfully halted by 2007 and by 2012 the stock in the North Sea had recovered to just below the level at which its viability is considered to be at risk [Source E].

Impact on fisheries policy, 2004-2012:

The Recovery Plan required EU member states to enforce drastic reductions in catch quotas for cod and overall fishing capacity [Source F]. In the case of the UK this was achieved by a scheme for decommissioning vessels and restricting the permitted number of days a vessel was allowed to spend at sea [Source G].

Economic impact:

The peak value of the North Sea cod fishery was more than £450 million per annum in the late 1970's (first sale value, standardised by the Consumer Price Index to year 2000). However, this was not sustainable and resulted in the overfishing which caused the decline in stocks. Current estimates of the long-term sustainable value are around £150 million per year. Between 1978 and 2007 the first sale value of cod landings declined by an average £14 million per year to a minimum of less than £35 million. Since 2008 the quay-side value has increased, and by 2011 the Recovery Plan and its successors had restored the annual value of the North Sea cod landings to £52 million. Hence, the Strathclyde research contributed to a £17 million per annum increase in the value of the cod fishery by 2011 compared to the low-point in 2007. The UK share of this international fishery is around 45%.[Source H]

Public awareness of recovery of cod stocks:

The crisis in the fishing industry precipitated by the Closed Area Policy and the Recovery Plan attracted media attention and raised public awareness of the state of the stocks. High profile conservation campaigns encouraged consumers to avoid buying cod. However there is evidence that public opinion now recognises that cod stocks are recovering. Recent media interest, for example via the BBC [Source I], reports that Barrie Deas, the Chief Executive of the National Federation of Fishermen's Organisations, which represents fisherman in England, Wales and Northern Ireland, told Radio 4's Today programme that the recovery of stocks was a "*dramatic turnaround …I think a major part of it is there are fewer vessels out there. There have been big*

decommissioning schemes. There's also been a change in the mindset in the industry. We work very closely with the scientists now." Another recent example of media interest was an item in the Daily Telegraph (10th June 2013) quoting Richard Benyon, the Fisheries Minister, as saying: "*We should not be complacent, there is still a long way to go, but this is really good news. People can eat cod without feeling guilty because there are large quantities being caught further north, and our cod stocks in the North Sea are recovering. Much of the credit for this must rest with the fishermen who have introduced a vast number of [sustainable fishing] measures*" [Source J]. This reflects both the impact of the Recovery Plan, and the extent of public awareness of the issue.

Reach and significance: The impact extended through the UK government fisheries agencies (Defra and Marine Scotland), to the EU Commission [B,C,D]. Cod is the most important fish species targeted by trawl fisheries in the North Sea [E], and the crisis in the fishing industry associated with its decline and recovery raised public awareness of the research that underpins fisheries policy [I,J]. The short-term hardship (due to curtailed fishing opportunities [G]) and the accruing economic benefits due to recovering cod stocks [H] are being felt by fishing communities and industries throughout Europe and Norway which have an economic interest in the North Sea demersal fisheries. The general public are now more aware that cod stocks are recovering.

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. Commission Regulation (EC) No 259/2001 of 7 February 2001 establishing measures for the recovery of the stock of cod in the North Sea (ICES subarea IV) and associated conditions for the control of activities of fishing vessels. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:039:0007:0010:EN:PDF

B. EU Council Regulation (EC) No 423/2004 of 26 February 2004 establishing measures for the recovery of cod stocks http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:070:0008:0011:EN:PDF

C. Darby C., Hutton T., Andrews J., Gurney W.S.C., Beveridge D., Hiddinck J.G. (2006) Investigations into closed area management of the North Sea cod. Cefas Contract report, p62-75. (Peer reviewed final report from a research project commissioned by Defra to investigate the effectiveness of closed area policies for conserving cod using the Strathclyde model - Defra Reference: SFCD15, January-May 2005).

D. http://www.cefas.co.uk/publications/files/EU_Norway_expert_gp_codrecovery-may-2003.pdf STECF meeting on cod assessment and technical measures, Brussels, 28 April–7 May 2003 127 pp.

E. ICES (2012). Advice Book 2012. Section 6.4.2 Cod in Subarea IV (North Sea), Division VIId (Eastern Channel), and IIIa West (Skagerrak) http://www.ices.dk/sites/pub/Publication Reports/ICES Advice/2012/ICES ADVICE 2012 BOOK 6.pdf

F. Council Regulation (EC) No 1342/2008 of 18 December 2008 establishing a long-term plan for cod stocks and the fisheries exploiting those stocks and repealing Regulation (EC) No 423/2004 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008R1342:EN:NOT

G. Almond, S & Thomas, B. 2011. The UK fishing industry in 2010. Structure and activity. UK Marine Management Organisation, 62pp. http://marinemanagement.org.uk/fisheries/statistics/documents/ukseafish/2010/structure_activity.pdf

H. Evidence derived from: Almond, S & Thomas, B. 2011. The UK Sea Fisheries Statistics 2010. UK Marine Management Organisation, 158pp. http://www.marinemanagement.org.uk/fisheries/statistics/documents/ukseafish/2010/final.pdf

I. http://www.bbc.co.uk/news/science-environment-22820162 BBC coverage of cod recovery

J. Article in The Telegraph, 10 June 2013: Britons "*Should not feel guilty about eating cod".* (http://www.telegraph.co.uk/earth/wildlife/10108952/Britons-should-not-feel-guilty-about-eating-cod.html

Institution: University of Strathclyde

Unit of Assessment: 12

Title of case study: Economic benefits from spin out company, Nautricity Ltd, and adoption of new technology to extract energy from tidal flows.

1. Summary of the impact (indicative maximum 100 words)

A step change reduction in tidal energy costs has been achieved through the development of the novel Contra Rotating Marine Turbine 'CoRMaT' tidal energy technology. The internationally patent-protected CoRMaT system reduces capital, operational and maintenance costs while increasing the extractable tidal energy resource by harnessing flows in deeper waters and from less energetic sites, which were previously considered to be uneconomic. A University spin-out company, Nautricity Ltd, was formed in 2010 to commercialise this technology. The development of this technology has changed both Scottish and UK Government policy via their introduction of programmes which demonstrate a step change reduction in the costs of marine renewables.

2. Underpinning research (indicative maximum 500 words)

Context: The economic potential of the commercial exploitation of marine power is vast, with global business opportunities estimated at £60billion per annum. The UK is leading the international development of a marine renewable industry, which is contributing to the realisation of 2020 targets for renewable energy capture. The research described here investigated and established a more efficient and cost effective engineering solution to extracting energy from tidal flows. The forces generated by the gravitational attraction of the moon and the sun's movements relative to the earth produce strong marine tidal flows, which are locally concentrated by landmasses. These strong tidal currents represent a vast renewable energy resource.

Key findings: The outcomes from the research identified a novel, more efficient tidal turbine configuration consisting of dual-contra-rotating rotors with a dissimilar number of fixed pitched blades per rotor. On the back of this, a Scottish Enterprise Proof of Concept (PoC) award was secured by Clarke, Grant and Johnstone in 2004 - 2008 to investigate whether this new approach was physically viable and delivered the expectations of the initial research. The PoC award enabled prototypes of the turbine to be built, tested and proven in both laboratory and real-sea test conditions at 1/30th and 1/10th scale respectively. The results confirmed this new engineering approach to tidal turbine technology delivered class leading performance via:

- an enhanced coefficient of performance (Cp) approaching 42%;
- reactive torque minimisation, providing the ability of the turbine to be held on station using a lower cost, tensioned mooring system, and for the turbine to passively align with the tidal stream direction under all anticipated operating conditions of the tidal diamond;
- reduced wake development and propagation delivering a reduction in downstream swirl (this has beneficial implications for reducing inter-device spacing within a tidal array);
- a significant reduction in the dynamic forces on each blade unit delivering beneficial implications for robustness; and
- confirmation of device stability throughout the duration of the tidal cycle.

The prototype delivered higher efficiencies of tidal power capture to delivered electrical power output through its more efficient rotor system directly driving a ground breaking sea-water flooded/ cooled, contra-rotating generator. These, together with the use of a tensioned mooring system incorporating passive yaw control, delivered step-change cost reductions in hardware when compared with current best practice.

The successful outcomes from the initial research has led to further research funding being secured from RCUK in 2010 by Johnstone, and in 2013 by Stack and Johnstone; and from EC Framework 7 in 2011 by Johnstone to investigate improving the durability of tidal energy technology sub-components through the development of apposite advance structural materials for the marine environment.

Key Researchers: This research was undertaken between 2000 – 2004 by a team in the Energy Systems Research Unit, Department of Mechanical and Aerospace Engineering, University of

Strathclyde. The key researchers were - J A Clarke (academic member of staff 1977 – present, currently Professor), A D Grant (Research Fellow 1972 to 2010, now retired), C M Johnstone (Senior Lecturer 1991 to present).

3. References to the research (indicative maximum of six references)

References 1, 2 and 3 best exemplify the quality of the underpinning research. References 1 and 2 are also included in the UoA 12 REF2 submission

1. Johnstone C.M., Pratt D., Clarke J.A. and Grant A.D. 'A techno-economic analysis of tidal energy technology' Renewable Energy an International Journal Vol. 49, pp101-106, January 2013, UK, ISSN 0960-1481

2. Clarke J A, Connor G, Grant A D, Johnstone C M and Ordonez-Sanchez S 'Analysis of a single point tensioned mooring system for station keeping of a contra-rotating marine current turbine', Nov-2010 In : IET Renewable Power Generation. 4, 6, p. 473-487, 15 p.

3. Clarke J A, Connor G, Grant A D, and Johnstone C M 'Design and testing of a contra-rotating tidal current turbine', Power and Energy, V221(A2), pp171-179, May 2007, ISSN: 0957-6509.

4. Johnstone C M, Pratt D, Clarke J A and Grant A D 'The need for tidal energy to be cost competitive with off-shore wind power', Proc. 3rd Int. Conf. on Ocean Energy, Bilbao, Spain, 6-8 October 2010.

5. Clarke J A, Connor G, Grant A D, Johnstone C M and Ordonez-Sanchez S 'Contra-rotating marine turbines: single point tethered floating system – stability and performance', Proc. 8th European Wave and Tidal Energy Conf., Uppsala, Sweden, 2009.

6. Clarke J A, Connor G, Grant A D, Johnstone C M 'Development and in-sea performance testing of a single point mooring supported contra-rotating tidal turbine', Proc. 28th Int. Conf. on Ocean, Offshore and Arctic Engineering, Hawaii, USA, 2009.

Evidence for quality of research (grants, patents etc.).

- International Patent No. GB2005/ 0516149.2 "Contra-rotating tidal current turbine" Clarke, Conner, Grant and Johnstone 2005-2012
- European Patent No. GB2010 /1104524.2 "Hydro-Buoy tidal energy mooring system" Johnstone and Pratt 2012
- 2010-13 Knowledge Transfer: Secondment of an ESRU academic to lead Nautricity and ensure technical continuity with the commercialisation of the CoRMaT tidal turbine, £210,000.
- 2011-12 Knowledge Transfer: REP Award to second an ESRU researcher into Nautricity to inform of hydrodynamic design processes associated with rotor development, £25,000.
- 2011-15, EC FP7, Marinet - Implementation of best practice testing procedures for wave and tidal energy converters, €555,000.
- 2012-12, Nautricity: EC FP7, Tidal Sense Demo - Development and demonstration at full scale of condition monitoring capabilities on large scale commercial tidal rotors and foils. €240,000.
- 2012-13 Nautricity: Waters II grant for the deployment of a commercial CoRMaT device under the Waters II competition, Scottish Government, £1.4 million.
- 2010-13, BIS, UK/Korean research collaboration: tidal energy flow mapping and fluid-structure interaction study of tidal stream turbines, £69,500.
- 2011-12, UK SI-TI, UK-Asia tidal energy scoping meeting: agglomeration of UK-Asia tidal energy developers to develop a tidal energy industry in Asia while learning from UK experiences.
- 2012-13 Nautricity: Smart Scotland award to demonstrate a full scale Hydro-buoy mooring system to facilitate the station keeping of tidal turbines. Scottish Government £250,000
- 2013-2016, RC UK – Research award to develop robust large tidal rotors through development of advanced structural materials. £1.1million

4. Details of the impact (indicative maximum 750 words)

Process from research to impact

Research outputs have been disseminated by Clarke, Connor, Grant and Johnstone through extensive publishing of journal and conference papers. New IP has been generated and secured via UK and international patent applications. This new technology has been the recipient of awards from professional institutions and industry bodies. To realise the commercial benefits, a University spin out company has been formed to bring the Contra Rotating Marine Turbine (CoRMaT) technology to market, creating the following types of impact:

New spin out created: Nautricity Limited was registered in 2009, and secured £5M industrial investment from First Tech, the investment arm of First Oil, in 2010 (Source A). To provide continuity in the development and commercialisation of the CoRMaT technology, Nautricity has seconded Johnstone as its CEO to lead the development of both the company and the CoRMaT technology within UK, North American and South Korean markets. In 2012/13 Nautricity built pre-commercial full scale systems for deployment in UK and International waters and to demonstrate economic viability.

Adoption of new renewable energy technology

The CoRMaT technology is considered unique and pioneering in that it can be deployed at mid water column, in deeper water, and where the flow velocities are faster. Due to the reduced complexity and inherent passive control integrated into the CoRMaT technology, this has delivered 'step changing' cost reductions in harnessing tidal energy. These reduced costs make it economically viable to harness power from less 'energetic' tidal sites and sites located in deeper waters, neither of which were previously considered feasible. This substantively increases the exploitable tidal resource.

CoRMaT is a proven, next generation, tidal stream turbine. The technology is regarded by the Carbon Trust, Scottish Enterprise and both UK and Scottish Governments as being a next generation technology which is 'disruptive' to the industry. This 'disruptive' nature is associated with the delivery of necessary step changes to make it more cost competitive with other forms of renewable energy. The capital cost has been assessed by the Carbon Trust, UK (Source B) and the Scottish Government to deliver £3,240/kW for a 500 kW device, approximately 40% of the costs quoted for competing 1st generation technologies. The projected electricity generating cost, 14p/kWh, is currently within the predicted 2020 band (12 to 18p/kWh) for tidal stream turbines operating in a velocity between 2.5 m/s and 3.5 m/s. The costs for CoRMaT are expected to be profitable. Operational costs have been calculated at £160/ MWh while existing Government incentives of 5 Renewable Obligation Certificates (ROC's) will provide a revenue of approximately £230/ MWh. The university spin-out company, Nautricity, is in the process of demonstrating the commercial viability of CoRMaT when deployed at full scale to capitalise on this.

In 2011 Nautricity secured an agreement to lease for the development of a 3MW test array from The Crown Estates. This led to the development of the first small array at the Mull of Kintyre off the south-west coast of Scotland, with the potential to build out to a 30MW tidal array. Nautricity has secured outline consent for a tidal site together with grid connection approval to facilitate the development of the site in 2014 (Source C). In February 2012 Nautricity secured a £250k SmartScotland award from the Scottish government for a £900k project developing and proving a novel tidal energy mooring system to augment the performance of the CoRMaT system. The prototype mooring system with a full scale CoRMaT turbine was deployed at the European Marine Energy Centre, Orkney in February 2013. In July 2012, Nautricity secured a Scottish Government WATERS II award of £1.4M against a £5.5M project to deploy and demonstrate a commercial system in deeper waters off the west coast of Scotland, to be deployed and commissioned during the summer of 2014.

Influence on Government Policy: The delivery of the CoRMaT technology has changed both UK and Scottish Government marine renewable policy. The realisation of next generation technology being available has scoped the development of the Scottish Government's Waters II competition in 2012 to specifically support the delivery of next generation wave and tidal energy technologies

which promise to deliver 'step-change' cost reductions (Source D). Subsequently, the Carbon Trust is using the cost benefits of the CoRMaT technology as a bench mark for the capital and operational costs of tidal technologies (Source B). Nautricity personnel have been invited (January 2012) to sit on the Scottish Government's reconvened Marine Energy Group (Source E), and Scottish Renewables: Marine Energy Working Group (Source F). Both these groups have a remit to inform both the Scottish and UK Government of necessary policy development in order to deliver a marine renewable industry. These groups informed the recent Waters II, Wave Energy Acceleration, and Marine Renewable Consolidation Fund calls, which are managed by the Scottish Government and the Carbon Trust.

Commercial benefit to utility companies and other organisations: Nautricity have demonstrated the commercial viability of marine power extraction to the energy utilities. This is bringing commercial benefit to the European Marine Energy Centre (EMEC) and its supply chain in the Orkney Islands and the Kintyre peninsula, where the commercial deployment of the technology at the Mull of Kintyre is taking place. The CoRMaT design is protected internationally by Patents GB2005/161492 and GB2010/ 1104524.2 and once an indigenous UK market is developed an International market will be exploited. In overseas market development, Nautricity's CoRMaT technology has been shortlisted as a preferred technology by Fundy Tidal Inc. for a 3MW project it is developing in the Bay of Fundy, Nova Scotia Canada, and by Haida Gwaii Tidal, British Columbia Canada for a 1.5MW community tidal energy project. With the growth in electricity supplies from renewables, especially in Asia, Nautricity has been invited to develop and deploy its CoRMaT technology in these emerging markets. The recent Memorandum of Understanding between the Scottish Government and the Incheon Authority, South Korea (in May 2013) to collaborate in the development of tidal energy in the Incheon region provides the delivery vehicle for the tidal energy technology. The Director of Incheon Metropolitan City Green Energy Policy Division said: "*The MoU gives momentum to encourage joint studies and knowledge sharing, thus helping to establish Incheon as a "mecca" for tidal energy*." (Source G).

Wider implications: To summarise, currently the impact is in terms of the adoption of the new technology and its influence on Government policy on renewable energy companies. The wider implementation of the technology will lead to benefits to the local economy through job creation within Nautricity, and its strategic supply chain partners, and commercial expenditure within communities where the technology is being deployed. The eventual cost reduction and environmental benefits will be to the consumer.

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. http://www.nautricity.com/docs/014_001_files_Sep10_firsttech_funding_1283276898.pdf spin out company secures significant investment
B. Marine Technology Accelerator Manager, Carbon Trust, London UK can be contacted to support the claim(s) that the application of the CoRMaT tidal technology is a cost benchmark for next generation tidal energy systems.
C. http://www.nautricity.com/news/mull-of-kintrye-tidal-array/ Nautricity development at Mull of Kintyre
D. Scottish Enterprise/ Scottish Government WATERS II Program Manager can be contacted to support the claim(s) that CoRMaT technology is changing Scottish and UK government policy on supporting next generation wave and tidal technology to deliver the necessary 'step-change' cost reductions.
E. http://www.scotland.gov.uk/Resource/0039/00395516.pdf Report from marine Energy Group
F. http://www.scottishrenewables.com/technologies/marine/ Report from Scottish Renewables: Marine Energy Working Group
G. http://www.scotland.gov.uk/News/Releases/2013/05/marine-energyu06052013 Scottish Government Press release 'Scotland makes waves in South Korea'

Institution: University of Strathclyde

Unit of Assessment: 12

Title of case study: Improving maritime safety through the implementation of new international rules and standards.

1. Summary of the impact (indicative maximum 100 words)

Research on the theoretical and experimental assessment of the stability of damaged ships in the Department of Naval Architecture and Marine Engineering from the mid-1990s to the present day has been pivotal in the development, adoption and implementation of the latest amendment of the International Convention on Safety of Life At Sea (SOLAS 2009) by the International Maritime Organization (IMO), the UN body regulating maritime safety. The impact of these regulations has been a significant reduction in the risk to human life at sea by enabling ship design and operation with higher standards of damage stability. SOLAS 2009 represents a step change from deterministic to probabilistic rules and from rule compliance to goal-based standards; it has improved design and operation of all commercial ships built worldwide from 2009, and has thus resulted in far-reaching and long-lasting impact on maritime safety.

2. Underpinning research (indicative maximum 500 words)

Context*:* Safety of Life At Sea (SOLAS) regulations were originally introduced in the aftermath of the sinking of the *SS Titanic* and have developed over many years, being periodically updated to reflect advances in maritime safety. The step change from deterministic to probabilistic rules has been considered for around fifty years, but was successfully implemented for the first time in SOLAS 2009, based on knowledge developed over 17 years through initiatives spearheaded by The Department of Naval Architecture and Marine Engineering (NA-ME), involving national and international research projects and working groups. These regulations target risk reduction, aiming for zero tolerance of risk to human safety.

Key Findings: After the 1987 capsize of the passenger-car ferry *Herald of Free Enterprise* with the loss of 193 lives, a new approach and numerical simulation tools were developed to study the behaviour and capsizing of damaged passenger ships, which take into account progressive flooding in waves as a function of time (Reference 1). After the capsize and sinking of *Estonia* in 1994 with the loss of 853 lives, UK, Germany, Norway, Sweden, Finland, and Denmark set up the Joint North West European Project with the aim of understanding rapid capsize of passenger-car ferries and developing improved survivability standards. In this project, NA-ME researchers formulated the first performance-based (quantitative) assessment of ship survivability, using first-principles tools, representing a landmark contribution in the history of maritime safety legislation. This research led to the establishment of a European standard known as the 'Stockholm Agreement' (Reference 2), the precursor of performance-based approaches to safety that led to the development of risk-based approaches and goal-based standards implemented in SOLAS 2009.

The cornerstone of the NA-ME contribution to maritime safety is the introduction of techniques for measurement of safety using first-principles tools to assess the safety performance of ships following collision/grounding and/or large scale flooding in realistic operational conditions. These techniques enable safety to be considered as a quantitative design objective rather than an attribute achieved by rule compliance, contributing to a fundamental shift in the perception of ship safety. NA-ME research, funded by the UK Department of Transport through a string of projects from 1995 to 2000, enabled determination of the survival time (time taken for a ship to capsize) of damaged passenger ships and the subsequent development of time-based survival criteria (Reference 3), allowing the development of ship designs and arrangements offering sufficient time for passengers to evacuate damaged ships. This research led to second and third generation numerical models to assess the survivability of damaged ships offering improved accuracy and flexibility in handling any damage scenario, in conjunction with improved computational speed. These technical developments, coupled with societal demands for improved maritime safety deriving from major maritime accidents (such as *Estonia*), led to the establishment in 1996 of the Ship Safety Research Centre (SSRC), by Vassalos & Turan, to provide a focus for international collaboration on maritime safety research, to support the implementation of the new standards being introduced throughout Europe via the provision of numerical tools, the development of experiment methodology, and provision of model testing facilities. NA-ME thus played a key role in supporting the EU maritime industry in re-designing existing ferries to the new standards. Between

2000 and 2003, the EU-funded projects ROROPROB (*Probabilistic Rules-Based Optimal Design of RoRo Passenger Ships,* Ref: G3RD-CT-2000-00030) and HARDER (RP1), initiated by NA-ME, provided the foundation for SOLAS 2009. These projects were truly international, involving European industry, research and regulatory bodies, IMO, the US Coast Guard and Japan. The IMO Working Group, with support from the HARDER project developed the harmonised regulations in draft form in 2004; following various amendments for ease and consistency of implementation, these entered into force in January 2009. NA-ME was involved in the Working Group and played a pivotal role in the formulation of the SOLAS 2009 rules.

NA-ME has continued to spearhead the implementation of probabilistic rules in practical ship design via a series of large-scale research programmes (7 projects between 2009 and 2013 amounting to some €1.5M). In addition, SSRC run SOLAS 2009 Passenger Ship Safety workshops to help industry understand the fundamentals and the implementation of the new rules to help ensure safer designs can be generated cost-effectively (References 5 and 6). Research has also focussed on development of global safety standards for damaged ships, to harmonise existing fragmented regulations and replace prescriptive rules-based standards with a performance-based approach.

Key Researchers at Strathclyde at time of research 1994 - 2009:

Vassalos, D. (Professor), Turan, O. (PhD Student, Research Fellow, Lecturer & Senior Lecturer), Konovessis, D. (PhD student, Lecturer & Senior Lecturer), Jasionowski, A. (PhD student, Research Fellow & Lecturer) – all were staff in the Department of Naval Architecture and Marine Engineering (NA-ME).

3. References to the research (indicative maximum of six references)

Outputs which best illustrate the quality of the research are References 1, 2 and 4.

1. Turan, O. & Vassalos, D. (1994) "Dynamic Stability Assessment of Damaged Passenger Ships", Trans. RINA, **136**, pp. 79-104.
2. Vassalos D., Turan O**,** & Pawlowski, M. (1997), 'Dynamic Stability Assessment of Damaged Ships and Proposal of Rational Survival Criteria', Mar. Tech., **34**, No 4, pp. 241-266.
3. Jasionowski A., Vassalos D. & Guarin L.(2003) 'Time Based Survival Criteria for Passenger Ro-Ro vessels', Mar. Tech., **40**, No 4, pp. 278-287.
4. Vassalos, D (2008) Chapter 2: Risk-Based Ship Design, in Papanikolaou, A (Ed): "Risk-Based Ship Design – Methods, Tools and Applications", Springer, ISBN 978-3-540-89042-6, pp. 17-98.
5. Vassalos, D, York, A, Jasionowski, A, Kanerva, M and Scott, A (2008) "Design Implications of the New Harmonised Probabilistic Damage Stability Regulations", Int. Shipbuilding Progress, **54**, No. 4, pp. 339-361.
6. Guarin, L., Konovessis, D. & Vassalos, D. (2009) "Safety Levels of Damaged RoPax Ships: Risk Modelling and Cost-Effectiveness Analysis", Ocean Eng., **36**, pp. 941-951.

Other evidence for research quality:

The importance of this research has recently been acknowledged by the award of the Royal Academy of Engineering 2011 Sustained Achievement Award to Prof Dracos Vassalos as well as the Gold Medal of the Royal Institution of Naval Architects.

The underpinning research was developed through more than a dozen projects with around £4M of total funding. Key projects were:

RP1: HARDER – Harmonisation of Rules and Design Rationale Ref:GRD1-1999 10721; (2000-2003) Vassalos & Konovessis; Funder: EC; (€518,768)

RP2: SAFEDOR – Design, Operation, Regulation for Safety Ref:TIP4-CT-2005-516278 (2005-2009) Vassalos and Jasionowski; Funder: EC (€1.52M)

RP3: GOALDS – Goal-Based Damage Stability Ref:FP7-SST-2008-RTD-1-233876; (2009-2012), Vassalos and Konovessis; Funder: EC (€822,000)

4. Details of the impact (indicative maximum 750 words)

Process/Events From Research to Impact: The underpinning research made a significant contribution to changing the practice of the profession from rule compliance to goal-based regulations with specific emphasis on ship damage stability (Source 1). This provided the platform

for introducing and developing a workable rule-set of probabilistic regulations via a series of large-scale international research projects. In particular the HARDER project provided all requisite input to IMO for SOLAS 2009. On this basis, the IMO Working Group, with the support of the HARDER project findings (Source 6) developed the harmonised regulations in draft form in 2004. Following various amendments for ease and consistency of implementation, these entered into force in January 2009. NA-ME researchers were involved in the Working Group and played a pivotal role in the development of the SOLAS 2009 rules. The underpinning research towards the development of SOLAS 2009 also proved instrumental in the eventual adoption of the regulations by the international maritime community (Source 2). This effort has thus resulted in new worldwide safety policy and improved standards; ultimately to safer shipping.

Successful spin out company: NA-ME research by Vassalos and Turan led to the formation of a spin-out company Safety at Sea Ltd (SaS) in 1999 to offer specialist safety services to the marine industry and this spin out has continued to have impact since 2008. Safety at Sea is now a wholly owned subsidiary of Brookes Bell Partnership following its merger with that company in 2011, and is a successful marine consultancy, specialising in marine and offshore safety, engineering and cost effective operation (Source 3).

Impact on International Regulations: All new ships built worldwide after 2009 must comply with SOLAS 2009 regulations. Given that damage stability failure represents 90% of the risk to human lives in maritime accidents, this affects over 2 billion people who travel on passenger ships each year, and around 100,000 commercial vessels, operated by around 1.5 million crew. In 2009-2012, over 10,000 ships were built under SOLAS 2009 regulations (Source 7). Currently, over 2,500 ships worldwide (worth $100Bn) are being designed and built to SOLAS 2009 regulations. The impact of the NA-ME research in Europe is even greater, as the performance-based standards in the Stockholm agreement have been applied to existing Passenger/Car ferries as well as new builds since 1997. In Northern Europe more than 200 existing vessels were upgraded to the standards set out in the Stockholm agreement in the period up to 2009. The impact continues as 300 existing vessels in Southern Europe are being upgraded to the standard in the period 2009 to 2015. More than 200 million passengers and 15 million cars/trailers are transported annually throughout Europe on these vessels.

Reduction in risk to human life: IMO statistics show a reduction of around 15-20% per annum in the loss of life in maritime accidents since the introduction of SOLAS 2009 (Sources 8 and 9). This equates to an average of 200-300 fewer fatalities per annum due to safety failures since the introduction of SOLAS 2009; this rate of reduction will improve further as new ships are being built to the new rules. Since 2009, two billion passengers are travelling in a safer environment at sea. IHS Fairplay's 2010 World Casualty Statistics publication shows that the number of lives lost at sea fell sharply in 2010 compared with the previous 12 months. In 2010, 250 seafarers lost their lives, the lowest figures for loss of life since 2003 (quoted in Source 9 p.18).

Improvement to build and design: Since 2008 NA-ME researchers and the spin-out company Safety at Sea Ltd (SaS) have contributed to upgrading of some 130 EU vessels to new damaged stability standards, as well as design of new-build ships owned by international companies including P&O Ferries, Stena Line, Caledonian MacBrayne Ferries, Viking Line, Color Line, DFDS Ferries, Irish Ferries, Grandi Navi Velocci, Grimaldi, VShips and Blue Star Ferries. These ferries continue to operate in the UK and European waters providing safer maritime transport to the UK and EU public (Source 3).

Using the new rules and expertise gained via research, SaS has been involved in the design of cruise vessels and RoPax for EU-based companies including Caledonian MacBrayne, P&O Ferries, Color Line, Stena Line, Carnival Cruises and Royal Caribbean Cruise Lines (RCCL) (Source 3*)*. SaS are involved with design of some of the most innovative passenger ships ever built e.g., Royal Caribbean Cruise Lines' *Genesis* class, designed on the basis of the new rules with safety as the main objective and demonstrating significant and cost-effective safety enhancement (see Reference 4). SaS is now responsible for all aspects of safety for *Titanic II*, a replica of the legendary ship currently being designed (2013).

Similar support has been provided to other organisations around the world, including the US Coast Guard, Daewoo and Samsung Heavy Industries (Korea), Mitsubishi (Japan) and NCL (Singapore), to help increase safety performance and standards. Since 2009 more than 15 cruise ships have been built in Europe to SOLAS 2009 regulations at a cost of $15Bn to the ship building industry.

Economic Impact – cost savings and employment: The SOLAS 2009 performance-based

standards enable cost-effective safety improvements. This incentivises the maritime industry to invest in safety whilst offering significant economic savings, including substantial savings in insurance costs. SaS Ltd employs more than 25 engineers offering services worldwide and has strategic partnerships with Lloyds Register of Shipping and Brookes Bell (UK); Deltamarin (Finland); Alpha Marine Services (Greece); Maersk (Denmark) and Panama Canal (Panama).

Embedding a safety culture in the shipping industry*:* An important contribution of NA-ME led research on safety has been in incentivising a change of the industry mind-set from rules-based to performance-based safety standards, enabling measurement of safety and offering a mechanism to facilitate and sustain a maritime industry safety culture. This has impacted on promotion of safety awareness and a proactive approach to effective life-cycle risk management; promulgating a maritime safety culture; enabling safer shipping in a cost-effective manner and reducing risks to life, property and the environment. International standards developed at IMO form the foundation for national standards and rules of related regulatory bodies, e.g. classification societies. The Executive Vice President of Royal Caribbean Cruise Lines notes that "*Performance-based approaches to addressing maritime safety, in particular damage stability, provided the foundation for innovative designs with demonstrable safety, achieved cost-effectively. This has enabled a step change in the profession's mind-set and practice in addressing maritime safety at large*" (Source 1). To facilitate understanding of the new rules and the ensuing safety regime, a series of CPD Workshops has been organised regularly by NA-ME with participation from professionals worldwide. The training material developed is now a reference on maritime safety for the industry while training workshops have been attended by over 150 industrial practitioners. The Marketing Director, Deltamarin Ltd notes "*I was one of the designers called upon to help NA-ME combine theory and practice and to offer a course that has helped make a step change in design practice with focus on ensuring high levels of damage stability*" (Source 4).

Reach and significance This research reaches the worldwide shipping industry through IMO regulations. The IMO's rules are the most important international instrument addressing maritime safety today, covering such areas as ship design, construction and equipment, subdivision and stability, fire protection, radio-communications, safety of navigation, carriage of cargoes (including dangerous cargoes), safety management and maritime security. NA-ME research is promulgated through IMO, National Regulatory Bodies, Classification Societies, ship designers and builders, ship operators, and most importantly 2 billion passengers and 1.5 million seagoing crew worldwide (Source 5). Performance-based safety allows the introduction of safety as a design objective, which leads to improving the overall performance of ships, i.e., better designed and operated ships, finally, addressing safety rationally incentivises safety investment and encourages a safety culture, leading in turn, to a sustainable and continuous improvement (as evidenced in the SAFEDOR Project website, Source 10).

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Statement from Executive Vice President, RCCL will corroborate the impact of NA-ME research on maritime safety perception and implementation
2. Statement from Chairman of the Maritime Safety Committee, IMO will confirm the influence of NA-ME research
3. http://www.safety-at-sea.co.uk/case-studies/ Safety at Sea website - case studies
4. Statement from Marketing Director, Deltamarin Ltd. will corroborate the significance of the training workshops in facilitating the introduction of the new rules
5. Statement from Technical Director, Lloyds Register of Shipping will corroborate the significance of the NA-ME research in affecting maritime safety at large
6. http://ec.europa.eu/research/transport/projects/items/eu_funded_safety_at_sea_project_has_worldwide_impact_en.htm
7. http://www.fairplay.co.uk/solutions/ships on order by ships type (Subscribed Magazine)
8. http://www.marineinsight.com/shipping-news/imo-calls-to-halve-seafarers-death-rate/
9. http://www.imo.org/KnowledgeCentre/ShipsAndShippingFactsAndFigures/TheRoleandImportanceofInternationalShipping/Documents/International%20Shipping%2020Facts%20and%20Figures.pdf
10. www.safedor.org

Institution: University of Strathclyde

Unit of Assessment: 12

Title of case study: Improved efficiency and design practice in European maritime industry.

1. Summary of the impact (indicative maximum 100 words)

The impact relates to improved productivity, operational efficiency, working practice and knowledge management within the European maritime industry through the use of a Virtual Integration Platform (VIP). The platform is a software package developed within the University of Strathclyde that has been used by eleven European ship design, engineering and project management consultancies, which specialise in the application of advanced computational design, analysis and physical modelling techniques within projects on an international scale. Specific company benefits of using the VIP include: 67% reduction in process time; guaranteed data consistency; additional productivity of 15 hours/day from automated over-night operation; capturing and reuse of expertise; cost effectiveness (lack of data consistency typically costs €100k per project); and ease of operation within complex design processes.

2. Underpinning research (indicative maximum 500 words)

Context: In the collaborative design of complex manufactured systems such as ships, effective product data management is extremely challenging when applied across organisationally and geographically distributed designers and analysts. The lack of effective support by existing solutions has been reported to cost the general US industry "billions of dollars" (Szykman et al., Source E). The management required in order to overcome these challenges exists within three layers: conceptual, physical and data management. Previous research by others has focussed on defining product data standards which have required significant development effort and expertise for implementation, resulting with industrial uptake that had minimal impact (Gielingh, Source F). In contrast, the Virtual Integration Platform (VIP) is a transformative platform that provides unique support for the collaborative design and analysis of complex manufactured systems such as ships and aircraft, and provides an integrated solution to these challenges through: translation and transfer of product data between tools; user-centred integration support; transaction management, access and version control; and change notification. The VIP was the first realisation of a fundamental architecture for a maritime Integrated Design Environment that would support distributed design. It has been developed exclusively within Strathclyde over a twelve year period within a number of EU funded projects (see also Section 3):

- VRShips-ROPAX 2001-2005. The concept for the VIP was devised exclusively within Strathclyde, and the platform developed collaboratively between Strathclyde (approx. 70%), National Technical University of Athens (approx. 20%), and Instituto Superior Téchnico (approx. 10%). Dr Whitfield was the principal system architect for the duration of the project.
- VIRTUE 2005-2009. The evolution of the VIP was devised and developed exclusively within Strathclyde with Dr Wu being the principal developer and system architect until 2007 and subsequently Dr Whitfield from 2007-2009.
- SAFEDOR 2005-2009. The VIP was devised and developed exclusively within Strathclyde with Dr Whitfield being the principal developer and system architect for the duration of the project. It was this version of the VIP that was used to achieve the impact described herein.
- EuroVIP 2011-2014. The focus of the EuroVIP project is the promotion of collaboration and the use of the VIP throughout industry, and not specifically VIP development.

Key findings: Research within Strathclyde on co-ordinating distributed design resulted in the creation of: a solution for ship product data integration [1]; a framework and solution for distributed design co-ordination [2, 3]; a solution for the management of distributed design resources [4]; techniques for the management of extremely large design models [5]; and, a platform for integrated risk and cost-based design [6].

The first development of the VIP within the VRShips project implemented a generic integration solution for over twenty ship design and analysis tools to support through-life design. The VRShips innovation was a radical modelling solution for structuring and managing the volume of engineering product data for complex manufactured systems such as ships; the project also resulted in the creation of a generic integration tool for design and analysis software aimed at ship designers rather than commercial software developers. These two solutions provided the core functionality that was needed to support the through-life design of ships [4]. The solution was unique in that no other product data management solution provided this level of integration within the industry

without being reliant on cumbersome product data and integration standards. The project demonstrated that the VIP concept was viable and highlighted the need for a number of enhancements that required further research to broaden the scope of industrial implementation. The VIP evolved within the VIRTUE project which focussed on integrating Computer Aided Design (CAD) and Computational Fluid Dynamics (CFD) tools and providing solutions to physical, and data management interoperability challenges. One of the greatest challenges related to the management of extremely large CFD datasets, which required the creation of a novel distributed data management solution that automatically propagated design change and maintained consistency of multiple versions of ship product data. The platform evolved through close industrial engagement (by an implement/test/evolve cycle) to support more efficient and effective collaborative design.

SAFEDOR demonstrated that first principle CAD and analysis tools could be integrated into the VIP to change the way that ships were designed and optimised for safety. This represented a radical change to the design process: adopting goal-based optimisation, rather than rule or regulation based design. Evolution of the VIP also demonstrated that a novel "dependency network" could provide a more effective way of supporting decision making relating to the design process, and provide more user-centric support for managing and visualising the exchange of product data than would otherwise be possible within more conventional workflows.

Key researchers within the Department of Design, Manufacture and Engineering Management, University of Strathclyde were Prof A.H.B. Duffy (Reader 1998 - 2004, Professor 2004 - present); Dr R.I. Whitfield (Senior Research Fellow 1998 - 2007, Lecturer 2007 - present); Dr Z. Wu (Research Fellow 2002 - 2007). Prof D. Vassalos was Professor in the Department of Naval Architecture and Marine Engineering 1996 - present. Other key researchers were Dr J. Marzi (HSVA), for VIRTUE and EuroVIP.

3. References to the research (indicative maximum of six references)

References 1, 4, and 5 best exemplify the quality of the body of research. References 1 and 5 are being returned within the UoA 12 REF2 submission.

[1] R.I. Whitfield, A.H.B. Duffy, P. York, D. Vassalos, P. Kaklis, Managing the exchange of engineering product data to support through-life ship design, Journal of Computer-Aided Design, 43 (2011) 516-532.

[2] A.H.B. Duffy, M.M. Andreasen, K.J. MacCallum, L.N. Reijers, Design Coordination for Concurrent Engineering, Journal of Engineering Design, 4 (1993) 251-265.

[3] G. Coates, A.H.B. Duffy, R.I. Whitfield, W. Hills, Engineering management: operational design co-ordination, Journal of Engineering Design, 15 (2004) 433-446.

[4] R.I. Whitfield, A.H.B. Duffy, G. Coates, W. Hills, Distributed design co-ordination, Research in Engineering Design, 13 (2002) 243-252.

[5] Whitfield, R., Duffy, A., Gatchell, S., Marzi, J., & Wang, W. (2012). A collaborative platform for integrating and optimising Computational Fluid Dynamics analysis requests. Computer-Aided Design, 44(3), 224–240, doi: 10.1016/j.cad.2011.04.004

[6] W. Wang, A.H.B. Duffy, R.I. Whitfield, K. Mohamed, H. Prins, S. Gatchell, Virtual Integration Platform for Computational Fluid Dynamics, in: 14th International Conference on Computer Applications in Shipbuilding, Royal Institution of Naval Architects, Shanghai, China, 2009.

Other evidence for quality of research (grants, patents etc.)

- VRShips-ROPAX (EU FP5, 36 partners, 2001-2005, €11.8M total, Technology Platform Project: GRD1-2000-25709; £1,100,000 awarded to Strathclyde).
- VIRTUE (EU FP6, 22 partners, 2005-2009, €17.4M, funded Sustainable Growth and Development project: TIP5-CT-2005-516201; £1,018,000 awarded to Strathclyde).
- SAFEDOR (EU FP6, 53 partners, 2005-2009, €20M, funded programme: TIP-CT-2005-516278; £1,095,000 awarded to Strathclyde).
- EURO VIP (EU FP7, 17 partners, 2011-2014, €1.8M SST-2010-266054; £367,000 awarded to Strathclyde).

4. Details of the impact (indicative maximum 750 words)

Process from research to impact:

The VRShips, VIRTUE and SAFEDOR projects had a combined and general theme of integrating advanced information technology into the collaborative design of ships. The projects were

industrially driven, with responsibility for applying the VIP being held by eleven associated maritime consultancies (detailed below). The VRShips project demonstrated that the VIP concept was viable for supporting European shipbuilding by focussing on capturing industrial requirements and needs, and prototyping the initial platform. The focus within VIRTUE and SAFEDOR was a fundamental shift in product data management to satisfy the identified industrial challenges and needs, and implement the VIP in industry. This industrially driven implementation ensured that the partners had the responsibility to deliver the case study demonstrations; had first-hand use of the VIP within their organisations; applied the VIP to their own problems; and were driven to exploit the opportunities that the VIP provided within the context of the case studies and also within further use within their organisation. These organisations were, therefore, adopting the research output (the VIP), adapting their ways of working by integrating their design and analysis tools into the VIP, and subsequently improving the way they operate. The success of the VIP development and more importantly, the industrially-driven implementation is highlighted within the VIRTUE final project review relating to the VIP: "*The Reviewers are pleased that excellent progress has been made and many user requirements set up during the project have been included, hence demonstrating large functionality which is indicated through the large number of test cases which have been provided and shown by the partners*"; Source A.

Types of Impact: The VIP has been applied within the VIRTUE, SAFEDOR and EuroVIP projects by world-leading European ship design, engineering and project management consultancies, that undertake projects on an international scale including: Arsenal (Portugal), Atkins (UK), ECN (France), Friendship Systems (Germany), HSVA (Germany), Insean (Italy), MARIN (Netherlands), Principia (France), Sirehna (France), SSPA (Sweden), and ZIB (Germany). Collaborative applications have included (and were led by): wave resistance studies (Scott Gatchell, HSVA), hydrofoil design and optimisation (Christine de Jouëtte, Principia), propeller design (Scott Gatchell, HSVA), sea-keeping (Christine de Jouëtte, Principia), hull/propeller interaction (Francesco Salvatore, Insean), and hull shape optimisation (Christophe Malibat, Atkins). Through this industrial implementation of Strathclyde's VIP, the enhancements to engineering design practice are exemplified through implementation in HSVA and MARIN. HSVA is a privately owned service and consultancy company with 21 shareholders, 90 employees, based in Hamburg Germany with customers worldwide. HSVA specialises in testing technology, methods, standardisation and numerical procedures to solve complex problems, and has a turnover of €10-12M, 56% of which is international. MARIN is an international leading provider of hydrodynamic and nautical research and development, based in Wageningen, The Netherlands, employing 350 people with an annual turnover of €42M of which 85% is realised by commercial projects for the international maritime industry. Marin provides innovative design solutions and advanced research to a wide range of international customers. The implementation of the VIP has had the following beneficial impact:
Improved efficiency: the VIP allows designers greater opportunity to focus upon design and analysis activities rather than the management of the process. Traditional integration approaches using technologies such as the Common Object Request Brokerage Architecture were not end-user oriented having a steep learning curve, were complex and hard to use correctly, and resulted in long development times and high defect rates (Henning, Source G). The Strathclyde platform delivered time savings with the same quality of delivery as other approaches to meet customer requirements, as exemplified by the comments from MARIN's R&D Manager:

- "*It took only three hours for a first-time user to be familiar with the platform, build up the process and finish configuration. Overall, designers in MARIN were positive about the applicability of the VIP in the future CFD computations*"; Source B.
- "*Time efficiency was significant. Automation of the workflow and data flow [within the VIP] resulted in the run time of the process being reduced from six to two days, which was a 67% time reduction*"; Source B.

Improved productivity: the platform supports both manual and automated design and analysis activity to be coordinated in a distributed manner with a view to best exploit the resources available. Productivity improvements are exemplified by comments from HSVA and MARIN:

- "*Allowing the process to run autonomously overnight could evaluate hundreds of design variations over a multiple parameter search field. Additionally, less time was required from the "expert user", especially for the in-between steps, where little decision-making was required";* Source C. *"This automation resulted with fifteen hours [per day] of achievement or progress*

that would otherwise be wasted if the design was performed manually"; Source C.

- "*The VIP users found it especially useful to automatically produce analysis reports following each analysis. It saved time for the designers by avoiding composing such reports, hence enabling them to focus on more design related tasks*"; Source B. "*The time saved automatically producing reports was in the region of hours for each report created*"; Source B. MARIN would typically create over 1000 reports each year resulting in a minimum annual saving of 2000 hours effort.

Improved working practice: the platform provided data and process integration that saved manual effort and ensured data consistency and integrity as reported by HSVA and MARIN:

- "*The VIP facilitated the improvement of legacy tools as a direct result of integrating the tool into the platform, which shows that the VIP can also be used for testing CFD/design tools being developed. The tools were expanded to include more interoperability options for input and output formats, in some cases for more adherence to a common data format. The VIP provided automation that eliminated the need for the user to manually input certain values*"; Source C.
- "*The VIP guaranteed data consistency across resistance, manoeuvring, and sea keeping calculation of the hull. Moreover, by storing the correct configuration of the tools used in this project in the platform, errors caused by human carelessness were eliminated*"; Source B. "*The likelihood of inconsistent data is very low due to project management practices, however the consequence is significant and can cost in the region €100k, easily outnumbering the costs of investing within such a platform*"; Source B.

Enhanced knowledge reuse: HSVA has reported that through use of the VIP valuable specialist designer time is released to focus on more value-added activities:

- "*By saving and reusing configuration files, the "know how" knowledge of expertise was captured and reused by non-specialist users. The VIP enabled error free enactment for non-specialist users to enact a process that previously could only be done by specialists*"; Source C.
- "*The specialist's expertise is only required at the end for a final evaluation to approve the outputs, and to provide assistance in resolving unusual results; this frees up the specialist to focus on suitable and meaningful work*"; Source C.

Wider adoption: The successes and advances that have been achieved through these projects led to the creation of the EU FP7 funded EuroVIP project which uses the VIP to exploit new developments, by partnering and collaboration throughout the European maritime sector. The focus is to broaden the reach of implementation for the VIP and promote collaboration which has now resulted in 64 European wide registered users including seven associations, the latter providing a conduit to over 1500 companies across Europe. The University of Strathclyde is also currently in discussion with Astrium Space Transportation (Source D) who have identified the VIP as being a promising technology for the Next Generation Launcher, demonstrating the generic applicability of the platform. A preliminary technology plan is being prepared to allow Astrium to lobby their partners in the adoption of the VIP, and open up implementation within an equally challenging sector.

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. Statement from Professor of Fluid Mechanics, Vrije Universiteit Brussel.
B. Statement from Research and Development Manager, Maritime Research Institute Netherlands.
C. Statement from CFD Specialist, HSVA Hamburgische Schiffbau-Versuchsanstalt GmbH.
D. Head of Operations for R&T Academic Partnerships TS1 can be contacted to provide evidence
E. Document: S. Szykman, S.J. Fenves, W. Keirouz, S.B. Shooter, "A foundation for interoperability in next-generation product development systems", Computer-Aided Design, 33 (2001), 545-559.
F. Document: W. Gielingh, "An assessment of the current state of product data technologies", Computer-Aided Design, 40 (2008), 750-759.
G: Document: Henning, Michi (30 June 2006). "The rise and fall of CORBA", ACM Queue (Association for Computing Machinery) 4 (5).

Institution: University of Strathclyde

Unit of Assessment: 12

Title of case study: Guidelines and standards which improve design and safety of marine structures subject to steep wave impact

1. Summary of the impact (indicative maximum 100 words)

Guidelines and standards underpinned by Strathclyde research have improved the design, assessment and the safety of marine structures subjected to wave impact in large steep waves. The guidelines and standards are widely used in the design of floating structures, particularly Floating Production, Storage and Offloading vessels (*FPSO*s) and offshore wind turbines. Since January 2008 the work has impacted the design, strength assessment and failure analysis of fixed offshore oil and gas platforms, renewable energy devices and ships. The guidelines and standards are used by designers to mitigate against damage caused by breaking wave impact, thereby improving the safety of mariners and offshore workers, reducing lost production due to downtime, and cutting the risk of environmental impact due to oil pollution. The research has also been used by Strathclyde researchers in industry-focussed studies, in legal work related to the loss of the oil tanker Prestige (2009-2013), in the assessment of the Schiehallion FPSO for BP (2010), and design of a Scottish harbour wave screen (2009) that allows ferries to access and stay in the harbour in more severe weather.

2. Underpinning research (indicative maximum 500 words)

Context:

The research began when three inter-related collaborative proposals were awarded by EPSRC (1999-2002) to Barltrop and Huang, Incecik, and Vassalos and Turan to investigate the response of Floating Production, Storage and Offloading vessels (FPSOs) in extreme conditions. The proposals were triggered by Barltrop' s observation that Health and Safety Executive (HSE) 'guidance notes', he had written previously for offshore structures, needed further research in order to properly address wave impact. The FPSO *Schiehallion* was proposed as a test case, as it had been damaged in 1999 by wave impact in severe conditions, confirming that existing approaches to design and construction of FPSOs and estimation of wave loading were inadequate.

Key findings:

An extended program of research was subsequently performed for BP which continued from 2001 to 2003 under the EU *SAFEFLOW* project in parallel with the Industry-funded *FLOW* Joint Industry Project and PhD research. Barltrop supervised research on instrumented three-metre models of the curved bow *Schiehallion* and conventional tanker *Loch Rannoch* that were tested in the Kelvin Hydrodynamics Laboratory with all data analysed by Strathclyde. In parallel, a flat bow was tested in a large test tank operated by MARIN (Maritime Research Institute Netherlands), with data analysis carried out by researchers from Strathclyde and Atkins. The Strathclyde study was validated by comparison with full scale data obtained from *Schiehallion*.

Further insight into the importance of reflected waves on impact loads was gained through a research study undertaken in conjunction with the University of Glasgow in 2004-2005 on the effect of large waves impacting Shetland cliffs. A subsequent CFD study (2005-2009) investigated the nature of deep-water breaking waves, vessel motions, global loads on hull structures, and local pressure loads caused by extreme wave impact events.

A further programme of CFD and acoustic-based research was funded between 2009 and 2013 by insurance companies, via lawyers, addressing the loss of the tanker "MV Prestige" as a result of a breaking wave impact. The Prestige sank in 2002 causing extensive pollution, especially to Spain's NW coast. This work considered side impact and the effect of air in water on impact pressures. Related studies using the techniques developed have been carried out by Barltrop, Huang and Incecik (2000-2004) on wave impact loading on wind turbine structures, funded by EPSRC (2000-2004), and on ship side impact by Day and Barltrop (2010-2012).

The key findings of the research all relate to the development of better insight into the phenomena

related to wave impact on floating structures. In particular the findings lead to improved understanding of the probability of extreme wave impact (Section 3: Reference 1and 2, G1, G4), the types of wave leading to the greatest loads (Reference 1 and 3, G1), the effect of detailed hydrodynamics (including surface tension and aeration) on wave impact loading (Reference 3), the significance of the role of wave reflection in loading (Reference 4) the importance of added mass effects in the fluid-structure interaction (G4), the importance of "green water on deck" phenomena (G4), and the effect of water depth (G3).

The research also led to development of simplified equations and time domain simulations for impact pressures suitable for use in design, and improved estimates for safety factors for 100-year return period wave impacts (Reference 2, G1, G4)

Key Researchers at Strathclyde
The key researchers were employed in the Dept. of Naval Architecture and Marine Engineering at the time of the research. Prof N Barltrop (1999-2013); Prof D Vassalos (1999-2002); Prof O Turan (1999-2002); Prof Huang (2001-04); Prof A Day (2010-12); Prof A Incecik (2011-2012).

3. References to the research (indicative maximum of six references)
References 1, 2 & 3 best indicate the quality of the research

1. Xu L., Barltrop N. and Okan B. (2008) "Bow impact loading on FPSOs 1 - experimental investigation" Ocean Eng. Vol 35, No 11-12, pp1148 - 1157 http://dx.doi.org/10.1016/j.oceaneng.2008.04.013

2. Xu L. and Barltrop N., (2008) Bow impact loading on FPSOs 2 - theoretical investigation, Ocean Engineering Vol 35, No. 11-12, pp1158-1165 http://dx.doi.org/10.1016/j.oceaneng.2008.04.012

3. Ojieh, N., Barltrop, N. and Xu, L. (2009), RANS investigation of the kinematics of an alternative extreme wave,Ocean Engineering, 36 (17-18), pp1415-1424, http://dx.doi.org/10.1016/j.oceaneng.2009.08.009

4. Hansom J., Barltrop N. and Hall A., (2008) Modelling the processes of cliff-top erosion and deposition under extreme storm waves, Marine Geology Vol 253, pp. 36-50 http://dx.doi.org/10.1016/j.margeo.2008.02.015

Other evidence for research quality
Key research was supported by the following EPSRC funded projects
G1 GR/M62525/01 *COMPARISON OF MODEL TESTS & FULL SCALE DATA WITH THEORY;* PI Barltrop, Professor N. Oct 1999-Dec 2002. £86k
G2 GR/M62501/01 *FPSO SAFETY IN EXTREME ENVIRONMENTS* PI Vassalos, Professor D, Oct 1999-Dec 2002. £42k
G3 GR/N04539/01 *DYNAMIC RESPONSE OF WIND TURBINE STRUCTURE IN WAVES* PI Barltrop, Professor N., Co-I Huang, Dr S. Oct 2000-June 2004. £141k
G1 & G2 were supported by W.S Atkins, BP, Lloyds Register, Shell, Harland & Wolff and Technip.

EU SAFEFLOW & Flow JIP (Joint Industry Project)
G4 Prof Bas Buchner (Scientific Co-ordinator), MARIN, Haagsteeg 2, PO Box 28, NL-6700 AA Wageningen; Jan 2001 – Dec 2003, sponsors/partners: Regulators: ABS, Bureau Veritas, DNV, HSE, NPD; Industry: Amerada Hess, Astano/Izar, Atkins, Bluewater, BP, Chevron, Conoco, Daewoo, FMC Sofec, IHC Gusto/SBM, Norsk Hydro, Offshore Design, PAFA, Phillips Petroleum, Shell, Statoil, Texaco; Universities: IST-Lisbon, University of Groningen.

4. Details of the impact (indicative maximum 750 words)
Process from Research to Impact:
The key process through which the research generated impact was the development of guidelines and standards used in the maritime industries to design vessels/structures with improved resistance to wave impact loading and thus improved safety and economics**.** Results and

recommendations from the laboratory studies on wave impact were published as guidance by HSE in 2005 (*Wave Slap Loading on FPSO Bows, Source 6)*. The results from the *SAFEFLOW* and *FLOW JIP* projects were published as *Summary Report on Design Guidance and Assessment Methodologies for Wave Slam and Green Water Impact Loading* (Source 7). These documents are still the most detailed and up to date guidance for the design of Floating Offshore Platforms against wave impact. The guidance covers wave loading on the hull, deck and deck mounted equipment. Whilst Safety Cases for offshore platforms in the UK sector of the North Sea are not based on mandatory guidance, industry would be expected by the regulators to refer to the HSE and SafeFlow guidance. The two guidance documents underpinned by Strathclyde research have been used to design (or redesign) offshore structures to ensure safe operation, thus reducing the risks to the vessel crew, and the risks of oil spillage to the environment, and loss of oil supply to the public, whilst reducing economic losses to oil producers.

The Strathclyde research on waves and wave impact has directly informed the oil industry and regulator sponsors; furthermore, through Barltrop's membership of the standards committees has informed the ISO standards (*19904-1 Floating Offshore Structures* (Source 8),*19902 Fixed Steel Offshore Structures* (Source 9) for offshore oil and gas platforms. Barltrop also contributed to the International Electrotechnical Commission IEC TC 88, which developed IEC/BS standard *61400-3 Wind turbines - Part 3: Design requirements for offshore wind turbines* (Source 10) incorporating guidance on wave loading, published in **2009.** Barltrop is currently working on the revision of both the ISO and IEC documents, providing essential reference for the safe design of fixed and floating offshore structures in the fields of oil, gas and wind energy.

Impact on Marine and Offshore Design and Safety:
In **2010** the *Schiehallion* FPSO bow impact loading was reassessed for BP by Atkins and Strathclyde, using the Strathclyde simple rule formulae and both the Strathclyde and Marin time domain models. This structure has subsequently operated safely until **2013** in the Schiehallion field, West of Shetland. (Source 1) The cost of the lost production due to 10 days downtime due to the damage incurred in 1999 was estimated to be about $35 million. The Strathclyde and Safeflow research has been the basis for the estimation of bow loading on the Schiehallion replacement vessel. This has been approved by BP, accounting for the HSE/Safeflow guidance and data from the Strathclyde/ Atkins **2010** wave impact studies. The replacement vessel (likely to cost in the region of $2-3 billion) is currently in-build and will be installed in **2014** (Source 1).

The series of circular FPSO vessels designed by Sevan Marine ASA Oslo, were designed according to this guidance based on input to design consultants British Maritime Technology (BMT). This series of vessels including *Hummingbird* (launched in **2008**) and *Voyager* (launched in **2009**), now owned by Teekay Shipping, are still operating. Each of these vessels are worth around $US 0.5-1 billion (Source 2).

Knowledge gained from Strathclyde research has been used by Barltrop in the assessment of safety of the structure during possible impact loading on the deck of the North Rankin-A fixed platform off Western Australia for Woodside Petroleum in **2009**. Value of the North Rankin Platform is estimated to be worth around $2-3 billion. Work by Barltrop contributed to the decision that the platform could continue to operate safely (Source 3).

In **2009** a damaged wave screen protecting the ferry berths in Kirkwall Harbour, Orkney was subsequently assessed and redesigned using results, from Barltrop based on software developed for the *SAFEFLOW* project (Source 4). The value of this wave screen installed is estimated to be £300k; its presence has both a societal and financial benefit by allowing ferry operations to access and remain in the harbour in more severe weather for about 20% more time.

The expertise has also been exploited to examine and provide guidance on wave load and wave impact for safe design of offshore wave energy devices; namely the Naval Dynamics AS device, designed in **2008** and the Aquamarine Oyster II built in **2011** and currently undergoing full scale testing at the European Marine Energy Centre (EMEC) in the UK.

Influence on legal proceedings:
The oil tanker *Prestige* sank after breaking in half in 2002 off the coast of Galicia, causing one of the most damaging oil spills in history, with a clean-up cost estimated at €2.5 billion. In October 2012 a Spanish court opened the trial of the former captain and three other defendants over their involvement in the oil spill. The main defendant is the captain of the Prestige, against whom prosecutors are seeking a 12-year prison sentence. Besides pursuing criminal charges, prosecutors are demanding financial compensation from the ship's insurers to cover the costs of the spill. The Spanish state raised its total claim to about €4.33 billion, from an initial estimate of €1.9 billion. France has so far claimed €86 million in damages.

Based on his wave impact research, Barltrop was asked to write expert reports (from 2009 to 2012) and to give expert testimony in the Spanish, Galicia Region, High Court, in 2013. In court there were two experts on hydrodynamics: Barltrop and another from Spanish Model Basin (Cehipar). Results of the Strathclyde research played an important role in explaining the nature of the waves, wave loading, structural response and the interpretation of the model test results. Of particular importance, owing to the effects of air in the water, on the basis of his research, Barltrop argued that the scaling factors applied by Cehipar were only 60% of the correct values. This evidence is highly significant as it indicates the hull strength must have been 66% higher than was implied by the Spanish tests. This indicates a properly, rather than poorly, maintained hull and this will affect the court's decision as to the cause of and responsibility for pollution and clean-up costs (Source 5). Court judgement is expected in before the end of 2013.

Wider impact:
Research impact has been through the development of guidance and standards, use of these guidance and standards by other parties, and through consultancy and expert evidence by Prof Barltrop and Prof Incecik. The guidance and standards provide better understanding and quantification of the response of the shell plating of FPSOs and conventional tankers due to wave impact loads which in turn enables the designers to manage the risk of oil pollution and possible loss of life due to shell rupture. Inevitably, we only know the detail of a small proportion of the overall application of the standards and guidance: i.e. applications in which Strathclyde researchers have had some direct involvement.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1: Naval Architect at British Petroleum can be contacted to support claims related to work on Schiehallion
2: Technical Manager Fluid Mechanics Limited can be contacted to support claims related to work on Hummingbird and Voyager.
3: Structural Project Engineer, Woodside Energy Ltd can be contacted to support claims related to work on North Rankin-A
4: Leader**,** Advanced Technology Team, Scott Wilson Ltd can be contacted to support claims related to work on Kirkwall Harbour:
5: Lawyer from Ince & Co LLP can be contacted to support claims related to testimony on Prestige
6: Barltrop, N.D.P. Xu, L. HSE report RR324. (2005) Available at: http://www.hse.gov.uk/research/rrhtm/rr324.htm
7: *Summary Report on Design Guidance and Assessment Methodologies for Wave Slam and Green Water Impact Loading*, Buchner, Hodgson, Voogt, Ballard, Barltrop, Falkenberg, Fyfe, Guedes Soares, Iwanowski, Kleefsman. August 2004.
8: ISO19904-1 Floating Offshore Structures, 2006, http://www.iso.org/iso/catalogue_detail.htm?csnumber=22995
9: ISO 19902 Fixed Steel Offshore Structures, 2007, http://www.iso.org/iso/catalogue_detail.htm?csnumber=27507
10: IEC/BS EN 61400-3:2009 Wind turbines - Part 3: Design requirements for offshore wind turbines http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030170387

Institution: University of Strathclyde

Unit of Assessment: 19 Business and Management Studies

Title of case study: Enhancing the Scottish Government's policy evaluation capacity

1. Summary of the impact

Research at the University of Strathclyde has increased the economic and policy modelling capacity of the Scottish Government. This has been affected through collaboration between researchers at Strathclyde and the Office of the Chief Economic Advisor (OCEA) and the Scottish Government-funded Centre of Expertise in Climate Change, ClimateXChange. The improvement in modelling capability and scope has enhanced the process of policy formation and evaluation, as well as the outcomes from it. This has allowed for improved decision making in the Scottish Government, allowed significant budget savings, improved advice to Scottish Ministers, improved interaction with the Westminster Government and resulted in a more informed public debate on policy decisions.

2. Underpinning research

Context: This impact is based on extensions to Computable General Equilibrium (CGE) methods incorporated into AMOS, A macro-micro Model Of Scotland. The research programme was initiated in the 1990s with an ESRC grant to Dr. Frank Harrigan (now Director at the General Secretariat for Development Planning, Qatar) and Peter McGregor (University of Strathclyde). The Strathclyde academic contribution was to incorporate institutional, macroeconomic and market conditions that characterise regional economies in developed countries. Examples are imperfectly competitive labour markets, complex public sector budget constraints and high levels of capital and labour mobility.

Main research contributions: AMOS was one of the first regional CGE models and it has been continuously developed and extended over the last two decades. From the outset, applications were theory-informed and policy-relevant, an early example being analysis of a regional wage subsidy by Harrigan et al. in 1996 [1]. While the research has primarily focussed on applications to the Scottish economy, variants of the model have also been developed for other small, open regional and national economies and for inter-related systems of regions (e.g. Gilmartin et al., 2013 [2]). The ability to model economic activity has also been extended to incorporate environmental and energy issues (e.g. Hanley et al., 2009 [3]). The flexible structure of the model facilitates extensive sensitivity analysis with respect to key parameter values and behavioural relationships which may be uncertain at the regional level. Further, the model's set of multi-period options enables the tracking of impacts over time (Lecca et al., 2013 [5]). This makes the AMOS modelling framework particularly useful for policy analysis, and distinguishes it from many other CGE models.

A key strength of the model is the ability to incorporate both demand- and supply-side policy changes and other exogenous shocks in a unified framework. This is in contrast to the majority of regional models which are strongly demand-determined. However, most government policy, especially for a devolved region such as Scotland, involves supply-side initiatives. Over the REF period, applications of the model have included the measurement of the regional impacts of: Higher Education Institutions; demographic change (Lisenkova et al., 2010 [6]); and the likely economic and environmental impact of improvements in energy efficiency and the introduction of renewable technologies (Lecca et al., 2011 [4]). The work generates many non-technical papers directed at the wider business and policy communities, typically published in the Department's *Fraser Economic Commentary*, regarded as the leading source of independent commentary on the Scottish economy, and the focus of regular, extensive media coverage.

Key researchers. Beside Professors McGregor and Swales, over the REF period key researchers were: Grant Allan (Research Associate and Lecturer), Dr. Patrizio Lecca (PhD. Student and Research Associate), Dr. Karen Turner (Senior Lecturer at Strathclyde and now Professor at Heriot Watt University). A number of other research staff contributed to particular projects and membership of the modelling team has typically provided the basis of a successful subsequent

career as academic and professional economists.

The main conceptual, policy and methodological insights from the research are contained in the sample of relevant publications below. All of the references had significant impact prior to publication since they appeared initially as online Discussion Papers; for example, the forward looking version of the model was available to the Scottish Government well before the publication of Lecca et al. in 2013 [5].

3. References to the research

1. Harrigan, F., McGregor, P. G. and J. K.Swales (1996). "The System-Wide Impact on the Recipient Region of a Regional Wage Subsidy", Oxford Economic Papers, vol.48 (1), pp 105-133.

2. Gilmartin, M. , Learmonth, D. , McGregor, P. G. , Swales, J. K. & Turner, K., (2013), "The National Impact of Regional Policy: Demand-side Policy Simulation with Labour Market Constraints in a Two-region Computable General Equilibrium Model", Environment and Planning A, vol. 45, pp 814-834.

3. Hanley, N., McGregor, P.G., Swales, J.K. and Turner, K. (2009), Do Increases in Energy EfficiencyImprove Environmental Quality and Sustainability?", Ecological Economics, vol.68, pp. 692-709.

4. Lecca, P., Turner, K. and Swales, J.K. (2011), "An investigation of issues relating to where energy should enter the production function", Economic Modelling, vol. 28, pp. 2832-2841.

5. Lecca, P., McGregor, P.G. and Swales, J. K. (2013) "Forward Looking versus Myopic Regional Computable General Equilibrium Models: How Significant is the Distinction?" Economic Modelling, vol 31 (C), pp160-176.

6. Lisenkova, K., McGregor, P.G., Pappas, N., Swales, J.K., Turner, K. and Wright, R.E., (2010), "Scotland the Grey: A Linked Demographic-Computable General Equilibrium (CGE) Analysis of the Impact of Population Ageing and Decline", Regional Studies, vol. 44, pp. 1351-1368.

Over the current REF period the team attracted: five awards from ESRC (including the most recent, which will start in October 2013); six from EPSRC; two from the EU; three from the Scottish Government and one from the private sector (SSE). McGregor and Swales have been PI or CI on all of these grants, which have exceeded £3 million over the REF period. The outputs include: well over 30 papers in leading international refereed journals (15 in the current REF period); numerous presentations at major international conferences around the world (many of these invited). In 2010 McGregor co-edited, with Professors Mark Partridge (Ohio State) and Dan Rickman (Oklahoma State), a special issue of Regional Studies on *Innovations in Regional CGE Modelling*.

4. Details of the impact

Process leading to impact:

The modelling team has enjoyed a long-term relationship with the economists in the Scottish Government through e.g. the provision of short courses; periodic seminars; membership of advisory groups. However, there has been a step-change impact during the current REF period that it is not "one-off" in nature - linked to a particular policy initiative - but rather continuing through the policy development and evaluation process itself. As a direct consequence of our research, OCEA has become committed to routine use of CGE models to analyse policy options for Scotland under alternative constitutional arrangements. The Scottish Government have established a CGE modelling team with a commitment to further developing this activity, in part through pro-active engagement with Strathclyde. There are a number of dimensions to this engagement.

Nature of the Impact:

Impact on Office of the Chief Economic Advisor (OCEA). The process began in the summer of 2011 when the Economics Department ran a short CGE modelling course for members of OCEA. This course was to familiarise members of the Government Economic Service working for OCEA

on the operation of CGE models in general. The aim of the Scottish Government was to build modelling capacity in order to evaluate more effectively the impact of policy initiatives and possible external shocks to the economy. The motivation was to improve decision making over key economic policies and increase the quality of policy discussion in Scotland, thereby benefitting the performance of the devolved government in Scotland. Specifically, the Scottish Government wanted to operate a CGE model as part of a suite of modelling techniques, including forecasting and tax modelling, to improve the advice it gives to Scottish Ministers.

The Department subsequently worked with OCEA, on modelling the impact of a differential reduction in Corporation Tax in Scotland on the Scottish economy. This work is explicitly cited in the Scottish Government's submission to the Scotland Bill (Scottish Government, 2011) and is the subject of a report from the Scottish Parliament Information Centre (Marsh and Nicol, 2013). The research has subsequently been presented at a Scottish Institute for Research in Economics (SIRE) Conference on International Business Taxation, July 2012, and the Urban and Regional Economics Seminar Group, January 2012. Further collaboration on developing a CGE modelling capacity within OCEA involved the Scottish Government purchasing a version of the Strathclyde model and establishing a formal contract for Strathclyde to provide on-going technical support to help them further customise the model and run model simulations. Two members of the OCEA staff, Leila Akhoundova and Angela Nolte, have been assigned to develop the CGE modelling and Kim Swales has been a visiting advisor to OCEA.

Model simulations by the Scottish Government have been used to identify the impact of the present fiscal consolidation experienced by the Scottish Government. Simulation results are also currently a key input into internal evaluation within the Scottish Government on the impact of changes in current and capital expenditure on the Scottish economy and variations in employers' national insurance contributions. This research has also been used to inform the Council of Economic Advisers. OCEA reports (Source 2) that the relationship with the University of Strathclyde has led to significant increases to the quality advice provided to the Scottish Government.

"As a result of our relationship with the team at the University of Strathclyde, the breadth and quality of analytical advice that we have been able to provide has increased significantly." (Source 2)

In particular, the modelling frameworks designed by Strathclyde are shaping policy development at the highest levels within government.

"We have also been better able to inform the evaluation of past-policy initiatives. Recent examples of this work includes research to inform publication of major external consultation documents – e.g. on corporation tax – and internal policy advice to Ministers – e.g. capital investment, export promotion and labour market participation. The research has also been used to inform the deliberations of the Council of Economic Advisers…. Feedback from senior Ministers, include the First Minister and the Cabinet Secretary for Finance, Employment and Sustainable Growth, has been excellent." (Source 2)

The Strathclyde research has also yielded significant cost savings. According to OCEA, these are recurring and expected to save around 10% of OCEA's annual research budget (Source 2).

Impact on ClimateXChange. The Scottish Government initiated an interaction with academics in Scotland through a new body, ClimateXChange. Professors McGregor and Swales successfully competed for funding under this initiative and were founder members of the body, their inclusion depending primarily on their prior research in regional Environment–Energy-Economy CGE modelling. ClimateXChange is a unique collaboration in which research on areas of key policy interest to the Scottish Government are funded across academic groups in Scotland. The Strathclyde models developed and applied to policy issues in this context share the same basic multi-sectoral framework as those being developed by OCEA, though extended to include detailed links to energy demands and carbon emissions. It therefore becomes straightforward to track the

impact of any energy or economic policy on energy use and emissions. The support for this capacity building is motivated by a conviction of the value of CGE modelling of the type developed at Strathclyde as a tool for the policy formation process.

The way in which annual objectives are agreed and delivered ensures that priorities reflect the research needs of the Scottish Government. In April 2012, mid-way through the first year of the project, we reported to the ClimateXChange policy workshop on the changes in efficiency and/or subsidies for renewables required for the Scottish Government to meet its renewables targets. We also reported simulation results for the introduction of a carbon tax in Scotland, clearly a possibility under independence. We have also recently (Summer 2013) discussed with the Scottish Government on-going work on the wider economic and energy use impacts of improved energy efficiency in household consumption. In the second year of the project we are undertaking analysis of the potential economic impacts for Scotland of developments in "Community Renewables". We have also provided an analysis of the likely economic impact of the recent licensing for marine energy developments. This research will feed directly into the Scottish Government's deliberations on the current renewable energy targets in this area (Source 3 can corroborate).

Overall, increased capacity in economic modelling enhances the process of, and outcomes from, policy formation and evaluation. This allows for better decision making in the Scottish Government, improved advice to Scottish Ministers and a more informed public debate on policy decisions. These are central issues in the move towards greater devolved fiscal powers embodied in the Scotland Act (2012) and the discussions surrounding the independence referendum.

Continuing model innovation and sustainable impact. Furthermore, the Scottish Government is part-funding (with the ESRC) two PhD studentships within the Economics Department to expand the variant of the AMOS model that it has adopted, and continues to fund advice and technical assistance from the modelling team. The specific areas of improvement are the treatment of the Government sector, further labour market developments and greater household disaggregation. These are particular areas chosen by the Scottish Government where an enhanced understanding would improve their policy analysis. Continuing model innovation is also a feature of a very recent award to Strathclyde under the ESRC's *Future of the UK and Scotland pre and post referendum* initiative, which will explore alternative fiscal futures under a range of model developments, including: a separate North Sea Oil sector; the incorporation of public attitudes towards taxation and government expenditure (building on explicit monitoring of these attitudes in juries and panels run by multidisciplinary colleagues); and the completion of a "behavioural" single-region and a "New Economic Geography" inter-regional variant of the model. Sustained policy impact is virtually assured as a consequence of the current embeddedness of CGE modelling within the Scottish Government's policy formation and assessment process (Sources 1 and 2 can corroborate).

5. Sources to corroborate the impact

1. Chief Economic Adviser for the Scottish Government can be contacted to corroborate that sustained policy impact is virtually assured as a consequence of the current embeddedness of CGE modelling within the Scottish Government's policy formation and assessment process.
2. A letter from the Head of the Office of the Chief Economic Advisor (OCEA), Scottish Government, corroborating the Strathclyde modelling team's impact through OCEA.
3. Former Head of the Energy and Climate Change Directorate within the Scottish Government can be contacted to corroborate that the research and analysis provided of the likely economic impact of the recent licensing for marine energy developments, will feed directly into the Scottish Government's deliberations on the current renewable energy targets in this area.