ERC
Enterprise Research Centre

Innovation, quality management and learning: a dynamic analysis

Jane Bourke and Stephen Roper

ERC Research Paper No.30

May 2015

www.enterpriseresearch.ac.uk

Innovation, quality management and learning: a dynamic analysis

Jane Bourke
University College Cork
jane.bourke@ucc.ie

Stephen Roper
Warwick Business School
stephen.roper@wbs.ac.uk

This paper is published by the independent Enterprise Research Centre. The Enterprise Research Centre is a partnership between Warwick Business School, Aston Business School, Imperial College Business School, Strathclyde Business School, Birmingham Business School and De Montfort University. ERC is funded by the Economic and Social Research Council (ESRC); the Department for Business, Innovation & Skills (BIS); the Technology Strategy Board (TSB); and, through the British Bankers Association (BBA), by the Royal Bank of Scotland PLC; Bank of Scotland; HSBC Bank PLC; Barclays Bank PLC and Lloyds TSB Bank PLC. The support of the funders is acknowledged. The views expressed are those of the authors and do not necessarily represent the views of the funders.

CONTENTS

ABSTRACT

Quality improvement and innovation are central strategies for firms in an increasingly globalised marketplace. Implementing both quality improvement and innovation, however, poses significant managerial, organisational and technical challenges and may also involve significant lags before benefits are realised. Here, using panel data on a large group of Irish manufacturing firms and econometric analysis, we establish the dynamic influence of firms' adoption of quality improvement methods (QIMs) on firms' innovation performance. Our study highlights the short-term disruptive and longer-term beneficial effects of QIM adoption on innovation. The relationship between QIMs and innovation differs markedly given the organic and/or mechanistic nature of individual QIMs. Quality Certification (mechanistic) has a negative innovation effect; while QIMs with an organic component (TQM and Quality Circles) create strong long-term innovation benefits. In addition, we find evidence of complementarities and learning-by-using effects from QIM adoption. Our results suggest that maximising the returns to innovation and quality improvement requires consideration of the organic and/or mechanistic nature of individual QIMs and the timing and sequencing of their adoption.

Keywords: Innovation, Quality Improvement, TQM, ISO 9000

JEL Codes: O30, 032, L15

Acknowledgements
Useful comments on an earlier draft were received from Will White, InnovateUK.

1. INTRODUCTION

Innovation With increased market competition and globalisation, firms have become more quality and innovation orientated. Quality improvement and innovation have therefore become established strategies as firms seek to create and defend their competitive position (Pekovic and Galia 2009). Indeed, some authors have argued that quality improvement and innovation are the central concepts of new forms of economic theory of the firm and models of business behaviour (Anderson, Rungtusanatham, and Schroeder 1994; Black and Porter 1996; Rungtusanatham et al. 1998), viz. ‘Quality is a vital component of the business strategy, and quality improvement is a strategic variable employed in the highly competitive international business world’ (Adam, Flores, and Macias 2001, p. 43). And, on innovation Baumol (2002 p. ix) also comments: ‘firms cannot afford to leave innovation to chance. Rather, managements are forced by market pressures to support innovation activity systematically … The result is a ferocious arms race among firms in the most rapidly evolving sectors of the economy, with innovation as the prime weapon’.

The two functions – quality improvement and innovation – are clearly inter-related although views contradict on whether the relationship between innovation and quality improvement is complementary or opposing. Nowak (1997), for example, envisages a complementary relationship, commenting that: ‘quality and innovation processes are inter-linked and should not be treated separately. Technical change not enhancing quality is illusive because it does not contribute to a sustained and improved strategic competitive advantage, nor does it increase the value creation potential of available resources through quality creation’. Other writers have seen quality improvement processes – which may involve mechanistic routinisation and standardised business processes – as restricting creativity and innovation (Kanter 1983; Glynn 1996; Prajogo and Sohal 2004); Perdomo-Ortiz, Gonzalez-Benito, and Galende (2009). Where the relationship between quality improvement methods (QIMs) and innovation has been explored empirically relationships are generally positive Moura E

Sá and Abrunhosa (2007); Abrunhosa and Moura E Sá (2008); Martínez-Costa and Martínez-Lorente (2008); Santos-Vijande and Álvarez-González (2007); Hung et al. (2011). Other studies, however, have found either neutral or negative relationships between QIMs and innovation (Perdomo-Ortiz et al., 2009a).

One other commonality between QIMs and innovation noted in the literature is that both are often difficult to implement leading to significant lags in the realisation of any related benefits. Pekovic and Galia (2009) comment, for example, that 'implementation of the ISO 9000 standard … concerns the whole organisation and involves changes in the fundamental behaviour and applied routine of employees' (Pekovic and Galia 2009, p. 831). Likewise, innovation may result in short-term disruption before any longer-term benefits are accrued by the firm (Roper, Du, and Love 2008). Understanding the performance benefits of innovation and QIMs, and their interactions, is therefore likely to require longitudinal data covering a period of years in which causal mechanisms are clearly identifiable.

Here, using panel data on a large group of Irish manufacturing firms we focus on the relationship between innovation and the prior adoption of QIMs. Specifically we ask whether, and over what period, the adoption of QIMs (ISO9000, TQM and Quality Circles) impacts on firms' innovation success. Most, if not all, of the prior studies of the relationship between QIMs and innovation have been based on cross-sectional data making causality difficult to identify, and providing little information on the nature of the learning effects and lags involved in QIM adoption and its potential benefits for innovation. Our study makes four main contributions. First, it clearly highlights the temporal profile of the performance benefits of individual QIMs, highlighting short-term disruption effects but longer-term benefits. Second, we show how this disruption - benefit profile is influenced by the organic and/or mechanistic components of each QIM. Third, it highlights complementarities between the adoption of specific QIMs, and fourth it suggests the role of learning-by-using effects in the shaping the QIM– innovation relationship (Rosenberg 1982).

The paper is organised as follows. In Section 2 we briefly review previous perspectives on QIMs and innovation and identify four hypotheses related to the potential impacts of prior QIM adoption on innovation. Section 3 describes the data used in our study. Our empirical analysis is based on a panel dataset relating to Irish manufacturing firms which were surveyed at regular intervals over the 1994-2008 period. Section 4 outlines the main empirical results and Section 5 discusses the implications. Our results suggest relatively long – and variable - time lags before the innovation benefits of QIMs occur, contrasts in the innovation impacts of different QIMs, and complementarities between some quality improvement measures.

2. CONCEPTS AND HYPOTHESES

2.1 Quality improvement

With increased globalisation, market competition and developments in technology, the characteristics of business have changed drastically (Pekovic and Galia 2009). Many firms have responded to these changes by incorporating quality-based strategies into their business models (Foley et al. 1997). A commitment to quality can drive firms to make significant improvements in profitability, productivity and competitiveness (Deming 1986; Morgan and Vorhies 2001).

In the management literature, it is widely recognised that quality is a 'diffuse, multidimensional construct and little consensus exists regarding how it can be measured or operationalised' (Wieke cited in (Cameron and Barnett 2000)). However, two distinct components of quality management emerge. First, there is a mechanistic component to quality management which emphasises stability, conformity and discipline, and comprises 'hard' processes such as work design and statistical process control. These mechanistic components of QIMs relate to the control of processes and products to comply with quality standards and satisfy manufacturing specifications (López-Mielgo, Montes-Peón, and Vázquez-Ordás 2009).

Second, there is an organic component to quality management which stresses involvement, partnerships, and comparison with the market leaders. These ‘soft’ aspects of quality management focus on leadership, empowerment and training, and encourage employees to scan the environment for new trends, approaches and technologies (Moura E Sá and Abrunhosa 2007; McAdam 2000). These organic components of QIMs promote the more human and developmental aspects of the quality system allowing the firm to adapt to its changing environment and promoting continuous improvement (López-Mielgo, Montes-Peón, and Vázquez-Ordás 2009).

Three of the most widely recognised QIMs which span the range of organic and mechanistic components of quality improvement are Total Quality Management (TQM), Quality Certification (such as ISO9000) and Quality Circles. TQM has been described as a management philosophy that fosters an organisational culture committed to customer satisfaction through continuous improvement (Kanji 2002). The TQM philosophy essentially comprises three key elements: customer focus, people involvement and continuous improvement (Moura E Sá and Abrunhosa 2007). These elements combine organic and mechanistic components with implications for a number of management practices such as leadership, training, employee-management, information and analysis, supplier management, process management, customer focus, and continuous improvement. Although, there is no clear consensus as to the impact of TQM, many scholars conclude that TQM positively affects business performance (Sousa and Voss 2002; Kaynak 2003). Sadikogulu et al. 2010) in a comprehensive review of the literature, report positive relationships between TQM and business performance, including metrics such as market and financial performance, employee performance and customer satisfaction (see Table 1, p. 16).

Quality Certification initiatives - e.g. ISO 9000 - are more mechanistic in nature than TQM, as certification requires detailed review and documentation of a firm’s production processes, in accordance with the quality system requirements specified by ISO.[1] The ISO 9000 standard is based on eight principles that address the core values and concepts of quality management: customer focus, leadership, involvement of people, process approach, system approach to management, continual improvement and factual approach to decision making (Kartha 2004). Many of the principles of Quality Certification are similar to those of TQM. In practice, however, the programme's focus is on ensuring that organisations create consistent, stable processes through process documentation and adherence, which assures the delivery of quality products or services (Pekovic and Galia 2009). The implementation of Quality Certification or standards such as ISO 9000 is a top down change process, which concerns the whole organisation and involves changes in the fundamental behaviour and routines of employees. As with TQM, there is considerable evidence that ISO certification can deliver advantages for the firm, such as quality improvement (Douglas, Coleman, and Oddy 2003), sales growth (Terlaak and King 2006), business performance (Terziovski, Power, and Sohal 2003), financial performance (Corbett, Montes-Sancho, and Kirsch 2005), and firm productivity (Diaye, Greenan, and Pekovic 2009). However, critics of ISO 9000 have claimed that implementation of ISO9000 is costly and time-consuming, and is particularly difficult for small firms (Pekovic and Galia 2009).

Without the mechanistic aspects of TQM or ISO9000, Quality Circles (QC) represent a more organic QIM. Typically QCs are small groups of workers who meet regularly on a voluntary basis to discuss problems (not necessarily quality related) and determine possible solutions. Members of Quality Circles are generally given training in quality control and evaluation techniques (Trott 2008). QCs improve problem-solving capabilities through employees' participation and team work (Bodas Freitas 2008). Therefore, QCs are organic in nature and enhance a participative culture. While there is limited evidence of the influence of QCs on firm performance, there is evidence that human resource management practices, such as QCs, which

[1] ISO 9000 certification is undertaken by various certification bodies called registrars such as government laboratories, private testing organisations, early adopters of ISO, industry trade groups and accounting firms.

empower and involve employees positively, influence employee motivation and behaviour with positive consequences for firm performance (Subramony 2009).

2.2 Innovation and quality management

Innovation has been identified as a critical driver of business productivity and economic growth (Schumpeter 1934; Romer 1990). Schumpeter (1934) argued that innovation involves the transformation of knowledge into new products, services or business processes. The relationship between innovation output and innovation inputs has been explored extensively (Crepon, Duguet, and Mairessec 1998; McCann and Simonen 2005; Griffith et al. 2008.; Roper, Du, and Love 2008). Numerous scholars have attempted to explain why some firms are more likely to innovate, with firm characteristics, such as size, sector, ownership, and location being identified as influential drivers of innovation output (Audretsch and Feldman 1996; Boschma 2005; Gordon and McCann 2005; Jordan and O'Leary 2008; McCann and Simonen 2005; Tether 1998; Romer 1990; Roper, Du, and Love 2008). The importance of R&D to innovation activity within firms has been established by many authors (Roper, Du, and Love 2008; Freel 2003). Firms engaging in R&D increase their existing stock of knowledge resulting in commercial gains from the introduction of new products, processes and/ or organisational innovations (Roper, Hewitt-Dundas, and Love 2004). Likewise, managerial capabilities have been highlighted as an important factor in firm level innovation. Successful innovation requires that firms and managers provide clear and consistent signals to employees about the goals and objectives of the firm (Barnes et al. 2006). There is also considerable evidence of the importance of external sources to innovation outputs (Mansury and Love 2008). These external sources of knowledge may include linkages with customers, suppliers, competitors and/or research institutes (Roper, Du, and Love 2008)

It has long been recognised that innovation in processes is necessary when a company wants to increase productivity (Martínez-Costa and Martínez-Lorente 2008), implying a potential link between innovation and quality management. However, it seems likely that the organic and mechanistic components of quality improvement management may impact differently on firms' innovation activities. The organic component of QIM, comprising elements such as customer focus, employee training, teamwork and continuous improvement, seems likely to have a beneficial impact on innovation performance. Knowing your customer's needs and preferences is an important element of a firm's development of new products and services (Martínez-Costa and Martínez-Lorente 2008). Customer focus within an organisation encourages organisations to search consistently to meet customer needs and expectations, although it has also been argued that too close an alignment with customers' preferences can, in fact, hinder innovation (Martínez-Costa and Martínez-Lorente 2008). Similarly, the continuous improvement aspect of QIMs should also be reflected in the development of new products, services and processes. A commitment to continuous improvement encourages change and creative thinking in how work is organised and conducted (Prajogo and Sohal 2001). Zairi (1994) also explains that quality management has 'given organisations the impetus and commitment required for establishing climates of never-ending innovation or innovativeness'. These 'softer' aspects of quality management are therefore likely to be beneficial for innovation.

The more mechanistic components of quality management may, however, have a disruptive effect on the firm and its innovation activity. Many authors have argued that quality management systems which focus on conformance and error reduction can result in a rigidity that is not in line with innovation strategies (Kanter 1983; Glynn 1996). Standardisation can lead to lower flexibility and openness to change as a result of repeated tasks and routinised problem-solving (Prajogo and Sohal 2004). For instance, TQM in particular, emphasises the use of data for 'management by fact' problem-solving. Glynn (1996) suggests that if workers are allowed only to deal with routine operational problems, then it is unlikely that they will come up with innovative solutions. In addition, it has been suggested that the mechanistic component of quality management can trap organisations in improvement or incremental innovations and lead them to be 'narrow-minded' – only seeing the world through current customer eyes. Furthermore, TQM, in particular, focuses on cost efficiency which could limit the capacity and opportunity for innovation, and could hinder creativity due to the enforcement of standardisation or formalisation (Prajogo and Sohal 2001).

In brief, the organic component of quality management, which stresses involvement, partnerships, and comparison with the market leaders and so encourages employees to scan the environment for new trends, approaches and technologies (McAdam 2004), is likely to have a beneficial impact on innovation. However, the new introduction of more mechanistic QIMs which emphasise stability, conformity and discipline may actually discourage creativity and innovation. Any such disruptive effect of quality management is, however, likely to be short-term with the benefits of adopting these practices accruing over time. Any disruption effect is likely to decrease over time as firms improve the implementation of the new quality measures, a learning-by-using effect.

2.3 Hypotheses

The majority of existing studies of the relationship between QIM and innovation have considered the effects of TQM, reflecting a potential trade-off between the positive effects of the organic component of TQM for innovation and the potentially negative effects of the more mechanistic components. Moura E Sá and Abrunhosa (2007), in an investigation of the Portugese footwear industry, for example, report a positive relationship between TQM and innovation, although the relationship proves relatively weak. Martínez-Costa and Martínez-Lorente (2008), in a study of 451 Spanish companies, also report a significant and positive relationship between TQM and product and process innovation, while Prajogo and Hong (2008) find that TQM positively influences R&D in South Korean firms.

Other studies have focussed on different dimensions of TQM and their impact on innovation. Abrunhosa and Moura E Sá (2008), for example, report that communication, supportive people management practices and teamwork positively impact on innovation performance, whereas autonomy and consultation do not. Similarly, Prajogo and Sohal (2004), in an examination of the impact of TQM on product innovation within Australian firms, concluded that two elements of TQM - leadership and people management - positively influenced innovation. In a further study, Hoang, Igel, and Laosirihongthong (2006) find that TQM practices, in general, positively influence firm-level innovation, and illustrate how three specific dimensions of TQM, leadership and people management, process and strategic management, and open organisation have a positive impact on the innovation performance of firms in Vietnam. More recently, Hung et al. (2011) examined the impact of TQM and organisational learning on innovation performance in the high-tech industry in Taiwan. They report that TQM has significant and positive effects on organisational learning, and TQM and organisational learning both have significant and positive effects on innovation performance.

There is therefore considerable evidence of a positive relationship between TQM and innovation, suggesting that the more organic benefits of TQM dominate any negative influence of TQMs more mechanistic components. This positive evidence is not universal, however, with Perdomo-Ortiz, González-Benito, and Galende (2009) finding that only the (organic) human resource management element of TQM is linked positively to innovation in their study of 105 Spanish industrial firms[2]. They conclude that TQM contains a set of best practices related to human resource management that promote better innovation performance. In a further study, Perdomo-Ortiz, Gonzalez-Benito, and Galende (2009) examine the relationship between TQM and innovation while considering business innovation capacity (BIC) as both a moderating and mediating factor. They report limited evidence of a moderating effect. However, they find a significant,

[2] Perdomo-Ortiz, González-Benito, and Galende (2009) also considered five other aspects of TQM finding no positive link to innovation (management support, information for quality, process management, product design, and relations with agents).

negative interaction effect with respect to the (mechanistic) process management dimension of TQM with different dimensions of BIC. This suggests that the emphasis on the control and improvement of processes, in parallel with management practices of innovation, such as project planning, formulation and assessment, developing new knowledge and skills and external cooperation, may have a negative effect on technological innovation.

Less attention has been focussed on the relationship between other QIMs and innovation. We are not aware of any quantitative studies which relate Quality Circles to innovation, while only two studies appear to have examined the links between Quality Certification, (ISO9000) and innovation. Benner and Tushman (2002) find that the extent of process management activities in a firm are associated with an increase in exploitative innovations and exploitative innovation's share of total innovations in the paint and photography industry. Using two French microeconomic surveys, Pekovic and Galia (2009) also find that ISO 9000 certification is significantly and positively linked to seven out of nine innovation indicators[3].

Although these empirical studies generally find a positive link between QIMs and innovation, the use of cross-sectional data (and structural equation models or correlation analysis) limits their ability to provide causal insights[4]. In particular, it has been suggested that innovation cannot be realised without first implementing quality practices. Perdomo-Ortiz,

[3] Innovation measures used in these studies vary widely and include: business innovation capability (Perdomo-Ortiz et al., 2006), adoption of innovations (Moura E Sá and Abrunhosa, 2007, Abrunhosa and Moura E Sá, 2008, Santos-Vijande and Álvarez-González, 2007), timing of adoption of innovations (Abrunhosa and Moura E Sá, 2008), novelty of innovations adopted (Santos-Vijande and Álvarez-González, 2007) product innovation (Prajogo and Sohal, 2004, Martínez-Costa and Martínez-Lorente, 2008, Hung et al., 2011), R&D (Prajogo and Hong, 2008), process innovation (Martínez-Costa and Martínez-Lorente, 2008, Hung et al., 2011), organisation innovation (Hung et al., 2011) and own assessment of innovation performance relative to main competitors (Perdomo-Ortiz et al., 2009). Pekovic and Galia (2009) use a total of nine indicators of innovation, including innovation projects and turnover due to new or improved products, new or improved processes for the firm and share of new or improved products to the market.

[4] In fact, many of the studies reviewed highlight the static nature of their analysis as a limitation, with calls for dynamic analysis of the quality-innovation relationship (Perdomo-Ortiz, González-Benito, and Galende 2006; Martínez-Costa and Martínez-Lorente 2008; Pekovic and Galia 2009).

Gonzalez-Benito, and Galende (2009) state that ‘in general business practice first incorporates the concept of quality management and then gradually integrates innovation’. This argument draws on the resource-based and dynamic capabilities (RDBC) theory of the firm, which suggests that management priorities are path-dependent and that improving innovation performance requires greater organisational complexity than quality management (Perdomo-Ortiz, Gonzalez-Benito, and Galende 2009). The implications are that the payoffs from the implementation of any QIM may only occur in the longer term, with the potential for short-term disruption, and that lags may be evident in the impacts of QIM adoption on innovation (Perdomo-Ortiz, Gonzalez-Benito, and Galende 2009; Prajogo and Sohal 2003; Pekovic and Galia 2009). We therefore anticipate that the adoption of a QIM by a firm may result in disruption to innovation in the short-term but yield longer term benefits, i.e.

H1a: Adoption of QIMs will lead to a short term disruptive effect on innovation performance.

H1b: Adoption of QIMs will lead to longer-term beneficial effects on innovation performance.

While we might anticipate this temporal profile of benefits from each type of QIM, variations may be evident between the more organic and more mechanistic QIMs. For instance, some studies report that firms that implement organic QIMs tend to be more innovative (Santos-Vijande and Álvarez-González 2007; Moura E Sá and Abrunhosa 2007; Abrunhosa and Moura E Sá 2008; Hoang, Igel, and Laosirihongthong 2006; Perdomo-Ortiz, Gonzalez-Benito, and Galende 2009) as the organic elements of QIM favour incremental innovations (Prajogo and Sohal 2004; Abrunhosa and Moura E Sá 2008). On the other hand, there is evidence that the mechanistic dimensions of QIMs may hinder innovation, in particular radical innovation (Prajogo and Sohal 2004; Benner and Tushman 2002; Perdomo-Ortiz, Gonzalez-Benito, and Galende 2009). This is not particularly surprising as the rationality, efficiency and strict control of tasks required by mechanistic quality procedures inhibit creativity and improvisation (López-Mielgo, Montes-Peón, and Vázquez-Ordás 2009).

This suggests that the potential disruption effects of introducing QIM will be stronger for more mechanistic QIMs, such as Quality Certification. Conversely, the organic nature of QCs would suggest a less severe disruption effect with the benefits of adoption of QCs occurring sooner than the more mechanistic QIMs. For TQM, which embodies both organic and mechanistic components, it is likely that the beneficial effects owing to its organic components may come into effect sooner and offset the short-term disruptive effect caused by its more mechanistic components. As a result, we expect TQM to have the largest long-term beneficial effect with respect to innovation. We expect a lesser disruptive effect from QCs due to their purely organic nature, whereas Quality Certification may involve significant short-term disruption. In summary:

H2a: QIMs which are primarily organic will have weaker short-term disruption effects than those which have stronger mechanistic components.

H2b: QIMs which combine mechanistic and organic components will have the strongest long-term benefits for innovation.

Strategically, firms do not always adopt an individual QIM in isolation. Firms may adopt QIMs sequentially or simultaneously. Indeed, a crucial element in firms' strategic decision-making is the identification and effective harnessing of complementarities between different managerial activities, optimising resource use (Milgrom and Roberts, 1990, 1995)[5]. In the innovation literature, discussion of complementarities has often been related to the benefits of experiential learning. Rosenberg (1972), for example, describes how a firm increases itsstock of knowledge based on

[5] In terms of human resource management (HRM), for example, Laursen and Foss (2003) consider complementarity between different HRM practices in terms of their impact on innovation outputs (see also Michie and Sheehan, 2003), while in a more general context Lhuillery (2000) examines the impact of a range of organizational practices on the innovation capability of French companies (see also Labeaga and Martinez Ros (2003).

its previous experience with technologies as 'learning-by-using'. Previous studies have also highlighted the benefit to firms of learning-by-using new technology for subsequent adoption decision-making (Stoneman and Kwon 1994; Colombo and Mosconi 1995; McWilliams and Zilbermanfr 1996; Stoneman and Toivanen 1997; Arvantis and Hollenstein 2001). In the same way, the cumulative learning from earlier QIM adoption should ease the disruptive effects of subsequent QIM adoption. Two effects are possible here: complementarities in implementation where two QIMs are adopted simultaneously and/or the more dynamic type of learning-by-using effect envisaged by Rosenberg (1972) (see Figure 1). Hence:

H3a: Simultaneous QIM adoption generates positive complementarities increasing the benefits for innovation.

H3b: Early adoption of one QIM will generate learning-by-using effects increasing the innovation benefits of subsequent QIM adoption.

The scale of these complementary and learning-by-using effects may also depend on the organic and/or mechanistic nature of each QIM. For instance, we might anticipate the complementary benefits of QIM adoption being strongest when the quality mechanisms have contrasting attributes, e.g. QCs and Quality Certification, or vice-versa. Conversely, we might anticipate that learning-by-using effects - which relate to the effectiveness of adoption by firms - are likely to be strongest where QIMs share similar characteristics, e.g. TQM and Quality Certification (Columbo and Musconi, 1995). This implies:

H4a: Positive complementarities will be strongest where the QIMs adopted have contrasting mechanistic and organic components.

H4b: Learning by using effects will be strongest where the QIMs involved have similar mechanistic or organic components

3. DATA AND METHODS

Our empirical analysis is based on the Irish Innovation Panel (IIP) which provides data on the innovation activity and QIM adoption of around 1300 manufacturing plants in Ireland and Northern Ireland over the period 1994 to 2008. More specifically, this element of the IIP comprises five surveys or waves conducted using similar survey methodologies and common questions. Each of the five surveys covers the innovation activities of plants with 10 or more employees over a three-year reference period.[6] The resulting panel is highly unbalanced reflecting non-response in individual surveys but also the opening and closure of plants over the period covered. Plants' innovation activity in the IIP is represented by the standard indicator used in the European Community Innovation Survey: the proportion of plants' total sales (at the end of each three-year reference period) derived from products newly introduced during the previous three years. This variable has been widely used as an indicator of plants' innovation output (Laursen and Salter 2006; Roper, Du, and Love 2008; Love, Roper, and Du 2009), and reflects not only plants' ability to introduce new products to the market but also their short-term commercial success. Across those elements of the IIP used in the current analysis, 17.4 per cent of plants' sales were derived from newly introduced products (Table 1).

One rather unusual feature of the IIP is that alongside plants' innovation activity it also provides information on the use and timing of adoption of QIMs.[7] Data was collected on the three QIMs identified earlier: Quality Circles, TQM and ISO 9000. Respondents were asked: 'Please indicate if you use any of the following production techniques. Also, please indicate

[6] Individual survey response rates were: 1994-96, 32.9 per cent; 1997-99, 32.8 per cent; 2000-02, 34.1 per cent; 2003-05, 28.7 per cent; 2006-08, 38.0 per cent (Roper et al. 1996; Roper and Hewitt-Dundas 1998; Roper and Anderson 2000; Hewitt-Dundas and Roper 2008).

[7] While this data is helpful one important limitation of the IIP is also worth noting. The structure of the survey questionnaire means that this use and adoption data is only collected for plants which reported undertaking some process innovation during the previous three years. Plants need not, however, have undertaken product innovation.

the date when they were first introduced?' In terms of the timing of adoption, respondents were asked whether they had first introduced each QIM in the three year period covered by the survey, the previous three years, or prior to this. For each respondent this provides an indication of whether they are using each QIM and an indication of the length of time in which it has been in use in the plant. For example, around 53 per cent of IIP respondents reported using ISO 9000 with 27 per cent adopting it in the previous three years, 14.7 per cent adopting 3-6 years before the survey, and 10 per cent earlier than that (Table 1). Quality Circles are implemented in 12.4 per cent of plants with TQM implemented by just under a third of firms.

The IIP also provides information on a number of other plant characteristics which previous studies have linked to innovation outputs (Annex 1). For example, plants' in-house R&D activities are routinely linked to innovation performance in econometric studies with suggestions that the innovation-R&D relationship reflects both knowledge creation (Harris and Trainor 1995) and absorptive capacity effects (Griffith, Redding, and Van Reenan 2003). 54 per cent of plants were conducting in-house R&D at the time of the IIP surveys (Table 1). Reflecting recent writing on open innovation (Chesbrough 2007; Chesborough 2006) external innovation relationships have also been shown to play an important role in shaping innovation outputs (Oerlemans, Meeus, and Boekema 1998; Ritala et al. 2013), complementing plants' internal capabilities (He and Wong 2012; Cassiman and Veugelers 2006; Arora and Gambardella 1990; Belderbos, Carree, and Lokshin 2006; Cassiman and Veugelers 2006). Here, we include three separate variables representing plants' external innovation co-operation with customers, suppliers and other organisations outside the supply chain. Around 30.0 per cent of plants reported having innovation cooperation with customers, while 32.7 per cent had backwards innovation cooperation with suppliers (Table 1). Links outside the supply chain could be with a variety of different types of organisation (e.g. universities, consultants) and here we construct a count variable representing the number of types of partner with which a plant was cooperating. On average, plants were cooperating with around 0.8 organisations outside the supply chain (Table 1).

We also include in the analysis a group of variables which give an indication of the quality of firms' in-house knowledge base – e.g. skills, plant size, multi-nationality, plant vintage, and whether or not a plant is exporting. Skill levels are reflected in the proportion of each plant's workforce which have a degree level qualification to reflect potential labour quality impacts on innovation (Freel 2005; Leiponen 2005) or absorptive capacity. Multi-nationality is included here to reflect the potential for intra-firm knowledge transfer between national markets and plants, while plant vintage is intended to reflect the potential for cumulative accumulation of knowledge capital by older establishments (Klette and Johansen, 1998), or plant life-cycle effects (Atkeson and Kehoe, 2005). Finally, studies of the impact of publicly funded R&D have, since Griliches (1995), repeatedly suggested that government support for R&D and innovation can have positive effects on innovation activity both by boosting levels of investment (Hewitt-Dundas and Roper 2009) and through its positive effect on organisational capabilities (Buiseret, Cameron, and Georgiou 1995). Here, we therefore include a dummy variable where plants received public support for innovation.[8]

Our empirical approach focuses on the innovation or knowledge production function which represents the process through which plants' knowledge capital is transformed into innovation outputs (Griliches 1995; Love and Roper 2001; Laursen and Salter 2006). If I_i is an innovation output indicator for plant i the innovation production function might be summarised in cross-sectional terms as:

$$I_i = \beta_0 + \beta_1 QIM_i + \beta_2 RD_i + \beta_3 FS_i + \beta_4 BS_i + \beta_5 HS_i + \beta_6 CONT_i + \delta_i \quad (1)$$

[8] Elsewhere we profile the range of public support initiatives for innovation in Ireland and Northern Ireland over the period covered by the IIP (Meehan 2000; O'Malley, Roper, and Hewitt-Dundas 2008).

Where: QIM_i denotes plants' adoption of quality improvement methods, RD_i are plants' in-house R&D investments, FS_i, BS_i and HS_i are forwards, backwards and horizontal knowledge search respectively, and $CONT_i$ is a vector of other plant level controls (Annex 1). Typical of previous cross-sectional studies of the relationship between QIM and innovation, a positive association between QIM and innovation would here require $\beta_1>0$. Implicit in this formulation – and previous cross-sectional studies - is the restriction that the date of adoption of each QIM has no impact on its effect on innovation. To test our hypotheses – and inter alia this restriction – we estimate a dynamic version of equation (1) explicitly identifying QIM adoption in the current (three-year) period and in two previous periods, i.e.

$$I_i = \beta_0 + \beta_{10}QIM_t + \beta_{11}QIM_{it-1} + \beta_{12}QIM_{it-2} + \beta_2 RD_i + \beta_3 FS_i + \beta_4 BS_i + \beta_5 HS_i + \beta_6 CONT_i + \delta_i \quad (2)$$

Our first hypothesis suggests that in the short-term the adoption of use of QIMs might create disruption to firms' innovation activity (H1a) with longer term benefits (H1b). Support for H1a requires $\beta_{10}<0$, with H1b requiring $\beta_{11}>0$ and/or $\beta_{12}>0$. H2 relates to the relative size and impact of the alternative QIMs in equation (2).

Our third and fourth hypotheses relate to potential complementarities and learning-by-using effects between QIMs, denoted here QIM^A and QIM^B. If $QIM^B_{t-2} = 1$ where a firm is an early adopter of QIM^B and zero otherwise we estimate:

$$\begin{aligned} I_i = {} & \beta_0 + \beta_{101}QIM_t^A * QIM_{t-2}^B + \beta_{111}QIM_{t-1}^A * QIM_{t-2}^B + \beta_{121}QIM_{t-2}^A * QIM_{t-2}^B \\ & + \beta_{102}QIM_t^A * (1 - QIM_{t-2}^B) + \beta_{112}QIM_{t-1}^A * (1 - QIM_{t-2}^B) \\ & + \beta_{122}QIM_{t-2}^A * (1 - QIM_{t-2}^B) + \beta_2 RD_i + \beta_3 FS_i + \beta_4 BS_i + \beta_5 HS_i \\ & + \beta_6 CONT_i + \delta_i \end{aligned} \quad (3)$$

For Hypothesis 3, which reflects the complementary benefits of simultaneous adoption we anticipate that early adoption of QIM^A in period t-2 will have greater benefits where a firm also adopts QIM^B in period t-2.

Here, we test $\beta_{121}>\beta_{122}$. For Hypothesis 4 which reflects the potential learning-by-using effects from early adoption of QIM^B we test whether $\beta_{101}>\beta_{102}$ and/or $\beta_{111}>\beta_{112}$.

Our choice of estimation method is dictated largely by the fact that we are using plant-level data from a highly unbalanced panel and that our dependent variables are percentages. We therefore make use of tobit estimators, including in each model a set of sector controls at the 2- digit level and a series of time dummies to pick up any secular differences between the waves of the IIP. Observations are also weighted to provide representative results and take account of the structured nature of the IIP surveys.

4. RESULTS

4.1 Dynamic analysis

Replicating previous cross-sectional studies of the quality-innovation relationship, we initially undertake a static analysis to determine whether QIM use benefits firm innovation (Equation 1). As presented in Table 3, TQM use positively impacts innovation performance, although neither Quality Certification nor QC has a positive impact on innovation. In terms of TQM our results reflect those of previous studies which have also reported the benefits of implementing TQM for firm innovation (Moura E Sá and Abrunhosa 2007; Martínez-Costa and Martínez-Lorente 2008; Abrunhosa and Moura E Sá 2008; Prajogo and Sohal 2004; Hoang, Igel, and Laosirihongthong 2006; Hung et al. 2011). Our static results contrast with the limited number of previous studies that have reported that Quality Certification positively influences innovation (Benner and Tushman 2002; Pekovic and Galia 2009).

A limitation of this static approach to the quality-innovation relationship is that the QIM coefficients capture the effects of both current and lagged adoption. Our dynamic analysis (Eqn. 2) removes this implicit restriction and allows us to test H1 which envisages a short term disruption (H1a) and a longer term beneficial effect (H2b) from QIM adoption on firm innovation. Dynamic analysis of the impact of early (t-2), previous (t-1) and current QIM adoption on innovation performance is presented in Table 4. In relation to Quality Certification, we see significant disruption effects, and no evidence of dynamic beneficial effects. These significant disruption effects may be due to the formalised and mechanistic nature of Quality Certification. The absence of a positive relationship between Quality Certification and firm innovation in our dynamic analysis contrasts with results from previous (static) studies (Benner and Tushman 2002; Pekovic and Galia 2009). However, this finding is not altogether surprising as the implementation of Quality Certification concerns the whole organisation and involves considerable disruption to fundamental behaviour and routinised tasks (Pekovic and Galia 2009).

In relation to QC, we find no significant disruption effect, but significant longer-term beneficial effects. Early adoption of QC positively impacts on innovation, although this relationship is not present for firms who adopted QC in the current or previous time periods. QCs are primarily organic in nature and therefore their implementation should not cause particular disruption to the firm compared to the more mechanistic QIMs. Practices, such as QCs, which empower and involve employees have been shown to positively influence employee motivation and behaviour (Subramony 2009), and therefore the lagged beneficial effect is as anticipated.

For TQM, there is no significant disruption effect, but positive and significant beneficial effects. Firms that adopt TQM in the previous period realise innovative returns in the current period, and early adopters of TQM realise significantly larger returns (Table 4). The beneficial effects from TQM adoption are not particularly surprising given the strong positive relationship between TQM use and innovation reported in our static analysis and previous (static) studies (Moura E Sá and Abrunhosa 2007; Martínez-Costa and Martínez-Lorente 2008; Santos-Vijande and Álvarez-González 2007; Prajogo and Sohal 2003; Hoang, Igel, and Laosirihongthong 2006). Furthermore, the lack of an initial disruption effect may be due to the informal, participative or organic components of TQM. For instance, previous studies have highlighted the returns to innovation from softer TQM elements, such as resource management, leadership, people management and open organisation (Perdomo-Ortiz, González-Benito, and Galende 2009; Hoang, Igel, and Laosirihongthong 2006; Prajogo and Sohal 2004). The advantageous temporal profile of TQM may result from its multi-dimensionality nature. We hypothesised that QIM adoption would influence firm innovation in terms of a short term disruptive effect (H1a) and a longer term beneficial effect (H1b). We find support for H1a as Quality Certification adoption has a significant short-term disruption effect on firm innovation; and we find strong support for H1b with TQM and QC adoption resulting in longer-term beneficial effects for firm innovation.

Next, we consider our results in the context of H2 which suggests that QIMs which are primarily organic will have weaker short-term disruption effects than those which have stronger mechanistic components (H2a) while QIMs which comprise mechanistic and organic components will have the strongest long-term benefits for innovation (H2b). Quality Certification, which is primarily mechanistic, results in significant short-term disruption for firms' innovative performance, whereas QCs and TQM, QIMs comprising full or partial organic components, impose none of these short-term disruption effects on firm innovation. While there is no evidence of long-term beneficial effects with Quality Certification, we do find long-term beneficial effects for firm innovation in the case of QCs and TQM. In addition, the beneficial effects from TQM adoption arise more quickly than in the case of QCs, and the returns from TQM adoption are greater. Our results therefore suggest that the organic or mechanistic components of each QIM does impact the temporal profile of this disruptive –beneficial relationship. We find strong support for H2a as the more organic QIMs, QCs and TQM, have no short-term disruption effects on innovation in contrast to the mechanistic Quality Certification. We also find considerable support for H2b with TQM, comprising both organic and mechanistic components, exhibiting the strongest long-term benefits for innovation.

In line with previous studies, we find firm characteristics, such as R&D, linkages with suppliers, firm vintage, eternally-owned firms and an educated workforce, strongly impact on firm innovation (Roper, Hewitt-Dundas, and Love 2004; Roper, Du, and Love 2008; Freel 2003). In addition, we find that government support for innovation strongly and significantly impacts on innovation performance (Love, Roper, and Bryson 2011).

4.2 Complementarity and learning-by-using effects

In our investigation of complementarities and learning by using effects, we attempt to determine if simultaneous and sequential adoption of QIMs benefit the firm (see Figure 1). We hypothesise that simultaneous QIM adoption may generate positive complementarities increasing the benefits to innovation (H3a), and that early adoption of one QIM will generate learning-by-using effects increasing the innovation benefits of subsequent QIM adoption (H3b).

Complementarities exist if the sum of the benefits of adopting QIMs separately is less than the benefit of adopting them simultaneously. Empirically, we are examining the influence of simultaneous early adoption of two QIMs on innovative sales (see Table 5). For instance, in the first model in Table 5 we examine if early Quality Certification adoption and early QC adoption are complementarities for innovation. Specifically, we include two variables, one which captures the firms that are early quality certification and early QC adopters and another which captures those that are early quality certification adopters but not early QC adopters. The insignificant coefficients indicate that these two QIMs are not complementarities. The next regression model examines if early quality certification and early TQM adoption are complementarities, a pattern followed in each of the subsequent models.

Our analysis reveals that TQM and Quality Certification are complementary initiatives and the benefit of their simultaneous adoption is greater than if adopted individually. We find that benefits of TQM adoption are conditional on the simultaneous adoption of Quality Certification, and vice versa. Of particular interest is how simultaneous early adoption of Quality Certification and TQM offsets the short-term disruptive effects of Quality Certification. There is no evidence to suggest that Quality Circles and Quality Certification create complementarities for firm innovation. An interesting pattern emerges with respect to early QC and TQM adoption. We see that early TQM and early QC adoption benefits innovation, although early TQM adoption without early QC adoption also benefits innovation. This suggests that the benefits of TQM are not conditional on simultaneous adoption of QC. This is not particularly surprising given the strong positive TQM-innovation relationship. Therefore, we find some support for H3a that the simultaneous adoption of Quality Certification and TQM generates positive complementarities enhancing the benefits to firm innovation.

Next, we investigate whether early adoption of one QIM generates learning-by-using effects increasing the innovation benefits of subsequent QIM adoption. The motivation for investigating whether learning-by-using effects impact on firm innovation is that early adoption of one QIM creates the potential for learning and hence subsequent adoption and implementation of an additional QIM is likely to be less onerous. Empirically, we test for learning-by-using effects by including variables which capture sequential adoption patterns. For instance, in the first model in Table 5, we examine if early adoption of QC and subsequent quality certification adoption, in both the current (Current QCert* early QC & Current QCert*no early QC) and previous (Previous QCert*early QC & Previous QCert*no early QC) time periods, influence innovative sales. In the next model, we are examining if early TQM adoption and subsequent quality certification adoption benefits innovation, a pattern followed in subsequent models.

Interestingly, early adopters of QC and, to a lesser extent TQM, offset the disruptive effects of Quality Certification. Therefore, early adoption of QC generates learning-by-using effects for current Quality Certification adoption; the benefits (although still insignificant) of Quality Certification are conditional on prior adoption of QC. In relation to QC, there were no significant disruption effects for adopters of QC and so we see no significant offset or learning-by-using effect from earlier adoption of other QIMs. Neither does early adoption of another QIM augment the impact of subsequent QC adoption. In relation to TQM, we find that early adopters of QC enhance the longer-term benefits of subsequent TQM adoption. In other words, the benefits of TQM to firm innovation are conditional on prior adoption of QCs. These results are supportive of H3b, i.e. that early adoption of one QIM will enhance the innovation benefits from subsequent QIM adoption. In particular, we find considerable evidence of learning-by-using from early adoption of QC; a reduction in the disruption element of subsequent Quality Certification adoption and an enhancement of the beneficial effect of subsequent TQM adoption.

Finally, we examine the scale of these complementary and learning-by-using effects, hypothesising that positive complementarities will be strongest where the QIMs adopted have contrasting mechanistic and organic components (H4a) and suggesting that learning-by-using effects will be strongest where the QIMs involved have similar mechanistic or organic components (H4b). Our analysis reveals a complementary relationship between the mechanistic Quality Certification and the organic-mechanistic TQM for firm innovation. We find no evidence of a complementary relationship between the mechanistic Quality Certification and the organic QCs with respect to innovation performance. There is some evidence of a complementary relationship between QCs and TQM, although it is likely that early TQM adoption is driving that relationship. Therefore, we find little support for H4a that complementarities are strongest when QIMs comprise of contrasting mechanistic and organic components. Our primary finding in relation to learning-by-using effects is that early adoption of QCs generates learning-by-using effects for subsequent Quality Certification and TQM adoption. Given the similar organic components of QC and TQM and the contrasting organic and mechanistic components of QC and Quality Certification respectively, we cannot report stronger learning-by-using effects where the QIMs adopted have similar components (H4b).

4.3 Robustness tests

We conducted two robustness tests to evaluate our results with an alternative measure of innovative output, and using an alternative estimation approach allowing for the potential endogeneity of the 'treatment' represented by firms' QIM adoption (Maddala 1983). First, in our main analysis we use a dependent variable which reflects firms' sales derived from new products. This reflects an emphasis on more radical innovation rather than either imitation or more incremental product change (Schnaars 1994). To consider whether our results also hold for more imitative strategies we repeated the analysis using an alternative and more broadly defined dependent variable - innovative sales from *new and improved* products. Results were broadly similar to those reported in relation to our main dependent variable. In relation to the static analysis, and reflecting the weak results of the static analysis in Table 3, none of the QIMs have a significant effect on the broader measure of innovative sales. Likewise, dynamic analysis with our alternative innovation output measure generates results which are broadly similar to those reported earlier (Table 4). In relation to Quality Certification, the coefficient signs indicate the same pattern of disruption and long term beneficial effects as for innovative sales from new products but the short term disruption effect is not statistically significant. For QC, we still see insignificant disruption effects but evidence of longer term beneficial effects is insignificant. There is clear evidence of long term beneficial effects from TQM adoption, although these are generally weaker than for innovative sales. In summary, effects from QIM adoption are stronger for innovative sales from new products than the broader dependent variable which captures innovative sales from new and improved products.

We also repeated the learning-by-using and complementarity analysis using innovative sales from new and improved products as the dependent variable. Results from this robustness test are broadly similar to those reported in relation to the narrower dependent variable of innovative sales from new products (Table 5). The strong and significant complementary benefit of early Quality Certification and early TQM is also evident in relation to the broader dependent variables of innovative sales from new and improved products. We find that the benefits of TQM to firm innovation are conditional on prior adoption of QCs as previously reported for the narrower definition of innovation. There is no evidence of a learning-by-using effect from early QC adoption influencing the benefits to this broader definition of innovation from subsequent Quality Certification adoption. Although, in relation to this broader dependent variables we find the benefits of TQM to firm innovation are also conditional on the prior adoption of Quality Certification. The results from these robustness tests are therefore similar to those reported for the narrower dependent variable of innovative sales from new products.

In a second robustness test we sought to allow for the potential endogeneity of the adoption of each of the QIMs, i.e. the possibility that the determinants of adoption may also be the determinants of innovation outcomes. We estimated two-stage models estimating first a model for the probability of adoption and then including the implied Inverse Mills Ratio (IMRs) in equations (1) to (3) (Heckman 1979). For both our main and alternative dependent variables the IMRs proved insignificant with the coefficients of interest also remaining unchanged in sign and significance.

4.4 Discussion

Previous cross-sectional studies have suggested a positive correlation between QIMs and innovation, with a focus on the TQM-innovation relationship (Moura E Sá and Abrunhosa (2007); Martínez-Costa and Martínez-Lorente (2008); Prajogo and Hong (2008); Abrunhosa and Moura E Sá (2008); Hoang, Igel, and Laosirihongthong (2006); Hung et al. (2011). In cross-sectional terms our data also suggests a positive relationship between TQM and innovation outputs although we find no relationship, however, between either QC or Quality Certification and innovation performance (Table 3). As our dynamic analysis suggests, however, these cross-sectional relationships hide some rather complex dynamic effects on innovation, effects which differ markedly between QIMs (Table 4). In particular, we find evidence that QIMs can cause short-term disruption to firms' innovation activity before the development of longer-term benefits. These disruption effects are most significant for the more mechanistic Quality Certification but weaker for the more organic QIM, Quality Circles. TQM – which combines organic and mechanistic components has no significant disruption effect (Table 4). Those QIMs with an organic component - TQM and QC – which might encourage flexibility and creativity also have the most significant long term benefits for innovation (Table 4). Quality Certification has no significant longer-term effect on innovation.

Two implications follow from our dynamic analysis. First, our analysis suggests the importance of the dynamic effects implicit in the adoption of QIMs and the potential trade-off between short-term disruption and longer term innovation benefits. Benefitting from the adoption of QIMs takes some considerable time as firms revise and optimise organisational routines. Second, the relationship between QIMs and innovation performance differs markedly between those QIMs which have a strong organic component (i.e. TQM, QCs) and more mechanistic initiatives such as Quality Certification: mechanistic QIMs have negative innovation effects, while QIMs with an organic element have strong long-term innovation benefits[9].

These contrasts between the implications of alternative QIMs are also reflected in our results on the benefits of combinations of QIMs. For example, complementarities between QIMs adopted at the same time prove strongest between Quality Certification and TQM which share some mechanistic components. Conversely, and contrary to expectations, we find no evidence of complementarities between contrasting QIMs such as QC and Quality Certification. Quality Circles do, however, generate significant learning-by-using effects, enhancing the innovation benefits of both Quality Certification and TQM. The implication is that adoption of Quality Circles

[9] This is not to say, of course, that implementing mechanistic QIMs such as Quality Certification has no positive effects on wider business performance. Simply, that it has negative effects on innovation.

may have a dual advantage for innovation: a direct longer-term benefit and also an indirect longer-term benefit through its impact on enhancing the effects of other QIMs.

5. CONCLUSION

Our paper makes several theoretical contributions to the quality and innovation literature highlighting the temporal profile of the effects of individual QIMs, short-term disruptive and longer-term beneficial effects, on firm innovation performance. It also highlights the influence of the organic and/or mechanistic components of each QIM on the extent of this disruptive - beneficial temporal profile; and the role of complementarities and learning-by-using effects in shaping the quality–innovation relationship

Our empirical analysis of the quality-innovation relationship reveals complex dynamic effects not evident from previous cross-sectional studies. Panel data allows us to establish the temporal profile of the –short-term disruptive and longer-term beneficial - effects of QIMs on innovation (H1a&b). In addition, the three quality improvement measures in our dataset enabled us to examine the temporal profile of individual QIMs on firm innovation. Our analysis reveals a more pronounced short-term disruptive effect for mechanistic QIMs (e.g. Quality Certification), while the longer-term beneficial effects are stronger for QIMs which combine both organic and mechanistic components (e.g. TQM) (H2a&b). Interestingly, organic QCs have no short-term disruptive effect on innovation, but do have a longer term beneficial effect (albeit to a lesser extent than TQM) on firm innovation. Therefore, mechanistic QIMs have negative innovation effects, whereas the more organic QIMs have strong long-term benefits for innovation. Our examination of the benefits of combinations of QIMs supports our hypotheses that simultaneous and sequential QIM adoption generates positive complementarities and learning-by-using effects respectively enhancing innovation benefits (H3a&b). We expected complementarities to exist between contrasting QIMs, such as QCs and Quality Certification; but instead identified strong complementarities between Quality Certification and TQM. In addition, we also found the most significant learning-by-using effects for subsequent TQM and Quality Certification were generated from early adoption of QCs.

Two main managerial implications follow from our analysis. First, it is clear that the adoption of QIMs has significant implications for firms' innovation outputs, albeit with some time lags as internal routines are optimised. Quality improvement strategies and implementation plans need therefore to consider their innovation implications and any consequent impact on firm performance. Secondly, the synergies we identify between QIMs suggest the value in strategies which maximise complementarities and gains from learning-by-using. In particular, we find that the early adoption of Quality Circles – a relatively straightforward and low cost QIM - significantly enhances the value of TQM and Quality Certification where these are adopted subsequently. It may be, for example, that the adoption of QCs is stimulating an initial focus or interest in quality improvement in the firm which is then formalised in the adoption of TQM or Quality Certification. QC adoption may also be helping firms to overcome attitudinal barriers related to change and the implementation of more formal quality management systems. Our results, which highlight the dynamic nature of the relationship between QIMs and innovation and between QIMs themselves, also emphasise the limitations of analyses based on cross-sectional data. In particular, cross-sectoral analyses inevitably see QIM adoption – as a uniform treatment, obscuring any dynamic effects and/or interactions between QIMs.

Our analysis suffers from three main limitations. First, our analysis focuses on Irish manufacturing businesses only and may therefore be influenced by specific national circumstances. The 1994-2008 period considered here, however, was a period of rapidly changing institutions in Ireland as well as marked changes in the nation's economic fortunes - the Irish recovery of the late 1990s, the 2000-02 high-tech crash, and a period of rapid subsequent growth. Second, unlike some other – albeit static - studies we are unable to identify separately those elements of each QIM linked to changes in human resource management, quality management etc. This limits our ability to investigate the dynamic relationships between different dimensions of quality management and innovation and between different elements of QIMs. Both are areas in which future research would be valuable. Finally, it is worth re-iterating that the focus of the current paper is the QIM-innovation relationship. In future studies we propose to also consider the QIM-productivity link.

Table 1: Sample Descriptives

Variable Name & Description	Observations	Variable	Variable
Innovative Sales from New Products (%)	1358	18.493	23.110
Innovative Sales from New and Imp. Products	1356	31.827	30.971
Quality Certification (Q Cert) Use	1358	0.683	0.466
Quality Circles (QC)Use	1192	0.150	0.357
Total Quality Management (TQM) Use	1238	0.365	0.482
Current Q Cert Adoption	1358	0.356	0.479
Previous Q Cert Adoption	1358	0.197	0.197
Early Q Cert Adoption	1358	0.130	0.130
Current QC Adoption	1192	0.059	0.235
Previous QC Adoption	1192	0.039	0.039
Early QC Adoption	1192	0.052	0.222
Current TQM Adoption	1238	0.146	0.353
Previous TQM Adoption	1238	0.103	0.305
Early TQM Adoption	1238	0.116	0.320
In-plant R&D	1358	0.606	0.489
Linkages with Clients	1358	0.345	0.475
Linkages with Suppliers	1358	0.370	0.483
Horizontal Linkages	1358	0.965	1.496
Employment (Log)	1358	4.110	1.132
Firm Vintage	1358	28.261	28.196
Externally Owned	1358	0.304	0.460
Workforce with Degree (%)	1358	10.354	11.190
Government Support for Innovation	1358	0.323	0.468
Export Sales (%)	1358	26.964	34.665

Source: Irish Innovation Panel 1994-2008

Table 2: Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Sales from New Products	1.00																							
2	Sales New & Improved Prod.	0.76	1.00																						
3	Q Cert Use	0.04	0.08	1.00																					
4	QC Use	0.06	0.06	0.15	1.00																				
5	TQM Use	0.15	0.13	0.25	0.40	1.00																			
6	Current Q Cert Adoption	-0.04	0.01	0.52	0.15	0.20	1.00																		
7	Previous Q Cert Adoption	0.06	0.03	0.36	0.02	0.06	-0.33	1.00																	
8	Early Q Cert Adoption	0.05	0.06	0.29	-0.02	0.01	-0.27	-0.19	1.00																
9	Current QC Adoption	0.04	0.02	0.15	0.59	0.27	0.25	-0.06	-0.05	1.00															
10	Previous QC Adoption	-0.01	0.02	0.07	0.48	0.22	0.01	0.12	-0.05	-0.05	1.00														
11	Early QC Adoption	0.07	0.06	0.01	0.56	0.17	-0.04	0.00	0.07	-0.06	-0.05	1.00													
12	Current TQM Adoption	0.04	0.03	0.20	0.27	0.54	0.40	-0.11	-0.13	0.45	0.02	-0.04	1.00												
13	Previous TQM Adoption	0.08	0.09	0.11	0.14	0.46	-0.03	0.21	-0.04	-0.04	0.32	0.00	-0.13	1.00											
14	Early TQM Adoption	0.11	0.08	0.05	0.17	0.49	-0.11	0.02	0.20	-0.03	0.00	0.30	-0.13	-0.11	1.00										
15	In-plant R&D	0.16	0.26	0.06	0.04	0.04	0.10	0.00	-0.04	0.01	0.04	0.03	0.00	0.05	0.01	1.00									
16	Linkages with Clients	0.15	0.20	0.11	0.11	0.13	0.11	0.04	-0.06	0.10	0.06	0.02	0.09	0.07	0.03	0.16	1.00								
17	Linkages with Suppliers	0.15	0.19	0.10	0.11	0.10	0.12	0.02	-0.04	0.11	0.03	0.03	0.08	0.04	0.02	0.13	0.64	1.00							
18	Horizontal Linkages	0.13	0.19	0.18	0.14	0.19	0.18	0.05	-0.05	0.11	0.09	0.04	0.17	0.06	0.04	0.18	0.58	0.56	1.00						
19	Employment (Log)	0.13	0.15	0.31	0.18	0.27	0.23	0.12	-0.02	0.16	0.07	0.06	0.19	0.16	0.05	0.14	0.12	0.16	0.24	1.00					
20	Firm Vintage	-0.14	-0.08	0.04	-0.02	-0.04	0.14	-0.05	-0.09	0.02	-0.03	-0.03	0.05	-0.03	-0.08	-0.03	-0.02	0.01	0.09	0.10	1.00				
21	Externally Owned	0.11	0.09	0.25	0.09	0.21	0.18	0.10	-0.02	0.12	0.00	0.01	0.19	0.07	0.04	-0.06	0.04	0.10	0.10	0.43	0.05	1.00			
22	Workforce with Degree (%)	0.12	0.13	0.08	0.05	0.12	0.09	-0.02	0.02	0.06	-0.02	0.03	0.10	0.06	0.02	0.08	0.15	0.12	0.18	0.11	-0.01	0.18	1.00		
23	Government Support	0.13	0.20	0.08	0.06	0.06	0.09	-0.01	0.01	0.02	0.03	0.04	0.03	0.03	0.02	0.36	0.18	0.12	0.22	0.09	-0.01	-0.11	0.11	1.00	
24	Export Sales (%)	1.00																							

Table 3: Static models: Tobit Models of Innovative Sales of New Products

	Model 1	Model 2	Model 3
Q Cert Use	-1.896		
	(-1.401)		
QC Use		1.527	
		(-2.069)	
TQM Use			4.601***
			(-1.534)
In-plant R&D	5.194***	6.559***	5.829***
	(-1.364)	(-1.441)	(-1.43)
Linkages with Clients	1.621	1.391	1.692
	(-1.779)	(-1.884)	(-1.883)
Linkages with Suppliers	4.270**	4.036**	4.343**
	(-1.709)	(-1.784)	(-1.800)
Horizontal Linkages	0.053	0.311	-0.201
	(-0.538)	(-0.567)	(-0.563)
Employment (Log)	-0.523	-0.445	-0.899
	(-0.657)	(-0.690)	(-0.685)
Firm Vintage	-0.091***	-0.100***	-0.092***
	(-0.022)	(-0.024)	(-0.024)
Externally Owned	3.987**	3.725**	3.519**
	(-1.679)	(-1.784)	(-1.787)
Workforce with Degree	0.045	0.128**	0.086
	(-0.058)	(-0.065)	(-0.063)
Government Support	4.600***	3.399**	3.919***
	(-1.446)	(-1.54)	(-1.518)
Export Sales	0.028	0.014	0.019
	(-0.023)	(-0.025)	(-0.024)
Constant	11.584***	8.102**	9.402***
	(-3.186)	(-3.374)	(-3.341)
N	1358	1232	1295
Chi-squared	160.286	165.573	160.887
Pseudo – R^2	0.014	0.015	0.014

Notes: Standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1. All the figures in the table are marginal effects generated from Tobit models. All models include industry and wave dummies.

Table 4: Dynamic models: Tobit Models of Innovative Sales of New Products

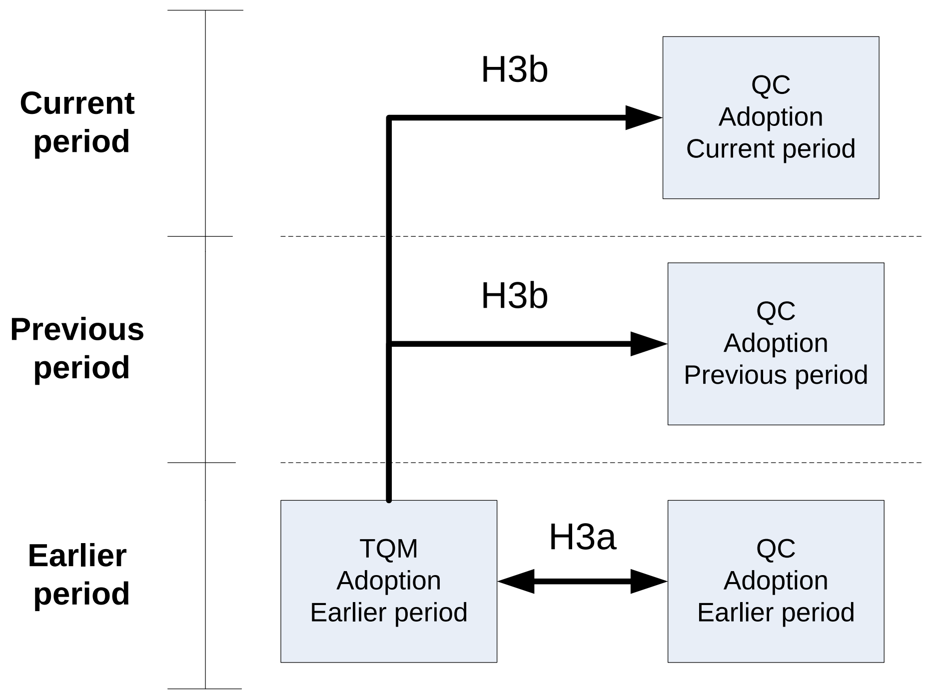
	Model 1	Model 2	Model 3
Current Q Cert Adoption	-4.328***		
	(1.351)		
Previous Q Cert Adoption	-0.643		
	(1.608)		
Early Q Cert Adoption	2.08		
	(1.814)		
Current QC Adoption		-0.075	
		(2.675)	
Previous QC Adoption		-2.613	
		(3.197)	
Early QC Adoption		5.427*	
		(2.868)	
Current TQM Adoption			1.548
			(1.798)
Previous TQM Adoption			3.806*
			(2.096)
Early TQM Adoption			7.326***
			(1.902)
In-plant R&D	5.238***	6.165***	5.616***
	(1.157)	(1.218)	(1.212)
Linkages with Clients	2.021	2.166	2.338
	(1.574)	(1.663)	(1.660)
Linkages with Suppliers	4.841***	4.443***	4.650***
	(1.482)	(1.542)	(1.554)
Horizontal Linkages	-0.137	0.045	-0.367
	(0.490)	(0.517)	(0.515)
Employment (Log)	0.481	0.389	0.075
	(0.557)	(0.578)	(0.580)
Firm Vintage	-0.064***	-0.077***	-0.068***
	(0.019)	(0.020)	(0.020)
Externally Owned	3.206**	2.414	2.257
	(1.493)	(1.575)	(1.581)
Workforce with Degree	0.088**	0.161***	0.139***
	(0.044)	(0.047)	(0.046)
Government Support	5.014***	3.739***	4.089***
	(1.302)	(1.377)	(1.363)
Export Sales	0.033*	0.024	0.029
	(0.020)	(0.021)	(0.021)
Constant	4.471*	2.445	3.201
	(2.558)	(2.709)	(2.697)
N	1715	1586	1648
Chi-squared	254.841	259.525	255.522
Pseudo – R^2	0.017	0.018	0.017

Notes: Standard errors in parentheses; ****p* < 0.01, ***p* < 0.05, **p* < 0.1. All the figures in the table are marginal effects generated from Tobit models. All models include industry and wave dummies.

Table 5: Complementarities and Learning By Using Effects: Tobit Models of Innovative Sales from New Products

	Innovation Sales		Innovation Sales		Innovation Sales		Innovation Sales		Innovation Sales		Innovation Sales
Simultaneous QIM Adoption: Complementarities											
Early QCert Adoption: w/wo earlyQC Adoption		***Early QCert Adoption: w/wo early TQM Adoption***		***Early QCert Adoption: w/wo early TQM Adoption***		***Early QC Adoption: w/wo early TQM Adoption***		***Early TQM Adoption: w/wo early QCert Adoption***		***Early TQM Adoption: w/wo early QC Adoption***	
Early QCert*	6.560	Early QCert*	11.70***	Early QC*	7.276	Early QC*	8.001*	Early TQM*	12.43***	Early TQM*	9.297**
early QC	(5.574)	early TQM	(3.204)	early QCert	(5.612)	early TQM	(4.103)	early Q Cert	(3.280)	early QC	(4.181)
Early QCert*	1.148	Early QCert*	-0.322	Early QC*	4.005	Early QC*	2.454	Early TQM*	4.085	Early TQM*	7.513***
no early QC	(2.090)	no early TQM	(2.276)	no early QCert	(3.584)	no early TQM	(4.433)	no early QCert	(2.512)	no early QC	(2.458)
Sequential QIM Adoption: Learning By Using Effects											
QCert Adoption: w/wo early QC adoption		***QCert Adoption : w/wo early TQM adoption***		***QC Adoption : w/wo early QCert adoption***		***QC Adoption : w/wo early TQM adoption***		***TQM Adoption : w/wo early QCert adoption***		***TQM Adoption : w/wo early QC adoption***	
Current QCert *	6.245	Current QCert *	0.489	Current QC*	-8.082	Current QC*	-4.273	Current TQM*	-11.14	Current TQM*	4.842
early QC	(6.019)	early TQM	(4.252)	early Q Cert	(10.78)	early TQM	(11.17)	early QCert	(15.67)	early QC	(11.95)
Current QCert*	-4.017**	Current QCert *	-3.438**	Current QC*	1.055	Current QC*	1.344	Current TQM*	0.353	Current TQM*	1.216
no early QC	(1.626)	no early TQM	(1.587)	no early QCert	(3.112)	no early TQM	(3.106)	no early QCert	(2.109)	no early QC	(2.177)
Previous QCert*	-2.889	Previous QCert *	5.023	Previous QC*	-8.073	Previous QC*	-3.278	Previous TQM*	-3.886	Previous TQM*	22.11**
early QC	(7.985)	early TQM	(4.510)	early QCert	(13.98)	early TQM	(11.35)	early QCert	(6.981)	early QC	(8.937)
Previous QCert*	0.142	Previous QCert *	-0.367	Previous QC*	-3.432	Previous QC*	-3.618	Previous TQM*	4.288*	Previous TQM*	2.755
no early QC	(1.899)	no early TQM	(1.887)	no early QCert	(3.737)	no early TQM	(3.792)	no early QCert	(2.401)	no early QC	(2.413)
In-plant R&D	5.343***		5.461***		6.544***		6.632***		5.896***		5.748***
	(1.362)		(1.356)		(1.440)		(1.440)		(1.428)		(1.426)
Clients Linkages	1.764		1.631		1.486		1.537		1.837		1.730
	(1.775)		(1.771)		(1.884)		(1.882)		(1.880)		(1.877)
Supplier Linkages	4.363**		4.304**		3.882**		4.006**		4.201**		4.267**
	(1.707)		(1.698)		(1.787)		(1.782)		(1.795)		(1.794)
Horz. Linkages	-0.00295		0.0329		0.376		0.328		-0.0696		-0.0759
	(0.538)		(0.535)		(0.567)		(0.566)		(0.563)		(0.560)
Employment (Log)	-0.421		-0.425		-0.412		-0.439		-0.696		-0.872
	(0.657)		(0.654)		(0.690)		(0.690)		(0.688)		(0.685)
Firm Vintage	-0.0864***		-0.0827***		-0.102***		-0.100***		-0.0901***		-0.0892***
	(0.0218)		(0.0217)		(0.0236)		(0.0236)		(0.0237)		(0.0237)
Externally Owned	4.177**		4.055**		3.813**		3.745**		3.753**		3.868**
	(1.677)		(1.677)		(1.784)		(1.781)		(1.786)		(1.782)
Workforce w Degree	0.0371		0.0358		0.122*		0.124*		0.0760		0.0934
	(0.0584)		(0.0580)		(0.0646)		(0.0645)		(0.0625)		(0.0626)
Govt. Support	4.588***		4.153***		3.324**		3.279**		3.654**		3.601**
	(1.447)		(1.441)		(1.538)		(1.541)		(1.517)		(1.515)
Export Sales	0.0265		0.0271		0.0136		0.0107		0.0205		0.0201
	(0.0232)		(0.0231)		(0.0248)		(0.0248)		(0.0241)		(0.0241)
Constant	11.09***		10.96***		8.213**		8.214**		9.485***		9.566***
	(3.190)		(3.174)		(3.378)		(3.370)		(3.325)		(3.331)
Observations	1,358		1,358		1,232		1,232		1,295		1,295
DV	Q Cert		Q Cert		QC		QC		TQM		TQM
conditional on	QC		TQM		Q Cert		TQM		Q Cert		QC
Complementarities	0.88		10.7***		0.25		0.87		4.45**		0.14
LBU Previous	0.14		1.35		0.1		0		1.27		4.46**
LBU Current	2.89*		0.83		0.68		0.24		0.53		0.09

Figure 1: Complementary and learning-by-using effects



Annex 1: Variable Definitions

Innovation	
Innovative sales (new) (% sales)	An indicator representing the percentage of firms' sales at the time of the survey accounted for by products which had been newly introduced over the previous three years.
QIM variables	
Current user	Static binary measure taking value 1 if the plant had implemented the QIM at the time of the survey and zero otherwise.
Current adopter	Dynamic binary variable taking value 1 if the plant had first introduced the QIM in the previous three years and zero otherwise.
Early adopter	Dynamic binary variable taking value 1 if the plant had first introduced the QIM 4-6 years prior to the survey date and zero otherwise.
Previous adopter	Dynamic binary variable taking value 1 if the plant had introduced the QIM more than 6 years prior to the survey date and zero otherwise.
Firm Controls	
In plant R&D	A binary indictor taking value one if the plant has an in-house R&D capacity.
Clients Linkages	A binary indicator taking value one if the plant is co-operating with customers as part of its innovation activity.
Supplier Linkages	A binary indicator taking value one if the plant is co-operating with suppliers as part of its innovation activity.
Horiz. Linkages	A count indicator of the breadth of plants' other innovation partnering activity. Takes values 0 to 7 depending on how many different types of partner the plant is working with: consultant, competitor, joint venture, government laboratory, university, private laboratory, industry research centre.
Employment	Employment at the time of the survey.
Firm vintage	The time in years between the establishment date of the plant and the date of the survey.
Externally owned	A binary indicator taking value 1 if the firm was externally-owned. For plants in Ireland this means owned outside the country. For plants in Northern Ireland this means plants owned outside the region.
Workforce with degree	The percentage of the workforce with a degree or equivalent qualification.
Government support	A binary indicator taking value one if the plant had received government support for product innovation over the previous three years.
Export sales	A binary indicator taking value one if the plant was selling outside the UK and Ireland at the time of the survey and zero otherwise

REFERENCES

Abrunhosa, A. and P. Moura E Sá. 2008. Are TQM principles supporting innovation in the Portuguese footwear industry? *Technovation* 28(4):208-221.

Adam, E.E.; B.E. Flores; and A. Macias. 2001. Quality improvement practices and the effect on manufacturing firm performance: evidence from Mexico and the USA. *International Journal of Production Research* 39(1):43-63.

Anderson, J.C.; M. Rungtusanatham; and R.G. Schroeder. 1994. A theory of quality managment underlying the deming management method. *Academy of Management Review* 19(3):472-509.

Arora, A. and A. Gambardella. 1990. Complementarity and external linkages: the strategies of the large firms in biotechnology. *Journal of Industrial Economics* 38, 361-379.

Audretsch, D.B. and M.P. Feldman. 1996. R&D Spillovers and the Geography of Innovation and Production. *The American Economic Review* 86(3):630-640.

Barnes, J.W.; D.W.J. Jackson; M.D. Hutt; and A. Kumar. 2006. The role of culture strength in shaping sales force outcomes *Journal of Personal Selling & Sales Management* 26(3):255-270.

Baumol, W.J. 2002. *The free market innovation machine*. Princeton Princeton University Press.

Belderbos, R.; M. Carree; and B. Lokshin. 2006. Complementarity in R&D cooperation strategies. *Review of Industrial Organization* 28(4):401-426.

Benner, M. and M. Tushman. 2002. Process Management and Technological Innovation: A Longitudinal Study of the Photography and Paint Industries. *Administrative Science Quarterly* 47(4):676-706.

Black, S.A. and L.J. Porter. 1996. Identification of the Critical Factors of TQM*. *Decision Sciences* 27(1):1-21.

Bodas Freitas, I.M. 2008. Sources of differences in the pattern of adoption of organizational and managerial innovations from early to late 1990s, in the UK. *Research Policy* 37(1):131-148.

Boschma, R. 2005. Proximity and Innovation: A Critical Assessment. *Regional Studies* 39, 61-74.

Buiseret, T.; H.M. Cameron; and L. Georgiou. 1995. What differences does it make? Additionality in the public support of R&D in large firms. *International Journal Of Technology Management* 10(4-6):587-600.

Cameron, K. and C. Barnett. 2000. Organizational quality as a cultural variable. . In *The Quality Movement &*

Organization Theory, ed. R. Cole and W. Richard, 271–294. Beverly Hills, CA: Sage Publications.

Cassiman, B. and R. Veugelers. 2006. In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition. *Management Science* 52(1):68-82.

Cassiman, B. and R. Veugelers. 2006. In Search of Complementarity in Innovation Strategy:Cooperation in R&D Internal R&D and External Technology Acquisition *Management Science & Public Policy* 52(1):68-82.

Chesborough, H.W. 2006. *Open Innovation: a new paradign for understanding industrial innovation*. Oxford: Oxford University Press.

Chesbrough, H.W. 2007. Why companies should have open business models. *MIT Sloan Management Review* 48(2):22-+.

Colombo, M.G. and R. Mosconi. 1995. Complementarity and Cumulative Learning Effects in the Early Diffusion of Multiple Technologies. *The Journal of Industrial Economics* 43(1):13-48.

Corbett, C.J.; M.J. Montes-Sancho; and D.A. Kirsch. 2005. The financial Impact of ISO 9000 Certification in the US: an empirical analysis. . *Management Science* 51(7):1046–1059.

Crepon, B.; E. Duguet; and J. Mairessec. 1998. Research, Innovation And Productivi[Ty: An Econometric Analysis At The Firm Level. *Economics of Innovation and New Technology* 7(2):115-158.

Deming, W.E. 1986. *Out of the Crisis*. Cambridge: MIT Press.

Diaye, M.-A.; N. Greenan; and S. Pekovic. 2009. ISO 9000 Norm as a Club Good: network effect evidence from French Employer Survey. *mimeo.*

Douglas, A.; S. Coleman; and R. Oddy. 2003. The case for ISO 9000. *The TQM Magazine* 15(5):316-324.

Foley, K.; R. Barton; K. Busteed; J. Hulbert; and J. Sprouster. 1997. *Quality, Productivity and Competitiveness: The Role of Quality in Australia's Social and Economic Development*. Sydney: Standards Australia.

Freel, M.S. 2003. Sectoral Patterns of Small Firm Innovation: Networking and Proximity. *Research Policy* 32, 751-770.

Freel, M.S. 2005. Patterns of Innovation and skills in small firms. *Technovation* 25, 123-134.

Glynn, M.A. 1996. Innovative Genius: A Framework for Relating Individual and Organizational Intelligences to Innovation. *Academy of Management Review* 21(4):1081-1111.

Gordon, N.R. and P. McCann. 2005. Innovation, agglomeration, and regional development. Vol. 5, Issue 5, pp. 523-543, 2005. . *Journal of Economic Geography* 5(5):523-543.

Griffith, R.; E. Huergo; J. Mairesse; and B. Peters. 2008. Innovation and Productivity Across Four European Countries. *Oxford Review of Economic Policy* 22, 483-498.

Griffith, R.; S. Redding; and J. Van Reenan. 2003. R&D and Absorptive Capacity: Theory and Empirical Evidence. *Scandinavian Journal of Economics* 105(1):99-118.

Griliches, Z. 1995. *R&D and Productivity: Econometric Results and Measurement Issues*. Oxford: Blackwell.

Harris, R.I.D. and M. Trainor. 1995. Innovation and R&D in Northern Ireland Manufacturing: A Schumpeterian Approach. *Regional Studies* 29, 593-604.

He, Z.L. and P.K. Wong. 2012. Reaching Out and Reaching Within: A Study of the Relationship between Innovation Collaboration and Innovation Performance. *Industry and Innovation* 19(7):539-561.

Heckman, J. 1979. Sample Selection Bias as a specification error. *Econometrica* 47(1):153-161.

Hewitt-Dundas, N. and S. Roper. 2008. Ireland's Innovation Performance: 1991-2005. *Quarterly Economic Commentary, ESRI, Dublin.*(Summer 2008):46-68

Hewitt-Dundas, N. and S. Roper. 2009. Output Additionality of Public Support for Innovation: Evidence for Irish Manufacturing Plants. *European Planning Studies* 18(1):107-122.

Hoang, D.T.; B. Igel; and T. Laosirihongthong. 2006. The impact of total quality management on innovation. *International Journal of Quality & Reliability Management* 23(9):1092-1117.

Hung, R.Y.Y.; B.Y.-H. Lien; B. Yang; C.-M. Wu; and Y.-M. Kuo. 2011. Impact of TQM and organizational learning on innovation performance in the high-tech industry. *International Business Review* 20(2):213-225.

Jordan, D. and E. O'Leary. 2008. Is Irish Innovation Policy Working? Evidence from Irish High-Technology Businesses. *Journal of the Statistical and Social Inquiry Society of Ireland* XXXVII1-45.

Kanji, G.K. 2002. *Measuring Business Excellence. Routeledge*. London, UK: Routledge.

Kanter, R.M. 1983. *The Change Master: Innovation and Entrepreneuship in the American Corporation*. New York: Simon and Schuster.

Kartha, C.P. 2004. A comparison of ISO 9000:2000 quality systems standards, QS 9000, ISO/TS 16949 and Baldridge criteria. *TQM Magazine* 16(5):331-340.

Kaynak, H. 2003. The relationship between total quality management practices and their effects on firm performance. *Journal of Operations Management* 21(4):405-435.

Laursen, K. and A. Salter. 2006. Open for Innovation: The role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal* 27, 131-150.

Leiponen, A. 2005. Skills and innovation. *International Journal of Industrial Organization* 23(5-6):303-323.

López-Mielgo, N.; J.M. Montes-Peón; and C.J. Vázquez-Ordás. 2009. Are quality and innovation management conflicting activities? *Technovation* 29(8):537-545.

Love, J.H. and S. Roper. 2001. Networking and Innovation Success: A Comparison of UK, German and Irish Companies. *Research Policy* 30, 643-661.

Love, J.H.; S. Roper; and J.R. Bryson. 2011. Openness, knowledge, innovation and growth in UK business services. *Research Policy* 40(10):1438-1452.

Love, J.H.; S. Roper; and J. Du. 2009. Innovation, Ownership and Profitability. *Internation Journal of Industrial Organization*.

Maddala, G. 1983. *Limited Dependent and Qualitative Variables in Econometrics*. New York: Cambridge University Press.

Mansury, M.A. and J.H. Love. 2008. Innovation, productivity and growth in US business services: A firm-level analysis. *Technovation* 28(1–2):52-62.

Martínez-Costa, M. and A.R. Martínez-Lorente. 2008. Does quality management foster or hinder innovation? An empirical study of Spanish companies. *Total Quality Management & Business Excellence* 19(3):209-221.

McAdam, R. 2000. Quality Models in an SME Context: a Critical Perspective Using a Grounded Approach. *International Journal of Quality & Reliability Management* 17, 305-323.

———. 2004. Knowledge creation and idea generation: a critical quality perspective. *Technovation* 24(9):697-705.

McCann, P. and J. Simonen. 2005. Innovation, knowledge spillovers and local labour markets. *Papers in Regional Science* 84(3):465-485.

Meehan, E. 2000. Britain's Irish Question: Britain's European Question?: British-Irish relations in the context of the European Union and the Belfast Agreement. *Review of International Studies* 26(1):83-97.

Morgan, N.A. and D.W. Vorhies. 2001. Product quality alignment and business unit performance. *Journal of Product Innovation Management* 18(6):396-407.

Moura E Sá, P. and A. Abrunhosa. 2007. The Role of TQM Practices in Technological Innovation: The Portuguese Footwear Industry Case. *Total Quality Management & Business Excellence* 18(1-2):57-66.

Nowak, A. 1997. Strategic relationship between quality management and product innovation. *The Mid-Atlantic Journal of Business* 33(2):119-135.

O'Malley, E.; S. Roper; and N. Hewitt-Dundas. 2008. High growth and innovation with low R&D: The case of Ireland. In *Small Economy Innovation System; Comparing Globalization, Change and Policy in Asia and Europe*, ed. C. Edquist and L. Hommen: Elgar.

Oerlemans, L.; M. Meeus; and F. Boekema. 1998. Do networks matter for innovation? The usefulness of the economic network approach in analysing innovation. *Tijdschrift voor Economische en Sociale Gcografie* 89, 298-309.

Pekovic, S. and F. Galia. 2009. From quality to innovation: Evidence from two French Employer Surveys. *Technovation* 29(12):829-842.

Perdomo-Ortiz, J.; J. Gonzalez-Benito; and J. Galende. 2009. The intervening effect of business innovation capability on the relationship between Total Quality Management and technological innovation. *International Journal of Production Economics* 47(18):5087-5107.

Perdomo-Ortiz, J.; J. González-Benito; and J. Galende. 2006. Total quality management as a forerunner of business innovation capability. *Technovation* 26(10):1170-1185.

———. 2009. An analysis of the relationship between total quality management-based human resource management practices and innovation. *The International Journal of Human Resource Management* 20(5):1191-1218.

Prajogo, D.I. and S.W. Hong. 2008. The effect of TQM on performance in R&D environments: a perspective from South Korean firms *Technovation* 28(12):855-863.

Prajogo, D.I. and A.S. Sohal. 2001. TQM and innovation: a literature review and research framework. *Technovation* 21(9):539-558.

Prajogo, D.I. and A.S. Sohal. 2003. The relationship between TQM practices, quality performance, and innovation performance. *International Journal of Quality & Reliability Management* 20(8):901-918.

Prajogo, D.I. and A.S. Sohal. 2004. The multidimensionality of TQM practices in determining quality and innovation performance—an empirical examination. *Technovation* 24(6):443-453.

Ritala, P.; K. Henttonen; H. Salojarvi; L.M. Sainio; and S. Saarenketo. 2013. Gone fishing for knowledge? The effect of strategic orientations on the scope of open knowledge search. *Baltic Journal of Management* 8(3):328-348.

Romer, P.M. 1990. Endogenous Technological Change. *Journal of Political Economy* 98(5):S71-S102.

Roper, S. and J. Anderson. 2000. Innovation and E-Commerce - A Cross-Border Comparison of Irish Manufacturing Plants. Belfast.

Roper, S.; B. Ashcroft; J.H. Love; S. Dunlop; H. Hofmann; and K. Vogler-Ludwig. 1996. Product Innovation and Development in UK, German and Irish Manufacturing: Queen's University of Belfast/University of Strathclyde/ifo Institut.

Roper, S.; J. Du; and J.H. Love. 2008. Modelling the Innovation Value Chain. *Research Policy* 37(6-7):961-977.

Roper, S.; J. Du; and J.H. Love. 2008. Modelling the innovation value chain *Research Policy* 37, 961-977.

Roper, S. and N. Hewitt-Dundas. 1998. Innovation, Networks and the Diffusion of Manufacturing Best Practice: A Comparison of Northern Ireland and the Republic of Ireland. Belfast: NIERC.

Roper, S.; N. Hewitt-Dundas; and J.H. Love. 2004. An Ex Ante Evaluation Framework for the Regional Benefits of Publicly Supported R&D Projects. *Research Policy* 33, 487-509.

Rosenberg, N. 1982. *Inside the Black Box: Technology and Economics*. Cambridge: Cambridge University Press.

Rungtusanatham, M.; C. Forza; R. Filippini; and J.C. Anderson. 1998. A replication study of a theory of quality management underlying the Deming management method: insights from an Italian context. *Journal of Operations Management* 17(1):77-95.

Sadikoglu, E. and C. Zehir. 2010. Investigating the effects of innovation and employee performance on the relationship between total quality management practices and firm performance: An empirical study of Turkish firms. *International Journal of Production Economics* 127(1):13-26.

Santos-Vijande, M.L. and L.I. Álvarez-González. 2007. Innovativeness and organizational innovation in total quality oriented firms: The moderating role of market turbulence. *Technovation* 27(9):514-532.

Schnaars, S.P. 1994. *Managing Imitation Strategies*. New York: Free Press.

Schumpeter, J. 1934. *The Theory of Economic Development*. Cambridge, Mas: Harvard University Press.

Sousa, R. and C.A. Voss. 2002. Quality management re-visited: a reflective review and agenda for future research. *Journal of Operations Management* 20(1):91-109.

Subramony, M. 2009. A meta-analytic investigation of the relationship between HRM bundles and firm performance. *Human Resource Management* 48(5):745-768.

Terlaak, A. and A. King. 2006. The effect of certification with ISO 9000 Quality Management Standard: a signalling approach. *Journal of Economic Behaviour and Organization* 60(4):579-602.

Terziovski, M.; D. Power; and A. Sohal. 2003. 2003. The longitudinal effects of the ISO 9000 certification process on business performance. *European Journal of Operational Research* 146(3):580-595.

Tether, B.S. 1998. Small and large firms: sources of unequal innovations? *Research Policy* 27, 725-745.

Trott, P. 2008. *Innovation Management and New Product Development*. England: Pearson Eduction.

Zairi, M. 1994. Innovation or Innovativeness, results of a benchmarking study. *TQM Magazine* 5(3):10-16.

Enterprise Research Centre

Centre Manager
Enterprise Research Centre
Warwick Business School
Coventry, CV4 7AL
Enquiries@enterpriseresearch.ac.uk

Centre Manager
Enterprise Research Centre
Aston Business School
Birmingham, B1 7ET
Enquiries@enterpriseresearch.ac.uk

The Enterprise Research Centre is an independent research centre funded by the Economic and Social Research Council (ESRC); the Department for Business, Innovation & Skills (BIS); the Technology Strategy Board (TSB); and, through the British Bankers Association (BBA), by the Royal Bank of Scotland PLC; Bank of Scotland PLC; HSBC Bank PLC; Barclays Bank PLC and Lloyds TSB Bank PLC.