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DTI ECONOMICS PAPER NO.12

The Empirical Economics of Standards

JUNE 2005

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The thanks of the project team are due to the sponsors the Department of Trade and Industry (DTI), and to Dr Ray Lambert in particular. Members of the British Standards Institution (BSI) were also of great assistance at various stages, and we would like to acknowledge here the help of Mary Yates of the BSI Library, as well as participants at the meeting discussing the interim report, and whose comments proved extremely helpful.

Foreword

The dissemination of technological and other forms of knowledge is well understood to be essential for competitiveness. The results of research and knowledge creation find their maximum economic value when they spread through the economy. Standards as a source of codified knowledge, are an important vehicle for this dissemination process, but the contribution to the macro-economy of the take-up of knowledge via standards has been relatively under-researched.

This paper reports the results of significant original research on the impact of standards, on growth, productivity and innovation. It is complementary in its coverage to earlier papers in this series, such as 7 on The Innovation Challenge and 11 on R&D Intensive Businesses, which have focused more on the generation of technology and knowledge.

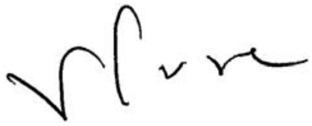
The results are set out in three individual reports and brought together in the Overview paper but in brief the main themes are:

Advanced econometric time series techniques have been used for the first time in analysing technology dissemination at the whole economy level, to establish the parameters of dissemination through standards. Around 13% of post war UK productivity growth can be attributed to standards mediated dissemination of technology, management practices and other knowledge, as part of the innovation system. This process complements and adds value to R&D and other investment in knowledge creation.

Standards are also shown to be an important part of the international technology transfer process and function alongside new technology (measured by patents), in facilitating technological progress across countries and across manufacturing sectors.

The net stock and vintage of standards relevant to different sectors can be integrated with innovation survey data on the perception of standards as information or a hampering factor. Standards are regarded as a net source of innovation relevant information, but the value contribution can start to fall if the stock available becomes too large, or if the stock is renewed too often or, on the contrary, allowed to age. The idea of an optimal number and vintage of standards for a sector emerges as a line of further inquiry.

This research has an immediate and important policy context. The DTI, in partnership with the Confederation of British Industry and the British Standards Institute, has established a National Standardisation Strategic Framework to raise the profile of standards making and use in both private industry and the public sector. The results presented here are part of a programme of research to establish the economic value of standards and how that value can be increased through the work of the partners. We are very pleased to have enabled this pathbreaking research and welcome comments on the results.



Vicky Pryce
Chief Economic Adviser and Director General Economics, DTI

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Introduction

This document is the final report on the 'empirical economics of standards', a research programme investigating the role and impact of standardisation on economic performance.

The overall programme consisted of three projects:

1: *Benchmark estimates of the impact of public standards upon Technological Change using UK data*

This project produced a 'count' of UK public standards published since 1901. It then examined the contribution of standards to growth at an aggregate level based on the work of Jungmittag, Blind and Grupp (1999) who found a substantial contribution from German standards to economic growth in Germany.

2: *Standards and the International Transmission of Technology*

This project introduces an international dimension and was conducted in collaboration with members of the *Fraunhofer Institute for Systems and Innovation Research*. The investigation here was particularly important given the emphasis given to the harmonisation of standards at the European level over the past fifteen years or so.

3: *Do Standards Enable or Constrain Innovation?*

This project – conducted by Peter Swann of the University of Nottingham Business School – considered the relationship between standardisation and innovation, using data from the Community Innovation Survey (CIS).

Executive Summary

Standards perform a range of useful functions in a modern economy. They may provide for compatibility between products or systems; they may serve to enhance quality; they may efficiently reduce variety and, more generally, they promote understanding of technology by providing information. Taken together, these functions promote the spread of new technology, a process that economists increasingly see as prone to market failure. 'Public' standards of the kind created by the BSI may possess additional important qualities such as 'openness' and 'credibility,' making them an important means by which these market failures may be ameliorated. The projects described below are based upon the belief that the development and maintenance of the 'catalogue' of BSI standards constitutes an important input into the process of technological change and the associated creation of new markets.

Standardisation in the UK, as measured by the activity of the BSI and its predecessor organisations, has been growing at an exponential rate since World War I. The long run rate of growth of the number of standards published averaged 3.7% between 1918 and 2003, while the growth in the catalogue itself – the 'stock' of standards available to producers – was even faster at 5.5% per annum. This is of course significantly faster than the growth of the economy as a whole.

In the post-war World War II period – the focus of our statistical attention in project 1 – the catalogue has continued to grow rapidly at 5.1% per annum, against a growth rate of output and labour productivity in the whole economy of 2.5% and 2.1% per annum respectively. We suspect that the 'standard intensive' nature of growth reflects the importance of the growth of product variety, the importance of standards to the growth of new sectors of the economy, and the increasing importance for the UK of technology developed overseas.

There have been substantial fluctuations in this long run growth picture, with a considerable slowdown in the growth of standardisation activity in the 1970s and 1980s. Since 1990 however, the growth of the BSI standards 'catalogue' has once again been very rapid, averaging 6.4% per annum between 1990 and 2003.

Apart from fluctuations in the size of the catalogue, variations in the rate of growth of the BSI catalogue have produced quite large changes in the *median age* of standards in the catalogue, a possible measure of the 'condition' (or quality) of the catalogue. This idea is exploited by Professor Swann in project 3.

The period since 1990 has been marked by a considerable change in the nature of standardisation activity. The emphasis in the last decade or so has been on *internationalisation and harmonisation* of standards. We estimate that in 1990, 64% of the BSI catalogue was accounted for by purely *'national'* standards; today this is less than 26%.

Harmonisation has resulted in considerable growth in the total BSI catalogue in the last decade as many existing national standards are 'pooled' at the European level, although this rate of growth is not outside historical experience. This process may conceivably have led to some 'dilution' of the catalogue as standards are adopted with less relevance for UK producers. The relationship between standards and productivity growth over the last decade has been investigated in more detail in project 2.

Our discussion of the role of public standards in a modern economy suggests that they are an important means by which the opportunities created by innovation and other 'deep' drivers of technological change – such as the accumulation of human capital and innovation – are realised. If this is the case, it may not be entirely sensible to divorce the impact of standards from that of domestic 'innovation' or other factors, such as the ability of the UK to 'import' technology from abroad.

Project 1 was directed principally at providing *benchmark estimates* of the contribution of standardisation to long run productivity growth in the UK. Using data from 1948 to 2002, we were able to estimate a statistically satisfactory model of labour productivity growth with standards exhibiting a positive and statistically significant correlation with labour productivity.

The statistical model developed in project 1 suggests, in line with theoretical expectations, that the impact of standards on labour productivity growth is *long-run* in nature, with the 'causation' appearing to run from standards to labour productivity growth rather than vice-versa.

Project 1 estimates suggest that the *elasticity of labour productivity with respect to the number of standards is about 0.05*. In other words, a 1% increase in the standards catalogue is associated with a 0.05% increase in labour productivity. Because of the very high rate of growth of the catalogue, the estimates imply that the role of standards is a big one, *with standards contributing to about 13% of the growth in labour productivity in the UK over the period 1948-2002*.

This benchmark estimate can be recast in terms of the contribution of standards to technological change and the contribution of the latter to total economic growth in the UK. Between 1948 and 2002 the economy as a whole (GDP) grew by 2.5% per year. The accumulation of conventional inputs – labour and capital – together accounted for 1.5 percentage points, and technological change from all sources 1.0 percentage points. *Standards were associated with over one quarter of this latter figure*.

However, this result needs to be interpreted with care, since we believe that standardisation primarily acts *in conjunction* with other – and more heavily researched – factors such as innovation – both at home and overseas.

The nature of the data did not permit the role of standards to be separated from these other inputs.

Simple statistical tests of the project 1 model were unable to detect any influence of the *internationalisation of the catalogue* in the 1990s on the reported coefficients (elasticities). Hence this project provided no evidence (at least as yet) of a possible weakening of the impact of standards resulting from the adoption of standards with potentially less relevance for the UK.

Project 2 examined the impact of standards on productivity for the UK and three other European economies – France, Germany, and Italy. It used data covering 12 manufacturing sectors for which it was possible, using the PERINORM© database and the International Standards Classification (ICS), to estimate standards stocks relevant to individual sectors.

In 1990, Germany had by far the largest stock of standards. Since then the other economies have established catalogues much closer to that of Germany. This reflects the strong growth of European standards and the harmonisation of 'national' standards at a European level. This has meant that stocks of national standards have been in decline (Germany, UK) or have grown only a little (France, Italy). This pattern is broadly reflected at the sectoral level. The UK standards stock – across 17 manufacturing sectors – between 1990 and 2003 grew by between 3 and 13% per annum. However, purely national standards were in decline in 14 of the 17 sectors.

Because of the richer data set available to project 2, it was able to estimate a range of models, allowing for examination of the separate impact of standards and innovation – using a measure of the latter based upon patent applications at the European Patent Office. It was also able to consider the differences between those standards whose origin appears to be purely 'national' and those which have an international origin – either from the European institutions (CEN, CENELEC, and ETSI) or from other international organisations such as ISO and the IEC.

Because of the strong internationalisation of the catalogue in the past decade, the results from project 2 are of particular interest. In particular, the adoption in national catalogues of standards developed at a European level may have resulted in some 'dilution' of the catalogue, with many of the 'new' standards of less relevance and benefit to national producers. On the other hand, the process of 'pooling' information at the European level, may make the development of standards an increasingly important mechanism for international technology transfer.

In fact, the models estimated in project 2 provide broad and robust support for the aggregate analysis of project 1. Nearly all the estimates of the elasticity of output with respect to the stock of standards suggest a positive and

statistically significant contribution from standards whether or not patents – a proxy for innovation – are included as additional explanatory variables.

Some puzzles remain from project 2. The attempt by Dr Blind and his colleagues to allow for a differential impact of standards produced estimates of insignificant impacts from international standards. However, these results in particular need to be treated with caution, not least because the estimates cover a period of transition for the various national standards bodies.

Economic theory suggests that the relationship between standards and innovation may be complex: according to the business situation, standards may either hinder or enable innovation. In project 3, Professor Swann examines this relationship empirically, using survey data from the Community Innovation Survey (CIS3) as well as data on standards available through PERINORM© and BSI ONLINE. In particular, he sought to explore how the *'condition'* of the standards stock – reflected not just in the *number* of standards (as in projects 1 and 2) but also in terms of the *median age* of the standards stock. As Professor Swann shows, the latter provides an important indicator as to whether the BSI is establishing standards in a timely fashion.

Professor Swann establishes that for any given company, there is considerable variation in the condition of the relevant part of the standards catalogue, in terms of both the *number* of standards available and the *age* of the typical standard available, according to the sector in which it operates.

Because they provide information, standards have a considerable role in stimulating a knowledge intensive activity such as innovation. The survey data in CIS3 validates the claim that innovators value the information content of public standards. The study finds that, in general, there is a *positive correlation between the informative content of standards and their constraining role on innovation* – a finding that appears at both the sectoral level and in a multivariate context. It appears that either standards are 'effective' and do both, or they are largely irrelevant to individual producers.

Using an econometric model, Professor Swann establishes that the information content of the stock of standards *increases with the number of standards available to an individual producer*. It also increases with *the age of the typical standard in the stock* (i.e. with its median age). However there is a limit to this. Beyond a certain point, an increasingly elderly stock of standards begins to lower the stock's information content. This finding is consistent with the need for standards to diffuse widely before they provide maximum information.

How can standards hinder innovation? One important issue relates to timing, for standardisation at an inappropriate time can lead to economic inefficiency. Too early, and a standard may effectively shut out promising and ultimately superior technologies. Too late, and the costs of transition to the standard may

be too high – preventing diffusion. A perceived shortening of product cycles suggest that the latter problem may be increasingly important. Again employing an econometric model, project 3 finds that – in line with economic theory – *that the constraining role of standards does indeed vary in a non-linear fashion with the median age of the standards stock*. Professor Swann argues that, 'it seems likely that both rather old and rather new standards constrain innovation – the first because it locks the innovator into legacy systems, and the latter because it challenges the innovator'. There is also a *non-linear relationship between the constraining role of standards and the number of standards*. The model suggests that as the number of standards relevant to a sector increases, producers are less likely to find standards as an impediment, but after a point, more standards increase the constraint on innovation.

Taken together, the models in project 3 imply that the median age of the stock which maximises the information content of the catalogue is rather higher than that which would minimise the innovation constraint.

1. An overview

1.1. Introduction

Standards have been with us for a very long time, and should be viewed as inextricably linked with the development of markets. The ancient world furnishes us with many examples where both measurement and quality standards helped in the creation and development of markets. The importance of the 'cubit' in stimulating trade and exchange is well known. In such cases standards assisted in the promotion of the division of labour, which as every student of Adam Smith has been made aware, is likely to have powerful effects on productivity. The relationship of standards with technical change however is more complicated, although we can still find early examples of standards promoting innovation. In Ancient Egypt, the demand for accurate measurement of property boundaries – despite the regular flooding of the Nile – created a market for sophisticated techniques and instruments of measurement. Nor do standards always arise spontaneously with the development of markets. Ancient history also gives us examples of the need for public service agencies which developed standards, tested, and provided certification.

That there might be a close connection between the development of standards, the associated process of standardisation, and the long run growth of productivity is not therefore surprising. That comparatively little has been done to explore this connection empirically is a little more puzzling. Certainly we have a body of case study evidence which points to the productivity gains to be realised through the adoption of *individual* standards, but this makes the comparative absence of an *overall* assessment of the contribution of standards to productivity even more apparent. A recent exception was a study of the role played by public standards in promoting growth in Germany (Jungmittag, Blind, and Grupp 1999) and which concluded that standards contributed substantially to economic expansion in the period 1960-1996. This report reviews a study – the Empirical Economics of Standards – sponsored by the DTI, which sought to contribute to such an overall assessment. It constitutes an overview of the contributions of three related projects, highlighting the main results, and providing additional contextual material relating to the role of standardisation and 'public' standards – those developed and issued through National Standards Bodies (NSBs) such as the BSI.

This overview is organised in the following way. The next section (1.2) considers further the relationship between standards and growth, as well as the economic methodology which is used to examine that relationship. Section 1.3 justifies the primary method we use for estimating the impact of standards – primarily a 'count' of standards that appear in the 'catalogue' of available standards. This we argue is an indicator of the demand for, and benefits from, the activity of NSBs. Section 1.4 describes the principal results from such a count under project 1 – which we were able to conduct for British standards from 1901 onward. Sections 1.5 -1.7 then describe the main results from each of the three projects in turn.

1.2. Technological change, standards, and long run economic growth

Economic growth – defined as the long run increase in labour productivity – is a process that clearly involves the complex interplay of both social and economic factors. However, the approach of conventional economics to its understanding has been relatively straightforward: to consider the relationship between inputs and outputs, summarised by a 'production function' which – in principle – can be either estimated using statistical methods, or can be imputed by means of the methods of 'growth accounting'.

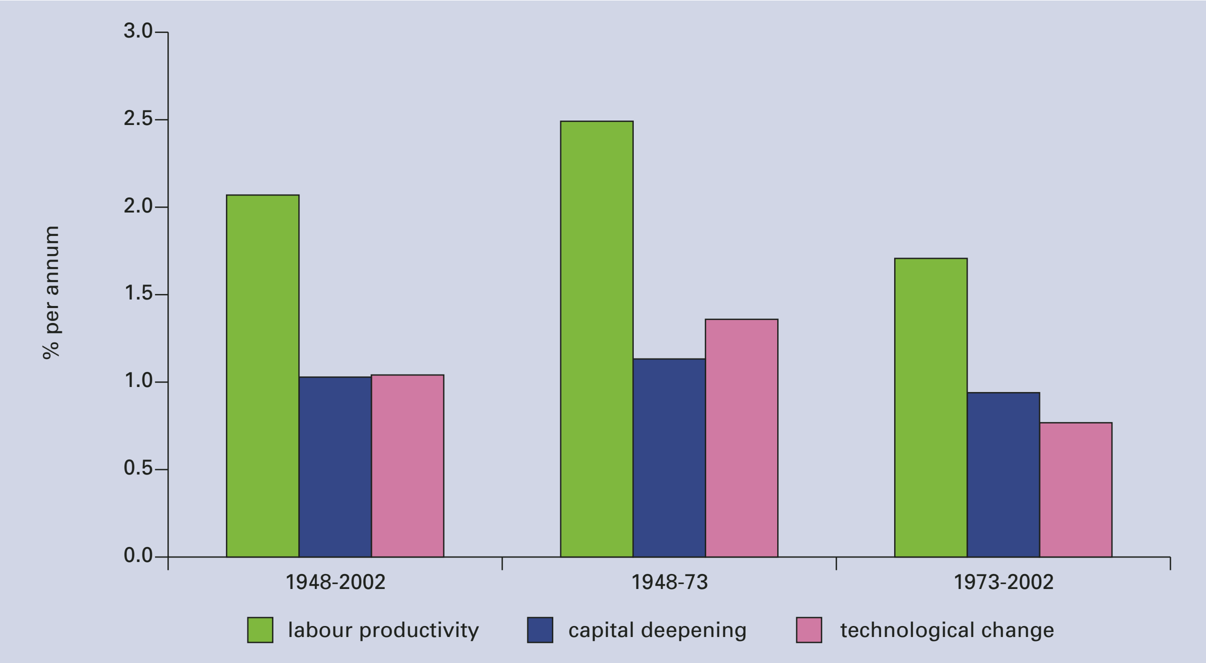
Typically, the inputs examined in the production function approach have been the 'conventional' ones of capital and labour services, with growth not accounted for by their accumulation being attributed to 'technological change'. Clearly this provides for a very broad definition of the latter which captures all manner of ways in which businesses, organisations, markets and other institutions mutually achieve efficiency increases. The work of NSBs provides an important example of such a process in action and can conceivably account for some part of the growth in productivity attributable to technological change. The first two projects endeavoured to provide some idea of how large this contribution may be. A robust finding in both is that standards are associated with a measurable proportion of the growth of productivity in the long run. The report emphasises however that the contribution of standards should not be considered as independent of other factors integral to technical change and provides no 'magic wand'. Without innovation and the creation of new products, processes, and organisational change, expanding numbers of standards would likely provide a rapidly dwindling contribution to welfare. In many business situations, the relationship between innovation and standards is a complementary one – both are necessary for innovations to succeed.

However the relationship between standards and innovation is not likely to be as simple as the above discussion implies. In other situations, standards may impede innovation. In the final contribution to this research, conducted by Professor Peter Swann, the relationship between standards and innovation is considered, focusing attention on the way in which the 'condition' of the available stock of standards may help or hinder the process of innovation.

Most studies of growth based upon the idea of a production function have concluded that technological change – in the form of changes in the underlying relationship between inputs and output, as opposed to the accumulation of inputs – has been responsible for a major share of improvements in productivity. The UK experience is no exception in this regard. For this project we produced estimates of productivity growth in the UK for almost the entire post-World War II period. Our estimates in project 1 suggest that the overall growth in labour productivity between 1948 and 2002 was 2.1%, and not far short of half of this was the result of technological change. Figure 1 illustrates this. The same story is roughly true for the two sub-periods shown – although

over the last thirty years or so capital accumulation has a slightly larger role attributed to it than technological change, albeit within a smaller overall rate of growth. If anything, the above estimates tend to under-record the importance of technological change, since a large part of the cause of the increase in the capital intensity of production may be due to technical progress.[1]

Figure 1
The Contribution of Technological Change to the Growth of Labour Productivity (UK 1948-2002)



Source: ONS/own estimates

Unsurprisingly, given the generally acknowledged importance of technological change, the emphasis in economics has shifted in more recent years to an examination of the underlying resources and processes which underpin technical advance. Here the Schumpeterian 'trilogy' of concepts: *invention, innovation, and diffusion*, has proved extremely useful. Invention concerns the new ideas or models which underpin new or improved products or processes. Since economic agents who specialise in invention alone are rarely observed, economists have tended to focus on 'new to world' innovation – the commitment of resources leading to the initial commercial transactions which incorporate the new idea, e.g. in a new product or a new process. By way of example, modern growth theory has increasingly moved to the consideration of so-called 'endogenous' innovation, where markets create incentives for firms to commit resources to research and development (R&D) activities, resulting in new and improved products and processes. An important reason for these theoretical developments is the belief that markets may – to some extent at

1 These figures are based upon subtracting an estimate of the contribution of inputs (capital accumulation and employment growth) from output growth. Growth accounting techniques, in which the contribution is inferred from the observed shares of capital and employment in aggregate income, tend to produce an even larger estimate of the contribution of technological change.

least – 'fail' to deploy the optimum level of resources in innovative activities. At least three factors are significant here. First, the commitment of resources to R&D (or other intangible assets[2]) which enhance productivity, may involve considerable fixed costs, so that issues of market size and competition are important. Second, the new economically valuable knowledge which underpins innovation may be appropriated by other firms. This is the so-called 'externality' problem. Finally, any such commitment of resources is subject to considerable risk. All three reasons help explain why endogenous innovation has been a focus of attention not only for theoretical economists but also for applied economists and policy analysts who are interested in institutions which may help to ameliorate the supposed market failures. These institutions clearly include such things as intellectual property rights (the patent system, copyright, trade marks etc) in helping to create excludability, as well as the role of scientific and other knowledge creating bodies.

Corresponding to the theoretical and policy interest in innovation, empirical research has also been important in a variety of areas. First it has sought to establish the relationships between inputs into and outputs from (and hence the productivity of) the innovation process and how these relate to such variables as market structure and individual firm characteristics. Secondly empirical analysis has examined the size and nature of externalities or spillovers associated with innovation – including the extent to which these are attributable to international sources. To try and capture some of the nature of these effects, applied economists have used a variety of measures of the resources committed to innovation, such as R&D expenditures or personnel, or in many applications, counts of patents.

In contrast to the attention given to 'new to world' innovation,[3] growth economics and its empirical counterpart have paid less attention to technological diffusion – the process by which new technologies spread across their potential markets over time. In a typical 'endogenous innovation' model, the concepts of innovation and diffusion are conflated: it is assumed that the results of R&D are adopted to their full potential immediately. There are important exceptions to this rule, as for example in those models which examine international development and for which an explanation is sought for the 'non-adoption' of technologies in some less developed economies, and the 'convergence' of levels of technology to that of more advanced economies seen in others.

At first sight the apparent oversight of diffusion processes in modern growth economics is a surprising one, given that it is widely acknowledged that they represent the means by which innovation is translated into productivity improvement. One reason may be the belief that market failures and policy solutions are concentrated in innovative activity and that, by contrast, markets

2 Which may indeed include the standardisation of organisational procedures.

3 Note that this may include organisational and managerial innovation. Also note that in some terminologies, including that of the DTI, innovation is much broader in conception, including diffusion, i.e. the adoption of products, processes etc which are new to the individual firm or other agent, even if not 'new to the world'.

can be relied on to 'produce' optimum welfare paths when it comes to the spread of technology. However, the literature on technology diffusion – which has developed relatively independently of growth economics – suggests otherwise. Issues of both market power and imperfect information may both figure in making a given diffusion path (or indeed a lack of one) sub-optimal. Recent economic literature has however stressed the importance of externalities in the spread of new technology, especially in situations of positive 'network externalities' – those where technology adoption by one user enhances the welfare of other users.

In all these situations where diffusion processes are subject to market failure, the development of 'standards' provides a means by which those failures can be corrected or at least ameliorated. Moreover, if market failures are indeed important in diffusion processes, then it is reasonable to hypothesise that institutions, which ameliorate those failures, may have an important and quantitatively significant effect on long run economic growth. Here we examine the impact of just such an institution – the BSI (and other similar institutions overseas) – which enables the development of 'public' standards in the UK.

In order to test this hypothesis, this study describes and develops an empirical measure – based upon the creation of 'public' standards such as those produced and made available by institutions such as the British Standards Institution (BSI) – which we argue captures some of the key elements of technological change in its own right. The methodology of much of the study involves simple 'counts' of standards – rather like the patent counts referred to above – which will be seen to vary considerably over time, across industries, and indeed across countries. The next section provides our justification for this methodology.

1.3. Why count standards? Standards as an indicator of the benefits of standardisation

To understand better the relationships between innovation, diffusion, the development of standards and their use (i.e. standardisation), we must now briefly consider the benefits of standards, conceived in terms of their economic function. The extant literature suggests any standard will have one or more of four main kinds of function:

- Providing for inter-operability or compatibility between different parts of a product or between products as part of a system or network.
- The provision of a minimum level of quality, which may be defined in terms of functionality or safety of products.
- The reduction of variety, allowing for economies of scale.
- The provision of information.

Many of the more recent studies of standards have focused on the first type of function, reckoned to be vital for the widespread adoption of ‘system technologies’ in (for example) computing or in communication technologies. Here the benefits from adoption and the extent of diffusion depend upon the number of existing users, either directly with the development of a network – of mobile telephones for example, or indirectly via ‘hardware-software’ effects in which the widespread adoption of a technology depends upon the existence of complementary products. In such examples, referred to as cases of *network externalities*, standards are clearly integral to adoption. In many cases it is the agreement and co-ordination that a standard achieves that is important – the precise characteristics of the standard – and whether it is actually the ‘best’ standard, are far less important. Consequently, we would argue that it is difficult to distinguish the impact of the standard from the impact of the innovation on the benefits which technological change engenders – both are essential, providing a *joint input* into the eventual productivity gains.

It is important that the network effects described above are not confined to ICT and may be considerably more widespread. The development of labour force skills – where these are closely related to a particular technology – may be particularly important.

Whether deliberately created for that purpose or not, the *provision of information* is a key element in the benefits provided by standards, and which may be important in stimulating and focusing innovation. The process through which standards are created is clearly important, and the source of information in many instances will be a global one. Standards therefore reduce the possibility that imperfect information creates market failures in diffusion processes.

The other two sources of the functionality of standards may also be linked to productivity gains. In the case of minimum quality, there may well be demonstrable gains in situations of information asymmetry, where buyers are unable to distinguish between ‘high’ and ‘low’ qualities – at least in advance of purchase. If, as is likely, high quality producers face higher costs than low quality producers, they might find it hard to survive in such market conditions, giving us a case of ‘Gresham’s Law’ in which the ‘bad drives out the good’. In such cases, minimum quality standards may help in mitigating the operation of the Law, helping consumers to distinguish different qualities.

If standards do have the effect of improving quality then this should be reflected in productivity statistics – provided of course that statisticians correctly measure the increased output that the improvement in quality represents. In fact, many economists believe that the contribution of quality is typically underestimated, with the price increases reflecting higher quality wrongly perceived as a rise in the general level of prices.[4]

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Since much innovation involves the deliberate development of variety on the part of firms, it might be thought that variety reduction standards may constrain innovation. While this may well be the case in some instances, there may be many others where variety is of little benefit to customers. Indeed the BSI reports that, as a result of successful negotiation at the first meeting of the Engineering Standards Committee, 'the variety of sizes of structural steel sections was reduced from 175 to 113 and the number of gauges of tramway rails was reduced from 75 to 5,' bringing 'estimated savings in steel production costs of £1 million a year.'[5]

In an important Appendix to his contribution, Professor Swann also draws attention to the complementarity between innovation and standardisation, strongly influencing the ways in which markets develop. Since, ultimately, many of the functions of standards help to define market characteristics, the resultant population by firms of the whole product space, should, as emphasised above, be seen as essentially a *joint input* into the process of technological change. Together, they make for the orderly *development of markets*, which increases the extent to which economies of scale are realised. Naturally however, the order imposed by a standard, in addition to the information it provides, tends to impose constraints on the nature of further innovation.

Standards of course are far from being the sole preserve of NSBs such as the BSI. Individual firms can and do develop their own standards to improve their own profitability (creating so-called 'proprietary standards'), while other consortia also develop standards for perceived mutual economic gain. The important point however is that the creation of standards is itself subject to market failure, and there is a strong presumption that, unaided, markets will under-provide for standards. This last point is probably well understood: the development of standards involves fixed costs, and the gains may not be appropriable by the individual firm which develops one. Together, these give standards properties akin to a 'public good'.

Less well understood than the public good argument are the peculiar *characteristics* of the type of standard produced by an NSB.

The first is *'openness'*. This means that it is available – on an equal basis – for all competitors. Some proprietary standards may be open – but there is no presumption of this – indeed probably the opposite. This characteristic is particularly important for small innovative firms.

The second characteristic of 'public' standards is that of *'credibility'*. Government sponsorship and other aspects of standards help to create confidence that a standard may achieve widespread use.

4 Conceivably, if quality improvement is especially 'standards intensive', then the development of standards may be associated with a disproportionately large part of the unrecorded productivity increase.

5 BSI, History of the BSI Group, available from BSI web-site.

Both characteristics suggest that the impact of NSB activity on productivity may be amplified by the peculiar character of public standards.

The above analysis suggests that counting the number of standards – and especially those made available by NSBs – may be a useful way of considering their productivity enhancing benefits. It also suggests that we would expect to find considerable complementarity between numbers of standards and other measures of innovation – such as R&D and patent counts. In statistical terms, this translates into a substantial degree of correlation between the various possible measures of technological change mentioned above. In the next section we discuss our standards counts.

It is however important to state the limitations of such a count. There is a clear distinction to be made between what it measures and what we would like it to measure. While it represents – to a reasonable degree of approximation – the activity of NSBs, it can only begin to proxy for standardisation in general – the process by which standards are taken up and used across the business community.

1.4. Results from Project 1: A UK 'Standards Count'

The discussion suggests in the last section: first that standardisation activities produce measurable impacts upon labour productivity and second, that a count of standards produced by national standards bodies (NSBs) provides a useful indicator of this process. In this section we summarize the main results that emerge from a unique count of standards in the UK over a long period of time – going back in fact to the first public offering of BSI's predecessor – the Engineering Standards Committee – in 1901.

The key data input in this project – and the most resource intensive – proved to be the development of our measures of standardisation activity. Here, the German study by Jungmittag et al (1999) focuses on what we term the *'Standards Catalogue Index'* (or SCI for short). This measures the contribution of publicly available standards by (roughly) the number of standards appearing in the catalogue of the relevant NSB at a particular time. More specifically, this is measured at any point t in time by:

$$SCI(t) \equiv \sum_{i=t-\infty}^{i=t} P(i) - \sum_{i=t-\infty}^{i=t} W(i)$$

Where $P(i)$ is the number of standards published in any year i, $W(i)$ is the number of standards withdrawn (or retired) in year i. So SCI is simply the accumulation of all publications up to year t less all withdrawals over the same period.

To what extent can we be sure that the standards catalogue is the appropriate measure of standardisation activity and its impact upon productivity? A notable feature of the SCI is that it treats both publications and retirements

symmetrically – what matters for productivity is the growth is the stock of publications net of retirements. A useful analogy in this regard is with the physical capital stock of the economy: plant and machinery, factories, vehicles etc. These contribute to production during their active life but cease to contribute once the assets are scrapped – or in the case of the individual firm – sold on to another firm. In estimating the impact of standards on the economy the approach is the same: once retired, a standard ceases to contribute to output. If it is matched by an extra published standard, then the SCI remains unchanged.

From the point of view of a new publication there is, as with the purchase of a piece of equipment, clearly a balance to be struck between the prospective benefits of the new standard and the costs incurred in constructing it – the labour time of committee members, technical committee overheads and so on. Of course, the actual economic benefits may be many times this because of the substantial externalities that are likely to exist, i.e. that participants may be unable to capture the full economic benefits, as discussed above.[6]

Why on the other hand are standards retired? In practice, there seem to be a number of reasons. Here, a broad analogy with capital assets also seems apposite. A relatively small number are simply declared 'obsolete'. Others are 'superseded': replaced by superior and more appropriate standards. In other cases, such as the adoption of harmonised international standards, the result is 'replacement'. In general then, as with capital assets, retirements of standards tend to reflect *declining economic efficiency* (at least relative to some alternative new standard).[7]

In order to calculate the SCI for the UK we had to combine two data-sources: The BSI *'History Book'*[8] and the PERINORM©[9] digital database. While the latter allowed for straightforward estimates of the SCI, the data was only available from 1985. The History Book in fact contains (in hard-copy form) data on all standards published prior to the end of the 1980s. While the information therein was relatively complete in relation to the publication date of standards, the data on retirements was far from complete,[10] although we were able to count roughly half of these. In order therefore to estimate the SCI for the UK, we had to combine both a count and an *estimate* of withdrawals.[11] The following pictures illustrate some of the principal findings from our 'count'.[12]

6 These mechanisms are discussed more fully in inter alia Swann (2000) and Temple and Williams (2002).

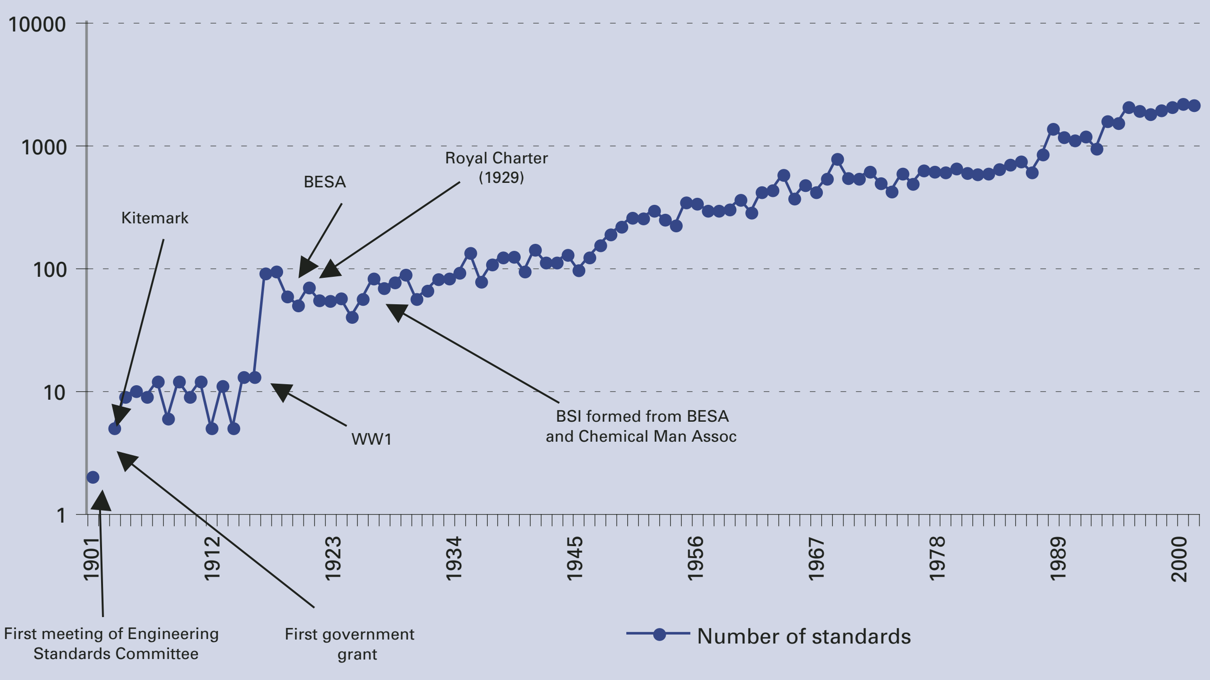
7 The analogy is not exact. When a standard is introduced, it needs to go through a process in which it's adopted by a population of firms. There is no exact equivalent with a capital asset, although in practice there may be a learning process before it achieves peak efficiency. Moreover, when a physical asset is scrapped, it ceases to have any productive life; the impact of a standard may well persist beyond the retirement date. These considerations led the team to consider alternatives to the measurement of standardisation using our estimates of the catalogue. In statistical terms however, we did not find the differences to be substantial, and the results reported in this overview all use the catalogue measure.

8 Kindly made available to us by Mary Yates of the BSI Library.

9 A consortium of BSI, DIN, and AFNOR.

10 At least in any reasonable timescale or resource cost.

Figure 2
BSI publications by year (1901-2003), log scale



Source: BSI/PERINORM©

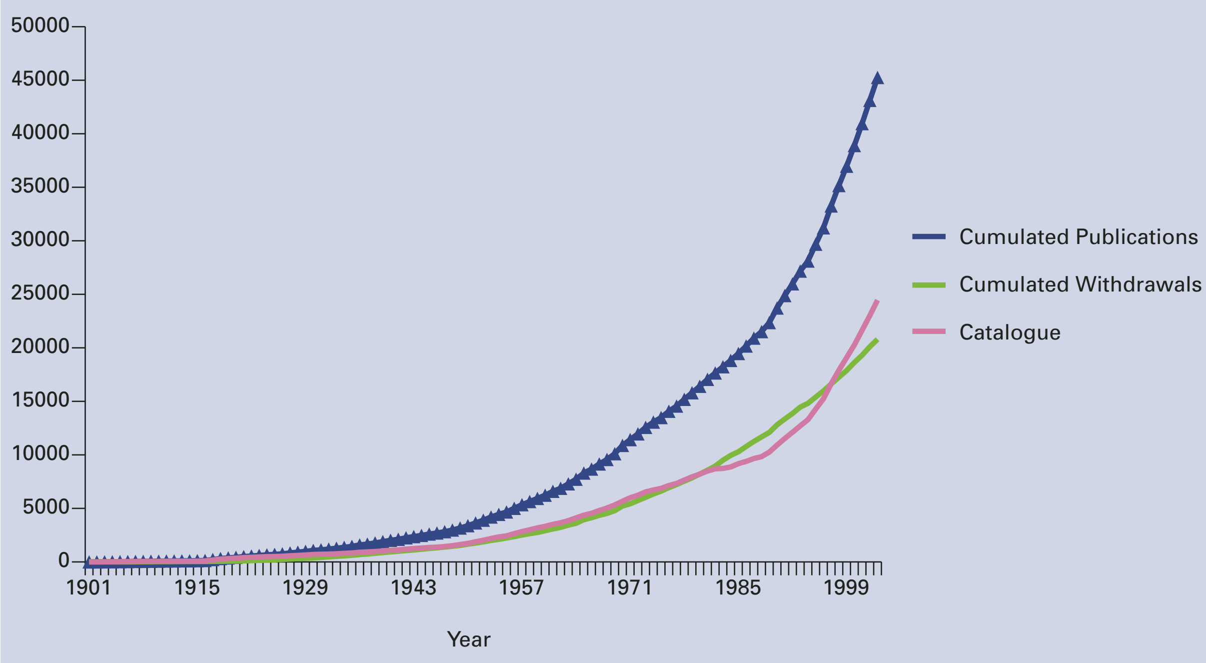
Figure 2 shows how publications have grown since the first 'public' standard in 1901. The importance of the First World War – which saw the SCI quadruple between 1913 and 1918 and the annual number of publications – is clearly visible. Since then, there has been a steady exponential growth; whereas the peak years of WWI in 1917 and 1918 saw just under 100 publications in the year, annual publications between 2001 and 2003 all topped 2000, representing a long run annual rate of growth of 3.7%.[13]

11 Details of this estimate can be found in Annex A.

12 As mentioned above, some estimates of retirements of standards were necessary to construct the SCI. How accurate are these estimates? A broad check can be made by comparing our estimates of the catalogue in 1984, with those available from PERINORM(c) which records standards from 1985. By our estimates the SCI at the end of 1984 is 8,871 which needs to be compared with 8,961 which PERINORM(c) records at the start of 1985, an undercount of about 1.12%.

13 1918-2003.

Figure 3
The Growth of the BSI Catalogue (1901-2003)

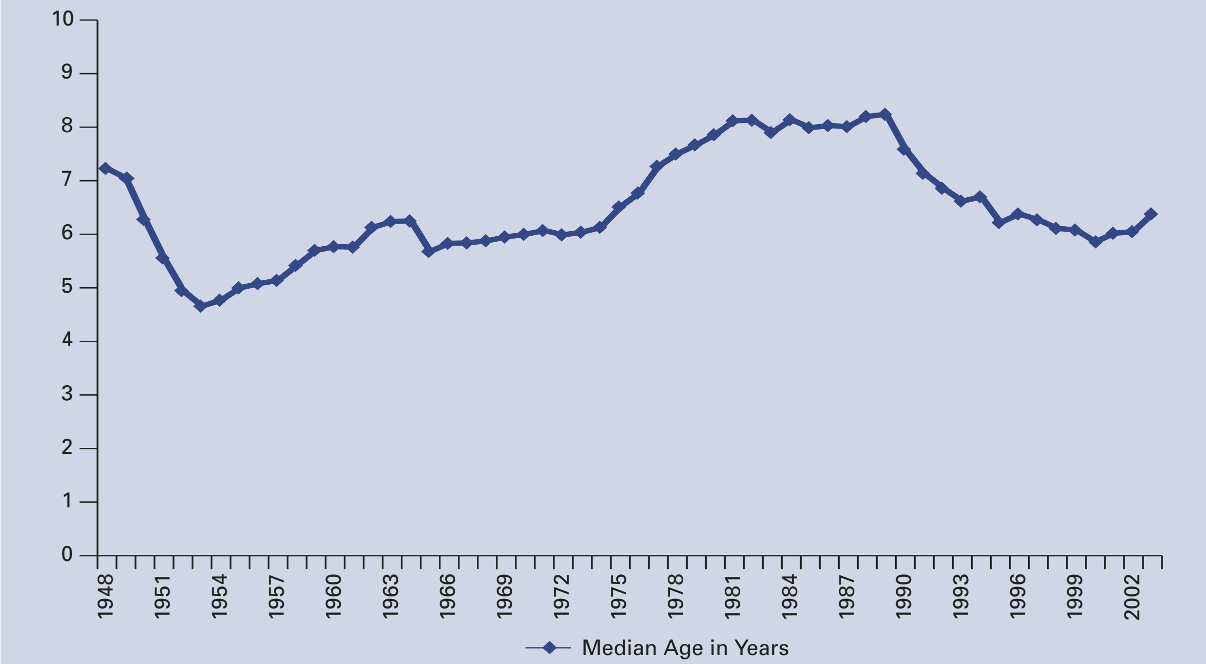


Source: BSI/PERINORM©

Figure 3 illustrates both cumulated publications and cumulated withdrawals and hence the growth of the catalogue itself. By the end of the Second World War, there were close to 1,500 standards in the catalogue. Strong expansion in the early post-war decades meant that this had increased to nearly 6,000 by 1970. The period 1970-1989 was a period of rather slower growth, but nevertheless the catalogue contained more than 10,000 in the latter year. Stronger growth has resumed over the last decade or so with the stock doubling again, with nearly 25,000 listed standards by the end of 2003.

The approach adopted also allowed us to provide some supplementary measures of the catalogue at any one time – and which may, tentatively at least, be thought of as a possible measure of *quality* or *'condition' of the standards stock* as Professor Swann describes it. First, there is the extent to which the catalogue represents current technologies and sectors of use. A potentially useful proxy for this is the median age of the stock of standards in the catalogue. Important use of this measure is made by Peter Swann in his discussion of the relationship between innovation and standards. He shows that there is important variation in this measure across 2-digit sectors of the UK economy. His particular contribution is discussed in section 1.7 below. Over time, the aggregate measure of the *median age* catalogue also shows variation, as Figure 4 illustrates.

Figure 4
The Median Age of the Standards Stock 1948-2003

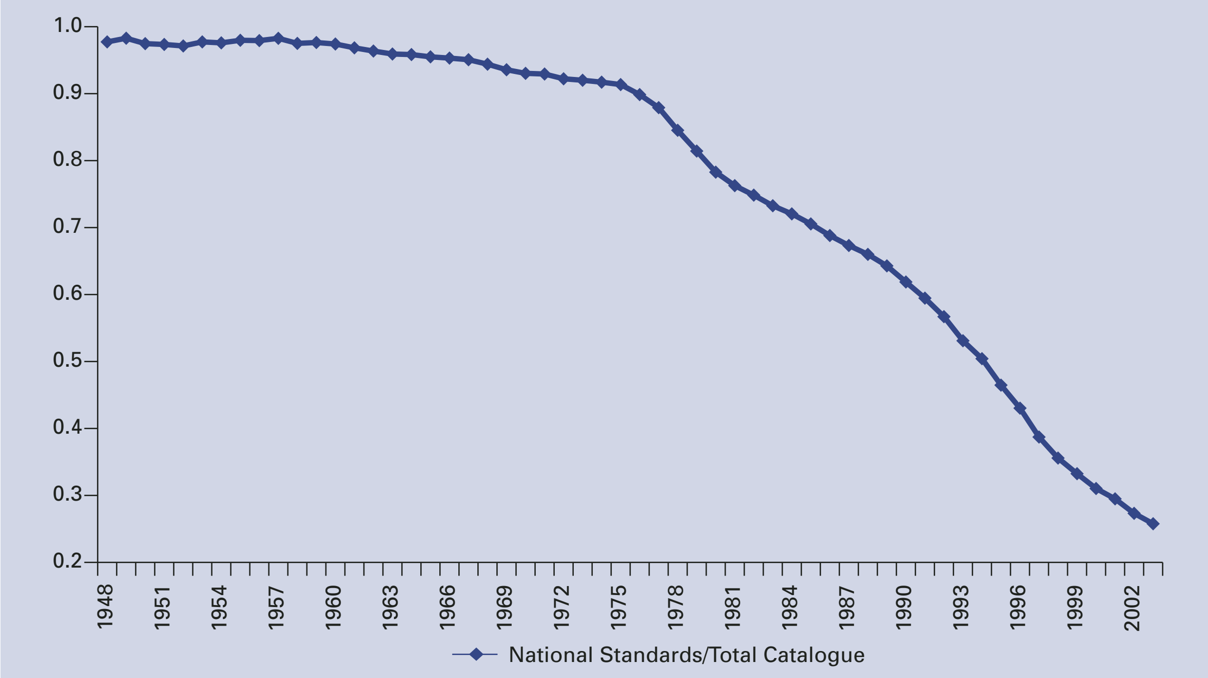


Source: BSI/PERINORM©

As a second important feature of the 'state' of the catalogue, there is the extent to which the catalogue reflects the *internationalisation* of standards, and the process of EU harmonisation in particular.[14] Purely 'national' standards are defined for the purposes of this study as those which are neither equivalent or identical to one issued by an international body – ISO, IEC, or in a European context of the EU – CEN, CENELEC or ETSI. As illustrated in Figure 5, our estimates suggest that in 1948 98% of the catalogue consisted of national standards. By the end of 2003, this had fallen to under 26%.

14 To produce long-run data on this, we needed to rely only upon PERINORM(c). In order to produce long-run data we needed to assume that the survival properties of 'international' standards were similar to those of 'national' standards.

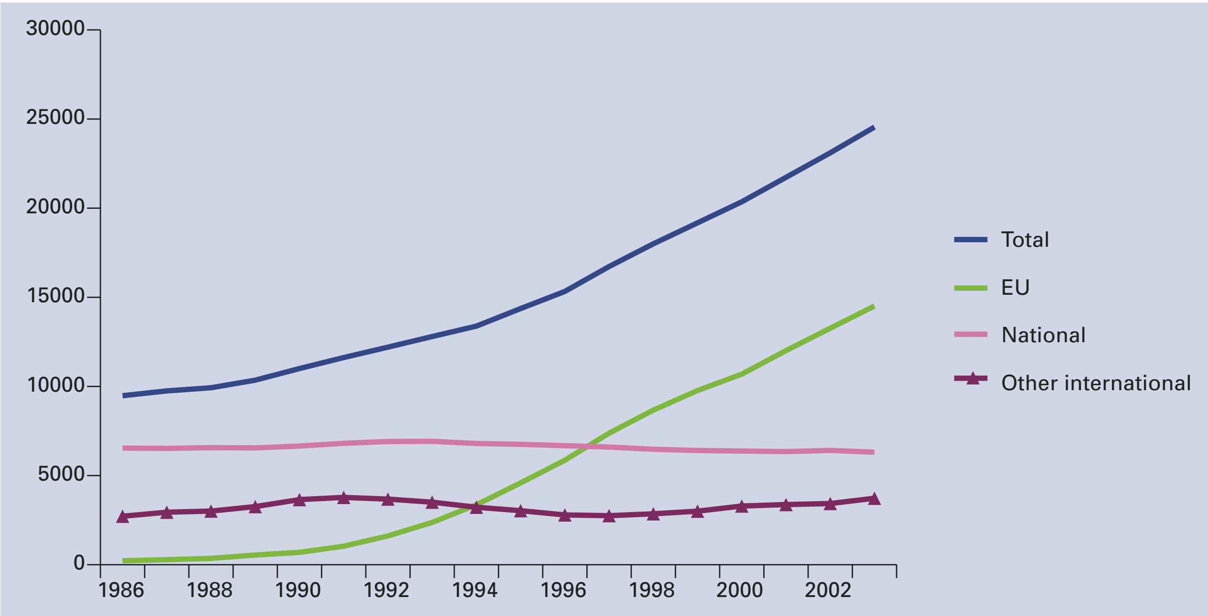
Figure 5
The Internationalisation of the BSI Catalogue (1948-2003)



Source: BSI/PERINORM©

For more recent years, Figure 6 confirms the role played by European level institutions in the growth of the BSI catalogue in the UK.

Figure 6
The International Composition of the BSI Catalogue (1986-2003)



Source: BSI/PERINORM©

It can be seen that:

- Although the total number of standards in the catalogue has been growing very rapidly over the last decade or so, purely national standards have been declining.
- Nearly all the growth in recent years has been the result of the increase in the numbers originating with the European institutions: CEN, CENELEC, or ETSI.

Note that the decline in national stocks does not mean that purely national standardisation activity has ceased, only that withdrawals of national standards have been greater than publications. We may conclude however, that, the UK has been in the process of a considerable shift in the pattern of deployment of its resources towards developing 'harmonised' European standards.

1.5. Results from Project 1: Benchmark Estimates

The starting point for this part of project 1 was the conclusion reached for Germany by Jungmittag, Blind and Grupp (henceforward JBG) which suggested that there, public standards exerted a strong impact on economic growth. The reasons for expecting such a result were discussed above. Here we describe the results of our attempt to replicate the German study and measure the contribution of standardisation to technological change at the level of the UK economy as a whole.[15]

The methodology adopted by JBG, is to incorporate a measure of standardisation into a so called *production function* in which economic output is related by a mathematical function to a set of inputs. The 'conventional' inputs usually considered for an advanced economy such as the UK are capital services and labour input.[16] Such a function can be written as:

$$Y(t) = F(K(t), L(t))$$

Where $Y(t)$ = output at time t
$K(t)$ = capital input at time t
$L(t)$ = labour input at time t

Technological change can then be introduced by assuming it acts in a neutral and multiplicative way to enhance the productivity of the two factors:

$$Y(t) = A(t)\ [F(K(t),L(t)]$$

15 The team considered whether the greater importance of standardisation activity within the manufacturing sector might make this sub-sector a more appropriate subject of analysis. This was ultimately rejected on the grounds that a) the catalogue pertains to the economy as a whole, and b) that productivity growth in non-manufacturing may well be attributable to standardisation within manufacturing.

16 These categories may be further sub-divided into various components of the capital stock such as plant and machinery or buildings or types of labour (skilled, manual etc).

Where $A(t)$ is an index of so-called *total factor productivity* or TFP for short. This can be thought of as the product of a number of influences. In the cited study, the authors consider three potentially measurable influences plus an exogenous time trend intended to capture other (unobservable) influences. The measurable factors are:

- Domestic innovative activity, proxied by a count of domestic patents
- The role of the domestic diffusion of technology, proxied by the catalogue measure of standardisation discussed above
- The import of technology from abroad, proxied by domestic payments to the rest of the world for intellectual property: technology licences, patent royalties etc.

If $Z(t)$ is the vector representing the above influences then we can write:

$$A(t) = A[Z(t)]$$

With $Z(t) = \exp(\lambda t)\, PAT(t)^{\gamma}\, LEX(t)^{\delta}\, STD(t)^{\epsilon}$

Where, $PAT(t)$ = stock of domestic patents at time t
$LEX\ (t)$ = imports of licenses, patent royalties etc
$STD\ (t)$ = effective stock of standards

t = time

Assuming the standard Cobb-Douglas functional form for the underlying production function, so that $Y = A[Z(t)][\ K^{\alpha}L^{\beta}]$ and taking logarithms yields a linear equation which can be estimated statistically and where logarithms are denoted by lower case):

$$y(t) = a + \alpha k(t) + \beta l(t) + \gamma\ pat(t) + \delta\ lex(t) + \epsilon\ std(t) + \lambda t + u(t) \qquad (1)$$

Here: $k(t)$ = log (capital input at time t)
$l(t)$ = log (employment input at time t)
$pat\ (t)$ = log (domestic patent stock at time t)
$lex\ (t)$ = log (imports of licenses, patent royalties etc)
$std\ (t)$ = log ('effective' stock of standards)

t = time

$u(t)$ = normally distributed error term

Our ability to estimate such a model for the UK was limited (but in some respects enhanced) by both data and methodological considerations, as well as the results of early experiments. We may note the following:

- First, given our standardisation data, and considerable efforts by the ONS in producing new estimates of the capital stock for the UK, we were able to estimate a model for the whole period 1948-2002, increasing the number of observations.

- However, official data for imports of technology is available only from 1964 onwards. This turned out to be statistically a quite 'noisy' variable with a large variance. Given this and the considerable reduction in data points, it was not surprising that a number of experiments with this variable proved unsatisfactory.
- Given (even with the extended sample size) the shortage of data points, we did not find it possible to estimate a model with as many parameters as in equation (1) above. Even without the licensing variable, we were unable to obtain satisfactory results with both patents and standards, which turned out to be highly co-linear. As noted above, this is not altogether surprising from a theoretical perspective, where as we saw above, the development of markets requires both standards and innovation as *joint* inputs.[17]
- To reduce the task of estimation still further, we considered it desirable to impose constant returns to scale on the underlying production function. This may not be unreasonable, since standards are themselves sources of any such economies.
- Taken together, the two last points must be taken to indicate that our final results need to be interpreted with care, and the elasticity estimates reported below need to be regarded as an *upper bound* on the estimated contribution of standards to the growth of labour productivity.
- Finally, and most importantly, we did extend the contribution of JBG to examine the potential endogeneity of the stock of standards – loosely a situation where the direction of causality runs from productivity to standards rather than vice-versa.

The above considerations left us with a rather parsimonious estimating equation of the form below and we concentrate on this specification in what follows:

$$y(t) - l(t) = a + \alpha\,(k(t) - l(t)) + \epsilon\,std(t) + \lambda t + u(t) \qquad (2)$$

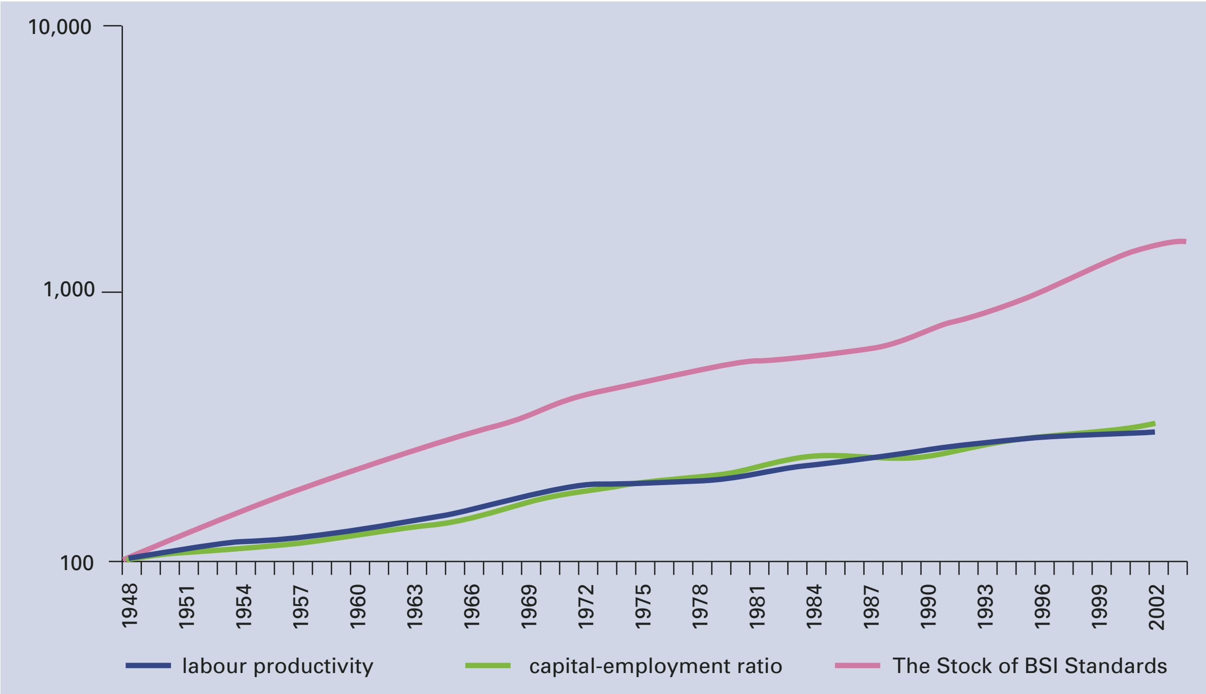
where, in addition to variables already defined:

$y(t) - l(t)$ = labour productivity
and $(k(t) - l(t))$ = the ratio of capital to employment

The following two figures illustrate the variables used in equation (2) over the sample period 1948-2002.

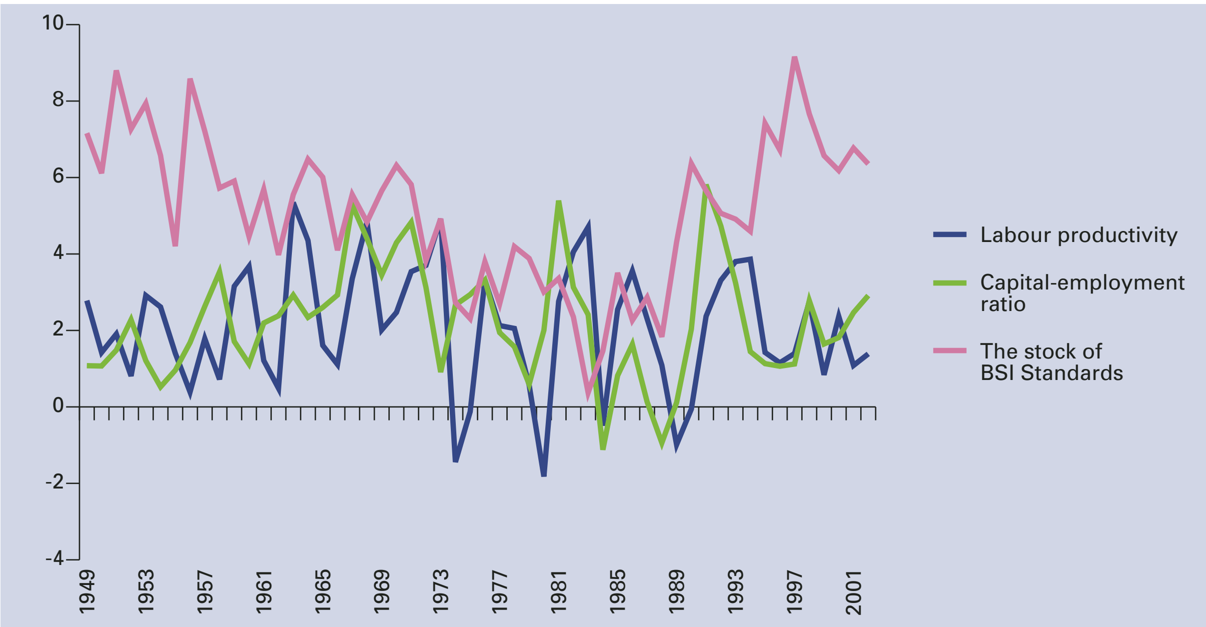
17 We may perhaps note here that our innovation variable was somewhat different from that of the JBG study in that it was based on an estimate of the stock of innovations based on numbers of patents granted in the US rather than domestically. If this more accurately represents significant innovation, then arguably this may be more closely associated with a demand for standards.

Figure 7
Long-Run Growth of Labour Productivity UK 1948-2002 (1948=100 log scale)



Source: ONS/own estimates

Figure 8
The Long-Run Growth in Labour Productivity: UK 1949-2002 (annual % change)



Source: ONS/own estimates

Figure 7 shows the relationship in terms of levels and Figure 8 in terms of year-on-year % rates of growth. Two features may be noted:

- As both figures illustrate, an important feature of the data is that the growth of the standard stock has been very fast in comparison with productivity growth. The average annual growth rate of the standards stock over the whole period 1948-2002 was 5.1%. This compares with 2.1% and 2.2% for labour productivity and the capital-employment ratio. The similarity in the latter two numbers exemplifies one of the great 'stylised facts' of growth economics – the relative stability of the ratio of capital to output.
- The growth in the stock of standards has been far from steady. The early post-war period shows rapid growth. Between 1948 and 1973, the growth rate in the standard stock averaged close to 6% per annum; it then fell to just 3.0% up until 1990. With the impact of the internationalisation of the standards stock reported above however, this rises again to 6.4% between 1990-2002. Importantly therefore, the rapid expansion in the BSI catalogue over the last decade is not outside the historical experience of the post-war years and is broadly similar to developments in the early post-war period.

Modern econometric time series analysis of the type required for estimating an equation such as (2) relies heavily on co-integration analysis, and this is particularly important in ascertaining the long run impact of standards on economic output. Broadly this involves ensuring that a spurious correlation does not result from the time series properties of the variables, especially where these are 'non-stationary'.[18] That this was a potential problem in estimating (2) was indicated by implementing standard tests[19] which indicated that each of the variables was indeed non-stationary but that the first difference of each variable was stationary. In order to avoid the possible problem of spurious correlation we employed the standard two-step procedure in which first a long-run 'static' relationship such as (2) is estimated. The computed residuals[20] or 'errors' $u(t)$ can then be used in a second stage in which a 'dynamic' equation is estimated and which specifies the process by which the 'error' is corrected over time. This is known as the 'error correction mechanism' or ECM.

Cointegration analysis guards against the possibility of estimating a spurious correlation between the variables in (2) by testing whether the residuals from the estimated relationship u(t) are themselves stationary. Table 1, column 2 shows the results from the static regression of (2). These suggest strongly that a co-integrating relationship exists between labour productivity, the capital-employment ratio, and the stock of standards. The ADF test on the residuals suggest that the null hypothesis – that there is no cointegrating relationship between the variables – can be rejected at the conventional 5% level of statistical significance. The computed long-run elasticity on the stock of

18 Loosely, that the moments and in particular the mean of the variable being considered is not invariant over time.

19 Augmented Dickey-Fuller (or ADF) tests.

20 With a one period 'lag'.

standards is 0.054 – roughly a 1% increase in the stock of standards is associated with a 0.05% increase in labour productivity.

For the purposes of economic interpretation it is important that only one cointegrating relationship between the variables exist. This is done by considering the main variables in turn as alternative dependent variables. Columns (3) and (4) of Table 1 accordingly show what happens when we ran regressions in which both the capital-employment ratio (3) and the standards stock (4) alternating as the dependent variable. Here we note that at the 5% level of significance we *cannot* reject the null of no co-integration in either regression. However, for (3), the null of no co-integration can be rejected at the 10% level, but only narrowly. The results therefore suggest just a single relationship, running from the standards stock and the capital-employment ratio to labour productivity.

Table 1:
Cointegrating Regressions using Ordinary Least Squares (sample 1948-2002)

(1) Variable	(2) Log (labour productivity)	(3) Log (Capital-Employment Ratio)	(4) Log (Stock of Standards)
Constant	2.064	-0.793	2.955
	(0.306)	(0.671)	(2.004)
Time	0.008	-0.001	0.024
	(0.002)	(0.003)	(0.009)
Log (Capital-Employment Ratio)	0.466	–	-0.287
	(0.057)		(0.420)
Log (Stock of Standards)	0.054	-0.032	–
	(0.028)	(0.046)	
Log (labour productivity)	–	1.216	1.277
		(0.149)	(0.658)
Model diagnostics			
RSS	0.017	0.045	0.408
$\hat{\sigma}$	0.018	0.030	0.089
R^2	0.997	0.994	0.985
$\overline{R}^2$	0.997	0.994	0.985
DW	0.723	0.488	0.100
t(ADF)	-4.507*	-3.696*	-2.202*
Time Period	1948 – 2002	1948 – 2002	1948 – 2002

Standard Errors are in parentheses
*Lag augmentation = 1. Approximate critical values (Davidson and Mackinnon 1993 p.722, Table 20.2) are -3.84 and -4.12 at the ten and five percent level, respectively.

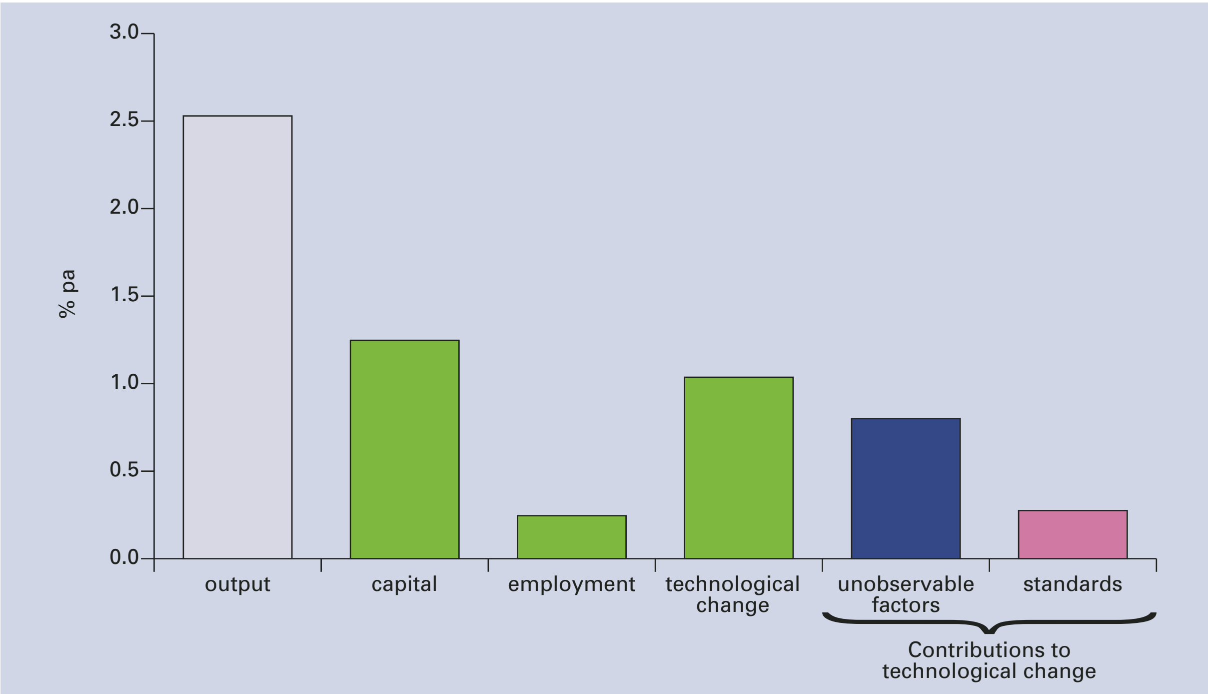
The second stage of the analysis consisted of a dynamic specification in which the errors from the static regressions in (2) are entered as an additional regressor. The results – reported in full in section 2.5 – continue to confirm the statistical significance of the long run cointegrating relationship,[21] while diagnostic tests do not suggest any model mis-specification. The results did not however suggest any significant short-run influence emanating from the standards catalogue. The lack of any *short run* impact from standards is of

21 In particular, the ECM term in the corresponding dynamic specification is highly significant at the 1% level.

course entirely consistent with both our theoretical discussion above – since standards take time to diffuse amongst a user population and with the contribution of Professor Swann – considered more fully below – in which standards have the maximum impact on information flows only after a considerable delay.

If we accept the estimated elasticities in Table 1, column 2, then we can make some rough calculations as to the extent to which standards are associated with long run productivity growth in the UK. Although the reported elasticity – at 0.054 – may appear low, this needs to be set against the high rate of growth of the standards stock. Together, the numbers suggest that standards are associated with growth in labour productivity of 0.28% per annum, or about 13% of the recorded growth in productivity over the period 1948-2002. This particular estimate can be recast into sources of overall growth of output in the UK. This is done in Figure 9, which breaks this down into growth due to the expansion of conventional inputs and that due to technological change. Our estimates of the overall impact of technological change is about 1.0% per annum over the same period – set against a growth rate of output in the whole economy (GDP) of 2.5%. The contribution of standards to technological change is over 25%.

Figure 9
Contributors to Output Growth in the UK (1948-2002)

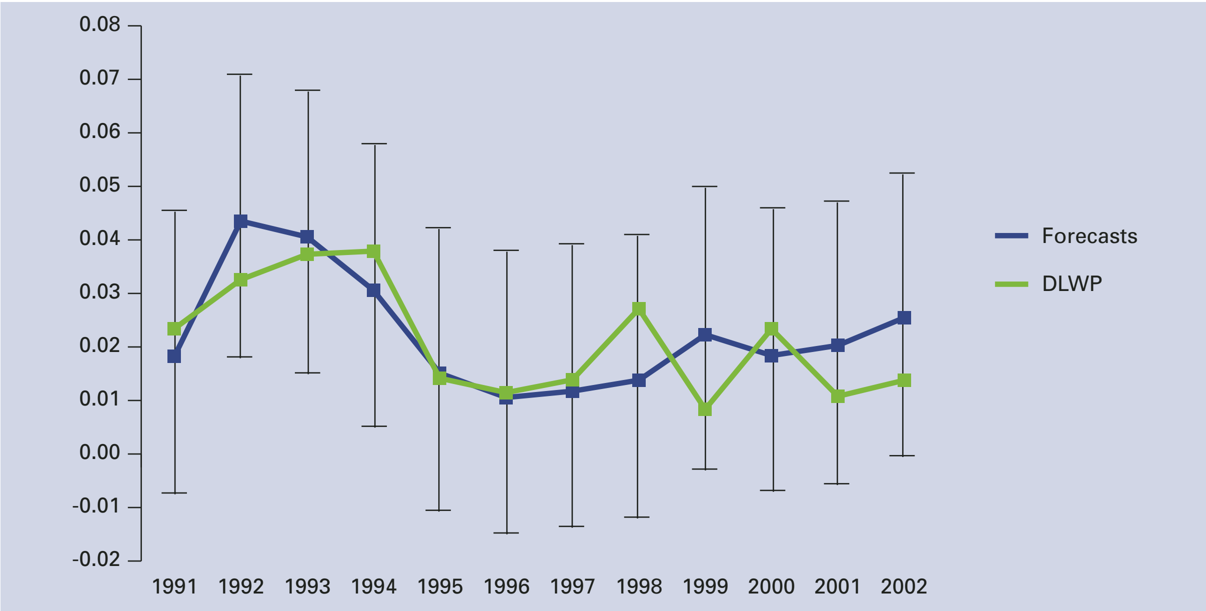


Source: ONS/project estimates

Great care of course needs to be taken in interpreting such figures, since – as we have stressed – standards should be regarded as a joint (if essential) input into the process by which new technologies are diffused, and markets are created.

A final experiment concerned the impact of the changing nature of the BSI catalogue – reported above. If there was significant 'inflation' of standards because of the internationalisation of the catalogue – and especially the pooling of standardisation efforts at a European level – and this were diminishing the impact of standards, then we might expect the estimated model to perform poorly in the recent past. In fact we find no such evidence. Figure 10 suggests that the dynamic model forecasts reasonably well over the period 1991-2002. Neither a conventional one step ahead forecast nor a Chow test of parameter stability suggest that the model 'breaks down' over the recent past.

Figure 10
Dynamic Model Forecasts (1991-2002)



Source: Own estimates

1.6. Results from Project 2: Standards and the International Transmission of Technology

For a number of reasons it was considered vital to supplement consideration of the impact of standards on productivity growth with a more detailed analysis of what has been happening over the last decade or so. The following considerations stand out:

- For modern open economies such as the UK, the global sourcing of technology is a key source of technological change. The creation of standards does not appear to be very different from the pattern revealed by other technological indicators. As we saw above (section 1.3) the contribution of purely national standards to the total BSI catalogue has been declining rapidly.
- On the other hand, the total stock of standards has been expanding rapidly over the past decade or so, reflecting a considerable shift in the use of

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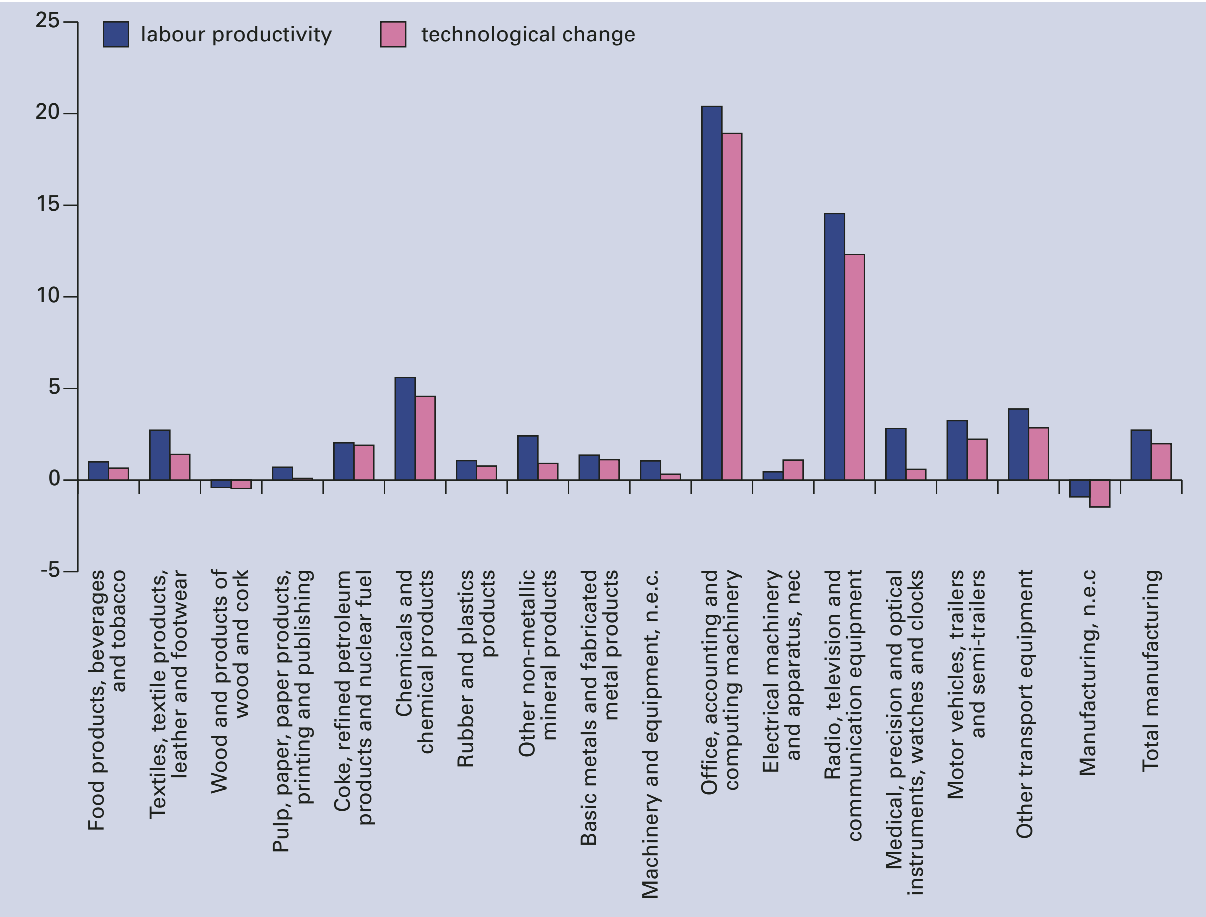
resources in standardisation activities toward the pooling of resources at the EU level and the adoption of standards originating with pan-European standards bodies – CEN, CENELEC, and ETSI. In part, these developments reflect the so-called 'new approach' of the EU regulatory framework in which standards figure as important mechanisms for its specification and implementation.

- Thirdly, it is important to assess how far the estimated impact of standards can be replicated at a sectoral level. Here we find that across some 17 manufacturing sectors and as Figure 11 illustrates – and as we saw at the level of the whole economy – that technological change apparently plays a major role in explaining productivity growth.[22]

Figure 11
Contribution of Technological Change to the Growth of Labour Productivity By Manufacturing Sector 1990-2000 (% per annum)



Source: OECD (STAN) database as at April 2004

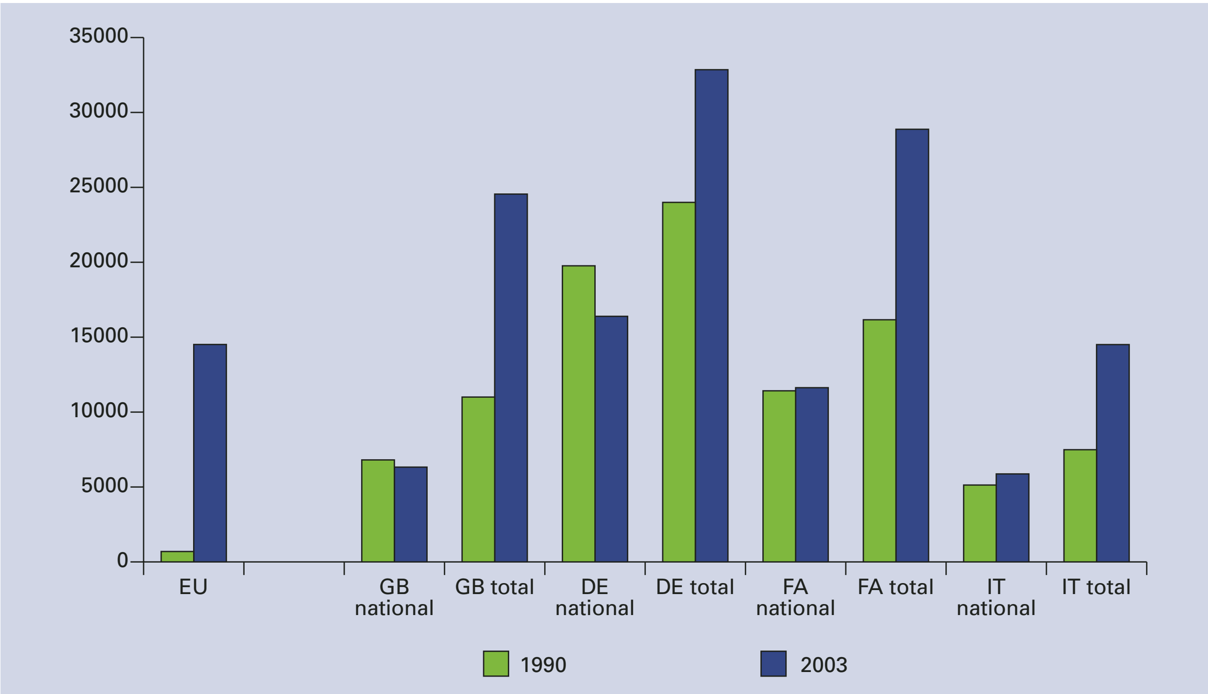
The implications of this considerable redeployment of the UK's public standardisation resources are far from clear. On the one hand, it may be that the trend to standardisation at the European level involves the creation of at least some standards of little relevance and benefit to UK producers. On the

22 These estimates of the contribution of technological change are based upon conventional growth accounting techniques and may differ from other estimates.

other, it may be a more efficient vehicle for the international transmission of technology. The balance of these two considerations and its long run implications for the UK is therefore, an empirical matter. While, as reported in the last section, the aggregate model of standardisation did not 'pick up' any major change in the contribution of standards to productivity growth in the recent past, the team felt it important to analyse this period more fully. This work has mainly been conducted by Dr Knut Blind and Dr Andre Jungmittag at the *Fraunhofer Institute for Systems and Innovation Research*.

The UK is of course not alone in experiencing both a rapid expansion of standards and a redeployment of resources. As Figure 12 indicates, all the four countries looked at in this project, the UK, Germany, France and Italy, experienced rapid rates of growth in their total standards stocks. The total EU standards available for use increased from a very small number in 1990 to nearly 15,000 by the end of 2003. In 1990, the German stock was by far the largest of the four economies and benefited least from the increase in 'EU' standards.

Figure 12
The Growth of the Standards Catalogue in Four Economies (1990-2003)



Source: PERINORM©

As far as 'national' standards are concerned, growth was negligible, and in the case of Britain and even more so for Germany, negative. The data suggest therefore that much of the growth in the EU stock may have taken the form of 'pooling' existing national standards. That Germany provided the biggest contribution to the pool provides a plausible explanation of why its national standards have declined the most, but this cannot be quantified using PERINORM©.

The basic methodology pursued by the Fraunhofer team was essentially similar to that of project 1 but applied instead across a number of manufacturing sectors and across the 4 European economies depicted in Figure 12. The study was made possible because of the richer data on standards available through PERINORM©, which permits the count of standards to be performed in terms of those that appear to be relevant to a particular sector. The dataset also allowed the team to distinguish between 'EU' standards (originating with CEN, CENELEC, ETSI), those which can be traced to ISO and the IEC (but not to CEN etc) and which we term 'other international' standards, and those which appear to have only national origins.

The shift in the pattern of resources toward what we might loosely turn harmonisation activity has been replicated in other European economies and at a sectoral level. Table 2 provides estimates of the growth in the BSI catalogue for a number of sectors of UK manufacturing over the period 1990-2002.[23] Nearly all sectors show declines in purely national standards but considerable growth overall. Only the office machinery and computing sector bucks this trend with especially strong growth at a national level. However, this is mainly explained by a very low starting point in 1990. In 2002 the national contribution in this sector to the relevant part of the catalogue was still less than one quarter.

Table 2:
Growth of the BSI Catalogue by sector: 1990-2002

	ISIC rev 3	National standards % p.a.	Total % p.a.
Food products, beverages and tobacco	15-16	0.5	5.4
Textiles, textile products, leather and footwear	17-19	-1.3	5.5
Wood and products of wood and cork	20	-5.0	6.4
Pulp, paper, paper products, printing and publishing	21-22	-2.3	4.8
Coke, refined petroleum products and nuclear fuel	23	-0.3	6.3
Chemicals and chemical products	24	-0.6	3.2
Rubber and plastics products	25	-1.4	6.8
Other non-metallic mineral products	26	-1.4	4.7
Basic metals and fabricated metal products	27-28	-1.8	6.2
Machinery and equipment, n.e.c.	29	-2.2	5.8
Office, accounting and computing machinery	30	15.5	12.9
Electrical machinery and apparatus, nec	31	0.2	7.6
Radio, television and communication equipment	32	-0.6	8.5
Medical, precision and optical instruments, watches and clocks	33	-3.0	5.9
Motor vehicles, trailers and semi-trailers	34	-3.0	2.9
Other transport equipment	35	-1.1	5.9
Manufacturing, n.e.c.	36-37	-1.4	7.8

Source: PERINORM©

23 With the exception of Germany, a slight adjustment was needed to correct for a 'bias' in the count of standards at a sectoral level. This is because the ICS classification of standards in PERINORM© is only available after 1994. Hence there is an undercount of standards which were published prior to 1994 but which were withdrawn in the period 1990-94. The correction was based upon aggregate withdrawals for this period.

Compared with the aggregate model, the sectoral model analysed by Dr Blind and Dr Jungmittag has both advantages and disadvantages. We may note:

First that the use of a number of sectors and countries considerably extends the number of observations. At a maximum, 11 years of data (1990-2001), 4 countries (UK, France, Germany, Italy), and 12 sectors. This gave a maximum of 528 observations (rather than 54). The twelve sectors covered (with ISIC/NACE codes) were as follows:

Sector	ISIC/NACE codes
Food products, beverages and tobacco	15–16
Textiles, textile products, leather and footwear	17–19
Wood and products of wood and cork	20
Pulp, paper, paper products, printing and publishing	21–22
Chemical, rubber, plastics and fuel products	23–25
Other non-metallic mineral products	26
Basic metals and fabricated metal products	27–28
Machinery and equipment, n.e.c.	29
Electrical and optical equipment	30–33
Motor vehicles, trailers and semi-trailers	34
Other transport equipment	35
Manufacturing, n.e.c.	36–37

Second, the cross-sectoral time variation in the data often reduces the problem of collinearity between standards and patents which we reported for the aggregate model. While the Fraunhofer team acknowledge that in many instances innovation and standardisation are effectively complements in the development of markets, they still felt it useful to analyse the model not just with standards but also with a measure of innovation. This was based on a series of patent applications at the European Patent Office and available at the two digit level of the NACE/ISIC industrial classifications. The panel approach allows the comparison of estimations separately by country and by sector, which is helpful for consistency checks.

Third, however, the shortage of the time dimension to this series meant that the Fraunhofer team felt unable to consider a 'dynamic' model of the kind employed in the aggregate analysis.

As a result of the above considerations, the basic 'panel' model used was similar to that in Jungmittag et al (1999), although data for payments for licences do not exist at a sectoral level and hence had to be excluded from the model.[24]

24 The full model can be written as:

$$y(i,j,t) = a_i + a_j + a_t + \alpha k(i,j,t) + \beta l(i,j,t) + \gamma\, pat(i,j,t) + \epsilon\, std(i,j,t) + u(i,j,t)$$

i = sectors 1,.....12
j = countries 1,....4
t = time periods 1990,......2001

where: a_i, a_j, a_t are the sector, country, and time effects
y (i,j,t) = added value in sector i, country j at time t
k (i,j,t) = capital input in sector i, country j at time t
l (i,j,t) = employment input in sector i, country j at time t
pat (i,j,t) = EPO patent stock in sector i, country j at time t
std (i,j,t) = effective stock of standards in sector i, country j at time t
u (i,t) = error term

Results for three variations on this basic model are presented here in Table 3: the first two columns show the results of ordinary least squares regressions (LSDV) both with time effects (column 1) and since these turn out to be statistically insignificant as a group, without the time effects (column 2). Country and industry effects are highly significant and retained in both models. The estimated elasticities on the standards stocks are rather similar to those reported in the aggregate model (section 1.5) although here of course patent stocks are also included.[25]

Table 3:
Estimation results for all four countries and 12 industries (n=509)

	Model 1 LSDV (1)	Model 2 LSDV (2)	Model 3 Ridge Regression (3)
Capital	0.104	0.118	0.230
	(3.998)[a)]	(4.490)	(11.639)
Labour	0.801	0.772	0.648
	(33.055)	(34.583)	(30.912)
Patent Stock	0.270	0.324	0.105
	(5.185)	(8.841)	(11.785)
Standards (total)	0.033	0.049	0.079
	(1.526)	(2.314)	(6.077)
F-Tests			
Country effects	47.990	51.650	Yes
	(0.000)[b)]	(0.000)	
Industry effects	21.447	28.395	Yes
	(0.000)	(0.000)	
Time effects	1.158	–	
	(0.314)		
Ridge parameter	–	–	0.015
R^2_{adj}	0.976	0.976	0.965

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White’s heteroscedasticity consistent t-values for LSDV estimation.
b) Significance levels in brackets.

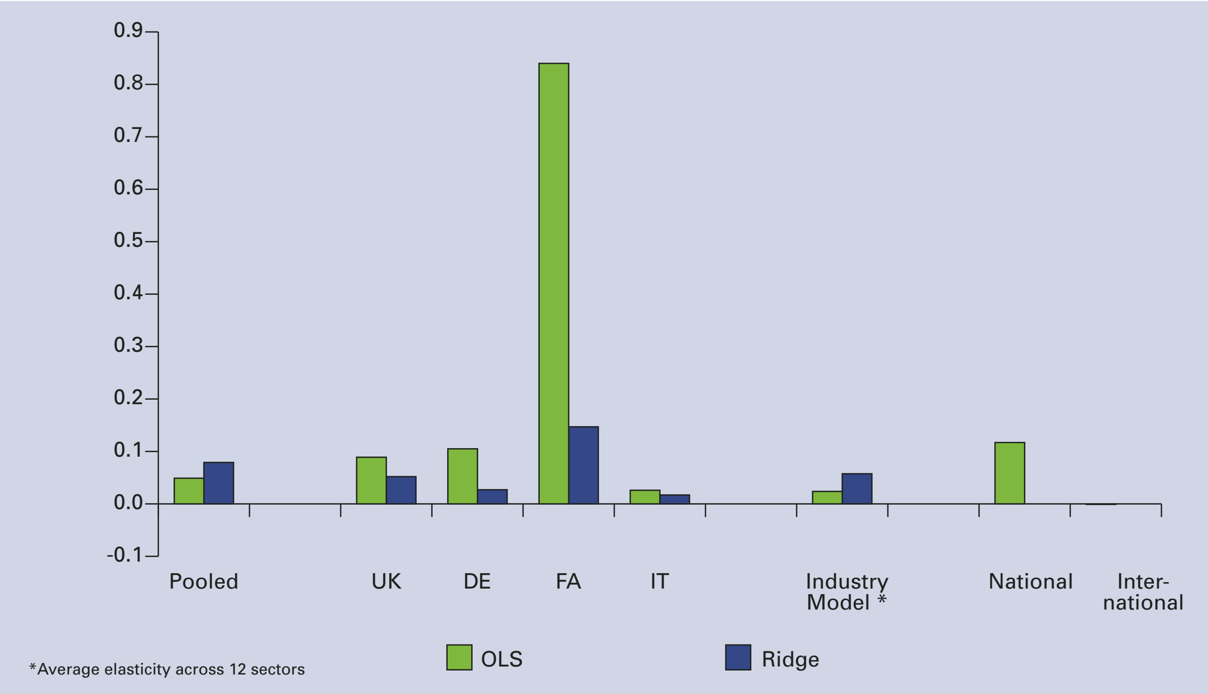
A feature of the underlying data is the high degree of statistical correlation between the standards and patent stocks, but also with the two other input factors which tends to result in imprecise estimates of the elasticities associated with each. The third model is an attempt to provide more precise estimates of the elasticities using a technique known as ‘ridge regression’. This however sacrifices the ‘unbiased’ properties of the estimated coefficient in columns 1 and 2. However, the results continue to support a positive impact from the standard stock and leads to more reasonable estimates of the contribution from the input factors, capital and labour. Note that the estimated impact (‘elasticities’) from standards is very similar across all the models to those reported in project 1, although allowance is now made for the impact of patents, which in Model 3 have an elasticity about 20% higher than that for the standards stock.

25 If the patent stock is not included in the panel model, the elasticity of the standard stock increases to 0.064.

A feature of the results reported in Table 3 is that the impact of standards is assumed to be invariant both across industries and across countries. There were in fact sufficient data points for the consideration of variations in this impact by country (the ‘country models’ reported in section 3.3.2) as well as by industry (the ‘industry models’ reported in section 3.3.3).[26] In addition the authors also report experiments with standards stocks differentiated by whether they are of national, European or ‘other international’ origin.

Rather than provide the details of the whole suite of models, which can be found in section 3, Figure 13 provides an overall summary of the results focusing on the elasticity estimates for the stock of standards. The figure first shows the results from the pooled model (Table 3), followed by the results from the ‘country model’ and the ‘industry model.’ Finally a variant of the ‘pooled model’ is shown (excluding Italy) which allows for a different impact from stocks of international and national standards.

Figure 13
Summary of Elasticities on Standards Stocks



Source: Own estimates

The following are the main points to note:

- The estimates of the elasticity on the standards these are mainly in the range 0.02-0.1 whether the OLS or Ridge estimates are considered or not.
- As far as the individual country models are concerned, the results fit the general pattern, except for the OLS results for the French panel which seem highly implausible, although here the Ridge estimates are closer to the general pattern. For the UK, the estimates for the two estimation techniques are 0.089 and 0.052 respectively.

26 The ‘country models’ continue to ‘pool’ data across industries, while the ‘industry models’ continue to ‘pool’ across countries.

- For the industry models, the authors note the limited number of data points available for these estimates. However, the average of the estimates across all the industries gives broadly similar overall results.
- As for variation between industries (not illustrated), the authors observe that a rough pattern can be discerned, with a significant impact from standards in the more mature (less R&D intensive) sectors and with a greater impact from the knowledge base (as measured by patents) as R&D intensity increases.
- The final estimates shown in Figure 13 are for a pooled model[27] in which the standards stocks are differentiated by whether they have national or international[28] origins. Here the impact of the latter is both negligible and statistically insignificant – and indeed not discernible in the figure. The authors note that – over the sample period – the standardisation process in Europe needs to be regarded as in a transition phase. When this is completed, 'more stable patterns of the division of work (within the NSBs) and their respective impacts should be observable'.

1.7. Results from Project 3: To what extent do Standards enable Innovation?

Earlier discussion suggested that standards and standardisation activities strongly supported the processes by which new technology is adopted and used by firms and consumers. Not least, publicly available standards have a potentially very powerful influence on the dissemination of information about technology, emanating from both domestic and, increasingly, global sources. Economic theory suggests however that the relationship between standardisation and innovation is more complex with the potential at least to impede innovation as well as to enable it. Here we report on the research conducted by Peter Swann which considers the relationship further. It is based upon a fusion of the standards data made available in PERINORM/BSI ONLINE, and that contained in the Community Innovation Survey (CIS3) which contains questions on the role of standards as a source of technical information, as well as the extent to which standards inhibit innovative activity.

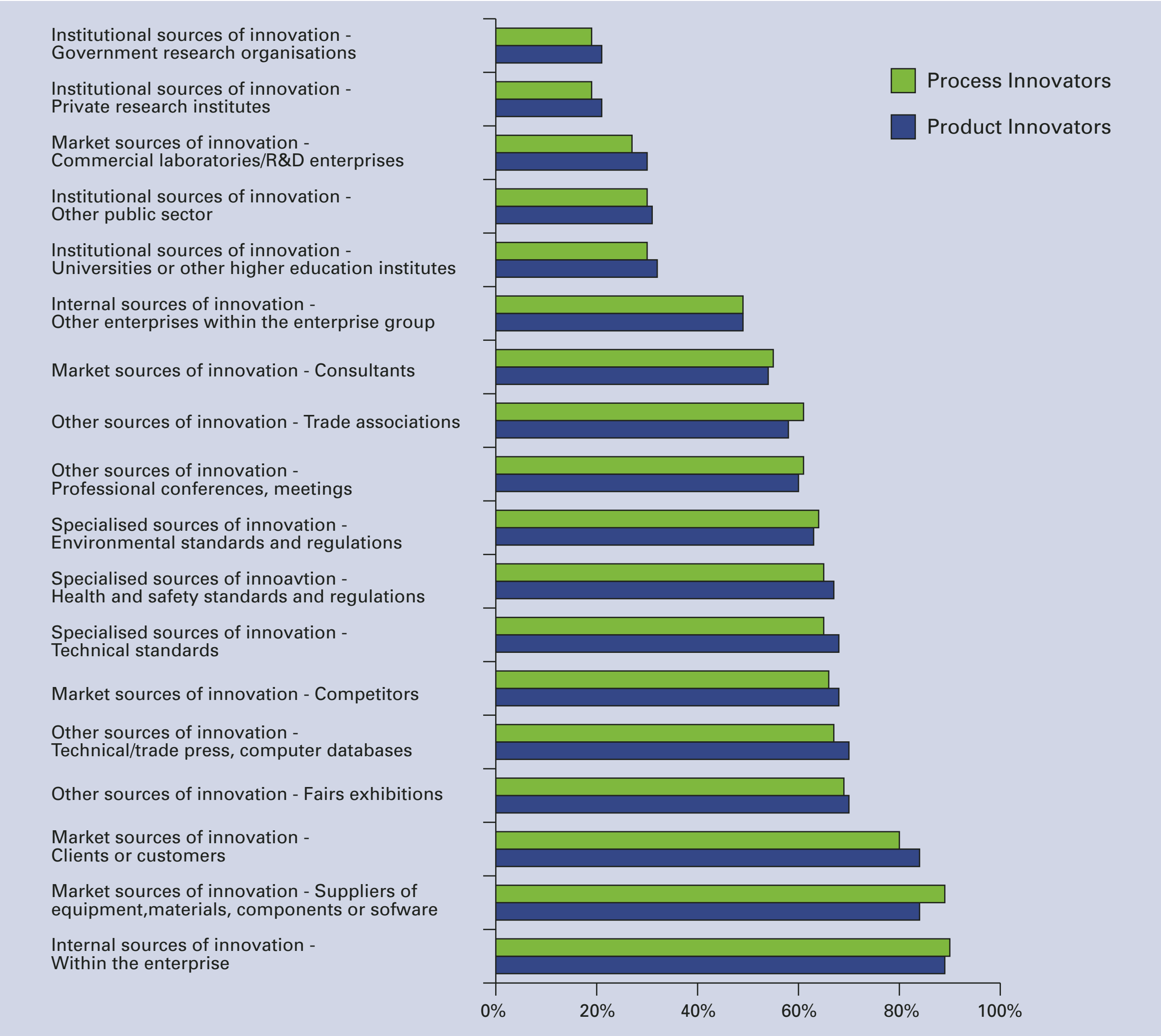
First and foremost, because they provide information, standards have a considerable role in stimulating a knowledge intensive activity such as innovation. As Knut Blind reports, 'Researchers, developers, construction engineers and marketing experts utilize … standardisation documents as important sources of information about the state of the art in technology' (Blind 2004). This is backed up by Figure 14 – based upon CIS3 and calculations kindly supplied by Peter Swann – which demonstrates the significance of the role played by standards as providers of information for innovating UK companies regardless of whether they are

27 The pooled model here includes all countries except Italy, which caused problems in identifying European or international standards within the total stock of standards due to missing information in the database.

28 The low initial starting point for the stock of 'European' standards effectively prevented further differentiation.

product or process innovators. It is worth noting that the data may here be *understating* the actual role played by standards and NSBs. This is because many of the cited sources of information in question 3 are 'proximate' causes: if for example Firm 1 cites a competitor – Firm 2 – as a source of information. But Firm 2 may be using standards as a source of information. The possible understatement may be important if, for example, the high ranking 'market sources' of information approximate to pure 'intermediaries' in the process of information dissemination,[29] while other agents and institutions are acting in a primary role. While it may be the case that NSBs are also intermediaries, the development of a standard typically involves the systematic screening of technology worldwide, including information contained in patents. A relevant analogy might then be with that of an important wholesaler (and importer) in the dissemination chain.

Figure 14:
Sources of Information for UK Innovating Companies



Source: Community Innovation Survey/Peter Swann

29 In his investigation of Innovative Businesses and the Science and Technology Base (2002) for the DTI, Peter Swann makes a similar point with respect to the input of Universities.

Economic theory suggests that standards may in certain ways impede the innovation process. One important issue relates to timing, for standardisation at an inappropriate time can lead to economic inefficiency. Too early, and a standard may effectively shut out promising and ultimately superior technologies. Too late and the costs of transition to the standard may be too high – preventing diffusion. A perceived shortening of product cycles suggest that the latter problem may be increasingly important. Indeed, standards bodies have already started to respond to the demand for a shorter time frame. Nowadays, many standards are available in draft form, such as the CEN 'workshop agreements'.[30] To measure this aspect of the 'condition' of the standards stock, Professor Swann proposes the median age of the standards stock, i.e. the age of the median 'vintage' or year of publication of the standards available during the time of the CIS3 Survey in 1998-2000.[31]

Given the preceding discussion, it is perhaps less surprising than it is at first sight, that Professor Swann finds – at both the level of the individual company and when aggregated to sectors – a *positive correlation* exists between standards as a constraint upon innovation, and standards as a source of information. It appears that 'effective' standards both provide relevant information and place constraints on innovation.

But what characteristics of the catalogue available for producers make standards effective? Here, Professor Swann's contribution employs the methodology of the standards count used in Projects 1 and 2, but develops it further in considering one additional measure of the *'condition'* of the standards stock. This is provided by the 'median age' of the stock – a highly relevant variable for those who believe that NSBs produce standards 'too slowly'. The study establishes that for any given company, there is considerable variation in the condition of the relevant part of the standards catalogue, in terms of both the *number* of standards available and the *age* of the typical standard available, according to the sector in which it operates.

To what extent do these two measures help us to predict the effectiveness of the standards stock either in providing information or constraining innovation? To answer this question two ordered logit models are estimated based on CIS3 questions 12.1 and 8.1,[32] one for the informative role of standards and one for their constraining role. In addition to the role played by the condition of the catalogue, the richness of the CIS dataset allowed a number of other variables to be considered alongside the questions concerning standards.[33]

30 For example PERINORM© listed 6725 'draft standards' as available through the BSI at end 2003, more than 25% of those available as finished documents.

31 Since the distribution of the number of standards by year of publication is approximately exponential, the median is a 'sufficient' statistic to describe the whole distribution.

32 The ordered logit model allows for the estimation of models in which the dependent variable is of a categorical nature but nevertheless allows for a ranking: in this case of responses to questions in CIS3. In the case of the informative model, Question 12.1 asks respondents to rank (among other sources) a) technical standard b) health and safety standards and regulations and c) environmental standards and regulations as either 'not used' or as being of 'low', 'medium, or 'high' importance. Question 8.1 asks respondents to rank (among other sources) the 'impact of regulations or standards' on the enterprise's ability to innovate. The categories are 'no effect', or of 'low' 'medium', or 'high importance'.

33 Apart from interest in their own right, they are also important in controlling for other influences.

As far as the model of *information provision* is concerned, the finding is that in general the more standards available to a producer then the more information is provided. However, there appears to be a non-linear effect of the median age on the provision of information: as the median age of the standards stock increases, more information is provided, but beyond a certain point the effect is reversed. An increase in the median age of the catalogue then begins to have a negative impact. The relatively simple explanation of this offered in the study is that newly published standards take time before they are widely used and it is only when they are widely used and understood that information provision reaches its greatest extent. At the other end, old standards are less informative, reflecting a life-cycle effect where the technologies, products etc. to which they refer become increasingly outdated. The model of information provision seems robust to whether it is technical standards, health and safety, or environmental standards that are being considered. As far as other co-variates are concerned the research indicates that:

- Innovating firms, those more with longer term innovation activities, those with a high proportion of scientists and engineers on the payroll, and those who co-operate in innovative activities are all more likely to find the information content of standards of value;
- Firms who find that standards constrain innovation are more likely to find them of value as sources of information, confirming the correlation noted above, but in a multi-variate setting.
- No relationship with size or exporting activity.

For the model estimating the *constraining role of standards*, the author finds a significant negative relationship with the number of standards but a positive relationship with its square. In other words, the model suggests that as the *number of standards* relevant to a sector increases, producers are less likely to find standards as an impediment, but after a point, the quadratic term starts to dominate so that more standards increase the constraint on innovation. A similar result is found for the *median age* of the standards stock: increasing age initially relaxing the constraint, but this is reversed beyond a certain point. The explanation advanced here is that, 'it seems likely that both rather old and rather new standards constrain innovation – the first because it locks the innovator into legacy systems, and the latter because it challenges the innovator'. We might add here that there must be a degree of uncertainty with a new standard as to whether it will be widely used.

Fewer co-variates are of importance in the innovation constraints model, although this model also confirms the positive association between the informative role of standards and the constraining role of standards.

Taken together, the parameters of the two models provide some clues as to the 'optimum condition' of the standards stock – with respect to both the number of standards and the median age. The median age of the standards stock that maximises its information content is rather higher than the median age that minimizes the innovation constraint. This reflects the fact that the informative role of standards depends on their widespread diffusion, and that diffusion takes time.

2. Long-Run Growth in the UK: The Role of Standards

2.1. Abstract

In this paper we consider the relationship between the standards created by national standards bodies and long run economic growth, exploring the relationship in the context of the UK and the British Standards Institution (BSI). We suggest that standards provide a key enabling mechanism for the widespread diffusion of major technologies, while being generally supportive of incremental innovation and general technological understanding. In order to further understanding of this mechanism we measure the 'output' of the BSI by estimating the size of the BSI 'catalogue' available to the economy since its inception in 1901. The measure allows us to estimate an augmented production function for the UK economy over the period 1948-2002. Within a co-integrating framework, we find a statistically significant and unique co-integrating vector between labour productivity, the capital-labour ratio, exogenous technological progress and the BSI catalogue. The long-run elasticity of labour productivity with respect to the standards stock is estimated to be about 0.05, so that the rapid growth of the catalogue in the post-war period is associated with about 13% of the aggregate growth in labour productivity.

2.2. Introduction

It is unarguable that individual standards – documents that provide technical specifications – can improve productivity. The first 'public' standard in Britain in 1901 reduced the number of types of steel sections from 175 to 113 and the number of tramway gauges from 75 to 5. Estimated cost savings to the steel industry amounted to £1 million a year.[34] But do the institutions that produce them have measurable impacts at the level of the whole economy? Below we tackle this question in the context of the British Standards Institution (BSI), arguing first that standards provide a key enabling device for the uptake (diffusion) of technology. Their input needs to be seen as complementary to other inputs into the process of technological change, most importantly by ameliorating possible market failures in the diffusion process. We then suggest that the 'catalogue' of standards provides a plausible indicator of the productivity enhancing benefits of the institution. Finally, an econometric model is used to show that there is a measurable and validated statistical association between the catalogue and productivity growth in the UK, at least in the period since World War II.

34 History of the BSI Group (BSI undated).

The plan is as follows. The next section considers the general relationship between public standards and economic growth, seeing the main contribution via the impact upon processes of technological diffusion. Section 2.4 then considers a measure of the 'output' of the BSI, seeing it in terms of the growth and maintenance of its 'catalogue'. This measure is then used to estimate a simple augmented production function model of labour productivity growth in the UK over the period 1948-2002. To anticipate our results, we find that that the growth of the catalogue is associated with around 13% of productivity growth. Section 2.5 interprets our results.

2.3. Standards, Technological Change and Productivity Growth

Both the theory and the empirical analysis of economic growth have come a long way in the last two decades. Broad agreement on the significance of the role played by technological progress in achieving growth has meant that much attention has focused on the stimuli provided by markets and institutions in creating such change. Here however, the well-known Schumpeterian distinction between 'innovation' and 'diffusion' as conceptually distinct elements in technological change, suggests an interesting point of difference, with an emphasis in modern (endogenous) growth theory on the part played by innovation. This is not perhaps surprising. It is commonly suspected that – unaided – firms will under-provide resources for innovation. It not only involves fixed costs, but is also risky, not least because a competitor may be in a position to reap the benefits. In situations of fixed costs, model builders have been keen to demonstrate the importance of the size of the market, while noting the potentially deleterious effects of competition. The recommended institutional support in such circumstances involves the creation of intellectual property rights, or the public support of research activities whether through direct provision for research or through R&D subsidies. By contrast, most endogenous growth theory has tended to downplay the significance of diffusion processes, with innovations being adopted at once.

Empirical analysis, while hardly denying the role played by innovation has also highlighted important differences between firms and economies in their access to, or uptake of, technology. At the same time a large body of theory has shown that markets may also fail in delivering efficient diffusion paths. Stoneman and Diederen provide a convenient summary of such failures, noting the role of imperfect information, market structure, and externalities (Stoneman and Diederen 1994). In economic policy moreover, an increasing interest in the diffusion of technology has been apparent for some time, not least in the UK.

How do standards fit into the Schumpeterian trilogy? In order to avoid contextual dependence, we define standards here as consisting of documents providing 'technical specifications that may be adhered to by a producer, either

tacitly or as a result of a formal agreement (David 1995)'. More particularly we shall be referring, unless stated otherwise, to the sub-set of these documents which are the measurable output of National Standards Bodies (NSBs). In the case of the UK this body is the British Standards Institution (BSI). The documents themselves are the outcome of a co-operative process among the participants of technical committees. Ideally the outcome should represent the interests of various 'stakeholders', communities of producers and users.

The potential benefits arising from individual standards are reasonably well known. Four main economic functions are usually identified:[35]

- Providing for *inter-operability* or compatibility between different parts of a product or more generally between different elements in a system or network.
- The provision of a *minimum level of quality*, which may be defined in terms of functionality or safety of products.
- The *reduction of variety*, allowing for economies of scale.
- The provision of *information*.

NSBs are not the sole source of such technical documents. Market processes do of course create standards of a similar nature (often described as 'de-facto' or 'proprietary' standards), where individual firms can and do develop their own standards to improve their own profitability, while consortia also develop standards for perceived mutual economic gain. The important point however is that the creation of standards is itself subject to market failure, and there is a strong presumption that, unaided, markets will under-provide for standards. This last point is probably well understood: the development of standards involves fixed costs, and the gains may not always be appropriable by the individual firm which develops one.[36] Together, these give standards properties akin to a 'public good'. Moreover, as Swann (2000) observes, these standards do not always possess two qualities of the institutionally produced standard:

- The first is *'openness'.* This means that it is available – on an equal basis – for all competitors. Some proprietary standards may be open – but there is no presumption of this – indeed probably the opposite. This characteristic may be particularly important for small firms. Proprietary standards tend to create market power, and higher prices may slow down the rate at which firms adopt an innovation. Inter-temporal price discrimination may enhance this effect (Stoneman and Diederen, 1994).

35 For a general survey of the economics of standardisation, see Swann (2000).

36 They may however be sufficiently appropriable to make standards 'contests' or 'races' an interesting phenomenon in their own right.

- The second characteristic of 'public' standards is that of *'credibility'*. Government sponsorship and other aspects of standards help to create confidence that a standard may achieve widespread use.

One other possible differentiating characteristic of the standard is that, being the outcome of the deliberations of a committee, and based upon the need to be based upon consensus, they may take longer to produce than market-led standards. This has been a frequent criticism of standards setting institutions, particularly in sectors where technological advance is rapid.

Arguably, each of the above functions and characteristics can be viewed as 'enabling' the spread of technology. In recent years economic theory has focused primarily on the first kind of function reckoned to be vital for the widespread adoption of 'system technologies' in (for example) computing or in communication technologies. Here the benefits from adoption and the extent of diffusion depend upon the number of existing users either directly with the development of a network – of mobile telephones for example, or indirectly via 'hardware-software' effects in which the widespread adoption of a technology depends upon the existence of complementary products. In such examples, referred to as cases of *network externalities*, standards are clearly integral to adoption. In many cases it is the agreement and co-ordination that a standard achieves that is important – the precise characteristics of the standard – and whether it is actually the 'best' standard, are far less important.[37]

It is well recognised in the literature that network externalities may be particularly important in the spread of several key technologies in the past century or so, especially so-called 'general purpose engines' as noted for example by David (1990). This term refers to significant innovations which serve as common modular units with a wide variety of applications using appropriate engineering designs. Familiar examples include Watt's steam engine (e.g. Crafts 2004), the dynamo (David 1990), or the computer as a component of information technology (Oliner and Sichel, 2000). In the development and diffusion of such major technologies, it is well known that 'standards' provide an essential input, establishing compatibility and interoperability between components in the system.

On occasion, historians have pointed to a lack of standardisation as a stumbling block to the diffusion of a key technology. In the UK, the early history of electrification was notorious for the variety of standards in operation. Landes for example reports that 'voltage varied from town to town or even from street to street; those systems that offered alternating current did so at different cycles; the effect on the electrical goods industry may easily be imagined' (Landes 1972, p. 434-5). It was only with the establishment of the

37 There are case studies beginning perhaps with David (1985) who used the example of the QWERTY design of keyboards, which suggest that the final standard selected is not always the 'best' from a technological standpoint. Because of the counter-factual nature of the exercise, it is very hard to substantiate. Although the accepted wisdom suggests that QWERTY is not as efficient a layout as others (notably the Dvorzak simplified), this conclusion is not universally accepted (see for example Liebwitz and Margolis, 1994).

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Central Electricity Board, that the dominant pressure of 230v became something of a norm in the industry. In any event, Germany was well ahead in the diffusion of electric power in the inter-war period, and here a diversity of standards does not appear to have been a problem (ibid, p. 436).

The diffusion enabling and productivity enhancing benefits of standards are not by any means restricted to major technologies. Some economists have argued that these hardware-software effects may be considerably more widespread than these familiar examples, especially in relation to the way that labour force skills may be harnessed.

Moreover, while *compatibility* standards have attracted much attention in business and amongst policy makers, as well as economists, the other functions of standards can also be seen as impacting upon technology adoption.

Insofar as they provide *information*, standards promote technological understanding. As a recent study of standards points out, 'Researchers, developers, construction engineers and marketing experts utilize ... standardisation documents as important sources of information about the state of the art in technology' (Blind 2004). As evidence in the UK, there is the fact that standards feature prominently as a source of information for innovators in the UK's Community Innovation Survey (CIS3).[38]

Many economic explanations of diffusion processes stress the role played by information in the uptake of a new technology. For example, the well-known epidemic model is based upon the idea that information passes on a 'word of mouth' basis amongst a homogeneous intermingling community. This model generates the familiar 'S-shaped' diffusion pattern[39] typically, but not universally, found in empirical studies.[40] In various respects however, the model is not entirely satisfactory[41] and more sophisticated models have begun to examine the nature and the quality of the information involved. A useful distinction is sometimes made between 'word of mouth' and common or 'broadcast' sources of information.[42] The initial broadcast may for example come from the manufacturers of the capital equipment or 'hardware' associated with the technology. In the CIS survey cited above for example, the response to the question of which sources of information are important, 'suppliers of equipment, materials, components or software' features as a leading source for innovators and non-innovators alike. Allowing for some random process[43] there will be early adopters as a result of this common

38 And to a lesser extent amongst non-innovators. The survey shows that while information from other firms is particularly important, standards are roughly as important as a source of information as the trade press, and rather more important than consulting firms or universities.

39 In which there is a relatively rapid period of growth some time after the initial innovation, which then slows at some particular date.

40 For a recent review of such models see Geroski (2000).

41 Geroski (2000) points to the fact that the we need an initial base of users before the process can begin, as well as the fact that the diffusion path is not usually as symmetrical as the simple theory predicts.

42 The broadcast form of information communication does not in general create an S-shaped diffusion path.

43 In a simple 'broadcast' model, some given % of the potential population adopt in any time period.

source of information. Arguably however the epidemic effect requires a different quality of information, one imbued with knowledge that comes from actual use of the technology.[44] Clearly such knowledge is more 'tacit' in character and may require 'word of mouth' transmission. This type of approach may for example help explain the importance of geographical agglomeration effects in industries where technological change is rapid. Arguably, the process of setting standards typically also adds economically valuable *user* information. Depending upon the context, we may wish to think of the publication of a standard as creating a more 'credible' broadcast effect, or substantially increasing the rate of interaction among the potential adopter population. The potential impact of a standard is even greater when, at the early stages of an innovation, there are several competing technologies, and standard setting resolves initial uncertainties. Clearly this effect is amplified in the presence of network externalities, and a series of case studies document the impact of a standard in such competitive situations.[45]

The other important model of diffusion processes in the literature is that based upon a heterogeneous target population – the 'probit' model which builds upon differing firm or consumer characteristics such as firm size or age. It is more popular with some economists because it is based upon individual profit maximising decisions, and does not rely on the imperfect spread of information. The diffusion process is then driven by some 'forcing' variable, such as rising real wages, or gradual improvements in the technology which reduce the price, which impact upon the decision to adopt. Standards setting can play a part in such models. Firm size is clearly relevant in that larger firms tend to have alternative strategies for overcoming the problems of the market where standards may be helpful, and which are not always available to smaller producers.[46] In such cases standards may induce smaller companies to adopt. The degree of risk aversion is another possibly relevant characteristic, where the credibility attached to a public standard affects the 'equilibrium' level of adoption.

Perhaps one more point needs to be made in relation to the probit model, namely that the distinction between diffusion and innovation becomes more blurred than in simple information models. One way of thinking about firm heterogeneity is in terms of the basic innovation being adapted and extended across a sequence of applications or markets through a process of incremental innovation according to user requirements. Swann (2000) evidently has this in mind when he develops models of product development with and without the direction given by formal standards acting as 'focusing devices'. While recognising that, in some sense, standards must constrain innovation at the outset, he argues that, when considered as a *sequential* process, the end result of the ordered process is one of 'thicker' markets, more competition, and less duplication of research effort, which is allowed to specialise instead on

44 Moreover, and for obvious reasons, the early broadcast information may not be entirely credible.

45 For citations see Swann (2000).

46 For example, the fixed costs that might attach to developing a reputation in some markets, or in developing a proprietary standard.

customer needs. His model also considers the impact of intellectual property rights in such a process. These may take the form of patent protection *or* proprietary standards, both of which hinder the opening up of the product variety space.

In the case of the minimum quality function of standards, there may well be demonstrable gains in situations of information asymmetry, where buyers are unable to distinguish between ‘high’ and low qualities – at least in advance of purchase. If – as is likely – high quality producers face higher costs than low quality producers, they might find it hard to survive in such market conditions, giving us a case of ‘Gresham’s Law’ in which the ‘bad drives out the good’. Although there may be other ways in which producers can prevent its operation, minimum quality standards may be an effective means of mitigating the operation of the Law.

In summary, we argue that public standards provide – under a variety of circumstances – a vital input into the diffusion processes that underpin technological change. This input should not be seen as acting independently of other – perhaps ‘deeper’ -influences on technological change. The list here includes not just innovation in particular, but also the contribution of human and physical capital accumulation as well as economies of scale.[47]

Before moving on to the econometric analysis, a brief discussion of other relevant empirical literature may be useful.

Much empirical investigation in the economic growth literature has focused upon cross sectional or panel studies across many countries.[48] Perforce, these have been unable to shed much light on the role of individual national institutions. In a recent review of the evidence, Temple (1999) remarks that ‘despite the popularity of this endeavour, many believe that it is fruitless, partly because there are not likely to be any general answers. The appropriate research questions and answers will depend upon a country’s particular situation, for instance whether a country is a technological leader or a

47 For example, it is commonly believed and entirely plausible that technological change has consistently been biased toward the employment of skilled labour. As far as such a concept is measurable the strong growth in human capital formation in most of the major economies has meant that the ‘premium’ on skills has not risen steadily in the long run. Although there is evidence of a rise in the last two decades, this does not seem to be the long-run picture; see for example Wood (1998) and evidence therein. A number of authors have examined the importance of skill-biased technological change in recent years in increasing the relative demand for skills. However the precise source of this acceleration in the demand for skills is a matter of dispute. Wood argues that the cause of the acceleration – as opposed to the long-run trend – may be attributed to increased trade in manufactured goods between the advanced economies and the rest of the world, and the resultant increased (and in his explanation complete) specialisation of the advanced economies in skill-intensive sectors. The availability of skilled labour is of course one factor explaining the supply of standards, since it provides almost certainly the major input into the work of the technical committees, impacting upon whether the prospective net benefits in developing a standard are positive. As far as economies of scale are concerned, again it is arguable that while the potential for economies of scale exists independently of institutional and other contexts, their realisation does not. In his study of economies of scale and scope for example, Chandler (1990) documents the simultaneous need for investments in organisational skills if economies of either scale or scope can be realised. Public standards provide another such mechanism.

48 I.e. those contained in the famous Summers-Heston dataset also known as the Penn World Tables. These data are obtained from benchmark studies of Purchasing Power Parities from the International Comparisons Programme (ICP) of the United Nations and national accounts data. For a description see Heston and Summers (1996).

developing country trying to catch up.' (p. 119). Standards institutions are a good example of this proposition even within the group of 'technological leaders', since the development of these institutions may vary considerably from country to country. In the US for example, the standards infrastructure is quite different from that of the UK, more sector specific and pluralistic in nature, and it would accordingly be very difficult to conceive of a measure that would capture the relative strength of standards setting institutions between these two countries.[49] There is therefore a genuine need for research on growth at the national level, if the institutional inputs into these processes are to be better understood.

There is however at least one substantial body of research that does develop in more detail the institutional structures that have a national and possibly idiosyncratic character. We speak here of a large number of contributions to the study of *national innovation systems*. While the term 'innovation' appears, it seems clear that this approach to technological change has a very broad understanding of the term, encompassing 'the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, whether or not they are new to the universe, or even to the nation' (Nelson 1992). Amongst those contributing in this field, there is broad agreement that both *firm specific* investments, and the *national institutions* which support those investments, are strong drivers of technological change at the level of the national economy.[50] In this regard, the focus of many of these studies was on the role of particular government policies, and that played by educational systems and especially universities and the science base, in what may be highly distinctive national contexts. The important point underpinning these studies however was that distinctive national institutions can and, in practice do, help to sustain patterns of national technological capability, through firm specific investments which have as a result a 'national flavour'. A central conclusion of this line of enquiry was that much technological knowledge is not 'codified' in the form of readily available information, but operates instead at the level of the firm, and the skilled individuals within it. Accordingly the major share of innovative effort is in the form of firm specific investments, particularly in more mature technologies. Nelson argues the reasons as stemming from the fact that knowledge about which types of incremental innovation is likely to yield a return, resides decisively with the *users* of the technology, who understand its strengths and limitations. Further, successful innovative strategies, frequently require the complex co-ordination of R&D, design, production, and marketing, which 'tends to proceed much more effectively within an organisation that itself does all of these' (Nelson, op cit, p. 278).

49 This is less obvious when the BSI catalogue is compared to say DIN in Germany or AFNOR in France, bodies which serve similar needs at the national level as BSI, both scope of their activities and the type of documents produced does differ from country to country.

50 Important evidence for this resides in the relevance of innovation and technology in explaining specialisation in international trade, evidence that begins with Macdougall (1951) in a simple test of the Ricardian model of trade. More recent evidence and a review see Wakelin (1997).

As yet, there is little hard evidence as to the relationship between aggregate 'public standards' and overall productivity growth. There is however a body of case study evidence which points to the importance of individual standards. The benefits from individual measurement and reference standards have for example been investigated by the US National Institute of Science and Technology, which reports social rates of return of the order of 63-423% (Tassey, 1995). Swann (2000) lists other cases, of relevance, particularly from the practitioner literature. The latter tends (naturally enough) to focus on individual company performance, rather than the overall social benefits from standardisation, which may of course be very different. However, the well-known problem with case-study evidence is one of sample selection bias, and to aggregate on the basis of it could be highly misleading.

At the level of the whole economy, the only explicit attempt to measure the impact of standards for growth was carried out for Germany by Jungmittag et al (1999), who suggested that standards were responsible for a significant proportion of the growth in output of the German business sector between 1960 and 1996. For example, in the period from 1960 to 1990 (i.e. prior to re-unification), the authors report that standards contributed an estimated 0.9 percentage points to an overall growth rate of output of 3.3% per annum. This was reckoned to be second in importance only to capital accumulation over the whole period – and more important than other sources of technological change such as domestic innovation and the direct payment for imports of technology from abroad. Other studies have examined the impact of standards on trade performance (e.g. Swann et al 1996, Blind 2001). These have shown that at a sectoral level, standards have positive measurable impacts on intra-industry trade, stimulating both exports and imports. These impacts were moreover additional to those impacts stemming from changes in productivity, since both studies used price competitiveness as variables in the estimating equations, in addition to the measures of standards adopted. These studies have utilised measures of the *size* of the relevant standards stock as explanatory variables. We now consider this measure in the current context in more detail.

2.4. A Measure of the Contribution of Standards to Productivity: the BSI 'Catalogue'

Before moving on to an empirical model of the relationship between standards and productivity, we first consider the proposed measure of standards output. Here, following the studies described above (Swann et al 1996, Jungmittag et al 1999), we use the number of standards in the 'catalogue' available to producers as providing a convenient starting point.

At any one time, the catalogue – call this the SCI – is made up of the cumulated *publications* of standards up to that time less those that have been *retired* or *withdrawn*, i.e.

$$SCI(t) \equiv \sum_{i=t-\infty}^{i=t} P(i) - \sum_{i=t-\infty}^{i=t} W(i) \tag{3}$$

where SCI is the measure of the standards catalogue at end of period t, $P(i)$ is the number of standards published during any year i, and $W(i)$ is the number of standards withdrawn (or retired) during any year i. $SCI(t)$ is therefore a measure of the 'stock' of standards current at the end of t periods and which we argue serves as a proxy for the 'flow' of benefits to the economy during any interval of time t.

Ideally perhaps, we would wish to supplement this measure with several aspects of the 'condition' or 'quality' of the catalogue, and in particular a count of the number of standards by economic function. However this was not practicable given the information available to us, and in any event is complicated by the fact that many standards have more than one function, while all have some information content.

In order to justify our approach, it is helpful to think not so much of individual standards but in terms of the publications of a particular year, i.e. a particular 'vintage'. While the standards published within any vintage may be expected to create a positive net benefit to the economy, over time these benefits will decline, as the technology in which the standard is embedded becomes less relevant, the physical equipment to which it refers becomes obsolete, and so on. As a result the standards of a particular year (vintage), are withdrawn from the catalogue. A few are declared obsolete, but the large majority are 'replaced' or 'superseded' by a newer standard, better fitted to the current technological and business situation. Arguably therefore, the declining efficiency of any vintage is fully reflected in its declining share of the overall catalogue.[51]

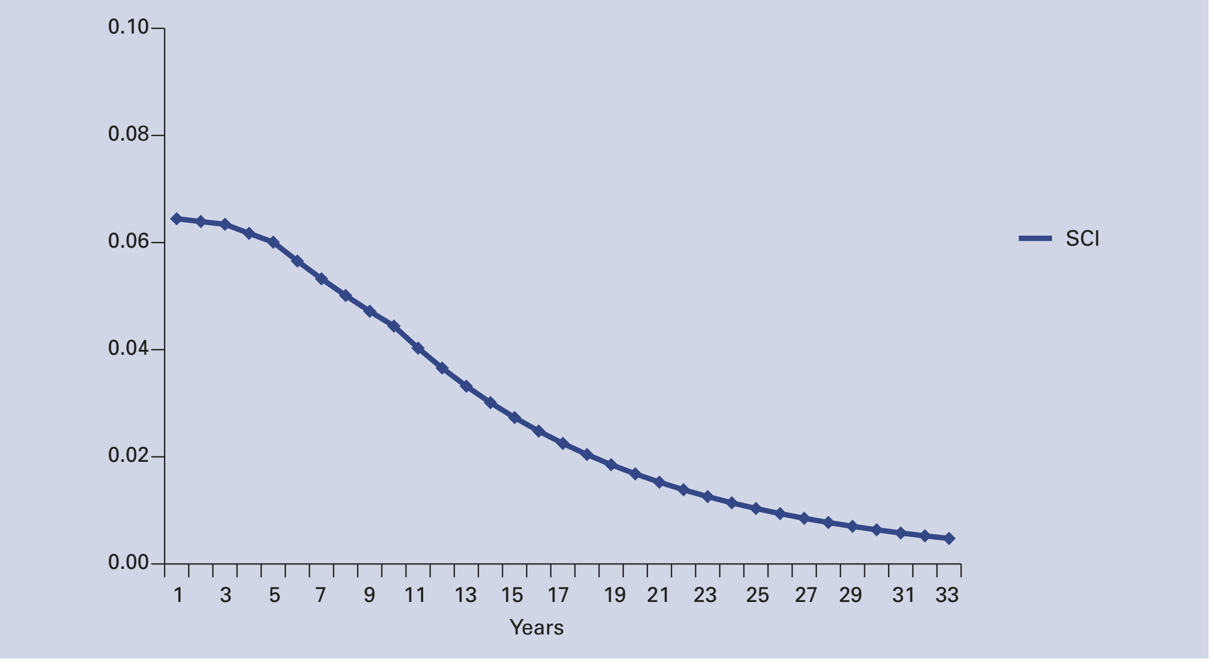
We can now illustrate the basic measure using our data on BSI standards. These were constructed from two data sources. First the BSI 'History Book' allowed us to count all BSI publications from the initial 'public' standard in 1901. This source was discontinued as computerised records were introduced in 1985. Accordingly, from that date we use the PERINORM©[52] database. While this allows for a complete count of withdrawals, and hence an accurate measure of the size of the catalogue (SCI) at any time t, we were unable to count all withdrawals using the History Book. Some estimates of withdrawals therefore had to be made for the period prior to 1985. Details of the methods adopted can be found in Annex A. However, given our arguments above, the

51 An alternative would be to impose or estimate an age-efficiency profile for any particular vintage. This approach is for example used in the conventional method of estimating the gross capital stock, where it is assumed that the productivity of an asset is constant until the estimated scrapping date, the latter being based upon assumptions regarding the lives of particular assets, which may follow a statistical distribution. Arguably the present approach is rather better, in that we possess a detailed knowledge of retirements.

52 A consortium of BSI, DIN, and AFNOR.

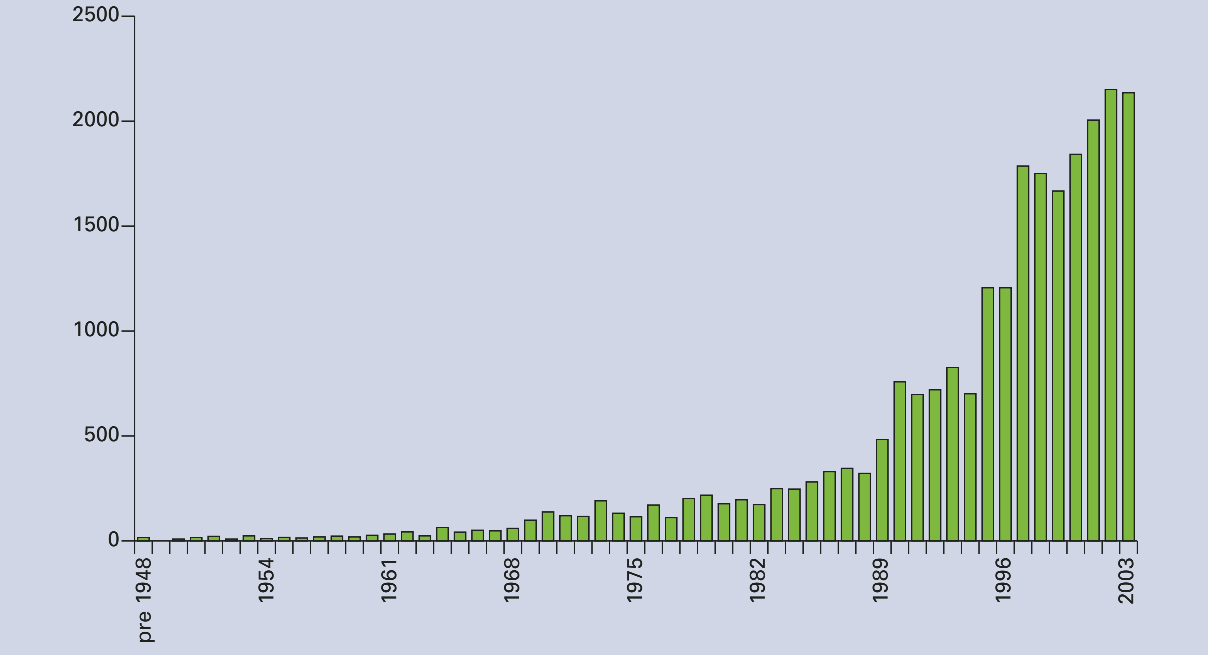
withdrawal of standards reflects the 'age-efficiency profile, of a particular vintage. The implied profile is shown in Figure 15 with the current state of the catalogue in terms of vintages in Figure 16. On the basis of this, about 50% of the efficiency enhancing impact has taken place after six years.

Figure 15
Age-Efficiency Profile for a Typical Vintage (proportion of benefits by age of vintage)



Source: BSI/PERINORM©

Figure 16
Composition of the BSI Catalogue at end 2003 by Vintage



Source: BSI/PERINORM©

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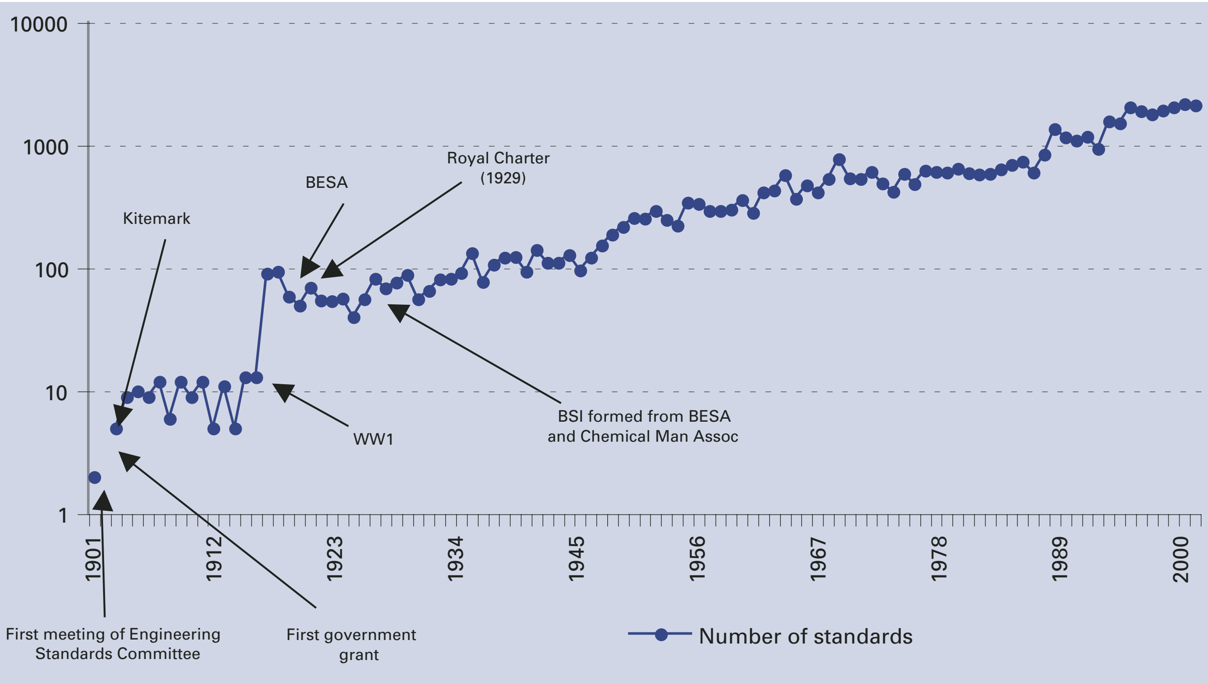
Figure 17 shows how publications have grown since the initial offering of the Engineering Standards Committee – a forerunner of the BSI – in 1901. The importance of the First World War in establishing a national standards body cannot be overemphasised. The catalogue itself quadrupled between 1913 and 1918 and the acceleration in the annual number of publications is clearly visible. Since then, there has been a steady exponential growth; whereas the peak years of WWI in 1917 and 1918 saw just under 100 publications in the year, annual publications between 2001 and 2003 all topped 2000, representing a long run annual rate of growth of 3.7%.[53] A number of key dates in the creation of a national institution are shown in the figure. For example, the first government sponsorship dates from 1902. The BSI itself was created in 1931, by the amalgamation of the Association of British Chemical Manufacturers and the British Engineering Standards Association (BESA).

Figure 17
BSI publications by year (1901-2003), log scale

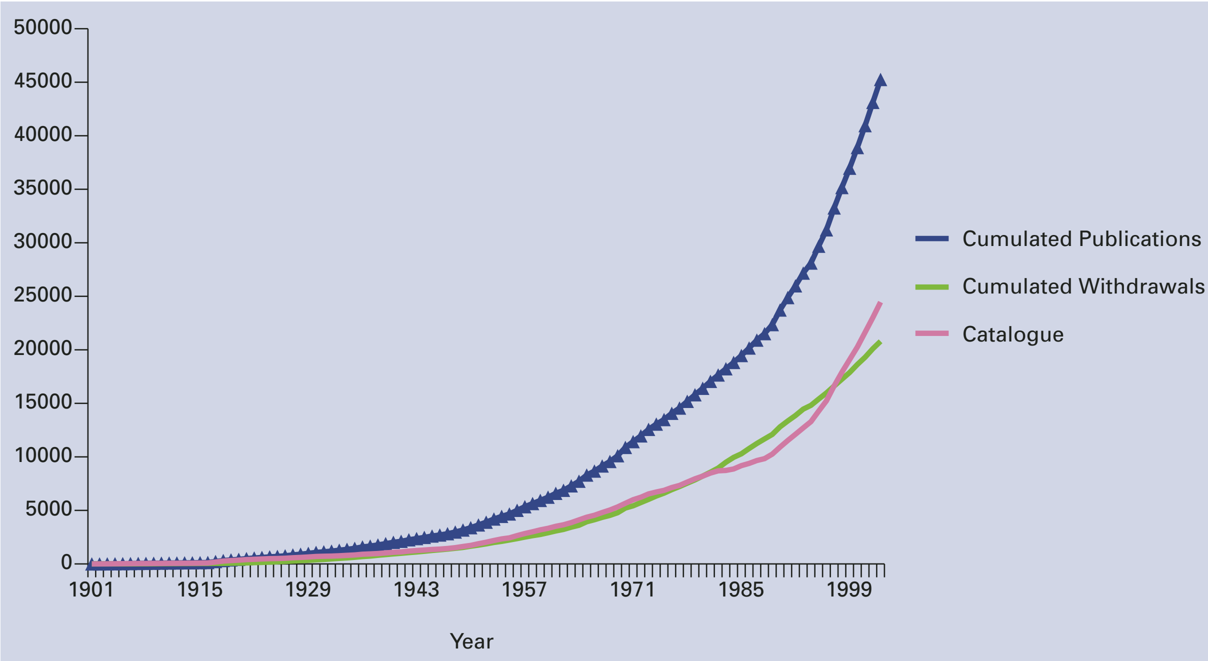


Source: BSI/PERINORM©

Figures 18 and 19 illustrate both cumulated publications and cumulated withdrawals and the corresponding growth of the catalogue itself. By the end of the Second World War, there were close to 1,500 standards in the catalogue. Strong expansion in the early post-war decades meant that this had increased to nearly 6,000 by 1970. The period 1970-1989 was a period of rather slower growth, but nevertheless the catalogue contained more than 10,000 in the latter year. Stronger growth has resumed over the last decade or so with the stock doubling again, with nearly 25,000 listed standards by the end of 2003. Overall, the post-war period (1948-2002) has seen a growth in the catalogue of over 5% per annum.

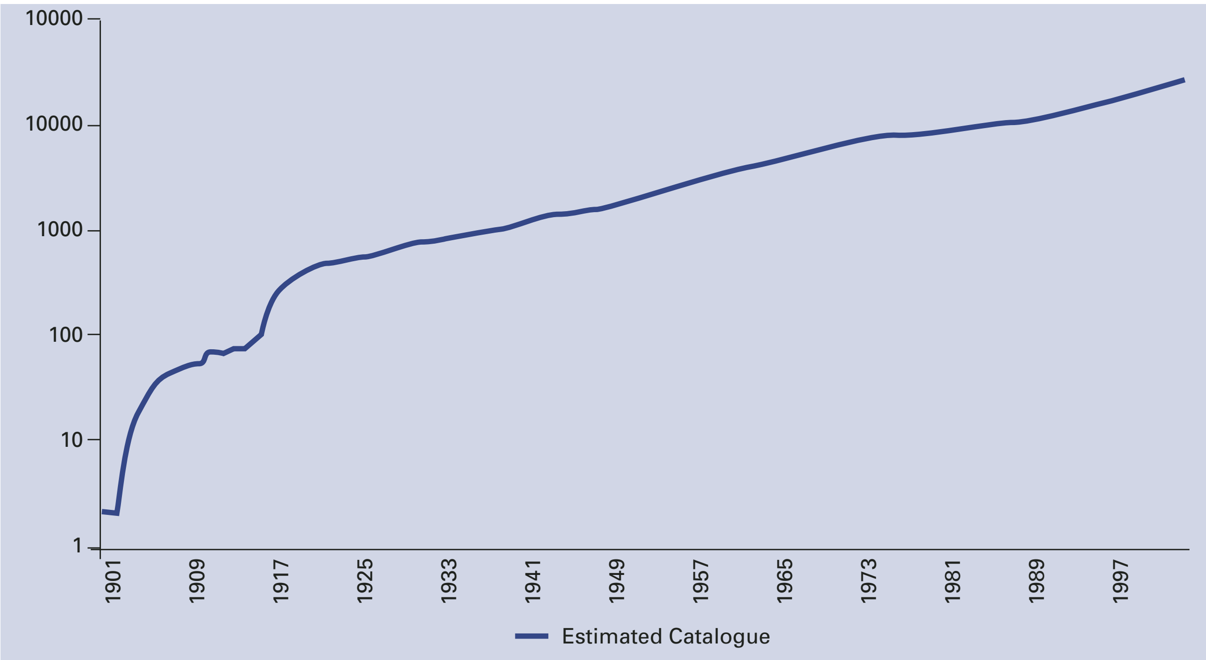
53 1918-2003

Figure 18
The Growth of the BSI Catalogue (1901-2003)



Source: BSI/PERINORM©

Figure 19
Estimates of standards stocks (1901-2003), log scale

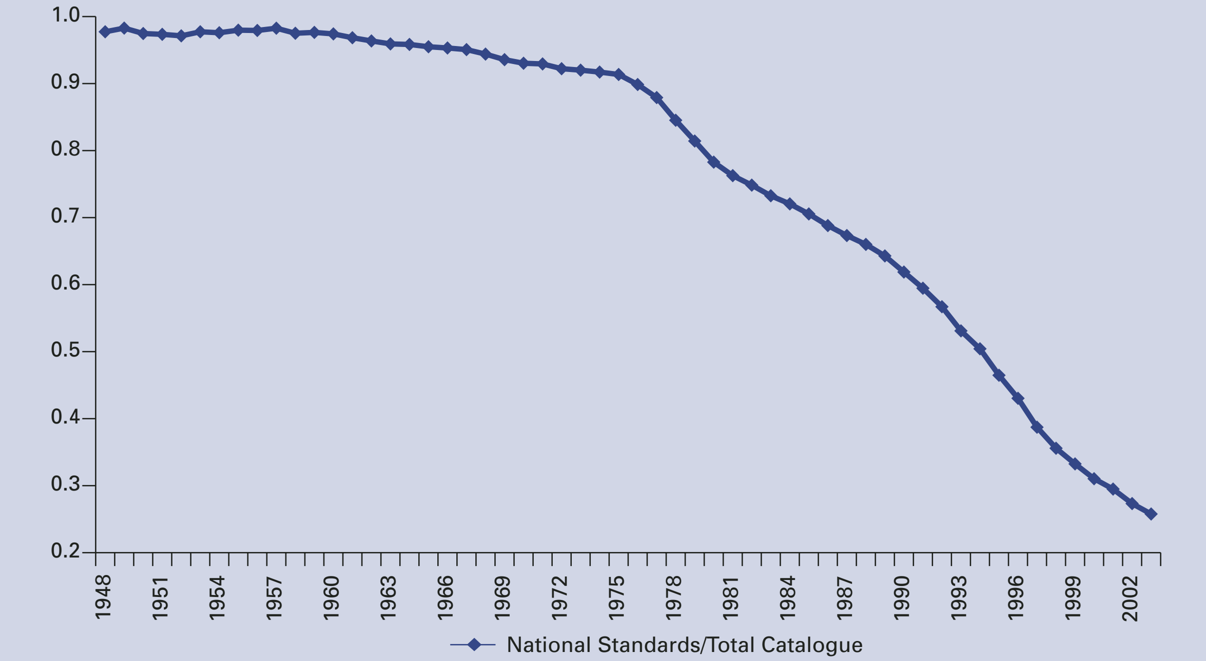


Source: BSI/PERINORM©

A final aspect of the catalogue is of importance. We have claimed that the BSI has been largely a national institution, developing standards largely of domestic origin. Certainly international standardisation is largely a post-war

phenomenon.[54] Figure 20, which is based upon an estimate of which standards are purely 'national' in character in the sense that they are not identical to an international standard nor do they appear to have any international equivalent. It can be seen that, although today, the overwhelming majority of standards are international, even as late as the early 1990s, well over half the catalogue consisted of national standards. The biggest share of the new standards introduced into the catalogue in the last decade have an origin in the European standards setting organisations – CEN, CENELEC, and ETSI – although some of these have their ultimate origin in the international organisations such as ISO. They represent a considerable redeployment and 'pooling' of national resources at the European level. Since the BSI is mandated to market standards emanating from Europe, it is possible that some 'dilution' of the catalogue has occurred with some of the additional standards having little relevance for UK producers. On the other hand, it is conceivable that these standards are an efficient vehicle for technology transfer from overseas.

Figure 20
The Internationalisation of the BSI Catalogue (1948 – 2003)



Source: BSI/PERINORM©

We can conclude this section by noting that growth in the UK appears to have been rather 'standards intensive'. This probably reflects not just the nature of the demand for standards emerging from the nature of technical change, but also from the supply of human capital, which has kept down the cost of standards development. The growth of international trade, largely based upon

54 There are exceptions to this general picture. The earliest truly international body is the International Electrotechnical Commission (IEC), which dates from 1906, with the support of seven countries (CEN 2002). Although the origins of International Telecommunication Union (ITU) can be traced back – as a convention – to 1865, it is only with the creation of the United Nations (UN) that truly international agencies of standardisation can be said to have been created The ITU was made a specialized agency of the UN in 1947, the same year as the foundation of the International Organisation for Standardisation (ISO), which acts as a federation of national standards bodies.

increasing product variety and intra-industry trade, has probably also been a factor in accelerating the demand for standards.

Having considered our measure of the output of standards by the BSI, we turn to see whether it can usefully be used in a model of UK productivity growth in the post World War II period.

2.5. An econometric model of standards and productivity

In order to produce benchmark estimates of the contribution of BSI standards to economic growth we next estimated a simple 'production function' for the whole UK economy. The period selected for the study was 1948-2002. The choice of period was dictated by the problem of data availability[55] but also in ensuring that the BSI was a truly national organisation reflecting the requirements of many sectors, not just its origins in the engineering and chemicals industries. Figure 17 is instructive in this regard, since it is noticeable that World War II had no comparable impact on the standards stock to that of the Great War of 1914-1918.

The approach we adopt here is based upon the work of Jungmittag et al (1999). This study sought however to distinguish the impact of standards from other sources of technological change – notably domestic innovation (proxied by the stock of domestic patents) and a measure of the 'import' of technology from overseas (proxied by payments to foreign companies for the use of intellectual property rights). In view of our discussion above, in which the activities of the BSI are best seen as an enabling device – *linking* innovation and human capital formation with the diffusion of technology and the development of markets, we did not consider this approach desirable. Nor did the strictly limited number of observations (54) available to us make this seem feasible.[56] Accordingly we estimated a rather more restricted production function in which conventional factors are augmented by the BSI catalogue and other 'unobservable' factors acting upon technological change.

Formally, a production function with both conventional inputs technological progress can be written as:

$$Y(t) = A(t)\ [F(K(t),L(t)]$$

Where:

- $Y(t)$ = output at time t
- $K(t)$ = capital input at time t
- $L(t)$ = labour input at time t
- $A(t)$ = a multiplicative factor representing the level of technology

55 Not least, the UK Office for National Statistics (ONS) has now produced consistent capital stock estimates for the whole period since 1948.

56 We did however experiment with a count of UK patents granted at the US Patent Office, a plausible indicator of significant innovations. In practice, this variable turned out to be highly collinear with the standards variable. Our argument again is that both are serving as joint inputs into the process of technological diffusion.

If the current level of technology is partly determined by an exogenous trend and partly by the current 'stock' of standards, then we can write:

$$Y(t) = \exp(\lambda t)\ SCI\ (t)^{\epsilon}\ [F(K(t),L(t)]$$

Where:

λ is an exogenous time trend representing unobservable influences on output;

ϵ is a parameter measuring the elasticity of output with respect to the standards stock, and

$SCI(t)$ is the standards stock at time t

If we impose both the familiar Cobb-Douglas functional form as well as constant returns to scale, then we can write the equation in terms of labour productivity:

$$Y(t)/L(t) = \exp(\lambda t)\ SCI\ (t)^{\epsilon}\ [K(t)/L(t)]^{\alpha}$$

Where α is the elasticity of labour productivity $[Y(t)/L(t)]$ with respect to the capital-labour ratio $[K(t)/L(t)]$

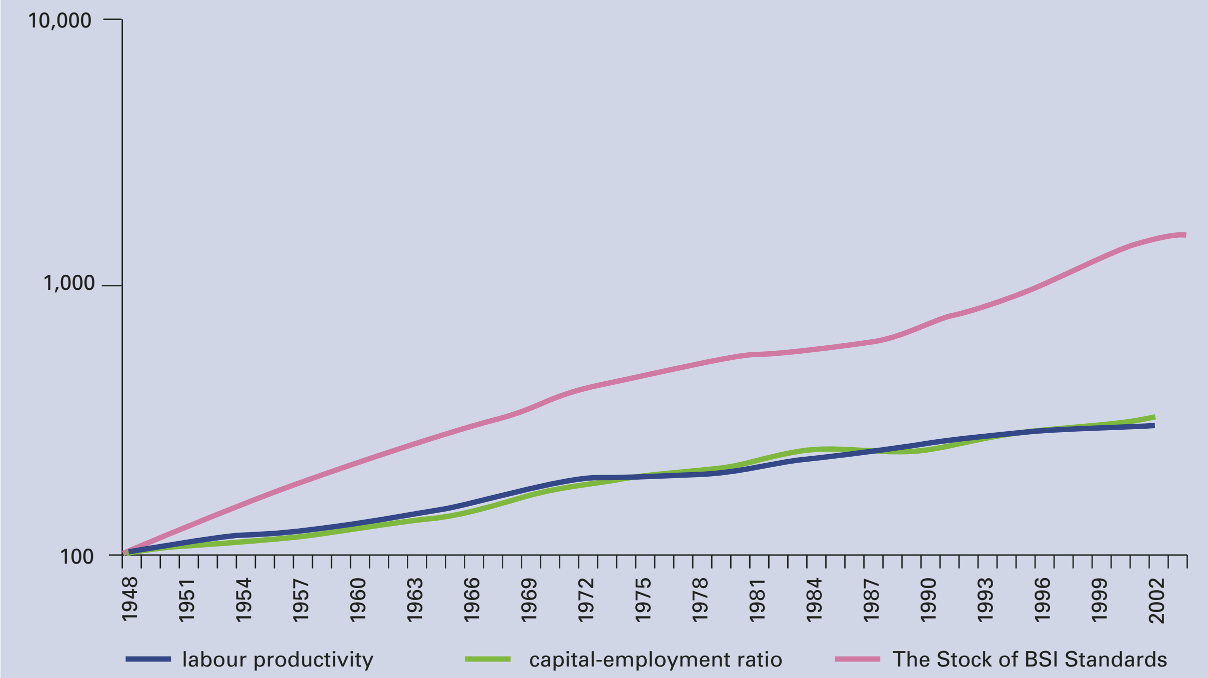
Taking logarithms (denoted in lower case) we then get a simple estimating equation with a normally distributed error term, $u(t)$:[57]

$$y(t) - l(t) = a + \lambda t + \epsilon\ sci(t) + \alpha\ [(k(t) - l(t)] + u(t) \qquad (4)$$

Figures 21 and 22 plot the observable variables in (4). Figure 21 shows the relationship in terms of levels and Figure 22 in terms of year-on-year percentage rates of growth. Two features may be noted. As both figures illustrate, an important feature of the data is that the growth of the standard stock has been very fast in comparison with productivity growth. The average annual growth rate of the standards stock over the whole period 1948-2002 was 5.1%. This compares with 2.1% and 2.2% for labour productivity and the capital-employment ratio. The similarity in the latter two numbers exemplifies one of the great 'stylised facts' of growth economics – the relative stability of the ratio of capital to output. Note that the growth in the stock of standards has been far from steady. The early post-war period shows rapid growth: between 1948 and 1973, the growth rate in the standard stock averaged close to 6% per annum; it then fell to just 3.0% up until 1990, when it accelerates again.

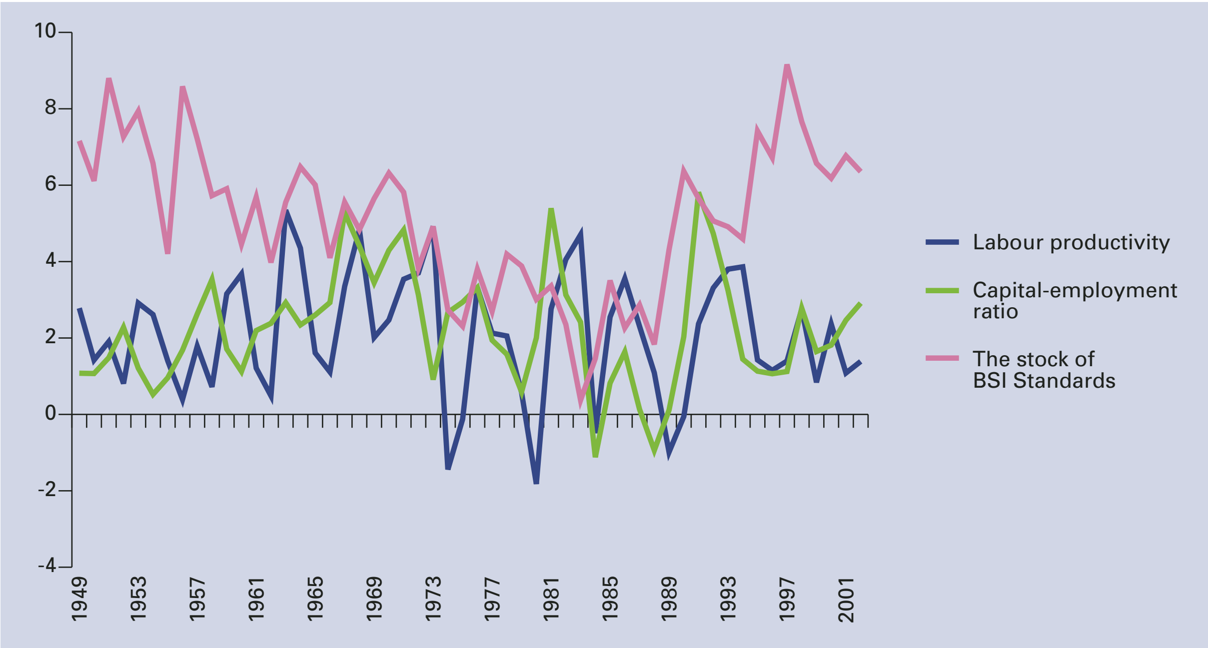
57 The resulting estimating equation is similar to one for total factor productivity, used in many studies which is produced by an initial growth accounting exercise which uses factor shares to impute the contribution of capital. Here however we estimate the contribution of capital deepening (the growth in the ratio of capital to employment).

Figure 21
Long-Run Growth of Labour Productivity UK 1948-2002 (1948=100 log scale)



Source: ONS/own estimates

Figure 22
The Long-Run Growth in Labour Productivity UK 1949-2002 (annual % change)



Source: ONS/own estimates

The inferential procedure adopted consisted of the well-known two step co-integrating approach, in which estimation in levels is followed by a dynamic specification using the error term (the ECM) from the first step. Standard augmented Dickey Fuller (ADF tests), not reported here, revealed that the logarithms of the stock of standards, were integrated of order one, making the co-integrating framework apposite.

Table 4, column 2 shows the results from the static regression of equation (4). These suggest strongly that a co-integrating relationship exists between the labour productivity, the capital-employment ratio, and the stock of standards. The ADF test on the residuals suggest that the null hypothesis – that there is no cointegrating relationship between the variables – can be rejected at the conventional 5% level of statistical significance. The computed long-run elasticity on the stock of standards is 0.054 – roughly a 1% increase in the stock of standards is associated with a 0.05% increase in labour productivity.

Table 4:
Cointegrating Regressions using Ordinary Least Squares (sample period: 1948-2002)

(1) Variable	(2) dependent variable = Log (labour productivity)	(3) dependent variable = Log (Capital-Employment Ratio)	(4) dependent variable = Log (Stock of Standards)
Constant	2.064	-0.793	2.955
	(0.306)	(0.671)	(2.004)
Time	0.008	-0.001	0.024
	(0.002)	(0.003)	(0.009)
Log (Capital-Employment Ratio)	0.466	–	-0.287
	(0.057)		(0.420)
Log (Stock of Standards)	0.054	-0.032	–
	(0.028)	(0.046)	
Log (labour productivity)	–	1.216	1.277
		(0.149)	(0.658)
Model diagnostics			
RSS	0.017	0.045	0.408
$\hat{\sigma}$	0.018	0.030	0.089
R^2	0.997	0.994	0.985
$\overline{R}^2$	0.997	0.994	0.985
DW	0.723	0.488	0.100
t(ADF)	-4.507*	-3.696*	-2.202*
Time Period	1948 – 2002	1948 –2002	1948 – 2002

Standard Errors are in parentheses
*Lag augmentation = 1. Approximate critical values (Davidson and Mackinnon 1993 p.722, Table 20.2) are -3.84 and -4.12 at the ten and five percent level, respectively.

There may however be more than one co-integrating association between the variables. Columns (3) and (4) of Table 4 show what happens when we ran regressions in which both the capital-employment ratio (3) and the standards stock (4) alternating as the dependent variable. At the 5% level of significance we cannot reject the null of no co-integration in either regression. However, for (3), the null of no co-integration can be rejected at the 10% level, but only narrowly.

The second stage of the analysis consisted of the dynamic specification in which the error (or ECM term) from the static regressions was entered as an additional regressor in a specification of (4) but now expressed in first differences. Here we considered a general specification in which the first

difference in the logarithm of labour productivity (roughly the proportionate change) was regressed on one lag of itself, and one lag of both the first difference of the standards stock and of the capital-employment ratio. The corresponding results for the static equation (4) are reported in Table 5, column 2. While it indicates the importance of the long-run impact of standards as a determinant of labour productivity – through the ECM term described above – it also shows that the short run influence is not significant. Note that the ECM term for this specification is highly significant at the 1% level. The lack of any short run impact from standards is of course entirely consistent with both our theoretical discussion above – since standards take time to diffuse amongst a user population. Table 5 also reports some conventional diagnostic tests, which indicate no obvious signs of mis-specification.[58]

Table 5:
General unrestricted specification of ECM models
(Sample period = 1948-2002)

(1) Variable	(2) Δ Log (Labour Productivity)	(3) Δ Log (Capital-Employment Ratio)	(4) Δ Log (Stock of Standards)
ECM t-1	-0.383**	-0.111	-0.031
	(0.117)	(0.058)	(0.026)
Δ Log (Labour Productivity) $_{t-1}$	0.171	-0.453**	-0.152
	(0.126)	(0.095)	(0.121)
ΔLog (Capital-Employment Ratio) $_{t-1}$	0.375*	0.785**	-0.061
	(0.145)	(0.115)	(0.153)
Δ Log (Stock of Standards) $_{t-1}$	-0.003	0.065	0.707**
	(0.093)	(0.082)	(0.097)
Constant	0.009	0.011*	0.019**
	(0.006)	(0.005)	(0.006)
Model Diagnostics			
RSS	0.008	0.005	0.008
$\hat{\sigma}$	0.013	0.010	0.013
R^2	0.437	0.556	0.547
$\overline{R}^2$	0.390	0.519	0.502
DW	2.06	2.26	2.43
Time Period	1950 – 2002	1950 – 2002	1950 – 2002
Other Model diagnostics:			
F_{ar} (1,47)	0.371 [0.55]	1.543 [0.22]	4.865 [0.03]*
F_{arch} (1,46)	0.296 [0.59]	0.802 [0.38]	0.260 [0.61]
F_{het} (14,33)	0.911 [0.56]	3.197 [0.00]**	1.670 [0.11]
F_{reset} (1,47)	0.895 [0.35]	0.442 [0.51]	1.424 [0.24]
χ^2_{norm} (2)	2.663 [0.26]	2.077 [0.35]	2.128 [0.35]

Standard Errors are in parentheses
*Denotes significance at the 5% level, **at the 1% level.

The additional columns in Table 5 provide further evidence that there is a single co-integrating vector linking labour productivity with standards and the capital-employment ratio. In column (4) where the first difference in the

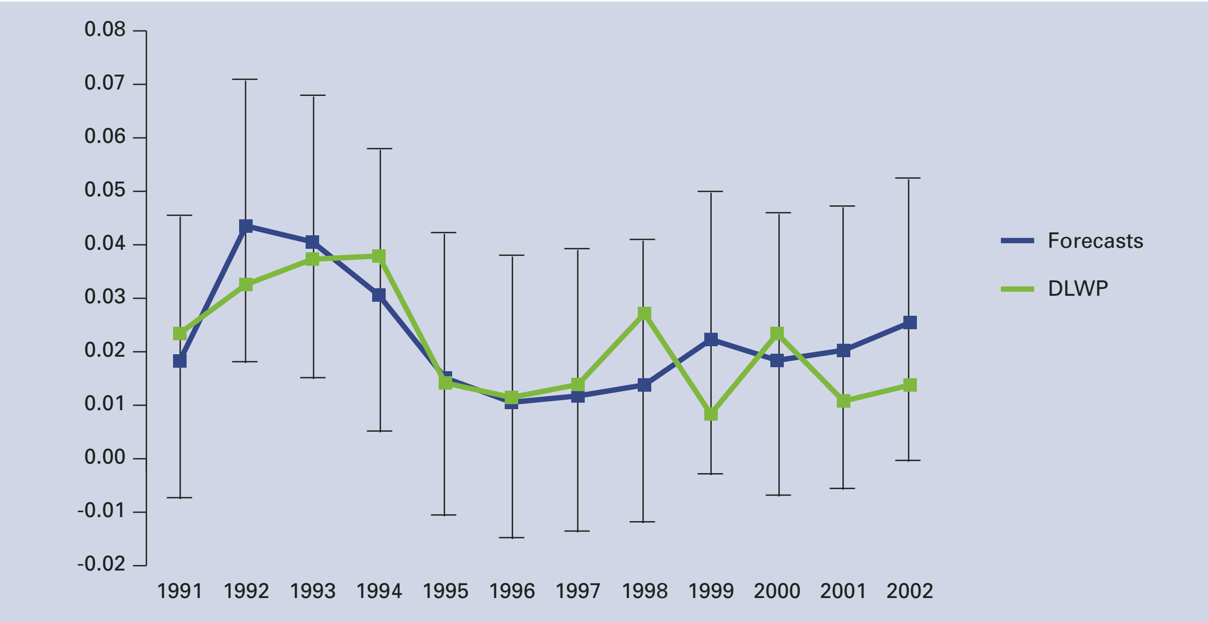
58 Further tests confirmed that the impact of standards on productivity is long-run rather than short-run in nature. These included Granger causality tests conducted on first differences and an unrestricted VAR model. Some additional results are reported in Annex B.

logarithm of the stock of standards is the dependent variable, the ECM term is insignificant and there is evidence of serial correlation. In column (3), where the first difference in the logarithm of the capital-employment ratio is the dependent variable, the ECM term is significant at only 10%, and there is also evidence of mis-specification in the form of heteroscedacity.

If we accept the estimated elasticities in Table 4, column 2, then we can make some rough calculations as to the extent to which standards are associated with long run productivity growth in the UK. Although the reported elasticity – at 0.054 – may appear low, this needs to be set against the high rate of growth of the standards stock. A simple calculation reveals that standards are associated with growth in labour productivity of 0.28% per annum, or about 13% of the recorded growth over the period 1948-2002 (2.1% per annum). Great care of course needs to be taken in interpreting such a figure, since as we have stressed – standards should be regarded as a joint (but essential) input into the process by which new technologies are diffused, and markets are created.

Because of the changing nature of the BSI catalogue – reported in the last section – an important test for the model is its 'stability'. If there was significant 'inflation' of standards because of the internationalisation of the catalogue – and especially the pooling of standardisation efforts at a European level – and this were diminishing the impact of standards, then we might expect the estimated model to perform poorly in the recent past. In fact we find no compelling evidence for such an effect. Figure 23 suggests that the model forecasts reasonably well over the period 1991-2002. Neither a conventional one step ahead forecast nor a Chow test of parameter stability suggest that the model 'breaks down' over the recent past.

Figure 23
Dynamic Model Forecasts (1991–2002)



Source: Own estimates

2.6. A Summary and Some Conclusions

This paper has examined the role of standards, and those created by formal standards institutions in particular. Attention was directed at the part played by these technical documents in enabling technological diffusion processes, by ameliorating associated market failures, which are increasingly being recognised as of considerable importance in the economics literature. Given that the uptake of technology is of fundamental importance for the translation of innovation into productivity growth, the attempt to assess the relationship between standards and long run productivity growth.

Standards influence the take up of technology by a population of potential users in a number of ways. Outside the case of establishing complementarities where network effects are important, they also have a role as providers of information with desirable characteristics (being government sponsored) such as credibility, also in many instances being imbued with knowledge gained through the use of technology.

Having established the potential role of standards in promoting technical change in industry, we then argue that the size of the catalogue provided by the institutional standard setter provides a possible proxy for both the output of the institution itself and its input into the wider process of productivity growth. Focusing on the post-war record in the UK, the BSI catalogue has grown extremely rapidly compared to the economy as a whole. In our view, this reflects the 'standard intensive' of much technical change, which in turn is influenced by importance of the development of information and communication technologies, the nature of the increasing international division of labour, and the skill-intensive nature of new technology.

Rather than argue for a separate and independent role for standards in promoting growth, we suggest that the development and maintenance of the standards catalogue is best seen as a 'coupling' device, linking the 'deep' drivers of productivity growth – the supply of human capital, innovation and the creation of knowledge, economies of scale etc. – with the orderly development of markets and the corresponding development of the division of labour. In summary, the institutional input from the BSI needs to be seen as an important aid to the development of markets where otherwise market failure might be important. As such, its role cannot easily be separated from other factors. This needs to be borne in mind in the interpretation of our statistical analysis which confirmed that, after controlling for the growth of 'conventional' inputs and exogenous influences on technology – a correlation exists between the BSI catalogue and productivity. The analysis suggests that standards were associated with around 13% of the growth of labour productivity. Since we interpret a large slide of the latter as being the result of factor accumulation, the contribution of standards to technological progress is even greater than that. We estimate the latter as contributing 1.0% per annum to UK output growth. As a proportion of this latter figure the contribution of standards is a substantial one – over one quarter.

The status of the BSI catalogue as a purely national institution has been changing significantly over the recent past and this may have a potentially important impact on this estimated relationship. Although we found no evidence for this, we note that it may be too early to evaluate these effects, especially given the rather long run nature of the impact of standards. Given that public support for standards in the UK dates from 1902, further research on the current redeployment of national standards activities will undoubtedly be important in the future.

3. The Impact of Standards on Productivity in Manufacturing: A Panel Approach Covering Four Countries and Twelve Sectors

3.1. Introduction

The empirical economics of standards is only in its infancy.[59] Recently, however, a macro-econometric study of the role of standards was carried out for Germany (Jungmittag et al. 1999). This study suggested that standards were responsible for a significant proportion of the growth in output of the German business sector between 1960 and 1996. For example, in the period from 1960 to 1990 (i.e. prior to re-unification), the authors report that standards contributed an estimated 0.9 percentage points to an overall growth rate of output of 3.3% per annum. This was reckoned to be second in importance only to capital accumulation over the whole period – and more important than other sources of technological change, such as domestic innovation and the direct payment for imports of technology from abroad. However, the contribution of the stock of standards decreased to 0.3 percent within an overall growth of 1.5% per annum after the reunification of Germany.

In order to confirm the results of Jungmittag et al. (1999), the approach was extended to the four largest economies in the EU, Germany, the United Kingdom, France and Italy. Due to data restrictions, only the period between 1990 and 2001 could serve as the data basis. This restriction was circumvented by setting up a database of sectoral time series, which were pooled in order to generate a sufficient number of observations. In addition, the data of the four countries also allowed a pooling of data by sector, which takes into account the differences of the impact of standards between sectors, although we are not able to differentiate the total stock of standards by their economic functions (Swann 2000). Finally, we tried for the first time to assess separately the impact of national and supranational standards on economic growth.

59 Blind (2004) provides an overview of existing macroeconomic and sectoral studies.

3.2. The model and the data

Besides the replication of this approach for the UK (Temple 2004), this paper differentiates the general approach by accounting for country and sector differences. This differentiated approach will follow and develop the work of Jungmittag et al. (Jungmittag et al. 1999), in which estimates of the contribution of standards to growth is based upon a neo-classical production function:

$$Y(t) = A(t)\ [F(K(t),L(t)].$$

Here, Y is a measure of aggregate value added, A is neutral technological change and K,L are measures of capital and labour input. The study by Jungmittag et al. (1999) seeks to establish the impact of standards by supposing that A is a function of various forces influencing technological change. If $Z(t)$ is a vector of such influences, we can write:

$$A(t) = A[Z(t)].$$

They distinguish here between:

- Technical progress which stems from domestic innovative activity,
- The import of technology from abroad,
- The role of domestic diffusion of technology.

They suggest that these can usefully be *proxied* by – respectively – *domestic* patent counts, the effective stock of standards at time t, and payments for technology licences.

Empirical implementation requires a specific functional form for the impact of $Z(t)$ on A and for F. Here the authors assume a simple multiplicative specification for $Z(t)$ and a standard Cobb-Douglas specification for F. This allows for an estimating equation, linear in logarithms (which are denoted by lower case):

$$y(t) = a + \alpha k(t) + \beta l(t) + \gamma\ pat(t) + \delta\ lex(t) + \epsilon\ std(t) + u(t), \qquad (5)$$

where:

$y(t)$ = added value at time t,
$k(t)$ = capital input at time t,
$l(t)$ = employment input at time t,
$pat(t)$ = domestic patent stock at time t,
$lex(t)$ = imports of licenses, patent royalties etc. at time t,
$std(t)$ = effective stock of standards at time t,
$u(t)$ = error term.

In a first step, we checked the feasibility of this approach by surveying the availability of the required data. After this screening of data sources together

with Paul Temple, we decided to focus on the four countries UK, Germany, Italy and France, dividing the manufacturing sector into 12 subgroups covering the time horizon between 1990 and 2001.[60] Furthermore, we had to adjust the methodology applied by Jungmittag et al. (1999), since we have no data for payments for foreign licenses. Furthermore, we will differentiate in a second step the stock of standards into national, European and other international standards based on searches in the standard database PERINORM, taking into account the massive influence of European standardisation on national standardisation activities.[61]

The available data allows for estimating the following general equations, linear in logarithms (which are denoted by lower case):

$$y_{ij}(t) = a_i + b_j + \alpha\, k_{ij}(t) + \beta\, l_{ij}(t) + \gamma\, pat_{ij}(t) + \delta\, totstd_{ij}(t) + u_{ij}(t) \quad (6)$$

$$y_{ij}(t) = a_i + b_j + \alpha\, k_{ij}(t) + \beta\, l_{ij}(t) + \gamma\, pat_{ij}(t) + \delta\, natstd_{ij}(t) + \epsilon\, eustd_{ij}(t) + \phi\, intstd_{ij}(t) + u_{ij}(t), \quad (7)$$

where:

$y(t)$ = added value at time t,
$k(t)$ = capital stock at time t,
$l(t)$ = employment input at time t,
$pat(t)$ = indicator of domestic patent stock applied for at the European Patent Office at time t,[62]
$totstd(t)$ = effective total stock of standards at time t,
$natstd(t)$ = effective national stock of standards at time t,
$eustd(t)$ = effective European stock of standards at time t,
$intstd(t)$ = effective other internatioal stock of standards at time t,
$u(t)$ = error term,
i = country (UK, Germany, France, Italy),
j = sector (see Table 6).

60 The first matching between standards data classified by the International Classification of Standards ICS and European industry classification NACE was performed by Blind (2002). This matching was revised within this project together with Paul Temple.

61 Since some standard documents (with the exception of German standards) are not classified by the international classification for standards ICS before 1994, we had to adjust the former stocks by a small correction factor in order to avoid too high growth rates.

62 Based on Schmoch et al. (2003), a series of patent applications at the European Patent Office differentiated by country and the NACE 2-digit classification were available. These data formed the basis for the construction of a patent stock indicator.

Table 6:
List of Sectors and their NACE codes

Sector	NACE code
Food products, beverages and tobacco	15–16
Textiles, textile products, leather and footwear	17–19
Wood and products of wood and cork	20
Pulp, paper, paper products, printing and publishing	21–22
Chemical, rubber, plastics and fuel products	23–25
Other non-metallic mineral products	26
Basic metals and fabricated metal products	27–28
Machinery and equipment, n.e.c.	29
Electrical and optical equipment	30–33
Motor vehicles, trailers and semi-trailers	34
Other transport equipment	35
Manufacturing, n.e.c.	36–37

Besides including sector and country fixed effects a_i and b_j in the total model, which will be based on more than 500 observations, it is also possible to estimate the model per country and for selected sectors.

The results of these estimations will generate significant progress in the research on the impact of standards on economic growth, controlling for country, and more important, for sector differences.

3.3. Results

In the following section, we present the results of the estimations of various versions of the equation (6) and (7). In addition to the traditional ordinary least square regressions including dummy variables for country, sector and time effects, we performed so-called Ridge regressions, since we are confronted with strong multicollinearity between the independent variables, which makes it difficult, if not impossible, to determine their separate effects on the dependent variable. Neter et al. (1996) define Ridge regression as one of several methods that have been proposed to remedy multicollinearity problems by modifying the method of least squares to allow biased estimators of the regression coefficients.[63] This method falls into the category of biased estimation techniques; that is, though ordinary least squares give unbiased and minimum variance regression estimates, there is no upper boundary on the variance of the estimators, and when multicollinearity occurs, it may produce large variances. When the variance is reduced using biased estimation, a noticeable increase in stability occurs in the regression coefficients. Reducing variance may provide benefits that offset any loss suffered due to using biased estimates. An estimator that has only a small bias, and that is substantially more precise, is the preferred estimator because it is more likely to be closest to the true value of the parameter (Myers 1990).

63 The method uses a 'ridge' parameter (r) to produce a set of coefficient estimates from the matrix X of independent variables and the dependent variable y according to $(X'X + rD)^{-1} X'y$. Here D is a diagonal matrix created from the diagonal from X'X and r is a scalar chosen such that small variations produce stable estimates. While this produces a biased estimator, its covariance matrix can be shown to be smaller than that of the ordinary least squares estimator $(X'X^{-1} X'y)$.

3.3.1 THE TOTAL MODEL

We start in Table 7 with the presentation of the results of the total model, which includes all four countries and all twelve sectors. The OLS regressions (LSDV) including dummy variables for country, sector and time effects reveal very significant partial production elasticities for the three input factors capital, labour and the patent stock.[64] Only the coefficient for the total stock of standards fails to be significant. However, the second model, not including time effects due to their insignificance in the first total model, reveals that all four input factors are significant. Nevertheless, the second LSDV model is not satisfactory with respect to the size of the partial production elasticities, because both the partial elasticity of labour and of the patent stock are rather high, and the partial elasticity of the capital stock is rather low. The performance of the ridge regression explained above yields a slightly more sensible range of partial production elasticities. First the coefficient for capital is 0.23, which comes closer to the share of one third, second the coefficient for employment is just below two thirds, and finally both the patent stock and the stock of patents are significant and in a range which corresponds to Jungmittag et al. (Jungmittag et al. 1999) and other studies based on German and OECD data (see below). The partial production elasticity of the patent stock is around 20% higher than the elasticity of the stock of standards. Since country and sector dummies are significant, we will also present and discuss the separate country and sector models in order to be able to identify more differentiated patterns and respective conclusions.

Table 7:
Estimation results for all four countries and 12 industries (n=509)

	Model 1 LSDV	Model 2 LSDV	Model 3 Ridge Regression
Capital	0.104	0.118	0.230
	(3.998)[a)]	(4.490)	(11.639)
Labour	0.801	0.772	0.648
	(33.055)	(34.583)	(30.912)
Patent Stock	0.270	0.324	0.105
	(5.185)	(8.841)	(11.785)
Standards (total)	0.033	0.049	0.079
	(1.526)	(2.314)	(6.077)
F-Tests			
Country effects	47.990	51.650	Yes
	(0.000)[b)]	(0.000)	
Industry effects	21.447	28.395	Yes
	(0.000)	(0.000)	
Time effects	1.158	–	
	(0.314)		
Ridge parameter[c)]	–	–	0.015
R^2_{adj}	0.976	0.976	0.965

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation.
b) Significance levels in brackets.
c) See footnote 63.

64 The inclusion of country, industry, and time effects allows us to catch all kinds of special effects, which also prohibit that these effects are attributed to contributions of the stocks of standards or other input factors.

3.3.2. THE COUNTRY MODELS

Since we have more than 100 observations for each of the four countries, we have also estimated four separate country models. These separate models are able to take into account national idiosyncrasies, not only of the national standardisation system and its impact on macroeconomic performance, but also of the national capital and labour markets and the specific patent system, although the completion of the Single Market and the establishment and success of the European patent system should have led to an increasing convergence between the different national systems. However, current growth, but also employment figures and technology indicators, like patent intensities, confirm that we still have different national economic systems, which cannot only be explained by different sector structures.

We start with the presentation and discussion of the results for the UK in Table 8. In the traditional LSDV model, only the coefficients or the partial production elasticities of the two major input factors capital and labour are significant. Both the coefficients for the patent stocks and the stocks of standards are not significant, although in the same sensible range as in the total model above. The insignificance of the two variables is explained by their high multicollinearity. Therefore, the ridge regression method was applied, which leads consequently to the expected significant coefficients. The two partial production elasticities of the patent and the standard stocks are in the same order of 0.05. Furthermore, the partial production elasticity of the factor capital is around one third, which corresponds closely to magnitudes known from other empirical studies (see Harrigan (1999) and below the references for Germany).

Table 8:
Estimation results for the United Kingdom and twelve industries (n=140)

	Model 1 LSDV	Model 2 Ridge Regression
Capital	0.635	0.344
	(5.151)[a]	(26.767)
Labour	0.404	0.455
	(4.086)	(18.235)
Patent Stock	0.148	0.047
	(1.270)	(9.465)
Standards (total)	0.089	0.052
	(0.973)	(4.485)
F-Tests		
Industry effects	38.881	Yes
	(0.000)[b]	
Time effects	2.322	Yes
	(0.013)	
Ridge parameter	–	0.015
R^2_{adj}	0.994	0.985

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation.
b) Significance levels in brackets.

The second country results of Germany are presented in Table 9. In the same way as for the UK, the traditional LSDV procedure yields significant coefficients of the two partial production elasticities for Germany only for the two most important input factors capital and labour, although in the second LSDV model without the insignificant time trends the coefficient of patent stock is significantly positive, but with a value of almost 0.20 obviously too high. Finally, the ridge regression generates an estimation equation with four significant and reasonable partial production elasticities.[65] However, the production elasticity of the patent stock is more than three times higher at 0.09 than that of the standard stocks at 0.03. As already indicated in Jungmittag et al. (1999), these results confirm that the macroeconomic impact of formal standards has lost in importance compared to its higher values in the 1970s and 1980s.

Table 9:
Estimation results for Germany and 12 industries (n=132)

	Model 1 LSDV	Model 2 LSDV	Model 3 Ridge Regression
Capital	0.362	0.274	0.227
	(2.011)[a)]	(1.892)	(10.704)
Labour	0.604	0.650	0.417
	(6.066)	(10.087)	(13.925)
Patent Stock	0.378	0.193	0.094
	(1.085)	(1.763)	(9.095)
Standards (total)	0.096	0.105	0.027
	(0.717)	(0.892)	(2.666)
F-Tests			
Industry effects	21.518	25.489	Yes
	(0.000)[b)]	(0.000)	
Time effects	0.607	–	
	(0.805)		
Ridge parameter	–	–	0.015
R^2_{adj}	0.990	0.990	0.984

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation.
b) Significance levels in brackets.

Just for information, we present the results of a model which pools the data of the British and German panel together in Table 10. The results of the ridge regression confirm the similar size of the two partial production elasticities of the patent and standard stocks of around 0.08.

65 Smolny (2000) finds for 51 German sectors based on time series between 1960 and 1990 production elasticities for capital between 0.269 and 0.415. On a macroeconomic level, Schröer and Stahlecker (1996) discover production elasticities of 0.666 for labour and 0.353 for capital.

Table 10:
Estimation results for the United Kingdom, Germany, and twelve industries (n=272)

	Model 1 LSDV	Model 2 Ridge Regression
Capital	0.170	0.204
	(4.460)[a]	(8.850)
Labour	0.797	0.715
	(31.732)	(29.199)
Patent Stock	0.682	0.086
	(8.735)	(10.541)
Standards (total)	0.092	0.084
	(2.400)	(4.937)
F-Tests		
Country effects	147.473	Yes
	(0.000)[b]	
Industry effects	35.276	Yes
	(0.000)	
Time effects	4.375	Yes
	(0.000)	
Ridge parameter	–	0.015
R^2_{adj}	0.989	0.974

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation.
b) Significance levels in brackets.

The conventional LSDV models do not lead to reasonable and satisfactory results for the French model, because the patent stock was supposed to be negative for the sector specific growth. Only the ridge regression generates realistic and significant partial production elasticities. Although the coefficient of 0.52 for the capital stock and of 0.30 for the employment are slightly different from those of the British and the German model, the partial production elasticity of 0.07 of the patent stocks and 0.15 of the standard stocks are in the same range as in the models presented above. However, the pattern itself is rather diametrical to the situation in Germany, where the patent stock has a partial production elasticity three times higher than the stocks of standards.

Table 11:
Estimation results for France and eleven industries (n=127)

	Model 1 LSDV	Model 2 LSDV	Model 3 Ridge Regression
Capital	2.019	1.826	0.518
	(6.162)[a]	(6.785)	(12.488)
Labour	0.336	0.571	0.302
	(2.184)	(3.606)	(5.540)
Patent Stock	-0.464	-0.834	0.072
	(-1.284)	(-3.123)	(5.210)
Standards (total)	0.837	0.850	0.147
	(3.643)	(3.958)	(5.754)
F-Tests			
Industry effects	11.789	19.358	Yes
	(0.000)[b]	(0.000)	
Time effects	1.040	–	
	(0.417)		
Ridge parameter	–	–	0.015
R^2_{adj}	0.976	0.976	0.955

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation.
b) Significance levels in brackets.

In the same way as for the French LSDV model, the traditional model applied to Italy generates a negative coefficient of the partial production elasticity for capital. However, the successful performance of a ridge regression required a rather high ridge parameter of 0.06 – four times higher than in the other ridge regressions. The ridge model produces partial production elasticities of around 0.30 for the two traditional production factors capital and labour, whereas the partial production elasticity of the patent stocks at 0.06 is more than three times higher than the partial production elasticity of the standard stocks.

Table 12:
Estimation results for Italy and ten industries (n=110)

	Model 1 LSDV	Model 2 Ridge Regression
Capital	-0.372	0.291
	(-4.941)[a)]	(33.989)
Labour	0.682	0.314
	(5.168)	(43.750)
Patent Stock	0.602	0.059
	(3.753)	(32.692)
Standards (total)	0.026	0.017
	(1.176)	(3.112)
F-Tests		
Industry effects	79.559	Yes
	(0.000)[b)]	
Time effects	3.172	Yes
	(0.002)	
Ridge parameter	–	0.06
R^2_{adj}	0.996	0.968

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation.
b) Significance levels in brackets.

In order to summarise the results of the country models, in Table 13 we present a comparison of the coefficient of the partial production elasticities for the four input factors. If we focus on the two knowledge stock indicators, we find for the total model a slightly higher coefficient for the patent stocks of 0.11 compared to the 0.08 of standard stocks. For the United Kingdom both are about 0.05 and lower than for the total model. In Germany the partial production elasticity of the patent stocks is more than three times higher than the partial production elasticity of the standard stocks. The same relationship – but on a level of one half – is found for Italy, whereas in France the partial production elasticity of the standard stocks is at 0.15, which is more than double that of the elasticity for the patent stocks.

In summary, there are rather similar partial production elasticities of the patent and standards stocks in the four countries. However, significant differences with respect to the relation between them can be observed. One explanation for these differences can be different sectoral structures, because the institutional settings both for the standardisation and the patent system are rather similar due to the harmonisation efforts at the European level. Therefore, in the next section we will have a look at the sectoral models.

Table 13:
Comparison of the partial production elasticities by country: Results of ridge regressions

	Total Model	United Kingdom	Germany	France	Italy
Capital	0.230	0.344	0.227	0.518	0.291
	(11.639)[a)]	(26.767)	(10.704)	(12.488)	(33.989)
Labour	0.648	0.455	0.417	0.302	0.314
	(30.912)	(18.235)	(13.925)	(5.540)	(43.750)
Patent Stock	0.105	0.047	0.094	0.072	0.059
	(11.785)	(9.465)	(9.095)	(5.210)	(32.692)
Standards (total)	0.079	0.052	0.027	0.147	0.017
	(6.077)	(4.485)	(2.666)	(5.754)	(3.112)

a) t-values in brackets, t=1.645 (or 2.325) for a significance level of 5 % (or 1 %) (one-sided test); White's heteroskedasticity consistent t-values for LSDV estimation.

3.3.3 THE INDUSTRY MODELS

In addition to separate country models, the data of the four countries allow also the estimation of industry or sector models. From a theoretical perspective, one would expect much more stable results in contrast to the country models, because the differences regarding the interplay between the input factors and their relation to the output between sectors should be much higher – and is significant as confirmed by the significant industry dummies in the various country models – than between the same sectors in different countries However, the number of available observations for the industry models is rather low and we still observe certain national idiosyncrasies of the same sectors in Europe, despite the efforts to complete the Single Market or the provision of similar framework conditions.

Table 14 gives an overview of all the twelve sector models. In the same way as for the country models, the traditional LSDV approaches do not lead to sensible results. However, even the performance of ridge regressions only causes significant improvements for some sectors. Although the signs or sizes of the coefficients of the partial production elasticities are not always realistic,[66] we observe a rough pattern regarding the impacts of the stock of patents and the stock of standards. We find mostly significant impacts of the stocks of standards in the sectors, characterised by low and medium R&D and technology intensity, whereas the stocks of patents gain in importance with the increasing R&D intensity of sectors. This very rough structure of a stronger importance of the knowledge base measured by patents in high-tech sectors and a dominance of standards in low- and medium-tech sectors is reasonable from the economics of innovation and technology, but has so far not yet been proved, based on sectoral data.

66 However, based on a panel estimation for 11 OECD countries from 1980 to 1989 Harrigan (1999) finds also some low production elasticities for the capital stock and the labour force differentiated by sector: Non-electrical machinery: C: 0.232 L: 0.611; Office and computing equipment: C: 0.209 L: 0.725; Electrical machinery, excl. comm.: C: -0.631 L: 1.258; Radio, TV, and comm. equipment: C: 0.222 L: 0.678; Shipbuilding and repairing: C: 0.422 L: 0.527; Motor vehicles: C: 0.548 L: 0.434; Aircraft: C: 0.189 L: 0.803; Other transport equipment: C: 0.342 L: 0.382.

Table 14:
Estimation results for the individual industries

	Industry 15-16	Industry 17-19	Industry 20	Industry 21-22	Industry 23-25	Industry 26	Industry 27-28	Industry 29	Industry 30-33	Industry 34	Industry 35	Industry 36-37
LSDV Estimation												
Capital	-0.135	0.157	0.931	0.081	0.369	0.663	0.051	0.570	-2.280	0.759	-1.060	-0.586
	(-0.898)[a]	(0.923)	(3.022)	(0.527)	(2.305)	(11.862)	(0.432)	(3.288)	(-4.447)	(3.318)	(-2.272)	(-1.222)
Labour	-0.224	0.766	0.788	0.521	0.245	-0.069	0.670	0.686	1.141	-0.157	0.837	0.712
	(-1.750)	(10.277)	(3.727)	(5.063)	(2.268)	(-0.928)	(8.447)	(2.812)	(3.148)	(-0.604)	(4.764)	(3.794)
Patent Stock	0.006	0.335	0.503	0.204	0.821	0.119	0.271	0.023	-2.852	-1.147	1.057	0.602
	(0.119)	(2.354)	(4.307)	(1.582)	(2.041)	(4.318)	(3.969)	(0.233)	(-4.555)	(-3.997)	(3.963)	(1.594)
Standards (total)	0.054	-0.006	0.172	-0.034	-0.348	0.128	-0.026	-0.295	0.609	-0.768	0.292	0.507
	(1.822)	(-0.080)	(1.230)	(-0.724)	(-4.182)	(2.999)	(-0.558)	(-3.717)	(2.991)	(-2.280)	(1.685)	(2.666)
R^2_{adj}	0.982	0.992	0.997	0.996	0.991	0.985	0.995	0.994	0.968	0.987	0.780	0.943
Ridge Regression												
Capital	0.110	0.181	0.358	0.197	0.315	0.461	0.314	0.354	0.131	0.846	0.523	0.060
	(4.410)[b]	(6.763)	(7.209)	(7.628)	(5.394)	(13.045)	(6.105)	(13.152)	(0.895)	(6.223)	(1.708)	(5.354)
Labour	0.158	0.509	0.353	0.365	0.070	0.179	0.301	0.317	0.528	0.062	0.504	0.122
	(9.057)	(15.059)	(6.147)	(12.168)	(1.401)	(4.063)	(9.906)	(11.174)	(4.190)	(0.744)	(2.907)	(3.587)
Patent Stock	0.046	-0.063	0.265	0.075	0.171	0.092	0.132	0.144	0.007	-0.083	0.243	0.070
	(4.211)	(-2.685)	(10.604)	(6.955)	(13.137)	(4.461)	(9.032)	(4.801)	(0.112)	(-0.934)	(3.301)	(7.420)
Standards (total)	0.043	0.101	0.088	0.013	-0.095	0.153	0.077	-0.057	0.052	0.065	0.140	0.110
	(4.683)	(2.380)	(1.435)	(0.589)	(-2.547)	(4.738)	(2.722)	(-1.078)	(0.754)	(0.348)	(1.273)	(5.274)
Ridge parameter	0.1	0.02	0.015	0.015	0.015	0.02	0.015	0.02	0.015	0.015	0.04	0.4
R^2_{adj}	0.931	0.974	0.970	0.990	0.972	0.959	0.985	0.980	0.907	0.954	0.653	0.571
Fixed Effects	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country
		Time		Time		Time	Time	Time	Time	Time		Time
NOBS	46	46	34	45	46	46	45	45	45	33	33	45

a) White heteroskedasticity consistent t-values in brackets.
b) t-values in brackets.

CONTENTS

3.3.4. MODELS DIFFERENTIATING NATIONAL AND SUPRANATIONAL STANDARDS

Since the national standardisation systems of the four countries are massively influenced by the emerging and expanding European institutions CEN, CENELEC and ETSI and their standardisation activities, but also by the international standards developed by ISO and IEC, we have also analysed in a last step the influence of the subsamples of national, European and international standards on the development of the value added in the four countries and twelve industries. We assume that the stock of national standards has a stronger impact on economic growth than the European and international standards, which do not necessarily reflect the preferences of domestic producers or customers, do not exclusively increase the national competitive advantage and may therefore even have negative impact on national economic growth in some sectors.

Since we observe a substitution of national standardisation activities especially by European standardisation, the problem of multicollinearity becomes even more severe for the regression analyses. Furthermore, we observe a very strong growth of European standards, starting more or less at a zero level, which is not reflected at all by economic activities. Finally, there is a close and often coordinated relationship between European and international standardisation processes. Based on the theoretical distinction between national standards, on the one hand, and European and international standards on the other hand, and taking into account the special characteristics of the data, we decided to separate the total stock of standards just into national and international standards. However, the standards data for Italy did not allow a clear-cut distinction between national and European or international standards. Therefore, in the following Table 15 we present the results of the total model, including only the UK, France and Germany. The production elasticity of the national stock of standards reaches a value of 0.12, which is similar to the value of the elasticity of the total stock of standards based on a total model, without relying on Italy. This is consistent, because the elasticity of the European and international standards is close to zero.

The three separate national models of the UK, France and Germany confirm the significant impact of the national stock of standards. However, in contrast to the UK, the stocks of European and international standards also have significant production elasticities. The value is rather small in the German model, but for France it reaches a value almost similar to the production elasticity of the national standards.

In summary, the approaches to analyse the impacts of national, European and international standards separately have to be improved in future research with regard to several dimensions. At first, the quality of the data should be improved in order to ensure a precise distinction between the three groups of standards. Additional information about the country of origin of European and international standards would be very helpful. Furthermore, one has to

develop hypotheses of how the changed division of labour in standardisation influences the economic sectors at the national level. Finally, at some time in the future the transition phase after the initiation and catching-up of the European standardisation system should be completed and a new equilibrium between the national and European activities should be reached. Then, more stable patterns of the division of work and their respective impacts should be observable.

Table 15:
Estimation results with differentiated standards for all countries without Italy (n=399)

	Model 1 LSDV	Model 2 LSDV
Capital	0.172	0.180
	(5.552)	(5.783)
Labour	0.789	0.782
	(27.332)	(27.030)
Patent Stock	0.500	0.479
	(7.451)	(8.774)
Standards (national)	0.117	0.117
	(5.373)	(5.434)
Standards (EU+international)	-0.001	0.009
	(-0.030)	(0.481)
F-Tests		
Country effects	52.198	74.783
	(0.000)	(0.000)
Industry effects	22.376	26.135
	(0.000)	(0.000)
Time effects	1.016	–
	(0.432)	
R^2_{adj}	0.980	0.980

3.4. Summary

In summarising the results of the various approaches, the following general observations must be noted. At first, the total model covering all four countries, but also the four separate country models, confirm the significant influence not only of the patent stock as important knowledge pool for economic growth, but also of the stock of formal standards. The production elasticity of the patent stock is slightly higher than the value for the stock of standards. The country models reveal for all countries except France higher production elasticities of the stocks of patents compared to the stocks of standards. These results do not contradict the findings of Jungmittag et al. (1999), who observe a decreasing impact of the stocks of standards since the 1980s.

Whereas the total model and the country models generate reasonable results, the sector models are only partly satisfying. However, we observe in the more mature and less R&D-intensive sectors higher impacts of the stocks of standards, whereas the knowledge pool measured by patent applications is more relevant for those sectors with high R&D intensity and a stronger use of high technology. This result confirms the requirement to analyse the impacts of standards differentiated by sector, due to the sector-specific functions of standards.

Finally, the institutional change in the European standardisation system and its impact on the national activities has to be mentioned. We tried to take into account the different impacts of national, European and international standards. However, the strong expansion of standardisation activities and the simultaneous stagnation of national activities generated additional multicollinearity problems for the regression analyses. However, the total model covering the three countries UK, France and Germany without Italy, which does not allow a precise distinction between national and supranational standards, reveals a significant positive production elasticity for the national stock of standard and a very small and insignificant production elasticity for the sum of the stocks of European and international standards. The results for the three separate country models generate also significant positive coefficients for the stocks of national standards. Analyses separating European and international standards resulted in negative production elasticities especially of the – from a zero-level – strongly growing European stocks of standards. It has to be noted that a differentiated analysis of the impact of national, European, and international standards on economic growth, at least within a Cobb-Douglas production function, will only be feasible after the completion of the institutional changes of the European standardisation system, also based on a more differentiated set of hypotheses.

4. Do Standards Enable or Constrain Innovation?

4.1 Summary

This project examines the impact of standards upon innovation. My report for the DTI on the *Economics of Standardisation* (Swann, 2000) discussed the management of the standards infrastructure to optimise the amount of innovation it promotes. That report argued that the condition of the standards stock influences the effectiveness of that stock in enabling innovation. The discussion in my 2000 paper was purely theoretical, and the aim of this project is to see whether we can apply it empirically.

This project merges two types of data: (a) the BSI Online website and *Perinorm* give details on the stock of current and recent standards, their dates of introduction and modification; (b) the Community Innovation Survey (CIS 3) contains questions on the role of standards as a source of technological information, and the extent to which standards inhibit innovative activity.

The main findings are as follows.

1. We might expect to find that for a particular user thinking of particular standards, that standard *either* constrains *or* helps innovation. Were we to correlate the answers to the CIS questions, 'do standards constrain innovation' and 'do standards provide information for innovation', we might expect a negative correlation. In fact, it is clear from CIS3 that the answers to these questions are *positively* correlated. Effective standards constrain innovation *and* provide information at the same time. Ineffective standards, by contrast, may not constrain, but neither do they provide information.

2. The pattern of responses to these CIS questions varies markedly across industrial sectors (SIC). In the following sectors, at least 70% of respondents say that standards constrain innovation *and* at least 70% say that standards are a source of technological information: SIC codes 19 (leather), 24 (chemicals), 27 (basic metals), 29 (machinery and equipment n.e.c.), 31 (electrical machinery n.e.c.), 32 (radio, TV, communications equipment), 33 (instruments), 62 (air transport). In some other sectors, by contrast, less than 50% of respondents say that standards constrain innovation *and* less than 50% say that standards are a source of technological information: SIC codes 10 (coal), 18 (clothing), 22 (publishing, printing), 70 (real estate).

3. From BSI Online, we find that during the period to which CIS3 refers (1998-2000), the stock of standards comprises many different vintages. We have examined this in detail for the full set of current (1998-2000) standards across all industries. The numbers of standards of each vintage closely follows an exponential distribution, with an exponent parameter of -0.106. (Very roughly this means that the number of standards of vintage *n* years is 10.6% higher than the number of standards of vintage *n+1* years – for any *n*. The exponential distribution is especially convenient, because the distribution is summarised by one parameter. We can also show that this parameter is inversely proportional to the *median* vintage.

4. BSI Online classifies each standard to one or more ICS codes (ICS = International Classification for Standards). For each 2 digit ICS Code we computed the vintage of the median standard. There vary markedly, from June 1989 for ICS 71 (Chemical Technology) to May 1998 for ICS 45 (Railway Engineering). The median for all ICS codes taken together is April 1995. Unfortunately, of course, this ICS is not identical to the Standard Industrial Classification (SIC) used by the Community Innovation Survey (CIS) – though some of the categories look very close.

5. Paul Temple has kindly produced the equivalent to 4, but relating to each SIC code rather than each ICS code, using the *Perinorm* word search function. This also gives a comparable spread of median vintages – but with the added advantages that they can be compared directly with the CIS responses by SIC.

6. In a preliminary report (19 June 2004) I presented a provisional and exploratory analysis of the relationship between CIS responses and the number and median vintages of standards by SIC. This was a very simple aggregate analysis. Working at the 2-digit level, there were few data points (around 30-34) so that it was hard to establish statistical significance. Moreover, the simple analysis took no account of several other factors that could impinge on the pattern of CIS responses. Nevertheless, that analysis provided some provisional findings which we have explored in more detail in this final version of the report.

7. In this final version of the report, we present some ordered logit models of these CIS responses using enterprise-level data. These are much more reliable than the exploratory analyses in the preliminary report, for several reasons:

- With the enterprise-level data, there are more observations allowing more reliable and precise estimates.

- We can confidently estimate *separate* models of the informing and constraining role of standards. This is important as there are interesting differences between these two models, and also because the *combined* model of information *and* constraint from the preliminary report was rather confusing.
- We can now take account of other explanatory variables from the CIS dataset – and some of these are interesting, as we see below.
- These models seem more robust (than the simple models) to data correction – see discussion in Sections 4.6 and 4.7.

8. Starting with our model of the informative role of standards, we find a significant quadratic relationship with median age, but only a linear relationship with the number of standards. The brand new standard is not as important a source of information as the somewhat older standard. But when standards get 'too old', they lose their information content. The first part of this is consistent with a diffusion effect, whereby standards need time to diffuse before they can play an important informative role. The second part is consistent with a life-cycle interpretation: old standards lose their relevance. The results are similar (though not identical) for the three different types of standard identified in CIS question 12.1.

9. With regard to the number of standards, the relationship seems just to be linear: 'more standards mean more information'. There does not seem to be a significant quadratic effect, nor therefore a clear optimum number beyond which, 'more standards means *less* information'.

10. This model also finds that the following types of enterprise are more likely than average to say that technical standards inform:

- Those with a higher proportion of scientists and engineers (question 3.4);
- Product innovators;
- Process innovators;
- Enterprises with longer term innovation activities;
- Enterprises who have some sort of cooperation in innovation.

The results for other standards (health and safety, and environmental) are rather different however.

11. Turning to our model of the constraining role of standards, this finds significant quadratic relationships with both the number *and* median age of standards. Thus, to begin with, as the number of standards increases, the standards are less likely to constrain. But as the number gets 'too large', then standards are more likely to constrain. Equally, to begin with, as the median age gets older, standards are less likely to constrain, but when they

get 'too old' then standards are more likely to constrain. This latter observation is consistent with a life cycle interpretation of median age.

12. This model also finds that some other variables have interesting associations with the constraining role of standards. For example, enterprises whose principal market is local or regional are more likely to say that standards constrain them, while enterprises whose principal market is national or international are less likely to say that standards constrain. This is not surprising. The competitiveness of enterprises operating in national (and especially international) markets depends on them meeting relevant standards. These enterprises are less likely to feel that the standard constrains them in a way that has adverse implications for their competitiveness.

4.2 Introduction

This project examines the impact of standards upon innovation – in particular, the association between the role of standards as enablers and/or inhibitors and the standards inventory. Do standards enable innovation or constrain innovation? Or does the answer depend on the condition of the standards stock? That is, does the effect of standardisation on innovation depend on whether the standards stock is current or out-of-date, and whether there are enough standards, too few or too many?

These questions are of interest in their own right, as their answers would give us a clearer structural account of *how* standards enable innovation, and hence economic growth. But the results of this sub-project will also be useful as a guide to measuring the effective stock of standards – which is relevant to the rest of this project.

My report for the DTI on the *Economics of Standardisation* (Swann, 2000) drew an analogy between the role of pruning in maximising yield from fruit trees and the management of the standards infrastructure to optimise the amount of innovation it promotes. That report argued that the condition of the standards stock influences the effectiveness of that stock in enabling innovation. The discussion in my 2000 paper was purely theoretical, and the aim of this project is to see whether we can apply it empirically.

In Annex C, I reproduce a section from that earlier report for DTI. This summarises the analogy. Of course, such analogies are dangerous if carried too far, but are powerful in suggesting ways of describing the *condition* of the standards stock. In what follows, we can only make a start in the empirical measurement of this *condition*, but focus on two measures that are essential components:

- The distribution of standards of different vintages
- The total number of standards

New standards may in principle be the ideal, but in practice they may not be fully effective until they are widely diffused. Old standards, by contrast, will tend to be ineffective. For these reasons, the optimum vintage of standard may in fact be of an intermediate age.

A sector with few standards will not enjoy the benefits that standardisation can deliver. On the other hand, we shall see in what follows that a sector with excessive standards may not benefit from these. There may be an optimum (intermediate) number of standards per sector.

In the empirical analysis that follows, we shall attempt to measure the association between these two measures of *condition* and the perceived effects of standards on innovation (as in the CIS survey). The approach taken will allow for the possibility that there is an optimum vintage and an optimum number of standards.

4.3 CIS Questions on Standards

The Community Innovation Survey 2001 (CIS3) asks some questions about the role of standards in the innovation process.

Question 8.1 asks the respondent to comment on a range of factors that may inhibit the enterprise's ability to innovate. The respondent is asked to grade the importance of these constraints during the period 1998-2000. These factors are listed below:

			Importance		
		No Effect	Low	Medium	High
Economic factors	Excessive perceived economic risks				
	Direct innovation costs too high				
	Cost of finance				
	Availability of finance				
Internal factors	Organisational rigidities within the enterprise				
	Lack of qualified personnel				
	Lack of information on technology				
	Lack of information on markets				
Other factors	Impact of regulations or standards				
	Lack of customer responsiveness to new goods or services				

The penultimate factor, ***impact of regulations or standards*** gives us a view on whether, as sometimes asserted, standards inhibit or constrain the enterprise's ability to innovate.

Question 12.1 asks respondents to rank the different sources of knowledge or information used in innovation activities, again with particular reference to the period 1998-2000. The different sources listed are as follows:

		Degree of Importance			
		Not used	Low	Medium	High
Internal	Within the enterprise				
	Other enterprises within the enterprise group				
Market	Suppliers of equipment, materials, components or software				
	Clients or customers				
	Competitors				
	Consultants				
	Commercial laboratories / R&D enterprises				
Institutional	Universities or other HEIs				
	Government research organisations				
	Other public sector (e.g. Business Links, Government Offices)				
	Private research institutes (e.g. charities)				
Other	Professional conferences, meetings				
	Trade associations				
	Technical/trade press, computer databases				
	Fairs, exhibitions				
Specialised	Technical standards				
	Health and safety standards and regulations				
	Environmental standards and regulations				

The last three factors give us a view on the value of standards as a source of information. For the initial analysis in this section, we have compressed the responses from these two questions into two binary variables:

	Yes	No
Do standards constrain innovation?	'low', 'medium' or 'high' in Question 8.1	'No effect' in Question 8.1
Are standards a source of information?	'low', 'medium' or 'high' for at least one type of standard in Question 12.1	'Not used' for all three types of standards in Question 12.1

We might expect the answers to these questions to be *negatively correlated*. That is, we might expect a particular respondent to reply *either* that standards constrain innovation *or* that standards are a source of information, *but not both*. However, that is not the general pattern, as we shall see.

Let us start with the aggregate picture (all CIS respondents in all SIC codes). The pattern of responses to these two binary questions is as follows:

	Don't constrain	Do constrain
No information	29.7%	17.8%
Some information	13.3%	39.2%

The conditional probabilities make the picture clear. If standards provide *no* information (row 1), then it is more likely that they *don't* constrain. But if they *do* provide information (row 2), then it is more likely that they *do* constrain. The same applies, *mutatis mutandis*. If standards *don't* constrain (column 1), then it is more likely that they contain *no* information. But if they *do* constrain, then it is more likely that they *do* contain information.

This may seem surprising at first sight, but with a little reflection it is perhaps not so surprising. Within the 'tree' model of Annex C, the informative role of standards goes hand in hand with the constraining effect. To provide valuable information, standards must constrain to some degree.

This positive correlation between the answers to these two binary questions is seen even more starkly within the following table.

	Conditional on 'No Information'	Conditional on 'Some Information'
Pr (Don't Constrain) > Pr (Do Constrain)	32 SIC codes	3 SIC codes
Pr (Don't Constrain) = Pr (Do Constrain)	2 SIC codes	0 SIC codes
Pr (Don't Constrain) < Pr (Do Constrain)	8 SIC codes	39 SIC codes

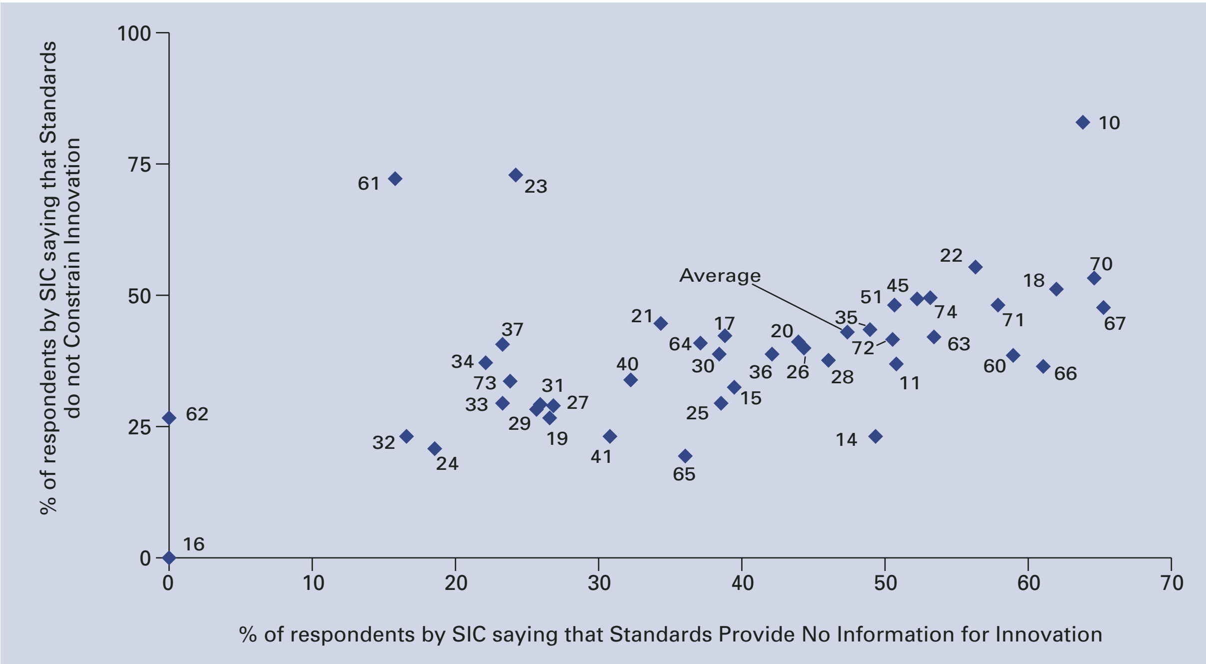
It should be read as follows. For all the respondents in each of 42 separate SIC codes, we separate them into two groups: those saying standards provide 'no information' and those saying 'some information'. For those respondents in each group in turn, we ask whether the number saying standard 'don't constrain' is greater than (row 1), equal to (row 2) or less than (row 3) the number saying 'do constrain'. In 32 out of 42 SIC codes, those respondents that say standards provide 'no information' are more likely to say that standards 'don't constrain'. And in 39 out of 42 SIC codes, those respondents that say standards provide 'some information' are more likely to say that standards 'do constrain'.

Figure 24 shows a simple scatter plot of the relationship between the proportion of respondents replying 'no information' and the proportion replying 'don't constrain'. Each data point relates to a 2-digit SIC code (listed in Table 16).

This shows a clear positive correlation, though with a few outliers. However, the pattern of responses to these CIS questions varies markedly across industrial sectors (SIC). In the following sectors, at least 70% of respondents say that standards constrain innovation *and* at least 70% say that standards are a source of technological information: SIC codes 19 (leather), 24 (chemicals), 27 (basic metals), 29 (machinery and equipment n.e.c.), 31 (electrical machinery n.e.c.), 32 (radio, TV, communications equipment), 33 (instruments), 62 (air transport). In some other sectors, by contrast, less than 50% of respondents say that standards constrain innovation *and* less than 50% say that standards are a source of technological information: SIC codes 10 (coal), 18 (clothing), 22 (publishing, printing), 70 (real estate).

In short it seems that in this sample, at least, the informative and the constraining role of standards go hand in hand. This positive association is also found in Section 4.7 when we look at the ordered logit models of CIS responses.

Figure 24:
Correlation between standards as non-information for innovation and not constraining on innovation 1998-2000



Source: CIS

Table 16
SIC 2 Digit Codes

SIC	Industry
10	Mining of Coal and Lignite; Extraction of Peat
11	Extraction of Crude Petroleum and Natural Gas; Service Activities Incidental to Oil and Gas Extraction, Excluding Surveying
14	Other Mining and Quarrying
15	Manufacture of Food Products and Beverages
16	Manufacture of Tobacco Products
17	Manufacture of Textiles
18	Manufacture of Wearing Apparel; Dressing and Dyeing of Fur
19	Tanning and Dressing of Leather; Manufacture of Handbags, Saddlery, Harness and Footwear
20	Manufacture of Wood and Products of Wood and Cork, Except Furniture; Manufacture of Articles of Straw and Plaiting Materials
21	Manufacture of Pulp, Paper and Paper Products
22	Publishing, Printing and Reproduction of Recorded Media
23	Manufacture of Coke, Refined Petroleum Products and Nuclear Fuel
24	Manufacture of Chemicals and Chemical Products
25	Manufacture of Rubber and Plastic Products
26	Manufacture of Other Non-metallic Mineral Products
27	Manufacture of Basic Metals
28	Manufacture of Fabricated Metal Products, Except Machinery and Equipment
29	Manufacture of Machinery and Equipment Not Elsewhere Classified
30	Manufacture of Office Machinery and Computers
31	Manufacture of Electrical Machinery and Apparatus Not Elsewhere Classified
32	Manufacture of Radio, Television and Communication Equipment and Apparatus
33	Manufacture of Medical, Precision and Optical Instruments, Watches and Clocks
34	Manufacture of Motor Vehicles, Trailers and Semi-trailers
35	Manufacture of Other Transport Equipment
36	Manufacture of Furniture; Manufacturing Not Elsewhere Classified
37	Recycling
40	Electricity, Gas, Steam and Hot Water Supply
41	Collection, Purification and Distribution of Water
45	Construction
51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
60	Land Transport; Transport via Pipelines
61	Water Transport
62	Air Transport
63	Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
64	Post and Telecommunications
65	Financial Intermediation, Except Insurance and Pension Funding
66	Insurance and Pension Funding, Except Compulsory Social Security
67	Activities Auxiliary to Financial Intermediation
70	Real Estate Activities
71	Renting of Machinery and Equipment without Operator and of Personal and Household Goods
72	Computer and Related Activities
73	Research and Development
74	Other Business Activities

4.4. BSI Online Data and the Distribution of Standards Vintages

BSI Online contains for almost all standards an introduction date, a date of revision or replacement and a date of withdrawal, as well as a relevant industrial classification (ICS – rather than SIC, however). Hence we can create more than just a count of standards, but also an inventory of standards of different vintages.

In this section we look at the vintages of all the standards that are deemed to be effective at some point during the period 1998-2000. The logic of the calculation is as follows. CIS asks enterprises to talk about the variables influencing their innovative activity over the period 1998-2000. Accordingly, I first compute the total set of standards introduced from day one (say 1900) until the end of 2000, and subtract the sub-set that were withdrawn by end-1997. Then taking the set that were in operation at some point during the period 1998-2000, I compute the number of each vintage (measured just in years).

The first histogram below (Figure 25) shows the resulting distribution for all standards (across all industrial sectors). Figure 26 shows that this distribution is closely approximated by the exponential distribution:

$$f(x) = \lambda \exp\{-\lambda x\} \qquad (8)$$

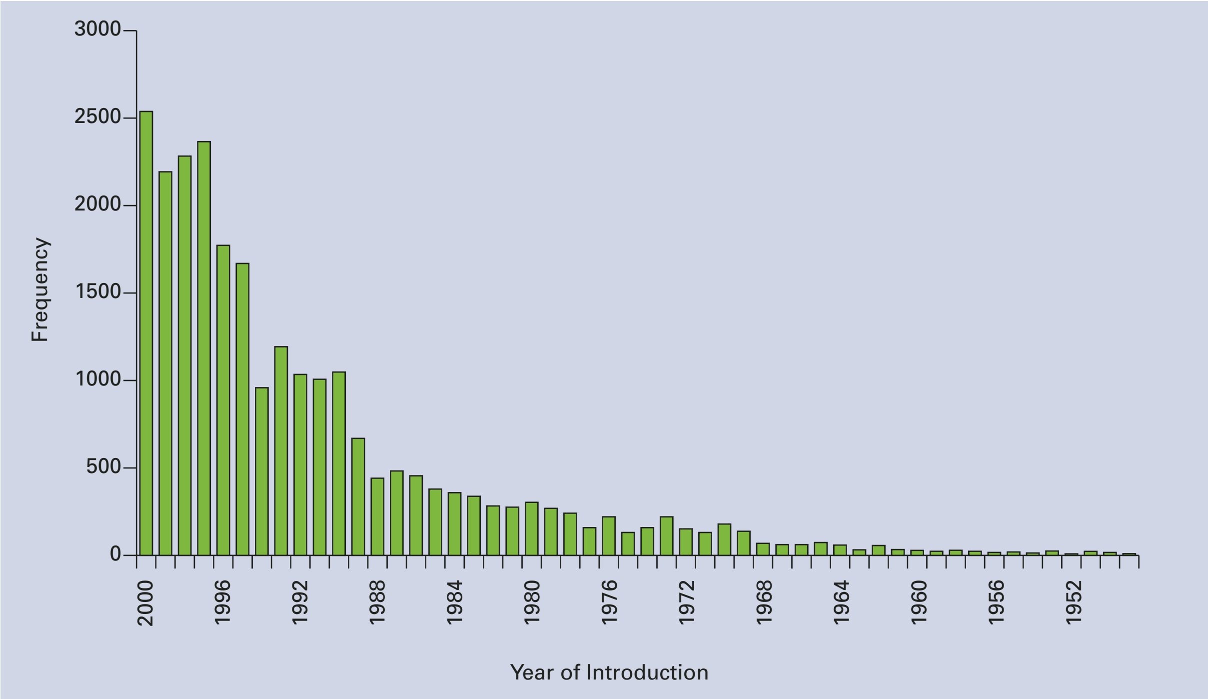
Figure 27 gives an even clearer indication. For if a variable follows an exponential distribution as in equation (8), then log of frequency is given by:

$$\log f(x) = \log(\lambda) - \lambda x \qquad (9)$$

That is, when frequency is drawn on a log scale, there should appear to be a straight line (and negatively sloping) relationship between log (frequency) and the age of the standard. In Figure 27, this relationship is very close to linear, with an estimated slope of -0.106 and an R^2 of 97.6%. Figure 28 shows the (cumulative) distribution function corresponding to Figures 24 and 25.

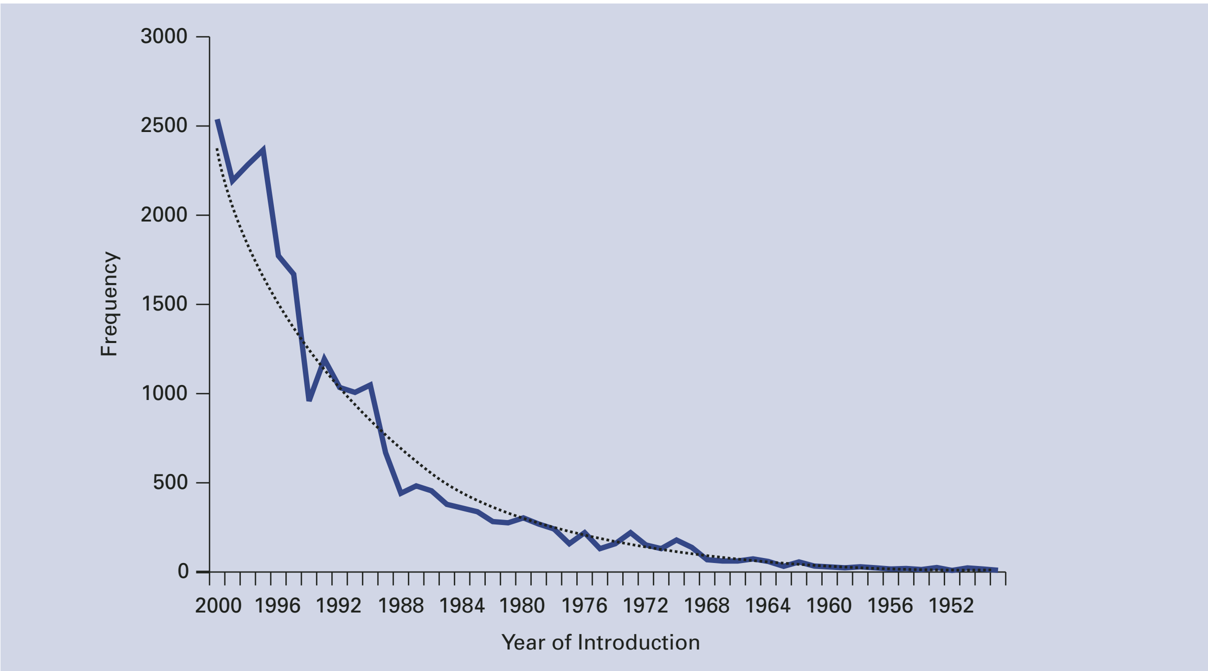
The exponential distribution has several convenient properties. One of these is that the median of the exponential distribution is inversely proportional to the parameter λ (as we see in Annex D).

Figure 25:
Vintages of Standards Available during 1998-2000



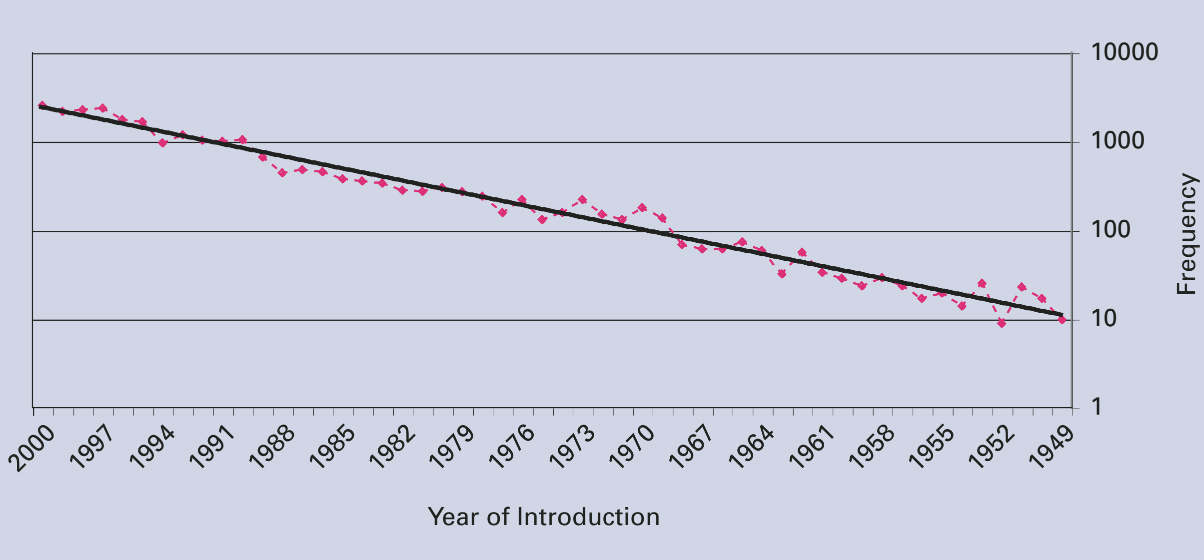
Source: BSI/PERINORM©

Figure 26:
Vintages of Standards Available during 1998-2000



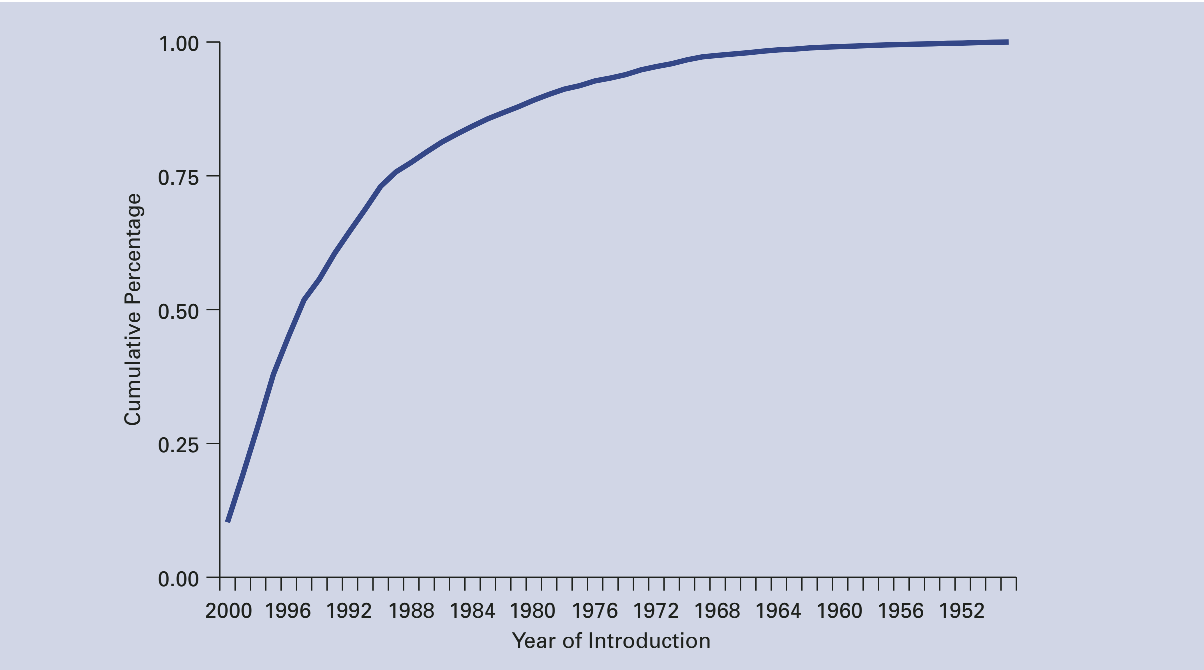
Source: BSI/PERINORM©

Figure 27:
Vintages of Standards Available during 1998-2000



Source: BSI/PERINORM©

Figure 28:
Vintages of Standards Available during 1998-2000 (Cumulative Percentage)



Source: BSI/PERINORM©

4.5. BSI Online Data and the Vintage of the Median Standard by ICS

In the BSI Online database,[67] standards are allocated to industrial sectors using the International Classification of Standards (ICS). While this is quite close to the Standard Industrial Classification (SIC) for some sectors, the two are not unfortunately the same.

67 Available at: http://bsonline.techindex.co.uk/

Using BSI Online's standard interface, it was not realistic to compute the entire distribution of standard vintages for each industrial sector.[68] However, it was relatively quick to compute the median vintage – or, to be more precise, the vintage of the median standard. When the underlying distribution is exponential, then the median is a sufficient statistic, because it is inversely proportional to the parameter λ – see Appendix A2. While we don't know that the distribution is exponential for each different sector, we saw in the last section that it was exponential for *all* standards (aggregated across *all* sectors).

To compute median vintage corresponding to each 2 digit ICS code, I first compute the total number of standards introduced from day one (say 1900) until the end of 2000, and subtract the number of those that were withdrawn by end-1997. Call this number, n. Then I search (using a sort of Newtonian variable-step algorithm) for a date mm:yy such that the total number of standards introduced between mm:yy and end-2000 less the number of those withdrawn by end-1997 is equal to n/2. Then mm:yy is the median vintage of those standards valid at some point during the period 1998-2000. This procedure very substantially reduces the amount of time taken – using the present BSI Online interface.

The following tables show the results in two ways. On the first page, they are sorted by ICS code. On the second page, they are sorted by median vintage. It is apparent that this median varies quite a bit (from June 1989 top May 1998). The median vintage for standards in all codes is April 1995.

68 Using this site online means that each data point in the histogram above (Figure 24) is the result of a separate enquiry. Each enquiry took at least 1 minute. For at least 50 data points (years) and 40 ICS codes, that means a minimum of 33 hours. (This would account for a substantial chunk of the time budget of 80 hours allocated to this sub-project.)

Table 17
Median Vintages, in Order of ICS

ICS Code	Description	Vintage of Median Standard
01	Generalities, Terminology, Standardisation, Documentation	July-93
03	Sociology, Services, Company Organisation and Management, Administration, Transport	August-96
07	Mathematics, Natural Sciences	March-97
11	Health Care Technology	August-96
13	Environment and Health Protection, Safety	January-97
17	Metrology and Measurement, Physical Phenomena	March-94
19	Testing	June-95
21	Mechanical Systems and Components for General Use	February-93
23	Fluid Systems and Components for General Use	August-96
25	Manufacturing Engineering	March-94
27	Energy and Heat Transfer Engineering	April-97
29	Electrical Engineering	September-95
31	Electronics	December-92
33	Telecommunications, Audio and Video Engineering	January-97
35	Information Technology, Office Machines	August-96
37	Image Technology	May-95
39	Precision Mechanics, Jewellery	September-95
43	Road Vehicle Engineering	October-95
45	Railway Engineering	May-98
47	Shipbuilding and Marine Structures	August-91
49	Aircraft and Space Vehicle Engineering	September-94
53	Materials Handling Equipment	March-93
55	Packaging and Distribution of Goods	July-94
59	Textile and Leather Technology	April-95
61	Clothing Industry	January-91
65	Agriculture	June-93
67	Food Technology	November-94
71	Chemical Technology	June-89
73	Mining and Minerals	July-90
75	Petroleum and Related Technologies	November-95
77	Metallurgy	June-93
79	Wood Technology	September-95
81	Glass and Ceramics Industries	May-95
83	Rubber and Plastics Industries	August-95
85	Paper Technology	December-92
87	Paint and Colour Industries	April-93
91	Construction Materials and Building	March-96
93	Civil Engineering	November-97
95	Military Engineering	n/a *
97	Domestic and Commercial Equipment, Entertainment, Sports	December-95
	ALL ICS Codes	**April-95**

* too few published BSI standards for this category to compute a meaningful median

Table 18
Median Vintages by ICS, Descending Order of Vintage

ICS Code	Description	Vintage of Median Standard
45	Railway Engineering	May-98
93	Civil Engineering	November-97
27	Energy and Heat Transfer Engineering	April-97
07	Mathematics, Natural Sciences	March-97
13	Environment and Health Protection, Safety	January-97
33	Telecommunications, Audio and Video Engineering	January-97
03	Sociology, Services, Company Organisation and Management, Administration, Transport	August-96
11	Health Care Technology	August-96
23	Fluid Systems and Components for General Use	August-96
35	Information Technology, Office Machines	August-96
91	Construction Materials and Building	March-96
97	Domestic and Commercial Equipment, Entertainment, Sports	December-95
75	Petroleum and Related Technologies	November-95
43	Road Vehicle Engineering	October-95
29	Electrical Engineering	September-95
39	Precision Mechanics, Jewellery	September-95
79	Wood Technology	September-95
83	Rubber and Plastics Industries	August-95
19	Testing	June-95
37	Image Technology	May-95
81	Glass and Ceramics Industries	May-95
59	Textile and Leather Technology	April-95
	ALL ICS Codes	**April-95**
67	Food Technology	November-94
49	Aircraft and Space Vehicle Engineering	September-94
55	Packaging and Distribution of Goods	July-94
17	Metrology and Measurement, Physical Phenomena	March-94
25	Manufacturing Engineering	March-94
01	Generalities, Terminology, Standardisation, Documentation	July-93
65	Agriculture	June-93
77	Metallurgy	June-93
87	Paint and Colour Industries	April-93
53	Materials Handling Equipment	March-93
21	Mechanical Systems and Components for General Use	February-93
31	Electronics	December-92
85	Paper Technology	December-92
47	Shipbuilding and Marine Structures	August-91
61	Clothing Industry	January-91
73	Mining and Minerals	July-90
71	Chemical Technology	June-89

4.6. *Perinorm* Data and the Vintage of the Median Standard by SIC

The problem with the data in Section 4.5 for our purposes is that the standards are allocated by ICS code rather than by SIC code. Though these two classifications have much in common, they are not the same, and that means it is difficult to link up the CIS data and the standards data.

I am grateful to Paul Temple who has computed the numbers of standards and median vintages using Perinorm. The technique is similar to that used in the last section, but it was necessary for Paul to use a correlator to map from ICS to SIC. The precise details of this correlator are given in Appendix E.

The two tables below are equivalent to those in the last section. The first gives the numbers and median vintages ordered by SIC code. The second sorts these by median vintage – latest vintages first.

The range of vintages is comparable to those computed in Section 4.5, though one SIC code (14) has a rather older median vintage (October 1979).

Table 19
Median Vintages, in Order of SIC[69]

ICS Code	Description	Number Active 1998-2000	Vintage of Median Standard
10	Mining of coal and lignite; extraction of peat	97	Jul-92
11	extraction of crude petroleum and natural gas; service industries incidental to oil and gas extraction exc. Surveying	105	Dec-97
14	Other mining and quarrying except metal ores and energy producing materials	30	Oct-79
15	Manufacture of food products and beverages	953	Feb-93
17	Manufacture of textiles	601	Dec-94
18	Manufacture of wearing apparel; dressing and dyeing of fur	121	Jan-91
19	Tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear	43	Jan-91
20	Manufacture of wood and wood products and products of cork, exc. Furniture	266	Aug-94
21	Manufacture of pulp, paper and paper products	183	Dec-92
22	Publishing, printing, and reproduction of recorded media	244	Dec-93
23	Manufacture of coke, refined petroleum products and nuclear fuel	482	Mar-95
24	Manufacture of chemicals and chemical products	854	May-89
25	Manufacture of rubber and plastics products	1089	Jul-95
26	Manufacture of other non-metallic mineral products	399	Sep-93
27	Manufacture of Basic Metals	1007	Dec-92
28	Manufacture of Fabricated Metal products excl. machinery and equipment	1617	Jan-95
29	Machinery and equipment, n.e.c.	2217	Sep-93
30	Office, accounting and computing machinery	1632	Jul-96
31	Electrical machinery and apparatus, n.e.c.	1637	Jun-95
32	Radio, television and communication equipment	1928	Mar-95
33	Medical, precision and optical instruments, watches and clocks	2285	Mar-95
34	Motor vehicles, trailers and semi-trailers	399	Jun-91
35	Other transport equipment	1707	Oct-90
36	Manufacture of Furniture; manufacture n.e.c.	860	Jul-95
37	Recycling	293	Aug-96
40	Electricity, gas, steam and hot water supply	246	Apr-97
41	Collection, purification, and distribution of water	549	Nov-96
45	Construction	1993	Apr-94
51/52	Wholesale and Commission trade (51): retail trade excl. of motor vehicles and motor cycles; repair of personal and l household goods	1198	Apr-95
60	Land transport; transport via pipelines	94	Feb-98
61	Water transport	222	Jun-90
62	Air transport	802	Feb-88
63	Supporting and auxiliary transport activities; travel agencies	74	Mar-95
64	Post and Telecommunications	552	Jun-96
65	Financial Intermediation	118	Sep-97
72	Computer and Related Activities	779	Mar-96
	All SIC Codes	**22368**	**May-94**

69 Our preliminary report (19th June 2004) contained an error for SIC 29, which is corrected here.

Table 20:
Median Vintages by SIC, Descending Order of Vintage[70]

ICS Code	Description	Number Active 1998-2000	Vintage of Median Standard
60	Land transport; transport via pipelines	94	Feb-98
11	extraction of crude petroleum and natural gas; service industries incidental to oil and gas extraction exc. Surveying	105	Dec-97
65	Financial Intermediation	118	Sep-97
40	Electricity, gas, steam and hot water supply	246	Apr-97
41	Collection, purification, and distribution of water	549	Nov-96
37	Recycling	293	Aug-96
30	Office, accounting and computing machinery	1632	Jul-96
64	Post and Telecommunications	552	Jun-96
72	Computer and Related Activities	779	Mar-96
29	Machinery and equipment, n.e.c.	2217	Sep-93
25	Manufacture of rubber and plastics products	1089	Jul-95
36	Manufacture of Furniture; manufacture n.e.c.	860	Jul-95
31	Electrical machinery and apparatus, n.e.c.	1637	Jun-95
51/52	Wholesale and Commission trade (51): retail trade excl. of motor vehicles and motor cycles; repair of personal and household goods	1198	Apr-95
23	Manufacture of coke, refined petroleum products and nuclear fuel	482	Mar-95
32	Radio, television and communication equipment	1928	Mar-95
33	Medical, precision and optical instruments, watches and clocks	2285	Mar-95
63	Supporting and auxiliary transport activities; travel agencies	74	Mar-95
28	Manufacture of Fabricated Metal products excl. machinery and equipment	1617	Jan-95
17	Manufacture of textiles	601	Dec-94
20	Manufacture of wood and wood products and products of cork, exc. Furniture	266	Aug-94
	All SIC Codes	**22368**	**May-94**
45	Construction	1993	Apr-94
22	Publishing, printing, and reproduction of recorded media	244	Dec-93
26	Manufacture of other non-metallic mineral products	399	Sep-93
15	Manufacture of food products and beverages	953	Feb-93
21	Manufacture of pulp, paper and paper products	183	Dec-92
27	Manufacture of Basic Metals	1007	Dec-92
10	Mining of coal and lignite; extraction of peat	97	Jul-92
34	Motor vehicles, trailers and semi-trailers	399	Jun-91
18	Manufacture of wearing apparel; dressing and dyeing of fur	121	Jan-91
19	Tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear	43	Jan-91
35	Other transport equipment	1707	Oct-90
61	Water transport	222	Jun-90
24	Manufacture of chemicals and chemical products	854	May-89
62	Air transport	802	Feb-88
14	Other mining and quarrying except metal ores and energy producing materials	30	Oct-79

70 To repeat footnote 69, our preliminary report (19th June 2004) contained an error for SIC 29, which is corrected here.

4.7. Association between CIS Responses and the Condition of the Standards Stock

The final (and in a sense, the *ultimate*) objective for this sub-project is to examine the association between the CIS responses, the number of relevant standards and the median vintage of relevant standards.

In our preliminary report (19 June 2004), we used a simple aggregate analysis at the 2-digit SIC level. This found some suggestive evidence of two relationships (*inter alia*) that are of particular interest in this context:

- There was some evidence of a quadratic relationship between the degree that standards constrain the innovator and the median age of the standards stock. That is, when the median age of the standards stock is especially low or especially high, then that tends to be associated with a constraint on innovation (as judged by the CIS responses); but at intermediate median ages, there tends to be less of a constraint on innovation.
- There was some evidence that a larger number of standards per SIC is associated with a higher information content to standards (as judged from the CIS responses).

The analysis in our preliminary report was rudimentary and unsatisfactory in several respects, however. First, it simply worked with SIC averages, and hence a small number of observations (around 34 observations, one for each SIC code). Second, the logistic regressions used there had to compress the CIS measures of information and constraints into binary variables, and could not make use of the full (ordered) character of the responses. Third, that analysis could not take account of any other related variables. And fourth, as we saw in the previous section, the standards data in the preliminary report contained an error for SIC 29 (see Tables 19 and 20 above), and the results in the preliminary report are somewhat sensitive to this.

For these reasons, we shall not replicate the analysis of the preliminary report here. Rather, we have developed two separate ordered logit models of the informing and constraining roles of standards using enterprise level data. The first model examines the extent to which standards inform innovation, and whether this relates to the size and median vintage of the standards stock, and indeed to other variables. The second model examines the extent to which standards constrain innovation, and whether this relates to the size and median vintage of the standards stock, and again to other variables.

These are much preferable to the earlier analysis, for several reasons:

- With the enterprise-level data, there are more observations allowing more reliable and precise estimates.

- We can confidently estimate separate models of the informing and constraining role of standards. This is important as there are interesting differences between these two models, and also because the combined model of information *and* constraint from the preliminary report was rather confusing.
- We can now take account of other explanatory variables from the CIS dataset – and some of these are interesting, as we see below.
- These models seem more robust (than the simple models) to the data correction noted above.

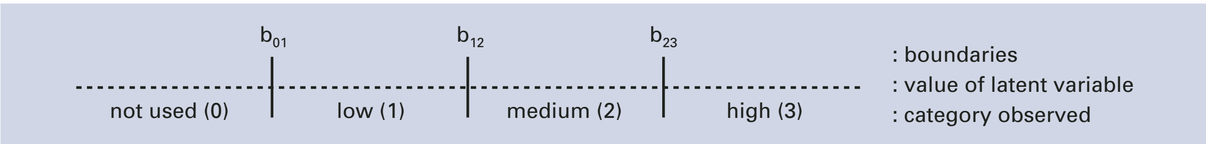
4.7.1. AN ORDERED LOGIT MODEL OF THE INFORMATIVE ROLE OF STANDARDS

This section describes the ordered logit models of the informative role of standards. There are three such models, corresponding to the three variables in the CIS dataset: IFSTAND (the informative role of technical standards), IFHEALTH (the informative role of health and safety standards and regulations) and IFENVIRO (the informative role of environmental standards and regulations).

The ordered logit[71] model is designed to model the behaviour of ordered variables – such as here, where an information source is ranked in terms of importance from 0 (not used) through 1 (low importance), 2 (medium importance) and 3 (high importance).[72]

The method assumes there is an underlying continuous latent variable such as ‘importance’, but this continuous variable cannot be measured. Instead, we observe different categories (0, 1, 2 or 3) when the latent variable falls in different bands, as shown in Figure 29.

Figure 29
Relationship between continuous latent variables and category variables



The estimation problem with ordered logit therefore has the added complication of estimating the boundaries between categories. So in the present context, it has to estimate three boundary values (b_{01}, b_{12}, b_{23}).

71 There is also an ordered probit equivalent to this ordered logit. The probit approach is widely used, but SPSS seems especially well set up to estimate the logit model. We have not considered any difference in results between ordered logit and ordered probit. Any differences are unlikely to be of huge importance.

72 Ordered logit is clearly preferable to the crude application of OLS using the categories (0-3) as if they were a linear scale. The reason for this is that OLS would assume that the ‘distance’ between 0 and 1 is the same as the distance between 1 and 2, and so on, but ordered logit can allow these distances to differ – as shown in Figure 29.

The ordered logit model makes use of a variety of CIS variables (as detailed in Table 22), and these variables are defined in Table 21. In this specific context, the latent variable ('importance') is implicitly assumed to be a linear function of the variables listed in Table 22.

In Table 22, the variable NSTDS is entered only in a linear form and the squared variable NSTDS2 is omitted throughout. In exploratory regressions (not reported here) we examined whether anything was to be gained from a quadratic form, including both NSTDS *and* $NSTDS^2$. However, we found that the two were not *both* statistically significant. For that reason, we focus our attention only on models of the informative role of standards that are *linear* in the number of standards. When we turn to the models of the constraining role of standards (Section 4.7.2), we find a quadratic relationship that is statistically significant.

Most of the results in Table 22 use the variable MEDAGE and its squared value. Column (1.2) however uses the deflated variable MEDAGE#. This variables adjusts median age to reflect the fact that an old standard in a rapidly changing industry is more likely to be 'out of date' than an old standard in a slowly changing industry. To create this deflated measure of median age we seek an estimate of the typical length of the product life cycle in each 2 digit SIC industry. To calculate this we proceed as follows.

Suppose that a typical enterprise has a portfolio of n products, each with equal sales revenue. Then each product accounts for a proportion 1/n of sales revenue. Suppose that these have a uniform age distribution: one is up to a year old, one is up to two years old, and so on, and the oldest is up to n years old. Suppose that at the end of each year, the oldest product (n years old) drops out of the portfolio and a new or improved product takes its place. From this we can deduce that the length of the typical product life cycle is n years. Hence, MEDAGE# should be calculated by deflating MEDAGE by n. We can also show that the new product accounts for a share 1/n of sales revenue. Now the CIS variables PRODNEW and PRODIMP (see Table 21) define the proportion of annual sales attributable to (respectively) new products and improved products. The sum of these two is the proportion of sales attributable to products that have changed within the year:

$$c = PRODNEW + PRODIMP$$

In terms of our simple model:

$$c = \frac{1}{n}$$

Hence we can compute:

$$MEDAGE\# = \frac{MEDAGE}{n} = MEDAGE * c = MEDAGE * (PRODNEW + PRODIMP)$$

Table 21: Variables in Ordered Logit Models

Variable	Definition	Units/Values
IFSTAND	Importance of technical standards as a source of information for innovative activities	0: not used 1: low importance 2: medium importance 3: high importance
IFHEALTH	Importance of health and safety standards and regulations as a source of information for innovative activities	0: not used 1: low importance 2: medium importance 3: high importance
IFENVIRO	Importance of environmental standards and regulations as a source of information for innovative activities	0: not used 1: low importance 2: medium importance 3: high importance
HPREGS	To what extent do regulations and /or standards constrain or hamper innovation?	0: no effect 1: low importance 2: medium importance 3: high importance
NSTDS	Count (thousands) of BSI standards relevant to the 2-digit SIC in which enterprise is based	Thousands
MEDAGE	Median age (on 31st December 2000) of those BSI standards relevant to the 2-digit SIC in which enterprise is based	Years
MEDAGE#	Median age of BSI standards (years) deflated by estimated length of product life cycle (years) – for 2-digit SIC in which enterprise is based. (See text for an explanation of how this is calculated.)	(dimensionless)
PRODNEW	Share of turnover in 2000 from products that are new to the firm	%
PRODIMP	Share of turnover in 2000 from improved products	%
TURN2000	Enterprise turnover in 2000	£Mn
EXPORT2000	Enterprise exports in 2000	£Mn
PRODINOV	Is enterprise a product innovator?	1: Yes 0: No
PROCINOV	Is enterprise a process innovator?	1: Yes 0: No
LONGTERM	Does enterprise have longer-term innovation activities?	1: Yes 0: No
PCOOP	Does enterprise have a co-operative arrangement for any innovation activities?	1: Yes 0: No
PROPSCI	Proportion of employees educated to degree level (or above) in science or engineering	%
FREGS	Importance of innovation activities in meeting standards or regulations	0: no importance 1: low importance 2: medium importance 3: high importance
MARKET	Which is the enterprise's largest market?	1: local 2: regional 3: national 4: international
HPLKTECH	To what extent does a lack of information on technology constrain or hamper innovation?	0: no effect 1: low importance 2: medium importance 3: high importance

Table 22:
Ordered Logit Model
Importance of Standards as a Source of Information for Innovation

	Dependent Variable				
	IFSTAND			IFHEALTH	IFENVIRO
	(1.1)	(1.2)	(1.3)	(2.1)	(3.1)
Boundary (0,1)	-1.85 *** (0.27)	-2.24 *** (0.19)	-1.98 ***) (0.28	-2.05 *** (0.26)	-2.10 *** (0.26)
Boundary (1,2)	-0.68 *** (0.27)	-1.07 *** (0.18)	-0.78 *** (0.27)	-0.77 *** (0.26)	-0.72 *** (0.26)
Boundary (2,3)	1.15 *** (0.27)	0.78 *** (0.18)	1.08 *** (0.27)	0.992 *** (0.26)	1.038 *** (0.26)
NSTDS (K)	0.33 *** (0.051)	0.33 *** (0.051)	0.33 *** (0.051)	0.13 *** (0.049)	0.0062 (0.0049)
NSTDS^2 (M)	_	_	_	_	_
MEDAGE	0.16 *** (0.048)	_	0.17 *** (0.048)	0.22 *** (0.046)	0.21 *** (0.046)
MEDAGE^2	-0.0058 *** (0.0023)	_	-0.0064 *** (0.0023)	-0.0082 *** (0.0021)	-0.0073 *** (0.0021)
MEDAGE#	_	1.21 *** (0.37)	_	_	
MEDAGE#^{2}	_	-0.60 *** (0.22)	_	_	
TURN2000 (M)	0.12 (0.23)	0.075 (0.23)	0.21 (0.23)	.0091 (0.21)	0.15 (0.23)
EXPORT2000 (M)	1.50 (1.20)	1.58 (1.18)	1.38 (1.27)	1.61 (1.16)	1.88 (1.26)
PRODINOV	0.55 *** (.080)	0.51 *** (0.081)	0.55 *** (.081)	0.14 * (0.079)	0.13 (0.080)
PROCINOV	0.31 *** (0.081)	0.31 *** (0.081)	0.30 *** (0.082)	0.219 *** (0.080)	0.25 *** (0.081)
LONGTERM	0.37 *** (0.092)	0.37 *** (0.092)	0.37 *** (0.092)	0.19 ** (0.091)	0.30 *** (0.091)
PCOOP	0.24 ** (0.099)	0.22 ** (0.099)	0.22 ** (0.10)	0.26 *** (0.098)	0.34 *** (0.10)
PROPSCI (100%)	1.06 *** (0.24)	0.85 *** (0.25)	0.99 *** (0.24)	-0.30 (0.25)	-0.29 (0.25)
FREGS=0	-2.65 *** (0.12)	-2.66 *** (0.12)	-2.35 *** (0.13)	-3.11 *** (0.13)	-3.07 *** (0.13)
FREGS=1	-1.16 *** (0.13)	-1.19 *** (0.13)	-1.06 *** (0.13)	-1.58 *** (0.13)	-1.44 *** (0.13)
FREGS=2	-0.76 *** (0.13)	-0.78 *** (0.13)	-0.72 *** (0.13)	-0.95 *** (0.13)	-0.87 *** (0.13)
HPREGS=0	_	_	-0.91 *** (0.11)	_	_
HPREGS=1	_	_	-0.21 ** (0.10)	_	_
HPREGS=2	_	_	-0.030 (0.11)	_	_
Number of observations	3728	3706	3675	3728	3278
Nagelkerke pseudo-R^2	0.35	0.35	0.38	0.34	0.35
λ^2 (d.f.)	1443 (13) ***	1445 (13) ***	1540 (16) ***	1398 (13) ***	1436 (13) ***

NB: coefficients for the following variables are set to zero: IFSTAND=3, FREGS=3, HPREGS=3
*: Significant at 10% level **: Significant at 5% level ***: Significant at 1% level

Columns (1.1) and (1.2) of Table 22 compare the same basic model, with the first using MEDAGE while the second uses MEDAGE#. There is not much difference between the two. Moreover (as we shall see in Section 4.7.2), in the model of the constraining role of standards, the version using MEDAGE# does not work as well as the version using MEDAGE. For these reasons we shall focus on the versions using MEDAGE hereafter.

The three versions of the model for the informative role of technical standards (columns 1.1, 1.2 and 1.3) all tell a similar story. As the number of standards increases, so the role of standards as a source of information tends to grow. As the median age increases, so also the role of standards as a source of information tends to grow – but only up to a point. The quadratic term enters with a significant and negative coefficient, so that beyond a certain median age, standards play a less important role as a source of information. Old standards contain little information. We can compute the optimum age to maximise information content as follows. If the latent variable 'importance' (I) is a quadratic function of median age:

$$I = a + b * MEDAGE - c * MEDAGE^2$$

then the maximum information is where:

$$\frac{\partial I}{\partial MEDAGE} = b - 2c * MEDAGE = 0$$

and hence where:

$$MEDAGE = \frac{b}{2c}$$

For columns 1.1 and 1.3 (respectively) this is a median age of 13.8 and 13.3 years. For column 1.2, using MEDAGE#, this is an optimum value of 1.0. This last result is rather remarkable because it implies that the optimum age to maximise the informative role of standards is almost exactly the length of one product life cycle!

We might expect that the optimum age to maximise the informative role of standards would be younger. However, this quadratic effect may arise because this calculation is really combining two factors: (a) the fact that (amongst those that know about and use new standards) the new standard contains more information than the old; (b) the fact that the use of a new standard may take some time to diffuse amongst a wide community of potential users. When these two are combined, we may find that the standard has to reach some age before it has maximum effect across a sector as a whole.

We find that the information content reported by enterprises is not significantly related to their size or exports. It is however related to several other characteristics of the enterprise. Product innovators, process innovators, enterprises with longer term innovation activities and enterprises who

co-operate in their innovative activities all report a larger role for standards as a source of information. Moreover, enterprises with a high proportion of scientists and engineers amongst their employees are more likely to find standards an important source of information for innovation.

The models contain two other (ordered) variables. The negative and significant coefficients on FREGS=0, FREGS=1 and FREGS=2 and the relative sizes of these coefficients imply that the importance of technical standards as a source of information is positively related to the importance of innovation activities in helping enterprises to meet standards and regulations. To put it another way, if one of the effects of innovation is to help enterprises meet standards, then enterprises are in turn more likely to find standards a source of information. This symbiotic relationship is not perhaps surprising.

The other variable (in column 1.3 only) is HPREGS – the extent to which standards and regulations hamper or constrain innovation. The negative and significant coefficients on HPREGS=0 and HPREGS=1 and the relative sizes of these coefficients imply that the importance of technical standards as a source of information is positively related to the extent to which standards constrain innovation. This is the same relationship as we illustrated in Section 4.3 – but now as a partial regression coefficient rather than a simple correlation. It may perhaps be surprising, but it just confirms the idea advanced above that the informative and constraining roles of standards tend to work together.

Columns 2.1 and 3.1 present the same model specification at column 1.1, but now for the informative role of the two other types of standards: IFHEALTH (health and safety standards and regulations) and IFENVIRO (environmental standards and regulations). The coefficients on the number of standards are smaller here (and not significant in column 3.1) suggesting that an increase in the number of standards does not increase information content as much as with technical standards. The coefficients on median age and its square are similar, and the optimum ages are similar too at (respectively) 13.4 and 14.4 years.

As before, the informative role is not significantly related to turnover and exports, nor in these cases to the proportion of employees qualifies as scientists or engineers. Nor is the informative role very sensitive to whether the enterprise is a product innovator. But as before, process innovators, enterprises with longer term innovation activities and enterprises who co-operate in their innovative activities all report a larger role for standards as a source of information. Finally, the coefficients on the FPREGS variables (and their relative magnitudes) once again suggest the same symbiotic role between standards and innovation. If innovation is important in helping enterprises meet standards, then once again, standards are an important source of information for innovation.

4.7.2. AN ORDERED LOGIT MODEL OF THE CONSTRAINING ROLE OF STANDARDS

The models for the constraining role of standards are summarised in Table 23. The first two columns (4.1 and 4.2) are for an equivalent specification to columns 1.1 and 1.2 of Table 22, with the same explanatory variables. However, as many of the variables that play a significant role in the information model do not do so here, we have also explored some alternative specifications (4.3, 4.4 and 4.5) using some additional variables to increase the explanatory power of the model.

In the first four versions of the model (4.1 to 4.4) there is a significant quadratic relationship between the extent to which standards constrain innovation and the number of standards. The coefficient on NSTDS is negative, suggesting that as the number of standards increases, these standards are less likely to constrain innovation. But there is also a positive coefficient on the squared term, and beyond a certain point that starts to dominate, so that with more standards we find greater constraint on innovation. Too many standards get in the way of innovation. The optimum number of standards (to minimise the constraint) is (respectively) 1100, 1100, 1200 and 1200 in columns 4.1, 4.2, 4.3 and 4.4.

In columns 4.1, 4.3, 4.4 and 4.5, we find a significant quadratic relationship between the extent to which standards constrain innovation and the median age of the standards. As with NSTDS, the coefficient on median age is negative, suggesting that as median age increases, standards are less likely to constrain innovation. But there is also a positive coefficient on the squared term, and beyond a certain point that starts to dominate, so that with and older median age we find greater constraint on innovation. The optimum median age (to minimise the constraint) is (respectively) 9.7, 10.3, 9.1 and 9.5 years in columns 4.1, 4.3, 4.4 and 4.5. Finally, Column 4.2 shows the model using deflated median age, but here neither the linear nor quadratic term are significant.

Table 23
Ordered Logit Model
Extent to which Standards and Regulations Constrain or Hamper Innovation

	Dependent Variable HPREGS				
	(4.1)	(4.2)	(4.3)	(4.4)	(4.5)
Boundary (0,1)	-2.23 *** -0.24	-2.06 *** -0.18	-2.66 *** -0.26	-2.41 *** -0.24	-4.28 *** -0.29
Boundary (1,2)	-1.06 *** -0.24	-0.89 *** -0.18	-1.46 *** -0.25	-1.22 *** -0.23	-2.87 *** -0.28
Boundary (2,3)	0.15 -0.24	0.32 * -0.18	-0.24 -0.25	0.008 -0.23	-1.55 *** -0.28
NSTDS (K)	-0.38 ** -0.17	-0.50 *** -0.17	-0.36 ** -0.17	-0.34 ** -0.17	-0.22 -0.17
$NSTDS^2$ (M)	0.18 ** -0.072	0.22 *** -0.07	0.15 ** -0.072	0.14 ** -0.069	0.11 -0.072
MEDAGE	-0.083 ** -0.042	_	-0.12 *** -0.043	-0.086 ** -0.041	-0.097 ** -0.042
$MEDAGE^2$	0.0043 ** -0.002	_	0.0058 *** -0.002	0.0047 ** -0.0019	0.0051 *** -0.0023
MEDAGE#	_	-0.36 -0.34	_	_	_
$MEDAGE\#^2$	_	0.14 -0.2	_	_	_
TURN2000 (M)	-0.19 -0.25	-0.32 -0.28	0.2 -0.26	_	_
EXPORT2000 (M)	0.77 -0.87	0.97 -0.89	0.62 ((0.88)	_	_
PRODINOV	-0.0065 -0.077	0.024 -0.078	-.0.080 -0.078	_	_
PROCINOV	0.0068 -0.078	0.011 -0.078	0.067 -0.079	_	_
LONGTERM	0.095 -0.088	0.1 -0.089	0.035 -0.089	_	_
PCOOP	0.055 -0.095	0.05 -0.096	0.0088 -0.096	_	_
PROPSCI (100%)	0.21 -0.23	0.34 -0.24	0.0068 -0.22	0.13 -0.24	0.13 -0.23
FREGS=0	-1.72 *** -0.12	-1.70 *** -0.12	-1.30 *** -0.12	-1.33 *** -0.11	-1.23 *** -0.12
FREGS=1	-0.78 *** -0.13	-0.75 *** -0.13	-0.63 *** -0.13	-0.67 *** -0.12	-0.81 *** -0.13
FREGS=2	-0.41 *** -0.12	-0.37 *** -0.12	-0.32 ** -0.13	-0.34 *** -0.12	-0.42 *** -0.12
IFSTAND=0	_	_	-1.09 *** -0.12	-1.15 *** -0.11	-1.03 *** -0.12
IFSTAND=1	_	_	-0.50 *** -0.12	-0.51 *** -0.12	-0.68 *** -0.12
IFSTAND=2	_	_	-0.31 *** -0.12	-0.34 *** -0.11	-0.48 *** -0.12
MARKET=1	_	_	_	0.36 *** -0.11	0.42 *** -0.11
MARKET=2	_	_	_	0.27 ** -0.11	0.26 ** -11
MARKET=3	_	_	_	0.16 -0.09	0.11 -0.094
HPLKTECH=0	_	_	_	_	-2.88 *** -0.15
HPLKTECH=1	_	_	_	_	-1.30 *** -0.15
HPLKTECH=2	_	_	_	_	-0.95 *** -0.15
Number of observations	3740	3718	3675	4092	4092
Nagelkerke pseudo-R^2	0.13	0.13	0.16	0.17	0.33
λ^2 (d.f.)	481 (14) ***	478 (14) ***	584 (17) ***	688 (14) ***	1484 (17) ***

NB: coefficients for the following are set to zero: HPREGS=3, FREGS=3, MARKET=4, IFSTAND=3, HPLKTECH=3
*: Significant at 10% level **: Significant at 5% level ***: Significant at 1% level

Why do we find this quadratic relationship? It seems likely that both rather old and rather new standards are likely to constrain innovation – the first because it locks the innovator into legacy systems, and the latter because it challenges the innovator.

The extent to which standards constrain innovation in the enterprise does not seem to have a significant association with enterprise turnover, exports, or the proportion of scientists and engineers amongst enterprise employees, nor does it relate to whether the enterprise is a product innovator, a process innovator, nor to whether it has longer term innovative activities or cooperates in innovation. Indeed, there are few significant coefficients in column 4.1. For that reason we have also estimated some variations on this basic model, with additional explanatory variables.

In all versions of the model, the FREGS variable enters in a significant way. The negative and significant coefficients on FREGS=0, FREGS=1 and FREGS=2 and the relative sizes of these coefficients imply that the extent to which standards constrain innovation is positively related to the importance of innovation activities in helping enterprises to meet standards and regulations. To put it another way, if one of the effects of innovation is to help enterprises meet standards, then enterprises are in turn more likely to say that standards constrain innovation. This is not perhaps surprising, and could possibly be tautologous – though the data do not show the perfect correlation that a tautology would imply.

Column 4.3 introduces IFSTAND – in the same fashion that column 1.3 of Table 22 included HPREGS. The negative and significant coefficients on IFSTAND=0, IFSTAND=1 and IFSTAND=2 and the relative sizes of these coefficients imply that the extent to which standards constrain innovation is positively related to the importance of technical standards as a source of information. This is the same relationship as we illustrated in Section 4.3 – and indeed in section 4.7.1 – but now as a partial regression coefficient rather than a simple correlation. As we said before, it just affirms the idea advanced above that the informative and constraining roles of standards tend to work together.

Column 4.4 introduces the MARKET variable, and this generates an interesting finding. The coefficients on variables, MARKET=1 and MARKET=2 are significant and positive. This means that when the principal market for the enterprise is local or regional -rather than national or international – then enterprises are more likely to say that standards constrain innovation. This is not surprising. Enterprises competing essentially in local or regional markets may not need standards to ensure their local/regional competitiveness, and indeed standards may constrain rather than help. But the competitiveness of enterprises operating in national (and especially international) markets depends on them meeting relevant standards. These enterprises are less likely to feel that the standard constrains them in a way that has adverse implications for their competitiveness.

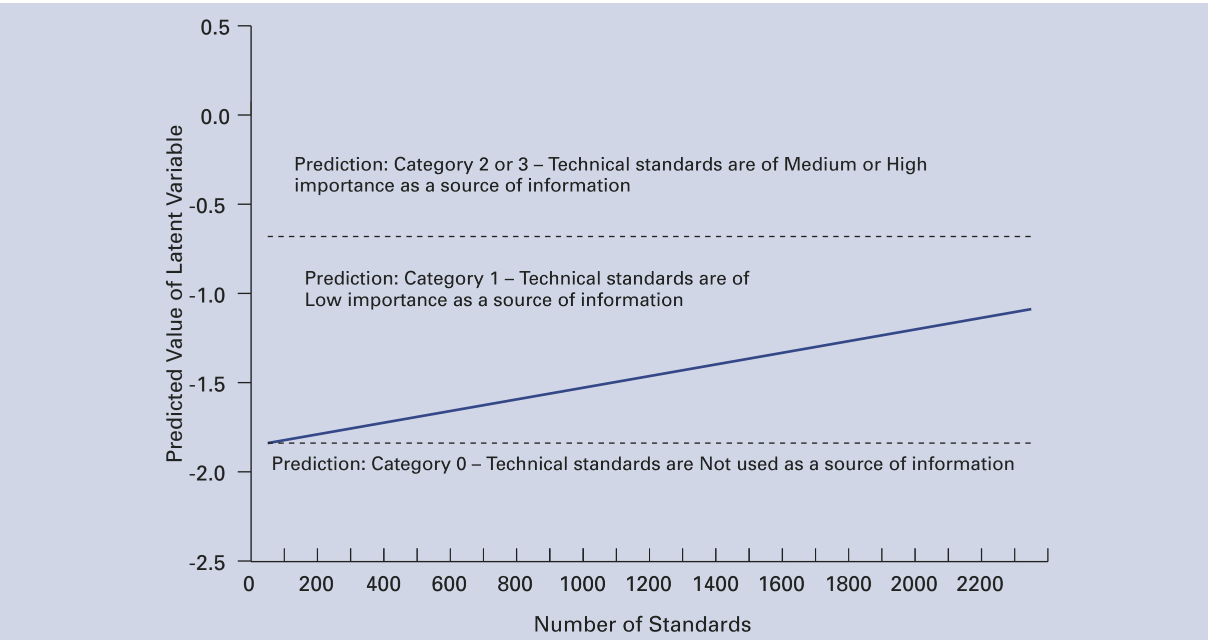
Finally, column 4.5 also introduces one further explanatory variable HPLKTECH – the extent to which innovation is constrained by a lack of technical knowledge. The negative and significant coefficients on HPLKTECH=0, HPLKTECH=1 and HPLKTECH=2 and the relative sizes of these coefficients imply that the extent to which standards constrain innovation is positively related to the extent to which innovation is constrained by a lack of technical knowledge. Enterprises whose innovation is not constrained by lack of technical knowledge will not be constrained by standards either, while those that are constrained by a lack of technical knowledge will also be constrained by standards. This is an interesting observation, open to more than one interpretation. It may suggest that those with sufficient technical knowledge can 'invent around' the constraints implied by a standard.

4.7.3. IMPORTANCE OF NUMBERS OF STANDARDS AND MEDIAN AGE

Our main interest in this report focuses on the role of the number of standards and their median age. We have seen that these variables have *statistically significant* effects in the models of sections 4.7.1 and 4.7.2. This just means that there is enough evidence here to reject the hypothesis that their effects are zero. But how important are they, numerically, in explaining the variation in the informative and constraining role of standards?

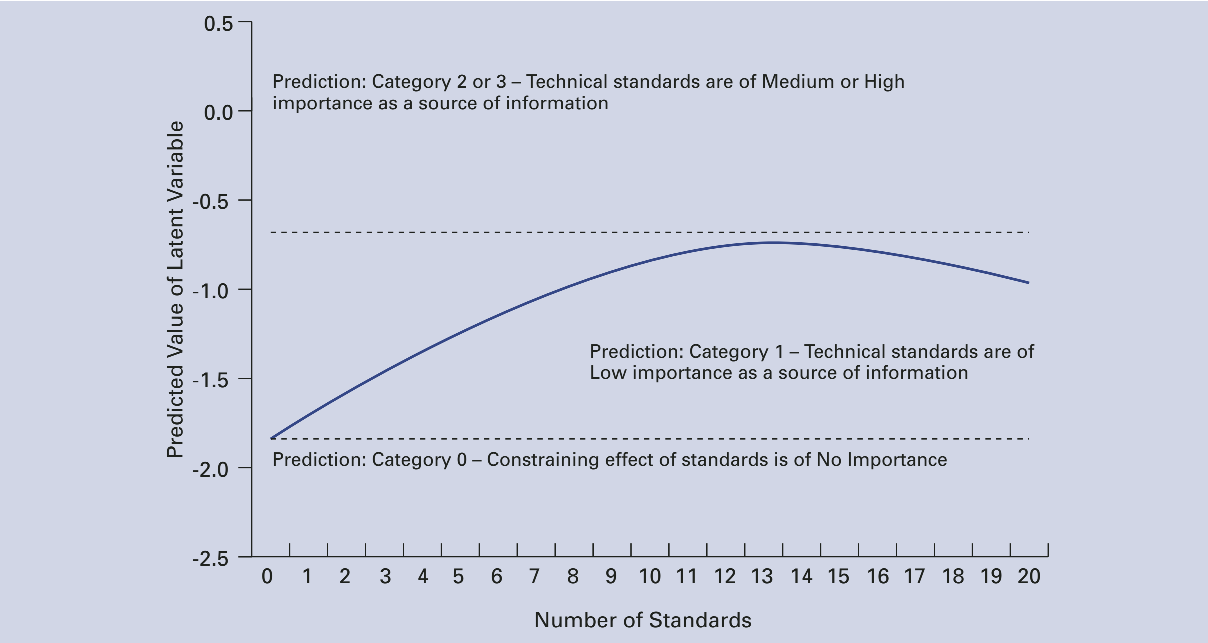
We can answer this with the next four diagrams (Figures 30, 31, 32, 33). These show the roles of these two variables in the two models (columns 1.1 and 4.1 respectively). In each diagram, the vertical axis shows the predicted value of the latent variable, 'importance' or 'constraint', while the horizontal axis shows either the number of standards or the median age. The range of the horizontal axis in each case is approximately the same as the range of that variable in our data-set.

Figure 30
Importance of Number of Standards in the Ordered Logit Model (Information)



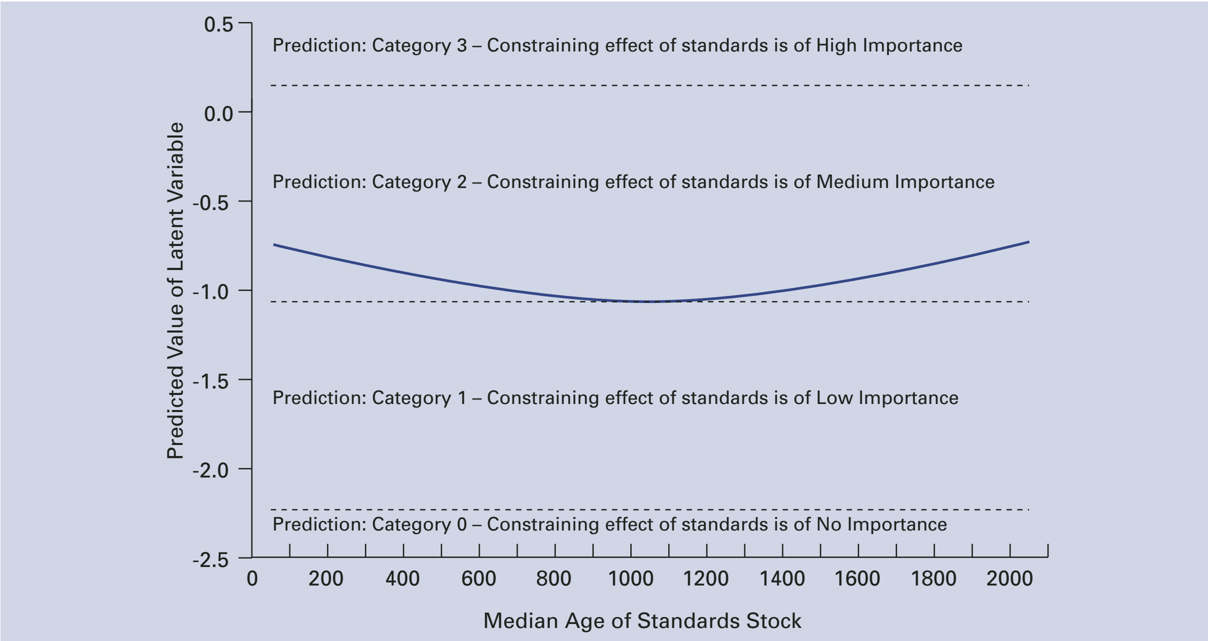
Source: CSI/BSI/PERINORM©/own estimates

Figure 31
Importance of Median Age of Standards in the Ordered Logit Model (Information)



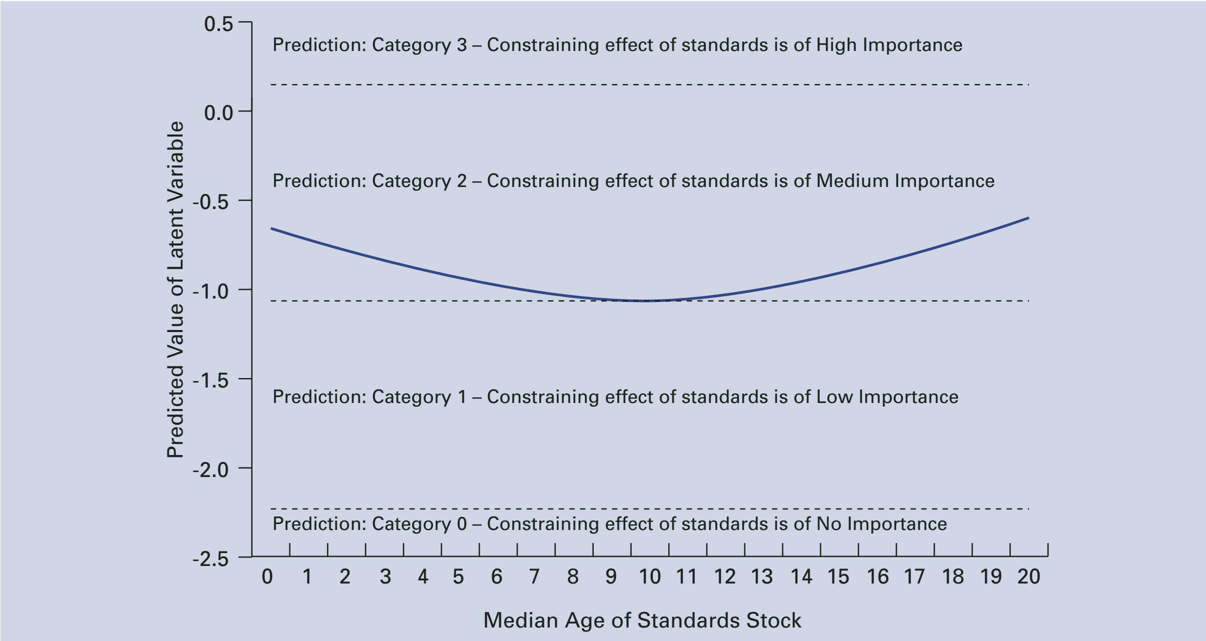
Source: CSI/BSI/PERINORM©/own estimates

Figure 32
Importance of Number of Standards in the Ordered Logit Model (Constraint)



Source: CSI/BSI/PERINORM©/own estimates

Figure 33
Importance of Median Age of Standards in the Ordered Logit Model (Constraint)



Source: CSI/own estimates

Figure 30 shows the relationship between the number of standards and the predicted value of the latent variable 'importance as a source of information', for given values of all the other variables.[73] The bold line shows the predicted value, while the dotted lines show the boundaries between one category and the next. With no standards, the model predicts a borderline between categories 0 (not used) and 1 (low importance); with 2300 standards (roughly the largest number found in any 2-digit SIC), the model predicts a substantially higher value of the latent variable, but still firmly in category 1 (low importance). In short, while the number of standards plays a statistically significant role in the 'information' model, and while this number also has a reasonably large effect, it is not enough to shift the predicted value from one borderline to the next.

Figure 31 shows the equivalent for the relationship between median age and the predicted value of the latent variable. This shows a maximum effect (at 13.8 years). It also shows that a change in median age from 0 to 13.8 is almost enough to shift the predicted value from one borderline to another. So here we can reasonably conclude that the median age has not only a statistically significant relationship to the importance of standards as an information source, but also that the magnitude of this effect is large.

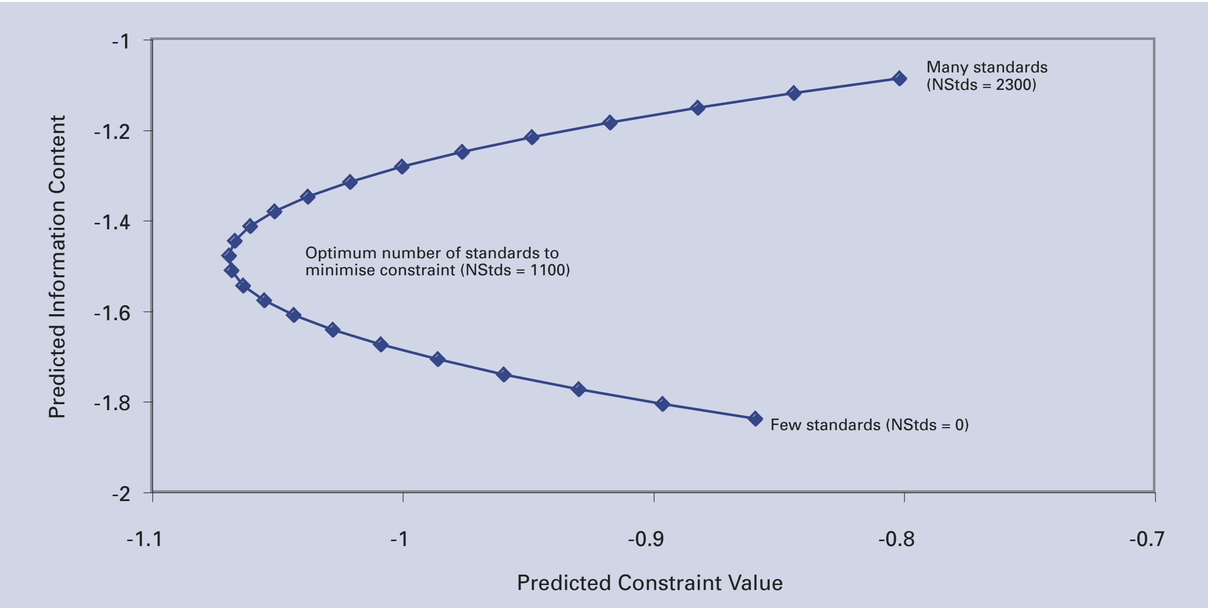
73 The assumed values of other variables in this model are as follows: NSTDS = 1160, MEDAGE = 2.66, TURN2000 = 20000, EXPORT2000 = 2000, PRODINOV = 0, PROCINOV = 1, LONGTERM = 0, PCOOP = 0, PROPSCI = 10%, FREGS = 0. These have been chosen arbitrarily to make the predicted value at the left hand side of the diagram equal to the boundary between categories 0 and 1.

Figure 32 shows the equivalent for the number of standards in the constraint model.[74] Here the magnitude of the relationship is small. As the number of standards increases from the optimum (1100) up to 2300, it only increases the predicted value slightly above the borderline. Figure 33 tells a similar story, though the magnitude of the effect is somewhat larger. In both of these cases, the relationships – though statistically significant – are not of large magnitude. It would take more than a change in the number of standards or their median age to deliver a large increase in the constraining effect of standards.

4.7.4. THE RELATIONSHIP BETWEEN INFORMATION AND CONSTRAINT: ANOTHER LOOK

In conclusion, it is interesting to look at the data of the last section in another way. Figures 34 and 35 show how the predicted values of the information and constraint models vary as we change the number of standards (Figure 34) and the median age (Figure 35).

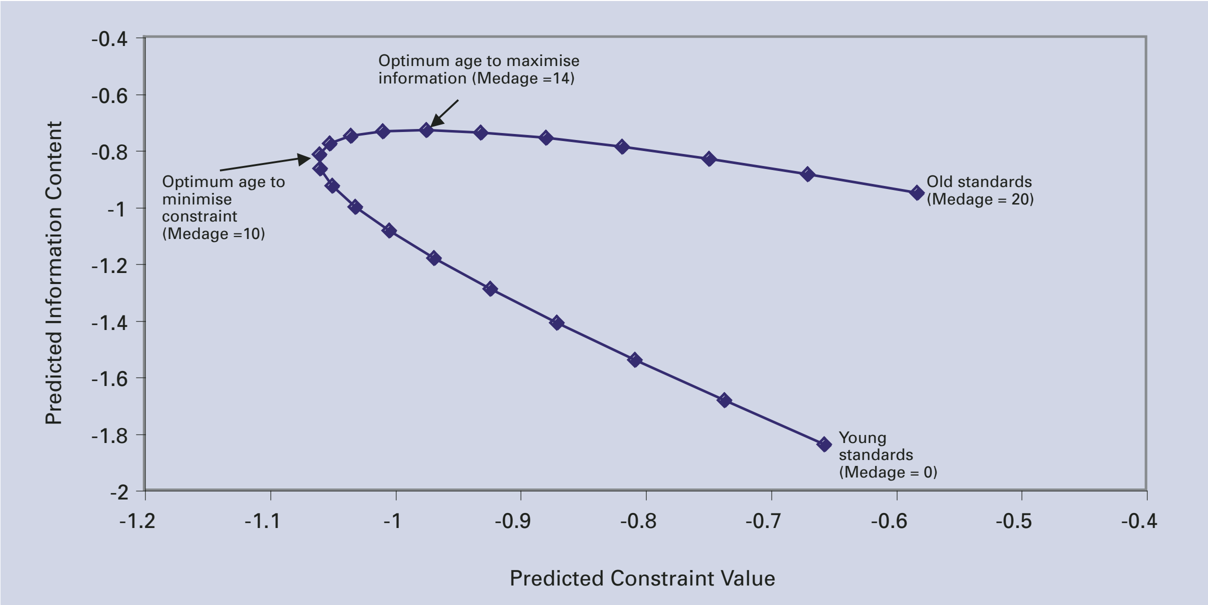
Figure 34
Relationship between Information and Constraint Predictions and the Number of Standards



Source: CSI/BSI/PERINORM©/own estimates

74 The assumed values of other variables in this model are as follows: NSTDS = 80, MEDAGE = 3.25, TURN2000 = 200000, EXPORT2000 = 20000, PRODINOV = 1, PROCINOV = 1, LONGTERM = 1, PCOOP = 1, PROPSCI = 10%, FREGS = 1. These have been chosen arbitrarily to create a tangency between the prediction curve (at its minimum) and the boundary between categories 0 and 1.

Figure 35
Relationship between Information and Constraint Predictions and the Median Age of Standards



Source: CSI/own estimates

In Figure 34, each dot corresponds to an increment of 100 in the number of standards – starting at zero in the lower right, moving up to 1100 in the left middle and up to 2300 in the top right. Starting at zero, as we increase the number of standards we find that the predicted information content increases while the predicted constraint value declines. As the number reaches 1100, the constraint value reaches a minimum. Beyond that, as the number of standards increases further, the information content continues to increase, but so also does the predicted constraint value. In short, we find a negative relationship between the two (information content and constraint value) in the lower part of the diagram, and a positive relationship in the upper part.

In Figure 35, each dot corresponds to an increment of one year in the median age of the relevant standards stock – starting at zero in the lower right, moving up to 10-14 in the top left, and then up to 20 in the top right. Starting at zero, here again the predicted constraint value falls and the predicted information content increases as the median age rises. But after reaching the two optima (the first, at which constraint is minimised, and the second at which information is maximised), the predicted constraint value increases as the information content falls. In short, here we find mainly a negative relationship between the two.

These observations are not made to imply that there is anything faulty in the simple observation of section 4.3 that the informative and constraining roles of standards tend to show a simple positive correlation in our dataset. Rather, our aim is to show that the precise correlation between these two will depend on what are the causes of any changes in information content and constraint

value. We can see from inspection of Tables 30 and 31 that there are some variables which lead information content and constraint value to change in the same direction. What we have shown with Figures 34 and 35 is that there are other variables which lead to more complex patterns of correlation between these two.[75]

4.8. Conclusion

The main findings of this report are described in the summary at the front of this document. They do not need to be repeated at length here, but the two main conclusions are these.

First, there is a relationship between the condition of the standards stock (measured by the number and vintage of those standards) and the extent to which standards inform and/or constrain innovation. The relationship is stronger for the informing role of standards than for the constraining role of standards.

Second, however, the extent to which standards inform and/or constrain innovation in a particular enterprise is strongly related to several characteristics of the enterprise. It does not depend on the condition of the standards stock on its own.

75 In the preliminary report we argued as follows. When the standards stock is in 'good condition', so that it provides information, then we may still find that it constrains innovation. In these circumstances, standards inform and constrain at the same time, so the CIS responses are positively correlated. By contrast, when it is in 'bad condition', then it has little information value, but it may still constrain. In these circumstances, the CIS responses are negatively correlated. This is another instance of this general phenomenon.

Annex A: Data

Output – Gross value added at 2000 basic prices (chained volume measure). Source: ONS Blue Book Time series data as at April 2004

Capital Stock – Gross capital stock (volume measure) of total capital stock excluding dwellings; from ONS Capital stock time series data as at April 2004

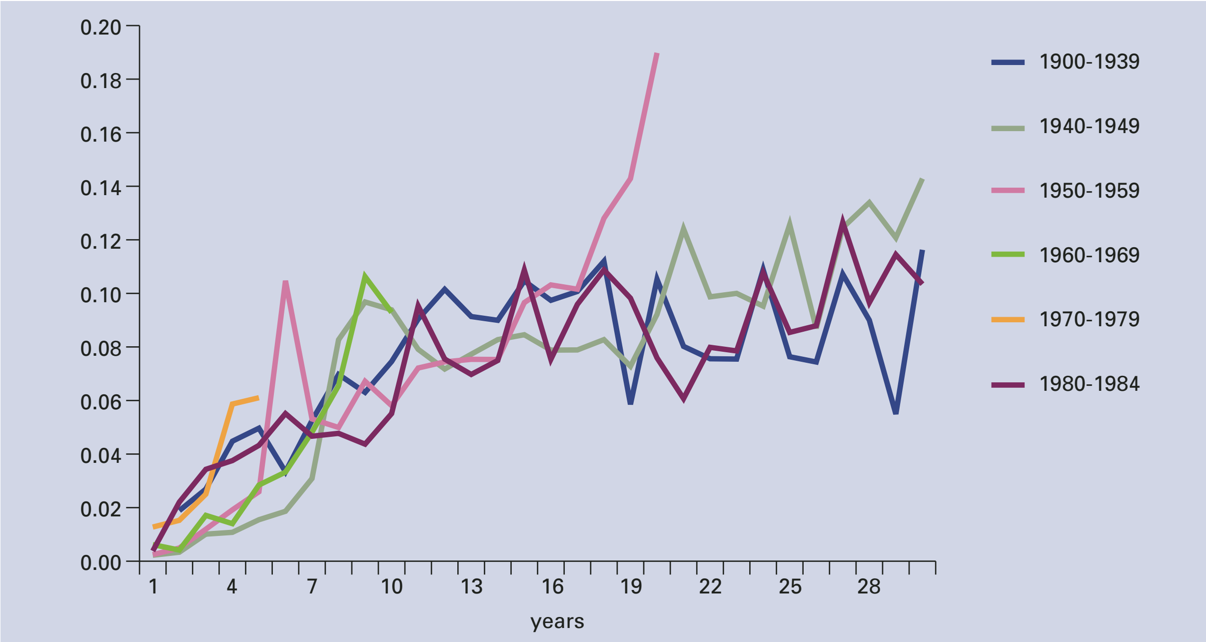
Employment – This was constructed from two series. 1948-1959 C.Feinstein (1972) and workforce jobs (both exclude HM armed forces) – Labour Market Trends (ONS) time series website.

SCI – The 'standards catalogue index', based upon end of year stocks, calculated from Equation (3) in the paper. This was estimated for the period 1901-1984 from the *BSI History Book*, and from 1985-2003 from PERINORM© – a database produced by a consortium of BSI, AFNOR, and DIN. The latter allowed for exact calculation of equation (3) in the text. While a complete count of publications was possible for the early period, only a proportion of total withdrawals was possible. A brief description of how the remainder was estimated is provided below.

The Retirement Dates of Standards

The need to estimate the retirement dates of certain standards led us to look at retirement patterns. Figure 36, which 'pools' annual 'vintages' of standards by decades, shows empirical probabilities of the likelihood of a standard being retired in year t given that it has survived up to the beginning of year t. This is the so-called hazard rate. The picture suggests that the hazard rate increases steadily up to about 10 years and then is relatively constant at around 10-11%. The pattern is rather similar for the vintages of different decades, and we in fact imposed a constant pattern for all standards for which we had no firm retirement dates from the 'History Book'. Experiments with altering these hazard rates had little important impact on our estimates of the 'state' of the BSI Catalogue in any particular year. The actual hazard rates used were: 0-2 years: 0.008; 2-5 years: 0.027; 5-10 years: 0.059; 10-20 years: 0.093; 20-30 years: 0.102; 30+ years: 0.100.

Figure 36
Hazard rates by vintage (t<=30)



Source: BSI/PERINORM©

Annex B: Estimation

To validate the results from the Engle-Granger procedure, we tested the annual data for cointegration using the maximum likelihood approach of Johansen (1988, 1991). We estimated a first-order vector-autoregression (VAR) in *y-l, sci* and *k-l* and a constant entered unrestrictedly. Our findings are recorded in Table 24. There is a single cointegrating vector on the basis of the maximum eigenvalue and trace test statistics at the 1 per cent level. The values of the resulting cointegrating vector are (standard errors in parentheses)

log (Labour Productivity) = 0.589 log (Capital-Employment Ratio) + 0.173 log(Standards)
(0.059) (0.031)

Both the estimated long-run capital-employment ratio and standards elasticities have the expected signs, but the latter is particularly large in magnitude. It needs to be remembered that, in not allowing for other factors explaining technological change that this particular model and the estimated elasticities are not comparable with those reported in the body of the paper which incorporate an exogenous time trend.

Table 24:
Cointegration statistics, (1948-2002)

Eigenvalue	Log likelihood	rank r
	441.551	0
0.4307	456.761	1
0.2358	464.021	2
0.0463	465.301	3

H0: 'rank = r'	Max-Eigen Statistic	99%	Trace Statistic	99%
r <= 0	30.42**	25.52	47.50**	35.65
r <= 1	14.52*	18.63	17.08*	20.04
r <= 2	2.56	6.65	2.56	6.65

Standardised β eigenvectors	y - l	k - l	sci	Standardised α eigenvectors	i = 1	i = 2	i = 3
i =1	1.000	-0.589	-0.173	y - l	-0.345	0.003	-0.003
i =2	-0.263	1.000	-6.169	k - l	-0.253	-0.113	0.001
i =3	7.170	-0.385	1.000	sci	0.301	-0.109	-0.003

Note:
** Denotes significance at the 1% level, * at the 5% level.

Annex C: Extract from Swann (2000, pp. 24-29)

The Standards Infrastructure or Standards 'Tree'

Standards form part of the infrastructure on which a canopy of new products and services are grown. The quality and usefulness of the standards system plays an important role in determining the growth of markets and the quality and number of products and services that can be built from those foundations. We shall see below that the growth of a standards system can be represented graphically in a manner that looks very similar to the growth of a tree. The analogy, moreover is a compelling one, because the health of the trunk and branch structure plays a key role in determining the vigour of growth, leaves and fruit.

Figure 37 offers a compact (and highly stylised) way to summarise the structure of a standards system. It shows how standards support innovation-led growth. It is easiest to use this diagram to represent product and service innovation, but an equivalent diagram could be constructed to describe process innovation. We must stress, however, that it is an incomplete representation of the different forms of standards. It describes standards that define product or service characteristics – product standards, in the main, and also those process standards that have a direct impact on achievable product characteristics. It does not capture the contribution made by meta standards, definitional standards, and so on. We could adapt and extend the model to do that, but it would lose its simplicity, and hence we have kept it in this form for the present discussion.

Figure 37
Product Innovation with Standardisation

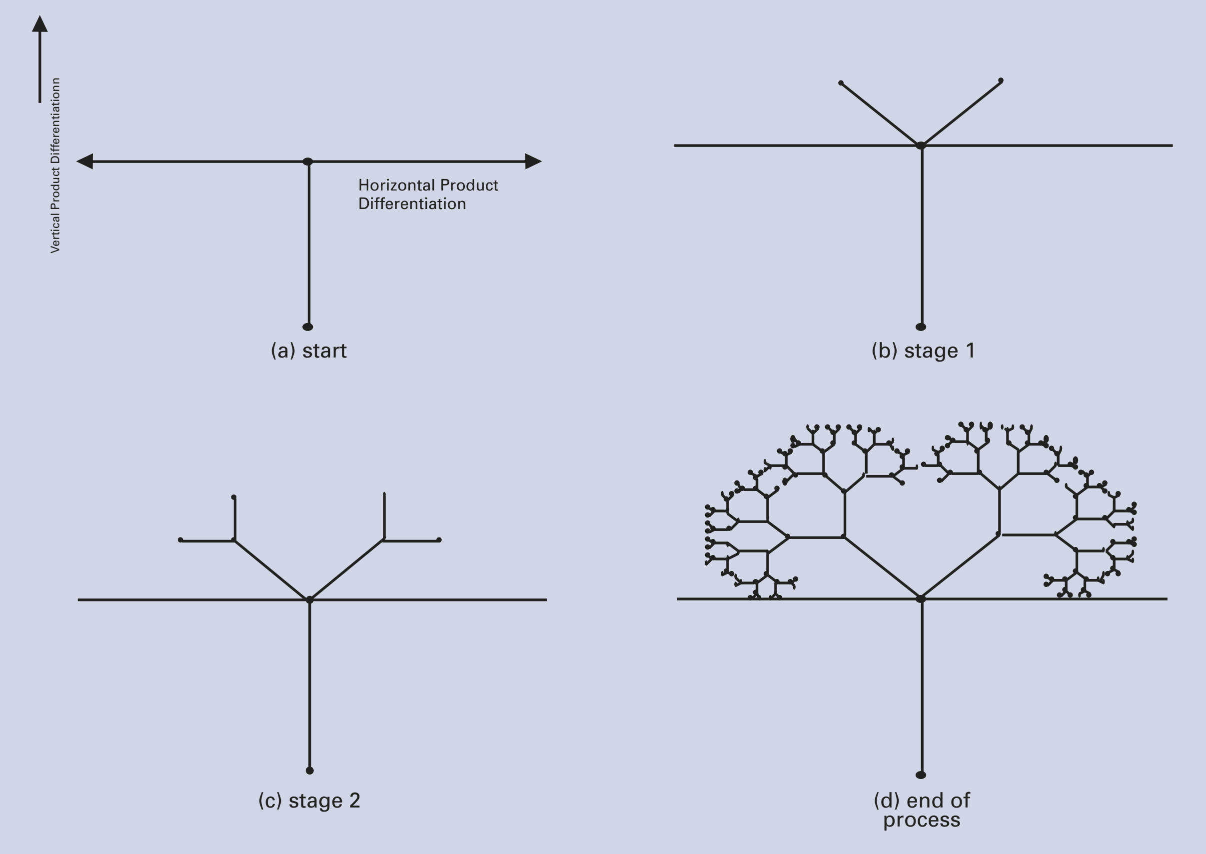


Figure 37 should be interpreted as follows. The diagram represents a technological or characteristics space. The vertical axis represents vertical product differentiation in the sense of Abbott's (1955) classic definition: that is, the further up the diagram, the greater the performance and/or functionality. The horizontal axis represents horizontal product differentiation: points along a horizontal line in this diagram represent products of different design and configuration but of roughly comparable functionality – again following Abbott's (1955) definition.[76]

The aim of growth led by product innovation is to fill up this product space with marketed products and services. (Hereafter, we shall just talk of products, and without loss of generality *within this framework*.) An efficient innovation process should be able to build up a large canopy of technologically feasible and marketable products. The health of the process can be measured by the size and richness of the canopy.

In Figure 37, we show a highly idealised pattern of innovation. Figure 37(a) shows the starting point. A key innovation opens up a new area of technological space. The upper dot defines the contribution of this innovation relative to what was achievable before. Part (b) then adds two subsequent innovations, which

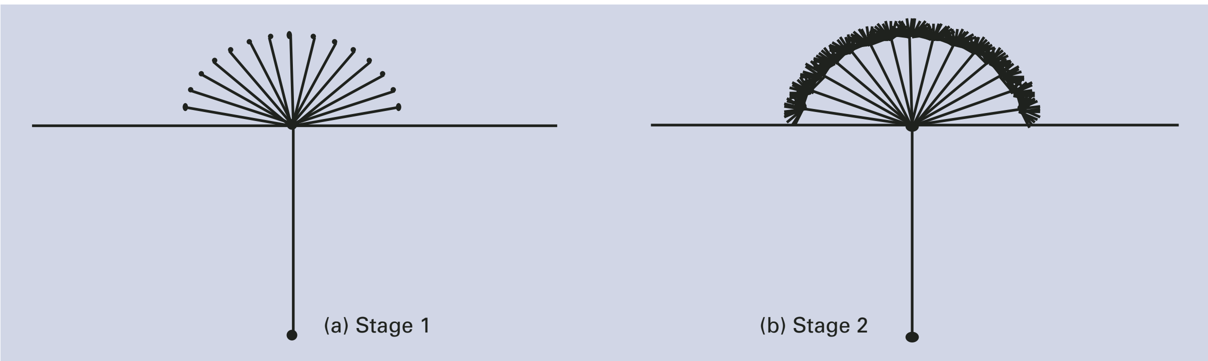
76 We restrict our attention here to a two-dimensional characteristics space, but Swann (1990d) shows that the process of product competition can lead to expansion of the dimensions of characteristics space.

draw on the basic standard, developing in two different (orthogonal) directions. In Figure 37(c) each of these subsidiaries give rise to two further innovations. On this basic infrastructure the usual forces of product innovation and product competition continue to build a canopy of competing products and services of differing technological characteristics – as in Figure 37(d).[77]

So far I have said nothing about standards in Figure 37. The role of standards is in enabling and in shaping this pattern of innovation. It may well be that some early standardisation is required to achieve the neat, compact infrastructure in Figure 37. **In short, the major branches in Figure 37 (a, b, c) represent not just innovations but standards**. But the smaller branches and sub-branches in Figure 37(d) do not. If these innovations are close enough (in this characteristics space) to a standard, then the greater the confidence of the consumer and the producer, and the greater the critical mass of supporting items around the standard. A good example of the profusion of products around a standard is the Lotus 1-2-3 phenomenon – Swann, 1990a).

We can draw a counterpart to Figure 37 in which the product space is gradually occupied, but in which there are no formal standards at all. In Figure 38, the same process of innovation-led growth takes place, but here (part a) a large number of slightly differentiated innovations follow different directions from the base point. The number of differentiated innovations depends on market structure – one of the conditioning variables that will be discussed shortly. But as drawn, there is at each stage a substantial amount of innovation. The result after two rounds of innovation (**part b**) is rather a messy one. The canopy is very well covered but does not reach as far or as wide as was the case in Figure 37. There are obvious opportunities for economies of scale, but these have not been taken. There must be much duplicated effort, and no one innovation covers as much ground as would have been possible if the economies of scale had been realised.

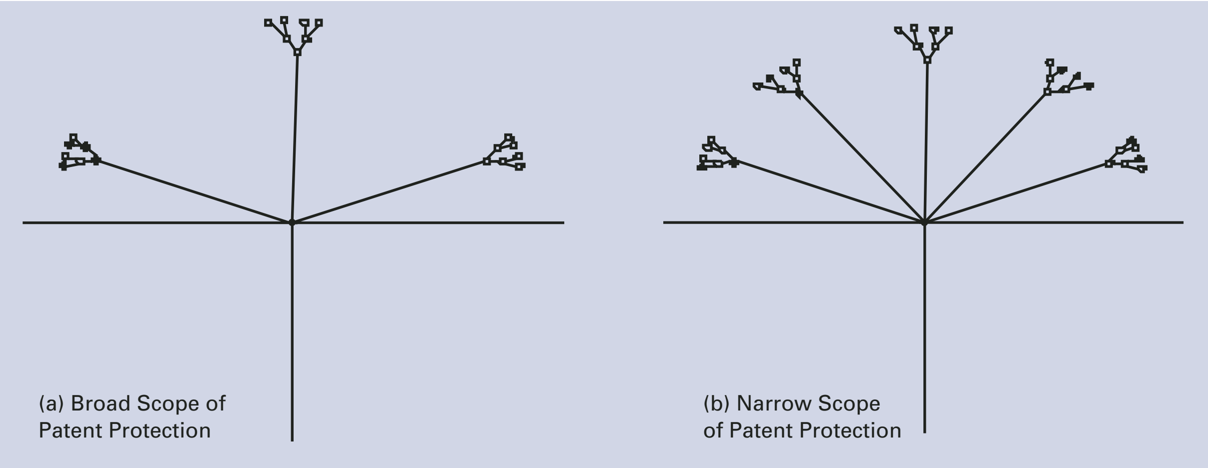
Figure 38
Product Innovation without Standardisation



77 These shapes are of course the familiar fractal structures popularised by the mathematician Mandelbrot. The fractal is a space-filling curve: or in this context, a curve that creates a large and complex canopy of differentiated products and services.

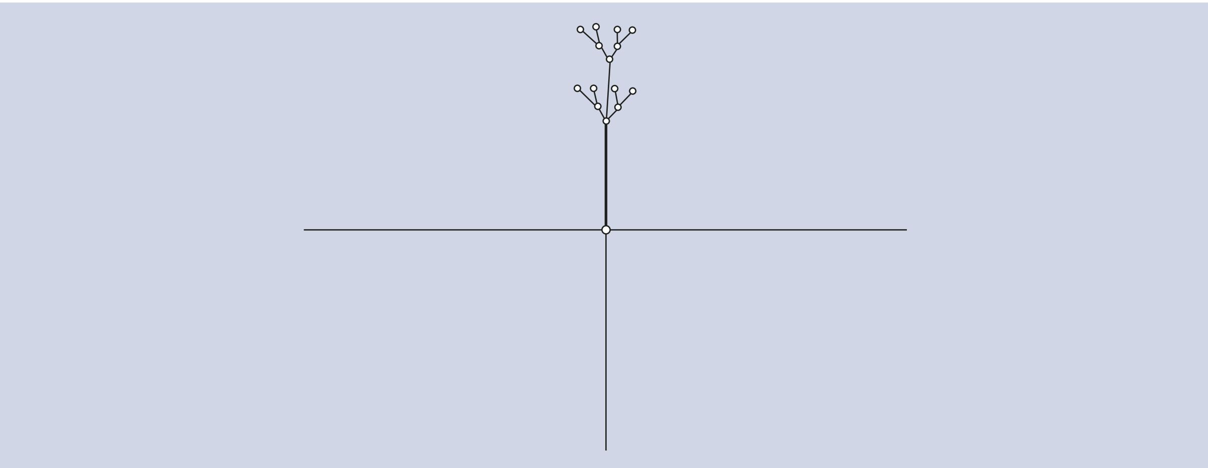
Figure 39 shows another variant on this theme. Here, however, each major branch is protected by a patent (c.f. Lea and Shurmer, 1994; Shurmer, 1996). It shows how the patent can indeed open up a new area of technological space. But assuming that the owner of the patent enforces property rights, we do not see the same canopy emerge. We may see a sparse canopy around a few major leading branches (Figure 39a) when the scope of patent protection is relatively broad. Or we see a fairly full canopy with much redundancy because of the proliferation of branches (Figure 39b). This is the case where the scope of patent protection is relatively narrow.

Figure 39
Product Innovation with Patenting



A final variation on this theme (Figure 40) shows the pattern obtained when standards are de facto and proprietary. It is rather like the picture *vis a vis* patenting, except that some supportive growth from other producers is allowed, but only in such a way as it supports the main leading branch.

Figure 40
Product Innovation with a Proprietary De Facto Standard



The quality of the infrastructure depends on the ultimate profusion of innovations that can be built. Admittedly, it may be dysfunctional to have too large a profusion while still in the formative stages of market and technological

development. Nevertheless, the *ability* of any node to support a wide variety of innovations is still important – even if these are not developed.

This, broadly speaking, is why there is such a strong presumption in favour of open-ness in standardisation (c.f. Krechmer, 1998): each node should be open to all competitors and not monopolised in *any* way. In principle, any company can build on an open standard, and in whatever direction its own distinctive capabilities suggest. By contrast, when the standard is closed – or when property rights are applied over a particular node in the product space, then it is not possible for a competitor to build a rival innovation using that node as a starting point. As a result, the ability of any node to support a profusion of subsequent innovations must be limited. (It is interesting, in the light of this, to review the findings of the DIN (2000) studies on the comparative contribution of standards and patents to economic growth.)

In addition, these observations also argue for open standardisation *processes*, for otherwise there must be a risk that those who dominate the process will dominate the application of the standard.

A 'Digression' on the Tree Analogy

Figures 37 to 40 are immediately reminiscent of tree shapes, and hence the analogy is obvious. From a horticultural point of view, Figure 37 is an attractive tree because a large canopy is built on a very simple and economical structure. Figure 38 is less attractive, aesthetically because it is messy, but economically because the ratio of canopy to structure is much smaller. Figure 39 is also less desirable than 37. Figure 39b does achieve a large canopy, but the ratio of canopy to structure is smaller because of the need to duplicate multiple leading branches. Figure 39a, by contrast, does not achieve a good canopy. Figure 40 does not achieve a large canopy.

There are arguably three objectives in pruning a tree. The first is to promote healthy growth of wood. The second, especially important in the early life of the tree, is to give the form desired. And that indeed plays an important part in achieving the third objective: to increase flowering and fruitfulness.

We can see how defining the first standard in a particular field is rather like choosing the first shoot of a tree. There are a number of possible shoots, and it is dysfunctional to let them all grow. That is why the tree is pruned and trained. Once one shoot has been selected, the plant concentrates its energies into the growth of that one leader, and the growth of lateral shoots can be left until later. In the same way, there are a number of possible paths in which to take the standard, but once it has been selected, it provides a focus, and it can be left until later to encourage competitive product offerings building on the technological and market knowledge contained in the standard.

At a later stage the tree is pruned again to send out a small number of lateral shoots, in the manner of Figure 37. Pruning and training is continued so long as it is helpful to restrict the structure of the tree. Thereafter, it is left to its own devices, apart from a modest annual treatment.

To achieve the maximum growth and fruitfulness from the tree requires keeping a delicate balance between innovation and standardisation. Standardisation at any stage does undoubtedly limit the amount of variety at that stage. But limiting variety in this way helps in the long run to develop a strong tree in good shape with a large and fruitful canopy.

The existence of a system of standards helps the customer to know what it is (s)he is getting, and encourages competitive entrants who can assimilate the necessary technological knowledge from the codified standards. However, there will always be a subset of innovative producers who wish to innovate away from the standard, because that allows them an opportunity to raise their margins by price discrimination based on product differentiation. These innovators help to grow the tree, but standardisation stops messy proliferation from holding back its subsequent growth.

However, as we have said already, we need to be careful about pushing this analogy too far. Nevertheless, we shall see in Chapter 4 (of Swann, 2000) that the basic taxonomy of pruning and training – including where and when it is required – can help us to assemble a comparable taxonomy for standardisation.

[End of Extract from Swann, 2000]

Annex D: The Median of the Exponential Distribution

RESULT 1:

Suppose that the vintages of standards follow an exponential distribution:

$$f(x) = \lambda \exp\{-\lambda x\} \tag{10}$$

where x is the age of the standard. The age of the median standard is:

$$x_{med} = \frac{\ln(2)}{\lambda}$$

PROOF:

The function $f(x)$ in equation (10) is a density function, so by definition the integral over the range of possible ages [0, ∞[is equal to 1. Then we can implicitly define the median, x_{med} as follows:

$$\int_0^{x_{med}} \lambda \exp\{-\lambda x\} dx = \frac{1}{2}$$

or,

$$[-\exp\{-\lambda x\}]_0^{x_{med}} = [1 - \exp\{-\lambda x_{med}\}] = \frac{1}{2}$$

hence,

$$-\lambda x_{med} = \ln\left[\frac{1}{2}\right]$$

and so,

$$x_{med} = \frac{\ln(2)}{\lambda}$$

QED.

Annex E: Correlator Between ICS and SIC

Paul Temple kindly provided a mapping between ICS and SIC to make it possible to compute the numbers of standards in each 2 digit SIC. This is summarised in the following table.

ISIC	ICS/PERINORM SEARCH
10*	73.020 OR 73.040 OR 75.160.10
11*	73.020 OR 73.080 OR 73.100 OR 73.120
14	73.020 OR 73.080 OR 73.100 OR 73.120
15	(65.* , '65') , (67.* , '67') without ((65.080) OR (65.100) OR ((65.160))
17	(59.* , '59') OR 55.060 OR 55.080 without (59.140.*)
18	(61.* , '61')
19	59.140.*
20	(79.* , '79') without (97.140.*),(97.040.10)
21	(85.* , '85')
22	publishing* or newspaper* or book* or journal* or periodical* or (recording and video) or (recording and audio) or reproduction*
23*	(75.* , '75')
24	(71.* , '71'),59.060.20,65.100.*, 65.080, , (87.* , '87') , (11.120.* , '11.120')
25	(83.* , '83')
26	(73.* , '73') , (81.* , '81')
27	(77.* , '77')
28	(21.* , '21') , 55.120 , 55.130 , 55.140 ,55.180.10 , (23.* , '23')
29	(35.* , '35') , (29.* , '29') , (31.* , '31') , (33.* , '33') , (11.* , '11'), (17.* , '17') , (19.* , '19') , (37.* , '37') , (39.* , '39') without 11.020 OR (11.120.* , '11.120') OR 39.060
30	(35.* , '35')
31	(29.* , '29')
32	(31.* , '31') , (33.* , '33')
33	(11.* , '11') , (17.* , '17') , (19.* , '19') , (37.* , '37') , (39.* , '39')
34	(43.* , '43')
35	(45.* , '45') , (47.* , '47') , (49.* , '49')
36	39.060 , (97.* , '97')
37*	recycling* or waste* or scrap*
40	(27.* , '27') without 27.020
41*	(water and supply) or (water and dist*) or (water and purif*) or (water and treat*) or (water and meter*) without (hot* and water)
45	(91.* , '91') , (93.* , '93')
51/52	retail* or wholesale* or shop* or sale* or selling or trade or trading*
60	(transport* or freight or pipeline) and (coach* or bus* or passenger or railway* or road or highway or vehicle or truck or trailer or container or rolling stock) without (air* or aero* or sea* or marine* or water* or coast* or storage* or warehous*)
61*	(transport* or freight* or cargo*) and (coast* or sea or water* or marine* or ship or boat or (sea and vessel) or (water and vessel)) without road* or railway* or storage* or warehous* or air* or aero* or space*
62*	(transport* or freight or cargo) and (air* or aero*) without road or railway or sea* or marine* or water* or coast* or storage* or warehous*
63	(cargo or freight) and (handling or storage or warehous*)
64	post* or mail* or courier* or telecom* or telex* or telegraph* or (broadcast*)
65	financ* or credit* or debt* or mortgage* without insurance* or (social and security)
72	(computer or computing) and data without production

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