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STANDARDS, LEARNING AND GROWTH IN BRITAIN – 1901-2009

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Standards, Learning and Growth in Britain - 1901-2009*

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Abstract
This paper considers the model of voluntary, consensus based standardization as developed through the British Standards Institution (BSI) and its contribution to learning and productivity growth. It discusses the contribution of professional engineers to the model's introduction, its extension at home and imitation overseas, arguing that by 1931 the BSI catalogue of standards represented a considerable stock of codified knowledge whose growth reflected underlying aggregate technological advance. To validate this claim we incorporate a measure of the BSI catalogue of standards into an econometric model of productivity growth in Britain. However, caution is required in the interpretation of this finding.

Key Words: standards, technological change, productivity.
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1 Introduction

There is now an extensive literature linking standardization - the creation and use of various kinds of industrial norm - with economic growth. The literature has addressed both the economic functions of standards, as well as the processes through which they are created. This paper focuses on the latter issue, examining the role of one organization - the British Standards Institution (henceforth BSI) - whose primary purpose has been and remains the creation and supply of standards. Under the auspices of this body, standards are developed by a process in which consensus is reached by various industry and enterprise stakeholders through committee deliberation. Using the historical record, we argue that the development of such standards constituted an important mechanism for 'collective learning' in the British economy, and whose relevance for productivity growth is assessed by considering an econometric model which complements the qualitative analysis.

The origins of the BSI are to be found within the professional engineering community which, operating through the Institute of Civil Engineers (ICE), established the Engineering Standards Committee in 1901. The committee played an important role in coordinating a response of British business to international competitive challenges, especially those from the US and Germany. It is argued below that the external economies of scale resulting from the Committee's work could - at least partially - replicate the alternative paths made possible - for example - by the frequently larger scale and greater vertical integration of US enterprise in which many of the benefits of standards could be internalised. We consider the development of the Committee as a model for inter-company coordination, how the committee was established at a national level, and how it was imitated elsewhere in Europe, most notably in Germany, where standard setting has provided an important example of what has been described as 'co-operative capitalism' (Chandler 1990). To assess the role of the institution, the paper goes on to discuss the merits of using the number of documents in the catalogue of the BSI as a measure of institutional output which represents a broad class of technological opportunities. This measure allows us to supplement the foregoing qualitative analysis with a corresponding quantitative analysis which focuses on the econometric relationship between standards and UK productivity growth between 1931 and

2009. A statistically significant relationship between productivity growth and our measure of the knowledge generated by the BSI through its standardization programme is found. This is taken as evidence for the relevance of this mechanism for learning.

The paper is organised as follows: the next section provides a brief résumé of the economics of standards and how the process of standardization links to the idea of learning. Section three considers the historical origins of the BSI. In section four, the evolution of the BSI and its committee structures into a genuine national standards setting body is explored. We argue that this event establishes a suitable initial starting point for the statistical analysis in section five, where the growth of the BSI standards 'catalogue' and its variation over several decades is discussed. In section six, this variable is used to augment a conventional production function; standards are found to account for a sizeable portion of economic growth over the period 1931-2009. The final section concludes.

2 Standards, Standardization and Learning

In general, standards provide a point of reference which allow for both conformity and consistency of expectation. In so doing, industrial standards - specifications for either a product or a process - typically provide for one or more economic functions. These include a reduction of variety, the provision of compatibility, or the achievement of a minimum level of quality which may be useful for regulatory purposes. The consistency of expectations generated by a widely utilised standard helps reduce problems of asymmetric information and in lowering transactions costs, enables the development of markets – aggregates of transactions where a standard functions as an underlying point of reference. As formal written documents, standards provide codified information regarding measures, reference materials, and processes which frequently support the other functions of standards, e.g. in the provision of legal metrology. The aggregate of the codified information creates what Tassey has described as a public good intensive `infratechnology', promoting profitable learning through the creation and deployment of proprietary technologies (Tassey 1995, 2004). This may produce contradictory outcomes from the variety reduction standard, since these forms of standard may well encourage product differentiation (Choudhary et al. 2013), generating product variety and providing an alternative channel for productivity growth in ways suggested *inter alia* by versions of endogenous growth theory in which up-stream variety generates productivity advance downstream (Ethier 1982; Romer 1990).

How standards relate to learning and productivity growth can usefully be explored with reference to the literature based on the concept of 'product' or 'technology' cycles which has attempted to establish certain regularities regarding the way in which new products are introduced and then become sufficiently important to be important sources of productivity growth. Phases of such cycles are frequently based upon a distinction between an 'innovation' phase from a 'standardization' phase, between which the focus for learning and technological change shifts from product innovation to process innovation. The historical variation in the means by which this transition occurs between economies is central to the discussion in the paper. More specifically, differences in the mechanism which provide for the coordination of standardization activities - not always adequately supplied by market - provide the theme for this section.

The transition from a phase of product innovation in which alternative designs and specifications compete, to one of standardization, is based on the emergence of a 'dominant design' (Abernathy and Utterback 1978), which functions as the point of reference for standardization, i.e. as a standard taking the form of specifications for certain 'core' product characteristics which provide the focus for increasingly coherent buyer preferences (Geroski 2003). At such a point price becomes a major consideration in what is now a more clearly 'market' and competition now centres on achieving economies of scale. Clearly the realisation of scale economies depends heavily on successful standardization - through the reduction in variety and the increased potential for making dedicated sunk-cost investments in both equipment and economic relationships (e.g. between employer and employee or between firms). The process may also allow for the substitution of unskilled for skilled labour, as in the recent model of Acemoglu et al. (2012) which distinguishes between innovating firms (skilled-labour/R&D intensive) and standardising firms (unskilled labour intensive) which possess a comparative advantage in implementing the dominant design. The authors here regard standardization as being associated with market entry and greater competition, suggesting that standardization acts not only as an 'engine of growth' in its own right, but also as a block to innovation in so far as it limits the expected profitability of skilled-labour intensive R&D projects. On the other hand, greater competition associated with standardization may encourage some firms to innovate again to 'escape competition'

(Aghion et al. 2005). But outcomes entailing more competition are far from certain, and a 'shake-out' of producers is often associated with standardization, especially where intellectual property in the dominant design can be protected. In such instances or when the switching costs between standards are sufficiently strong, a so-called standards 'battle of attrition' may ensue. Where distributional issues between firms are less strong, there is a coordination problem, as exemplified in the 'battle of sexes' game (for a discussion of both types of competitive situation see Besen and Farell 1994). The ability of firms to capture rents from standardization varies with both firm heterogeneity (a lead perhaps in product development) between industries (according to the varying appropriability conditions) and between institutional structures (e.g. the strength of intellectual property rights or, as we see below the nature of the standard setting body itself). The relevance of each of these games may change considerably over time. When for example the Model T Ford was introduced, creating a dominant design, the lack of standardization among other car assemblers and component suppliers was exposed, creating the need for a coordinated response which the market may not be able to supply. In this case, a cooperative organisation of firms, organised around a patent (the famous Selsden patent), made some early but unsuccessful attempts at cross-firm standardization. Eventually, efforts initiated by the Society of Automotive Engineers was able to provide the coordinated response required, although the credibility of the standards owed much their adoption by General Motors (see Thompson 1954).

While the product cycle literature has tended to emphasize the variety reduction function of a standard in the form of a dominant design, a largely complementary literature has focused on inter-operability and compatibility and their role in creating network externalities (Farrell and Saloner, 1985; Katz and Shapiro, 1985)[1]. A dominant design here operates as a technological platform, which may reflect a dominant market position. Generally, the presence of the network externalities makes for greater uncertainty because expectations play a larger role. The theory suggests the potential for market failure in either 'lock-in' to sub-optimal technologies (Arthur 1989) through chance factors and an early lead,

[1] This alternative emphasis has partly reflected the importance of compatibility standards for the development of information and communication technologies (ICT), but famous historical case studies have featured typewriters and the QWERTY keyboard (David 1985), or the adoption of standard railway gauges (Puffert 2002).

or ‘excess inertia’ in situations where the lack of an agreed standard inhibits the use of a technology. The implied scope here for the historian has not however gone unchallenged, with at least some authors contesting the idea that decentralised markets tend to under-provide standardization Liebowitz and Margolis (2001)[2].

Learning associated with standardization and process innovation was of course central to the industrial revolution. Standards were critical to both the successful emergence of the factory system when concentrations of people favoured both the coordination of activities advantageous for standardization and quality control, as well as learning by doing (Smith 1776). Mokyr (2009/2011) has even gone so far to claim that “standardization of both output and input may well be the most underrated technological development of the Industrial Revolution” (Mokyr 2011 p. 343). Such learning may also, as Smith claimed, have further implications for product innovation, especially in mechanical engineering. However it seems much of the benefit from standardization could be reaped at quite small scale, so that while factory size grew as in textiles, in the case of Britain at least this was less rapid than the size of the aggregate market (Hannah 1983). Rather it was in the new industries and technologies of the so-called ‘Second Industrial Revolution’ (c1870-1914) that scale economies became significant in terms of market size. Moreover, the new industries – such as steel, chemicals, electricity and in transport equipment – were able to benefit to a far greater extent from scientific knowledge and required significantly greater amounts of cross-firm and cross-industry coordination for success, most obviously but not exclusively in the new technological systems - in railways, telegraph and electricity. Variety reduction standards were necessarily fundamental for the process and the historical experience suggests that several mechanisms provided for the requisite coordination.

The new opportunities in this second wave of industrialization gave significantly greater leverage to organized and codified knowledge. While the emergence of formal in-house R&D facilities may have been a key innovation of the period (Mowery 2009) the learning associated with realising the latent potential for scale economies through standardization was probably much more important in explaining diverse economic outcomes, especially those between the US and Germany on the one hand and Britain on

[2] For a theoretical model of the circumstances in which compatibility standards are effectively provided by decentralised market based economies see Auriol and Benaim (2000).

the other. In the US, as argued by Chandler (1977), the qualitative changes required in the mechanisms for learning often took the form of large vertically integrated corporations where there were significant investments in management and distribution as well as production (Chandler 1977). But the necessity of the 'Chandlerian corporation' as a unique mechanism for seizing the opportunities of the Second Industrial Revolution has not gone unchallenged. Indeed, the importance of purely static internal scale economies in production may have been less important than sometimes supposed and, as Chandler himself realised, it was the ability to maintain high rates of capacity utilization that may well have been more important in many competitive contexts. If static scale economies in production were less important than technological change in explaining cost reductions, other factors certainly contributed substantially to the considerable growth in concentration observed in the US (see for example Scherer's (1990) review of Chandler's *Scale and Scope* [1990]). Besides the oft-cited influence of the Sherman Acts, the role played by branded marketing and mass consumption – 'learning by selling'(Thomson 1989) and creating firm-level rather than plant level economies – may have been particularly important in the US case (see also Marshall 1919; von Tunzelmann 1995).

If modern historical analysis has downgraded the role of internal economies of scale in the Second Industrial Revolution, it has also recognised a greater variety of mechanisms (than a simple market-hierarchy dichotomy) for coordinating transactions where asymmetric information is important and where external economies may be significant (Lamoreaux et al 2002). In the specific context of innovation, Wright (1999) has argued that the US developed considerable networks of 'collective learning,' operating nationally rather than simply through the familiar localised industrial district and outside the corporate hierarchies. He suggests that both 'informal colleges' of skilled mechanics and later professional engineering associations established norms favouring open information exchange. In specific contexts, Misa (1995) has observed the significance of professional bodies in facilitating user-producer interaction and standardization in the American steel industry, while Usselmann (2002) has shown how professional associations of engineers could effectively cooperate to achieve industry wide innovation, increasingly managed within the parameters of a clearly defined standardization process. The considerable diversity in railroad gauges had been reduced by the late 19th century, and the Master Car Builders played a critical role in establishing industry wide standards for rolling stock design.

Both the American Society of Civil Engineers (ASCE) and the American Institute of Mechanical Engineers (AIME) but, above all the American Society for Testing Materials (ASTM), which pioneered the formulation of specifications for steel rails. In fact, the ASTM was particularly important in establishing the technological infrastructure for the second industrial revolution more generally, which, as noted by Mowery and Rosenberg (1989), required the ability to predict more accurately the performance characteristics of both inputs and outputs and to bring "together in a systematised way the knowledge of the behaviour of materials that had been gleaned from the work of scientists working on these materials in innumerable industrial contexts" (pp. 46-7). In other words technological infrastructures founded on standards and other types of codified knowledge formed an important mediating link between science and learning at the level of the individual firm.

At a national level and alongside the US, the German economy is usually regarded as assuming economic leadership in at least in some of the industries associated with the second wave of industrialization. The significance of cross firm cooperation and coordination in the German case was probably even more important than in the US. It is worth noting that modern research indicates that both plant and establishment size were considerably lower in Germany than in the US or for that matter France or Britain (Kinghorn and Nye 1996). These authors hypothesize that German organizational forms (most notably the cartel) were able to substitute effectively for the much larger scale managerial hierarchies observed in the US. Given the traditional presumption of the instability of cartels, learning how to cooperate and coordinate transactions between firms was central to the German path of industrialization.

Both the German cartel and the professional association are examples of a wider and increasingly recognised genus of networks - coordinating mechanisms which can generate Marshallian external economies and which may substitute for internal economies. While these economies are most frequently cited in relation to geographical regions or industrial districts, similar mechanisms clearly operate at a national level, coordinated by government, trade or professional associations, or in other cases favoured firms (as in the case of the Japanese *Zaibatsu* Morck and Nakamura [2007])[3].

[3] For a discussion of varieties of coordination mechanisms in the case of US business history see Raff et al (2002).

This brief review of the standardization literature has established the significance of the relationship between standardization and processes by which agents collectively 'learn' to coordinate their activities and make certain kinds of technological advance appropriable. It has also suggested that in the context of the Second Industrial Revolution that in certain circumstances Marshallian style external economies may provide an effective substitute for the vertical integration strategies often successfully pursued in US business. In the next section we consider the case of Britain, and the role of professional engineers in establishing a model for voluntary consensus standardization which served as the basis for a national institution – not restricted to any particular industrial sector - and which was eventually widely emulated elsewhere.

3 The Origins of the British Standards Institution 1901-1918

The increasing challenge from international competition for British industry in the late Victorian era from the US and continental Europe provides the immediate context for the creation of a standards setting body which eventually evolved into a genuine, and possibly the first, `national' standards setting agency (SSA). This section situates this evolution within the context of the substantial and long-running debate concerning Britain's relative industrial decline (see, for instance, McCloskey (1971) and Foreman-Peck (1991)).

Much of the more recent economic literature surrounding Britain's economic performance in the later part of the 19th century has focused on the implications at the macro-level imposed by the fact that much technological advance, especially in the newer industries, was now taking place overseas, while differences in relative factor prices, especially in comparison with the US, constrained the extent to which that advance could be directly imitated – at least without local innovation and refinement at the very minimum (Broadberry 1994, 1997). Although there is no completely consistent pattern across industries, factors which are usually acknowledged to have favoured more rapid gains from scale economies achieved via standardisation in the US included the widespread diffusion of the American system of manufacture in combination with more homogeneous consumer tastes based upon a more equal distribution of income. Alongside the many other factors that have been examined, an additional factor important in the current context and stressed in some accounts is the role of the engineering profession as an intermediary, and the greater importance on Britain of the independent `consulting engineer'. Here for example, in attempting to account for the lack of competitiveness of some engineering sectors in the period from 1895-1914, Saul (1967) famously drew attention to the significance of senior engineers in Britain, whose role as consultants on engineering projects he regarded as contributing to the mixed and contrasting competitive outcomes in the different sectors of mechanical engineering. The consultant engineer was important in a number of industrial contexts, not least in the generation of exports resulting from railway building (and other construction projects) in the Empire and South America. Considering locomotive production, it was in Saul's view the "baleful influence" of the consulting engineer which created an unnecessary proliferation of variety in locomotive production and consequentially short production runs, rather than any lack of standardisation within the independent locomotive builders, who were heavily dependent on these export orders. The argument also seems to have extended to locomotive production in the generally vertically integrated railway companies, where Saul argued that the company locomotive workshops "were private empires largely isolated from the market" and in which "the strong individuality of the chief engineers meant that there was little inter-change of information or uniformity of practice." p.116). The engineer was also arguably central to variety proliferation in construction projects and hence in the demand for constructional iron and steel. In fact, the point about the unique position of the senior engineer (or architect) seems to have been well recognised by contemporaries as was the contrast with US practice. A leading engineer of the time, described in 1909 how both the US and Germany had generally adopted `standard lists' of rolled sections and it was "known that numerous orders had been refused by American steel-makers because the sections required differed from American standard sections" (Unwin 1909).

But the prominence of the senior consulting engineer in construction proved also to be the source of a credible competitive response, coordinated through the auspices of the ICE, whose membership spanned the various engineering disciplines[4]. The first document

[4] Founded in 1818, it had received a Royal Charter in 1828 and possessed the largest membership among engineering institutions up to World War I. By the 1820s it had established itself as a body where, "the reading, discussion, and publication of papers formed the principal activity, which occurred within an intricate hierarchy from associate or junior membership to full membership. ..... [which] virtually all senior engineers found ...necessary" (Buchanan 1985 pp.45-46). It was through the ICE that Whitworth had the credibility to promote the eponymous screw thread.

claiming recognition as a `British' standard was the output of a specially constituted Engineering Standards Committee (ESC) - of the ICE in 1903. The ESC's establishment was the result of the motion to the ICE Council by the prominent civil engineer Sir John Wolfe-Barry in 1901. The immediate case of concern - prompted by the British Iron Trades Association - was in the production of rolled steel - a major input into growing industries such as shipbuilding, railways, tramways and bridge-building[5]. For rolled steel shapes and sections, increasing international competition meant that cost reducing strategies were paramount, and attention was inevitably drawn to the diversity of shapes in use, and the role played by senior engineers themselves in the proliferation of variety. The need for a coordinated response to a competitive challenge taking the form of standardization was by no means a novelty by this time. For example, Velkar (2009) has shown how the competitive challenge from German producers being experienced around 1880 in the wire industry eventually produced a response based upon voluntary, consensus based standardization and cooperation among the leading producers.

The standardisation effort inaugurated in 1901 brought together five leading engineering institutions - initially and in addition to the ICE, the Institution of Mechanical Engineers, the Institution of Naval Architects, the Iron and Steel Institute and later the Institution of Electrical Engineers. Buyer interests were represented on the committee by the economy's major procurement bodies, so in addition to the five engineering institutions the ESC also brought in representatives from the British Admiralty and the India Office, both among the largest purchasing organizations in the world, and the War-Office. Other interests represented included the shipping registration societies, the railway companies (the biggest corporations at this time) and other large manufacturing interests. The government procurement agencies ensured that standard specifications for both Portland cement and railway locomotives were high on the list of objectives for this first phase of committee led standardisation.

The ESC model was clearly articulated in a retrospective lecture some sixteen years later, in which Wolfe-Barry made clear that there was no attempt to create standards ex

[5] In fact the debate which provided the inspiration for the motion seems to have been rumbling for some years. The BSI's own account refers to a letter to the London Times, dated January 15 1895 in which H. J. Skelton - a London based iron merchant - castigated both engineers and architects for specifying "such unnecessary diverse types of sectional material for given work that anything like economical and continuous manufacture becomes impossible..." (quoted in Woodward (1972), p. 8).

cathedra “but only after the fullest discussion by all concerned." The principle of voluntarism among both producers and consumers was established in order to “introduce order into a condition of things which had become more or less chaotic, or at any rate which urgently required intelligent regulation"; to ensure that work of economic value be undertaken, work would only be undertaken only after “important representations" (Wolfe-Barry 1917, p.337). At no stage was it envisaged that the ESC should become a testing and certificating body,
leaving the principle of *caveat emptor* as expressing “the limitation of the committee" (ibid., p.338). Here however, complementary services were provided by the newly established National Physical Laboratory (NPL), which had opened in 1902, in the creation of higher level scientific and metrological standards, as well as testing and reference methods, some of which were carried out in-house. Finally, and “most important perhaps of all" it was essential that the work of the Committee be “subject at all times to revision, so that improvement could be incorporated, and that the various trades should not become hide-bound, nor their methods stereotyped" (ibid, p.338).

The returns from the activities ESC can be gauged in a variety of ways. The coverage of the work of the ESC can be seen in terms of the development of the committee structure. With the main committee now undertaking the administration of the ESC, Unwin (1909) reported that by 1908 the standardisation work was undertaken by twelve sectional committees and 28 sub-committees. Three committees dealt with rolled steel sections - one for ships' sections, one for bridges and other constructional material and one for railway rolling stock and underframes. The other committees were responsible for locomotives, electrical plant, screw threads and limit-gauges, cement, cast-iron pipes and pipe flanges; additional committees were established for publications and finance. A section for vitrified ware pipes was created in 1911, and two sections for the emerging automobile industry in 1912 - one for road material and one for motor vehicle parts. The First World War had an obvious impact on the demand for standardisation work, with two new committees charged directly by the government with the coordination of the standards and specifications of the Air Board and Department of Aircraft for aircraft production and material for the war effort (British Standards Institution 1951). Eventually, these two committees spawned 15 sub-committees on their creation in 1917.

A number of empirical studies have used `counts' of the numbers of documents produced by SSAs in a manner now made familiar by the extensive use of patent counts. In this paper, the existence of a catalogue of standards which can be counted provides a means of measuring the `size' of their impact - a methodology used initially in Swann et al. (1996) and subsequently by Blind (2001, 2004), Blind and Jungmittag (2008), and Jungmittag et al. (1999). It is important to emphasise that the documents do more than satisfy one or more of the various immediate functions of a standard identified in the previous section. The publications themselves increasingly became important repositories of codified technological knowledge and hence provide an increasingly important form of institutional infrastructure. For example, the specification for Portland cement (BS 12) published in 1904, contained three test procedures for cement characteristics (McWilliam 2005). Figure 1 indicates both the number of ESC committees and the number of standards for the period to 1903-1918. Over 80 standards had been produced by 1918. Almost certainly, the economic benefits of these first British standards is likely to have been large, reflecting the pent-up demand for standards that had been building as competitive pressures on established business structures mounted.

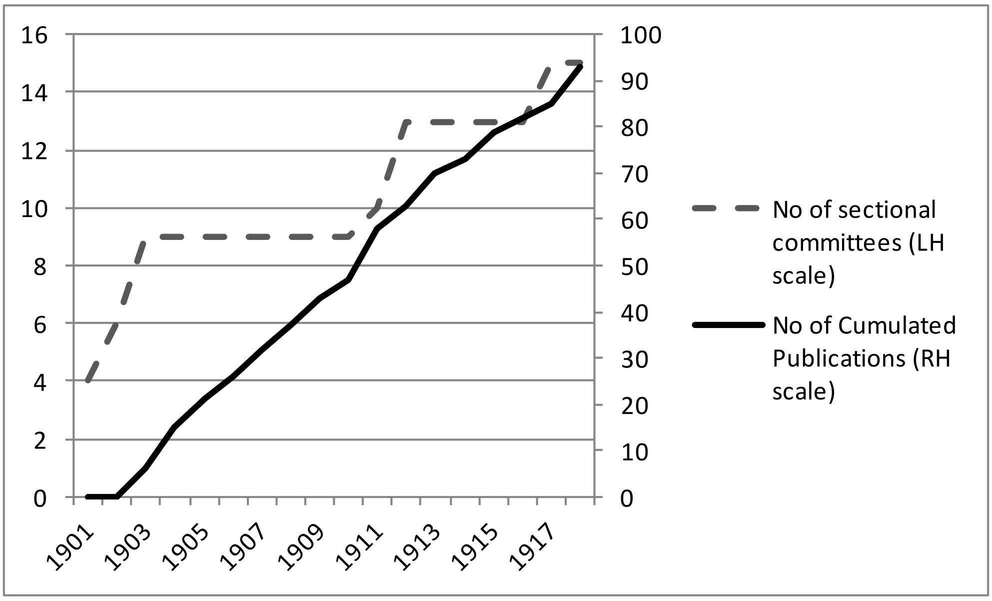

Figure 1
Output of the Engineering Standards Committee 1901-1918

Given the ESC model of standards development, it may be supposed that the anticipated economic benefits of these early standards outweighed the costs involved in committee deliberation. Ultimately this depends upon the up-take and diffusion of each individual standard. As far as rolled steel was concerned, the creation of a standard list appears to have been remarkably successful. Wolfe-Barry's 1917 review provided some estimates of the diffusion in the use of standard list for rolled steel parts - a joint product of the founding four sectional committees - shipbuilding, railway rolling stock, bridges and construction, rails. Wolfe-Barry [had] “asked leading manufacturers...[to provide] some estimate of the percentage in 1914 of their output which was produced in accordance with our standard specifications, and standard sections." (Wolfe-Barry 1917, p.344). These indicated that between 85-95 per cent of sections for both construction and shipbuilding were rolled to specifications from the standard list; 75 percent for tramway rails[6]; 90 per cent for bull-head railway rails (primarily for domestic use as demanded by the railway companies); and 90 percent for flathead rails (primarily for export). Despite the success of the standard list for rolled steel, and indeed of the specification for cement, Wolfe-Barry reported very little standardisation in locomotives built for domestic use (which he described as “lamentable" but considerable progress in India where [he believed]:

> “a broader view was taken, mainly I think, because Indian railways are under Government control, and was due to Lord George Hamilton, then secretary of state for India, who in 1901 instructed the locomotive superintendants of India to meet in conclave and arrive at a certain number of types suitable for that country."
> (ibid p.343)

For rolling stock an analogous situation pertained, with some progress in India but reportedly nothing being done in Britain. Important as these early standards were, and the high benefit-cost ratios which, with a high rate of diffusion, were arguably achieved, they reflect a back-log of demand for standardisation made possible by technological change in a few key sectors - and for steel products in particular. A situation had yet not been achieved in which the process of standardisation broadly reflects `steady-state' technological advance. In the next section, we consider the increase in scope of the committee model

[6] The BSI's educational arm suggests that the reduction in tramway specification from 75 to 5 as the result of the creation of a standard list saved industry about 1 million per year. No details of the calculation are made (http://www.bsieducation.org/Education/HE/about/history.shtml).

established by the ESC and its evolution into a genuine `national' standards setting agency, integrated into a wider system of innovation.

4. The Creation of a National Standards Setting Agency 1918-1931

The period 1901-1918 discussed in the last section was important in establishing the viability of the ESC model of standardisation around which the committee structure could be progressively rolled out. After 1918, the process may usefully be set within the wider industrial and political context, in which ideas had begun to move away from the received wisdoms of laissez-faire beliefs into something which was to develop into a broader current sometimes described as the `rationalization movement' (Hannah 1983; Wilson 1995). While rationalization in this context is often seen as primarily a question of the elimination of what some regarded as `wasteful' aspects of competition by means of horizontal merger and amalgamation, the experience of government intervention in the war indicated a degree of success in promoting more efficient production at the level of the individual firm and workplace. Such ideas naturally reinforced those spurred by the mounting overseas challenge to British industry discussed earlier.

Within the wider context of rationalization, the development of the ESC may be seen as one of a number of institutional `experiments' in cooperation and coordination (as well as in government intervention) that influenced economic policy between the wars. As far as Britain's economic capacity to create and standardise technology through research and innovation is concerned, Britain's backwardness had increasingly been recognised and mention has already been made of the creation of the government sponsored National Physical Laboratory (NPL) as early as 1902. During the war itself, there was renewed impetus for an organised research and development effort, resulting in the creation of a government department for industrial research in 1915, which became the Department of Scientific and Industrial Research in 1916. The department began to sponsor its own research deemed unsuitable for private effort, while also providing subsidies for the establishment of industry research associations. Early beneficiaries here include parts of the metal and engineering trades, textiles, leather industries, glass, laundries, grain milling, and food processing. Many of these research associations were able to form important links with

NPL, which was itself now under the remit of the new ministry, thereby creating a wider research network which also began to include the universities (Sayers 1950).

There has of course been much debate on the economic outcomes which eventually resulted from the increased inter-firm cooperation achieved during the First World War. In the post-war period however, the collapse of free-trade, which reduced the competitive need for policy aimed at international competitiveness, probably had a deleterious effect on the overall impact of inter-firm ventures, which now aimed more at traditional price collusion and price stability, than in technological cooperation aimed at collective learning. Moreover, various studies have shown that active monitoring by financial institutions did not provide an effective substitute for international competition, as it did in the US, and even more so in Germany (Edwards and Fischer 1994).

A reasonable assertion seems to be that the work of the ESC, with needs amplified in international comparison by both the fragmented and market led structures of much of British industry, as well as the exigencies of a hitherto unparalleled war effort, represented one of the more successful of the new initiatives, and where the complementary of its activities with those of NPL, seems to have borne fruit. Even as early as 1909, in his lectures to the ICE, Unwin provided substantial examples of the complementary activities of NPL and the ESC which clearly involved a wider network (Unwin 1909). By 1918 the tasks being undertaken by the ESC were considered to be sufficiently important to warrant its incorporation as the British Engineering Standards Association (BESA); the legal change was associated with the establishment of a distinct set of strategic principles. These enshrined existing practice as far as engineering was concerned, but now aimed for wider recognition in other parts of the economy; to obtain a Royal Charter; and to establish local committees in foreign and dominion countries. At the same time, the certification mark - later known as the `Kitemark' – obtained legal standing.

More important perhaps was that BESA carried on extending both coverage and membership. During the next decade, coverage had moved into new areas such as coal mining, paints and varnishes, petroleum, and illumination. In 1929 BESA duly received its Royal Charter which defined the objects and purposes of the Association, but these were broadly consistent with the strategy enunciated by BESA back in 1919. However, the charter was amended in 1931 to reflect the widening of activities to include the standardisation activities of the Association of British Chemical Manufacturers. The SSA's name was changed a final time to the British Standards Institution (BSI). This action created a new tier of responsibility – with Divisional Councils - Chemical, Building, and (from 1932) Engineering - separating a General Council from the Industry Standards Committees and the numerous technical committees, which by 1929 were already numbering around 500 (Woodward 1972).

Indicators of the success of the ESC included a renewal of government attention. In this regard, the role of standardisation in promoting productivity formed an important constituent of the factors" affecting the competitive position of British Industry addressed by the long standing Balfour Committee on Industry and Trade, set up in 1924, whose final Report appeared in 1929 (Committee on Industry and Trade 1929). Evidence was provided by the ESC to the Committee during 1925 in which considerable attention was paid to the comparative development of formal standardisation in Britain and elsewhere, largely focusing on efforts in the US and Germany and the role of competing national standards in export markets such as South America (PRO 1925), where concern was expressed about the use of standards in government procurement[7]. In evidence to the Committee, the Secretary of BESA referred to differences between standardisation efforts between both Britain and the US, and with Germany, which despite broad similarities with the British institutions where the Secretary took the view that "...when one takes a German standard and comparing it with our own, one finds that our standard is not necessarily superior in quality, but it is in most cases more practical than the German standard" (PRO 1925, para. 6865). Whatever the merits of this argument, it certainly seems as if the German engineering community took to the process of standardisation with alacrity. Germany was the first - in 1917 - of a number of European economies that had created national standards setting

[7] From the beginning, export markets were fundamental to the British standardisation efforts, as we have seen. The strong position of the British engineer in securing infrastructure projects associated with foreign outward portfolio investment, was threatened in many instances by insufficient standardisation, especially in countries lying beyond those with colonial ties. Moreover, even before the First World War, the issue of metrication was well to the fore and in his 1917 James Forrest lecture Wolfe-Barry was referring to "the thorny subject of a general change of British standards" which he did not dare broach for fear he "might transform this staid meeting into one of raging controversy," (Wolfe-Barry 1917, p.347) and which the ESC should not take a view. The ESC had however recommended to Government that specifications should be "at once translated into French, Spanish, and Russian, with metrical equivalents for the British measurements and formulae" (ibid., p. 347), with local committees in the main (non-Empire) trading centres. Moreover it was important that the price of all publications should be reduced to a rate comparable with the US, "who sell their specifications for a quarter of a dollar or less" (ibid, p. 348). In fact funds from both Government and industry helped achieve both aims.

agency as variants of BESA (UNIDO (2006) notes the creation of 15 between 1917 and 1925) and the Weimar Republic seems to have provided a fertile ground for both the rationalization movement in general and standardisation in particular (Brady 1933). German standardization efforts began in the war itself with the objective of standardizing `machine elements', but by 1926 this had - like the ESC - broadened in scope and was now operating under the name of the *Deutscher Normenausschuss*. Financially supported by the primary hub for rationalization - the *Reichs Kuratorium für Wirtschaftlichkeit* (Reich Board for Industrial Efficiency) - it acted as a 'federation' of various technical societies according to Karabasz (1928) who also notes that, at the level of the individual enterprise, the distinct profession of standardisation engineer was being developed, while some consulting engineers were beginning to specialise in standardisation work. He also records a remarkable growth in the numbers of national standards produced in Germany - with over 2100 in existence by the end of the decade 1917-27. Whether or not this number can be considered as commensurate, this was far in excess of just over 600 standards in the BESA catalogue by 1927 (see below); here Karabacz suggests a strong emphasis on `dimensional' standards - aimed at reducing variety. However the evidence does help to sustain the idea - consistent with the recent evidence presented in Shearer (1995) - that the rationalization movement in Germany was more than empty political rhetoric or a tool of the industrial capitalist, and that a standardisation movement formed a substantial component of a drive for efficiency. The data also suggest that assessments of the degree of success achieved through voluntary standardisation in Britain should be qualified when compared to Germany. In fact the period established a long standing difference in the apparent size of the voluntary standardisation efforts between Britain and Germany which extended well beyond World War II and into the 1980s, prior to the harmonization drive prompted by the creation of a European Single Market (see for example the comparative evidence in Swann et al. (1996)).

The US has generally been presented as developing along a more plural and fragmented route to standardisation than Britain or Germany, with a larger number of more or less formal standardising bodies, organised around trade associations or professional bodies (US OTA 1992; Tait 2001). While as we have seen, in-house standardisation provided a fundamental underpinning for the American system of manufacture and corporate strategy more generally, we have already noted early cooperative efforts at standardisation emanating through professional bodies associated with the railroad-steel and steel-construction nexuses.

The US Government's role in standardisation developed during the 20th century within the
field of metrology (the responsibility of the National Bureau of Standards in the Department of Commerce from 1901) and in the field of military procurement where mandated standards have been widely used. As in Britain and Germany private-public partnership in standardisation was boosted by the First World War. Coordination efforts during the war gave impetus to the creation of the American Engineering Standards Committee[8] in 1918 whose founding members included the `Big 5' professional engineering associations, and the Departments of Commerce, Navy and War. In the period after 1918, rationalization in industry received considerable support from the Secretary for Commerce, Herbert Hoover, who established a Division for Simplified Practice as part of the National Bureau of Standards to achieve variety reduction, acting mainly as a catalyst to spur coordination through various trade associations.

There were clear differences in the development of standardisation in the US and either Britain or Germany. Neither the AESC nor its successors (ASA and ANSI) functioned quite like BESA, i.e. as a `peak' standardisation body, eschewing the introduction (as opposed to the endorsement) of standards. As described by Adams (1919), standards development itself was the province of the many sponsoring bodies. In evidence to the Balfour Committee in 1925, BESA's secretary ventured that the American Engineering Standards Committee acted “rather as a `rubber-stamp' committee. The great difference between the Committee and ourselves is that we receive proposals and recommendations for standards, but we do not put a rubber stamp on them." (PRO 1925, para. 6946). The Committee was however more impressed by the work of the promotional work of the Division of Simplified Practice and by the relevance of American standards in export markets.

In summary, by the 1930s the BSI, founded and extended on the model of the ESC had considerably broadened its coverage to embrace much of the manufacturing and

[8] The forerunner of both the American Standards Association (ASA) and the American National Standards Institute (ANSI). The professional associations were ASCE, AIME, ASTM, the American Institute of Mining Engineers and the American Institute of Electrical Engineers.

construction industries, including chemicals. There is evidence of developing institutional complementarities with other elements of Britain's innovation structure. As an institution it had been imitated in a large number of European countries, including Germany, where the growth of the standards available to industry appears to have been considerably faster than in Britain in the decade after World War I. Standards development in the US took a different form, reflecting more pluralist and market oriented predispositions as well as the fact that the generally larger scale of much US enterprise had reduced the need for inter-company standardisation.

5 The Growth of the BSI `Catalogue'

Before moving on to an empirical model of the relationship between standards and productivity, we first consider our 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 is made up of the cumulated publications of standards up to that time less those that have been retired or withdrawn, such that:

$$STAN_t \quad = \sum_{t-\infty}^{t} P_i - \sum_{t-\infty}^{t} W_i$$

where $STAN_t$ 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. $STAN_t$ is therefore a measure of the `stock' of standards current at the end of *t* periods and that we argue serves as a proxy for the `flow' of benefits to the economy during any interval of time t. [9]

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, or put another way, a particular `vintage'. While the standards published within any vintage may be expected to create a positive net

[9] Ideally perhaps, we would wish to supplement this measure with several aspects of the `condition' or `quality' of the catalogue, and in particular measure 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.

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 reflected in its declining share of the overall catalogue.

We can now illustrate the basic measure using our data on BSI standards. Data on the size of the catalogue were constructed by amalgamating two data sources. First the BSI `History Book' allowed us to count all BSI publications from the initial `public' standard published in 1903[10]. This source was discontinued as computerised records were introduced in 1985. Accordingly, from that date we use the PERINORM(C) database. While this allows for a complete count of withdrawals, and hence an accurate measure of the size of the catalogue (STAN) 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 the Data Appendix to this paper.

Figure 2 illustrates significant variations in growth rates of the catalogue by decade. Rapid growth rates can be observed in the decades 1950-1960 and once again between 1990 and 2000. By contrast, the two decades from 1970 to 1990 were periods of relatively sluggish growth. The variation in growth rates between 1931 and 2009 reflected deeper changes in the stance of economic policy. Set against the benchmark rate of growth per annum, the period up to the end of the Second World War was one of rather slower growth, probably reflecting a declining rate of return on the marginal standard, which as argued above was partly engendered by a decline in international competition under tariff protection, in opposition to the pressures that had initiated the standardisation movement prior to the First World War.

[10] We acknowledge the assistance of the BSI and their library and information staff in this regard.

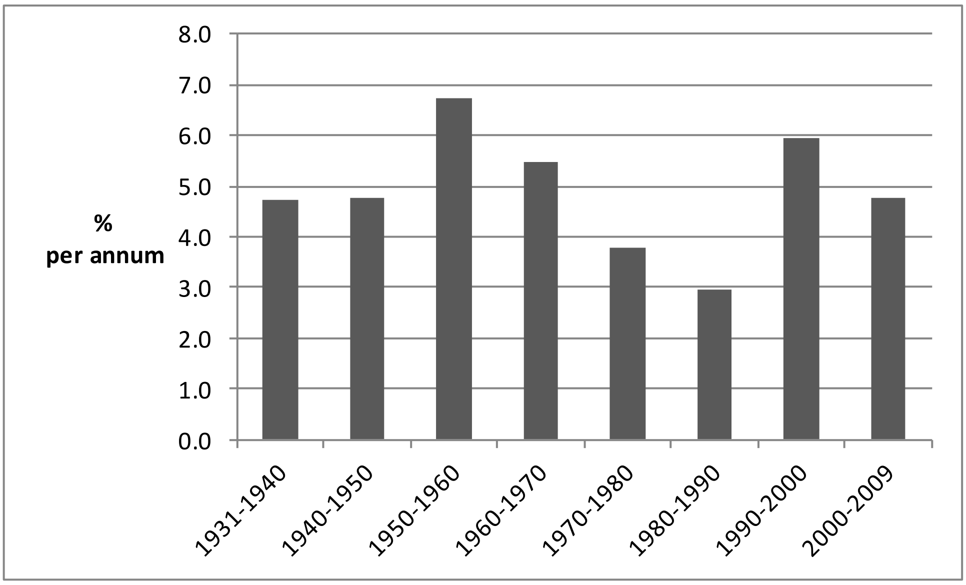

Figure 2
Output of the Engineering Standards Committee 1901-1918

The policy context for standardisation changed rather dramatically after the Second World War, when industrial productivity comparisons with the US came to the fore, and the will for industrial intervention under an incoming Labour administration, encouraged by fruitful tri-partite industrial cooperation during the war, was enhanced. Moreover, Marshall Aid - besides providing the much needed financial support - envisaged increased productivity through technology transfer from the US as a further means for avoiding political and social conflict (Tiratsoo and Tomlinson 1997). Beyond the establishment of the Anglo-American Productivity Councils (AACP), one of which was set up specifically to examine ‘simplification’ (as the engineering community referred to variety reducing standards), the productivity drive put policy emphasis on cross firm standardisation (AACP 1949).

After 1950, international agencies became an increasingly important source of new standards, notably the International Organization for Standardization (ISO), which was established with a secretariat in Geneva in 1946, and the International Electrical Commission (IEC), which resumed its work after the war. At ISO, 50 technical committees had been established by 1949. Much of the early work of ISO reflected the pattern of standardisation of earlier national development - steel specifications for example - but early work also included nuclear power. Nevertheless, Figure 2 clearly shows a progressive slow-down in the rate of growth of the catalogue by decade to a nadir in the 1980s. The slow-down in the decade 1960-1970 probably simply indicates the loss of interest shown in the early post-war period. Between 1970 and 1990 however, deindustrialization and other related factors almost certainly contributed to the deceleration. After 1990 however the marked acceleration was largely determined by the enhanced role of standards in the creation of the European Single Market. The biggest share of the new standards introduced into the catalogue in the last decade has its origin in the European standards setting organizations - CEN, CENELEC, and ETSI - although some of these have their ultimate origin in the international organizations such as ISO (DTI 2005, chapter 2). This new source of standards represented a considerable redeployment and `pooling' of national resources at the European level. Since the BSI in the single market era is mandated to market standards emanating from Europe, it is possible that some `dilution' of the catalogue has occurred with at least some of the additional standards having little relevance for British producers. On the other hand, it is conceivable that these standards are an efficient vehicle for technology transfer from overseas, especially within the EU.

We conclude this section by noting that growth in Britain appears to have been rather `standards intensive'. This probably owes something 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 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 British productivity growth in the post-1931 period.

6 An Econometric Model of Standards and Productivity Growth in Britain

To produce benchmark estimates of the contribution of BSI standards to economic growth, a standard production function for the whole British economy is estimated for the period 1931-2009. As argued above, from 1931 onwards the BSI can be construed as being a truly `national' organization, serving the requirements of many sectors, and not just those of the engineering intensive industries. Given that our aim is to estimate an economy-wide aggregate production function which implicitly encompasses all economic sectors, 1931 is thus a natural candidate for a start date[11].

6.1 The Model

A standard production function with both conventional inputs and technological progress can be written as:

$$Y_t = A_t f(K_t, L_t) \qquad (2)$$

where Y_t, K_t, L_t represent period t output, capital input, and labour input respectively while A_t is a multiplicative factor representing the level of technology. If the current level of technology is partly determined exogenously and partly by the current stock or catalogue of standards, we can write:

$$Y_t = e^{\lambda t} STAN_t{}^{\gamma} f(K_t, L_t) \qquad (3)$$

where λ is an exogenous time trend representing unobservable influences on output, γ is a parameter measuring the elasticity of output with respect to the standards stock, and $STAN_t$ is the standards stock at time t. Imposing both the familiar Cobb-Douglas functional form as well as constant returns to scale, permits us to express (3) in terms of labour productivity:

$$\frac{Y_t}{L_t} = e^{\lambda t} STAN^{\gamma} \left(\frac{K_t}{L_t}\right)^{\alpha} \qquad (4)$$

where α is the elasticity of labour productivity Y_t/L_t with respect to the capital-labour ratio, K_t/L_t. Taking natural logarithms of the relationship in (4), and setting $y_t = ln\ (Yt/Lt)$ and $k_t = ln\ (K_t/L_t)$ and $stan_t = ln\ STAN_t$, it is possible to obtain an estimating equation with a normally distributed error term u_t:

$$y_t = c + \lambda t + \gamma stan_t + \alpha k_t + u_t \qquad (5)$$

where c is a constant. Expression (5) is our primary economic relationship of interest, and permits us to gauge the the impact of standards on productivity. One estimation strategy would be to apply the two-step single-equation approach of Engle and Granger (1987) to

[11] Jungmittag et al. (1999) attempt to distinguish between the impact of standards and other sources of technological change. In view of our discussion above in which the activities of the BSI are best seen as an enabling device, as well as a limited umber of observations, we did not pursue this approach.

the relationship given in (5) to establish the presence of an economically meaningful long-run cointegrating relationship between labour productivity, the capital-output ratio and standards. However, given the well-known drawbacks associated with this procedure (Johansen 1988; Hamilton 1994), our econometric strategy will focus on the literature rooted in the maximum likelihood procedure of Johansen (1988) which allows for the possibility of there being more than one cointegrating vector.

6.2 Cointegration Analysis

Figure 3 plots the behaviour of the observed variables introduced in expression (5). It shows the relationship between labour-productivity, Y_t/L_t and the capital-labour ratio K_t/L_t relative to the stock of BSI standards ($STAN_t$). All variables are expressed in terms of levels (1931=100, log scale). Figure 4 presents the corresponding year-on year percentage rates of growth for these variables. As both figures illustrate, the growth of the standards stock has been very fast - at 4.8 per cent per annum over the whole period 1931-2009 - in comparison with labour productivity growth (1.7 per cent) and the capital-employment ratio (1.5 per cent).

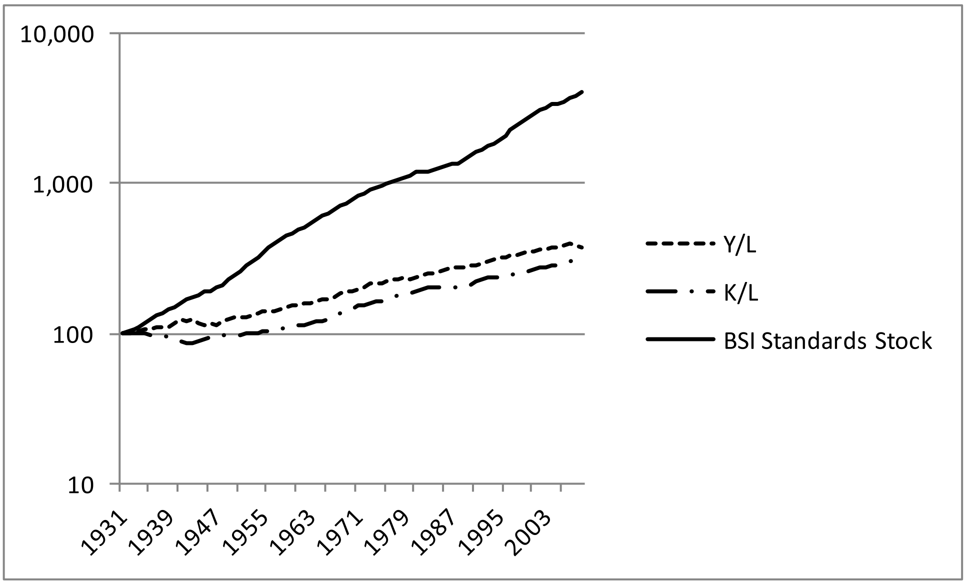

Figure 3
Long-run growth of labour productivity (Y/L), the capital-employment ratio (K/L), and the BSI standards stock, 1931-2009 (log scale, 1931=100)

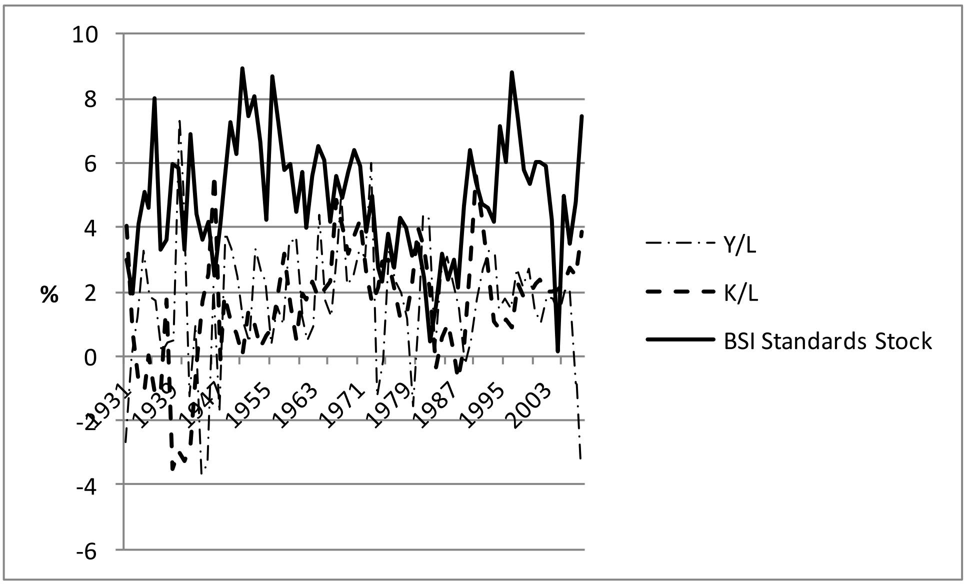

Figure 4
Year on year % changes in labour productivity (Y/L), the capital-employment ratio (K/L), and the
BSI standards stock, 1931-2009

Using the arsenal of unit-root tests proposed by Ng and Perron (2001) it was determined that our variables of interest in Figure 3 are all integrated of order 1. Test results are given in Appendix 8.B, Table B.1. This finding enables us to pursue the possibility of one or more economically meaningful cointegrating relationships existing between the levels of these variables. The presence of any cointegrating relationship(s) would also imply the existence of a valid vector error correction (VEC) representation of the data (Johansen and Juselius 1990). Prior to conducting cointegration tests, it is necessary to determine the appropriate lag length for a three equation vector auto regression (VAR). We begin by estimating an unrestricted VAR given by:

$$Z_t \;=\; \Phi_0 + \sum_{i=1}^{p} \Phi_{t-i} + \Xi D + \psi_t \;, \qquad \psi_t \sim iid\, N(0, \Psi) \qquad (6)$$

where p denotes the number of lags, Φ_0 is a 3 x 1 vector of constant terms, Φ_i is a 3 x 3 matrix of coefficients, and Z_t denotes a 3 x 1 vector of variables such that:

$$Z_t \;=\; \begin{bmatrix} y_t \\ k_t \\ stan_t \end{bmatrix} \qquad (7)$$

With respect to the role of a deterministic component, *D* represents a k x 1 vector containing k regressors such as a linear time trend and dummy variables, and Ξ is a 3 x k matrix of associated coefficients. Finally, ψ_t is a 3 x 1 vector of i.i.d. errors, and Ψ is a 3 x 3 covariance matrix. Our specification hence consists of three equations, such that the right hand side of each equation contains a common set of lagged and deterministic regressors. With respect to the elements of *D*, we include a time trend t, an extended mpulse dummy (*WARDUM*) which takes the value of one during the World War II years (1939-45) and zero otherwise, and a step dummy (*STEP*) which assumes a value of one from 1973 onwards, and zero otherwise.[12] In the case of the latter variable, we argue that 1973 represents a watershed year for reasons relating to the disruption of the productivity relationship in Britain. Most importantly it is widely regarded as marking the end of the so-called `Golden-Age' of growth in Europe (Crafts 1995; Crafts and Mills 1981), as well as the beginnings of pronounced de-industrialization, the oil-crisis, and the redirection of British markets following entry into the European Economic Community (EEC)[13].

In terms of selecting the appropriate lag-length, results based on Sim's sequential modified likelihood-ratio test, the final prediction error and the Akaike, Schwarz and Hannan-Quinn information criteria, unanimously suggested a lag length of order two, which given the annual frequency of the data, is plausible. These findings are presented in Table B.2. Additional tests revealed that the VAR(2) residuals were not serially-correlated (Lagrange Multiplier test, Table B.3), were multivariate normal (Jarque-Bera statistic, Table B.4), and not subject to heteroskedasticity (White test, χ^2_{109} = 119.1541, *p* = 0.1179). Further, all of the inverse roots of the characteristic polynomial were found to lie within the unit circle, indicating that the VAR satisfies the stability condition. Using this information, the presence of one or more cointegrating relationships was subsequently tested. However, the inclusion of dummy variables in our estimation framework precludes us from using the

[12] An impulse dummy was also included to address a residual outlier problem associated with the year 2009. Econometric estimates for this variable are not reported.

[13] A condition of joining the EEC was a requirement on the part of the UK to incorporate all EEC directives into domestic law within a five year period. This requirement also had important ramifications for standards setting, most notably with respect to process of metrication. Pre-empting EEC entry, and with the approval of the British government, the BSI took in 1965 an active lead in coordinating this process: by 1975, around 5200 standards based on imperial measures - the overwhelming majority of the stock of British standards - had been converted to metric units (see for instance http://www.hansard.millbanksystems.com/lords/1970/nov/30/metrication).

conventional maximum-likelihood procedure of Johansen (1988, 1991) since the inclusion of dummies has the effect of magnifying the corresponding test distributions, rendering conventional values invalid.[14] We therefore use the framework proposed by Saikkonen and Lütkepohl (2000a, 2000b, 2000c), which provides correct critical values even in the presence of shifter and extended impulse dummies. Cointegration test results, presented in Table 1, indicated the existence of a single cointegrating vector at the five percent level.[15]

Table 1:
Cointegration Test Results

Hypothesized Number of Cointegrating Vectors[1]	Likelihood Ratio Statistic	CV (10%)[2]	CV (5%)	CV (1%)	p-Value
None	30.16	26.07	28.52	33.50	0.0302
At most one	4.81	13.88	15.76	19.71	0.8861
At most two	1.89	5.47	6.79	9.73	0.5628

Notes
1 Denotes rejection of the null hypothesis of no cointegration
2 Critical values (CV) obtained using response surfaces according to Trenkler (2004)

The presence of a single cointegrating vector implies that the data should be estimated as a vector error correction (VEC) model. Expression (6) is thus manipulated to read:

$$\Delta Z_t = \pi + \Pi Z_{t-1} + \sum_{i=1}^{p-1} \Upsilon \Delta Z_{t-1} + \Xi D + \varepsilon_t \qquad (8)$$

[14] The presence of dummies to catch outliers, however, should not matter asymptotically, provided (i) thenumber used is small relative to the size of the sample, and (ii) the sample size itself is sufficiently large. However, this is not the case for shifter dummies or dummies that capture extended impulses. We thank Bent Nielsen for advice in this regard.

[15] In keeping with the model specification proposed in expression (5), a VAR(2) in y, k, stan, an unrestricted constant, WARDUM, STEP, and a linear time-trend was chosen. Cointegration tests were conducted using JMulTi (available at http://www.jmulti.de/). This free menu-driven programme has the advantage of offering a number of non-standard econometric tests that are unavailable in other widely available software packages.

where p is a vector of constant terms, and $\Pi = \alpha\beta'$, such that α is a matrix containing `speed of adjustment' parameters and β is a matrix containing the (long-run) coefficients of the cointegrating vector. [16] In our case, the presence of only a single cointegrating vector permits a simple interpretation of the model parameters, as identification is not an issue.

Accordingly, a single cointegrating equation of the form (with standard errors in parentheses):

$$y = 3.137 + \underset{(0.0336)}{0.435\,k} + \underset{(0.0315)}{0.080\,stan} + \underset{(0.00174)}{0.0756\,t} \tag{9}$$

The estimated elasticity of 0.08 on *stan* suggests that standards play an important role in fostering long-run productivity growth: using the reported elasticities in equation (9) in conjunction with the long-run annual growth rates of y, k and *stan* suggests that standards are associated with labour productivity growth of 0.38 per cent per annum, or about 21 per cent of the recorded productivity growth over the period 1931-2009. Care 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.

The extent to which standards affect short-run productivity growth is presented in Table 2. Whilst the speed of adjustment parameters corresponding to the error correction terms (ECT_{t-1}) are highly significant in the labour productivity (Δy_t) and the capital-labour ratio (Δk_t) equations, their coefficients are of opposite signs, indicating that that they move in opposite directions to restore equilibrium following a shock to the system. However, an interesting feature of the model is that ECT_{t-1} is not statistically different to zero in the standards equation ($\Delta stan_t$); moreover, the short-run adjustment parameters on Δy_{t-1} and Δk_{t-1} appear to be statistically no different to zero, suggesting that standards may be strongly exogenous. Testing the restriction that the adjustment parameter on standards is equal to zero ($\chi^2_1 = 0.130$ p = 0.717), coupled with block-exogeneity tests confirms this

[16] We do not dwell on the theory of cointegration here, given the large volume of literature published on the subject. For an excellent discussion of the issues involved in practical cointegration analysis, the reader is referred to Hendry and Juselius (2000, 2001).

Table 2

VECM Estimates 1931-2009

	Δy_t	Δk_t	$\Delta stan_t$
ECM_{t-1}	-0.51472 ***	0.24481 ***	-0.03270
	[0.08369]	[0.06011]	[0.08494]
Δy_{t-1}	0.35122 ***	-0.35359 ***	0.02630
	[0.09738]	[0.06994]	[0.09882]
Δk_{t-1}	-0.17715	0.61148 ***	-0.15421
	[0.11498]	[0.08258]	[0.11668]
$\Delta stan_{t-1}$	0.21509 **	0.16393 **	0.42394 ***
	[0.10679]	[0.07670]	[0.10837]
$STEP$	0.01255 **	-0.00054	-0.00524
	[0.00435]	[0.00313]	[0.00442]
$WARDUM$	0.02217 **	-0.02722 ***	-0.00475
	[0.00897]	[0.00644]	[0.00911]
$Constant$	-0.00400	0.00668	0.03181
	[0.00704]	[0.00505]	[0.00714] ***

standard errors in square brackets

***/**/** significance at 1/5/10% levels

Summary Statistics			
RSS	0.017	0.086	0.017
σ_{est}	0.015	0.011	0.016
R^2	0.454	0.662	0.304
adj.R^2	0.400	0.629	0.235
F-statistic	8.442	19.864	4.429
Log-L	222.2	248.4	221.1

conjecture[17] This finding is of interest for a number of reasons. It implies that first, whilst standards influence the long-run development of labour productivity and the capital-labour ratio, standards are not in the long run influenced by them. Put another way, labour productivity and the capital output ratio, and not standards, are responsible for returning the system to its long-run equilibrium. Second, standards influence, but are not influenced by short-run dynamics. From a more general perspective, the presence of strong exogeneity

[17] Strong exogeneity is defined as the simultaneous presence of weak exogeneity and Granger non-causality. The capital-labour ratio and labour-productivity variables were found to be neither strongly nor weakly exogenous.

suggests not only the independence of the institutional process of standard setting from short-run economic influences, but that the long-run role of policy in generating standards may be important, validating some of the discussion in section 5.

7 Conclusion

This paper has explored the important and distinct role of voluntary consensus based standards to economic growth in the Britain. Analysis of the historical record, coupled with an econometric analysis that utilises the size of the standards catalogue of the British Standards Institution as a proxy for the extent of learning and knowledge generated through standards, indicates that the institutional model of consensus standardisation adopted in Britain has exerted a non-negligible and positive impact on the growth of the British economy.

In terms of the history of the creation of the British Standards Institution, we emphasised the role of an elite cadre of British engineers, whose position was threatened both at home and in export markets by the increasing international challenges by the turn of the 20th century. The emergent model of committee based standardisation proved remarkably robust: it was not only imitated by other European economies, but persisted, in largely unmodified form. Moreover it provided a novel and distinct mode of collective learning which - at least in part - substituted a mechanism for achieving external economies of scale across firms for one based on vertical integration and economies internal to the firm - an alternative path of learning which is widely recognised as being of greater importance in the US. In contrast, Germany adopted a rather similar model of standardisation, but one with possibly even stronger linkages to the processes of technological change than in Britain.

Given the recognised role of standardisation in general for technological change and economic growth, the paper used cointegration analysis to examine the statistical relationship between the stock of standards made available through the British Standards Institution's catalogue and long-run labour productivity growth for the period since 1931, by which time we argue that the institution itself was firmly embedded into the broader processes of innovation and technological change. We found a statistically significant relationship between an exogenous stock of standards and long-run labour productivity. The estimated elasticity of productivity with respect to standards, when combined with the rather strong growth of the standards stock (when compared to the overall rate of labour productivity growth), suggests that the contribution of standards to economic growth has been large. We do however urge some caution regarding the interpretation of this latter finding: rather than argue for a separate and independent role for institutional standards in promoting economic growth, we would argue that it represents an important component of a particular path of learning, in which the process of standardisation itself cannot easily be separated from other factors. Thus the size of the catalogue provided by the BSI provides a proxy for both the output of the institute in itself and its input into the wider process of productivity growth. In this way, the development and maintenance of the standards catalogue may be interpreted as a coupling device, linking the deep drivers of productivity growth, such as human capital formation and innovation, with the orderly development of markets, where market failure might otherwise arise.

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Appendix

A. Data sources

Output (Y): For the period 1901-1947, we use estimates of GDP at 1985 prices obtained from Hendry (2001), who utilises Shadman-Mehta (1995). In turn, the GDP data in Shadman-Mehta (1995) draws heavily on Sleeman (1981) and Thomas (1984). GDP data for the period 1948-2009 were obtained from the Office for National Statistics (ONS), namely GDP chained volume measures (seasonally adjusted, identifier ABMI).

Capital stock (K): Gross total UK capital stock. For the period 1901-1947, estimates are constructed from Hendry (2001) and Feinstein (1972). For the period 1948-2009, ONS data is used (gross capital stock, volume measure excluding dwellings: identifier CIXX).

Employment (L): From 1901-1970, the source is Hendry (2001), which draws heavily on Feinstein (1972). From 1971-2009 we use the Labour Force Survey (LFS) for the number of individuals aged 16+ in full employment (identifier MGRZ), downloaded from the ONS website.

Stock of Standards ($STAN$): Estimated for the period 1901-1984 from the BSI History Book (kindly supplied by Mary Yates of the BSI Library), and from 1985-2009 from PERINORM, a database produced by a consortium of BSI, Association Francaise de Normalisation (AFNOR), and Deutsches Institut für Normung (DIN). The latter allowed for exact calculation of equation (1) in the text. While a complete count of publications was possible for the early period, only a proportion of total count of withdrawals was possible. Hazard rate analysis was hence subsequently employed to estimate the total number of withdrawals. Full details of our methodology are available from the authors on request.

B. Estimation Appendix

Table A1

Ng-Perron (2001) unit root test results [1,2]

	MZ_{α}	MZ_t	MSB	MPT	Lags	Reject H_0?
Intercept Only						
Levels						
y_t	1.47998	2.09355	1.41458	145.899	1	NO†
k_t	1.74291	1.58849	0.911400	67.6254	1	NO†
$stan_t$	-0.2572	-0.1238	0.48128	17.438	2	NO†
First Differences						
Δy_t	-43.21	-4.5186	0.10457	0.91559	0	YES††
Δk_t	-15.385	-2.7663	0.1798	1.6201	0	YES†††
$\Delta stan_t$	-18.662	-3.0462	0.16323	1.34385	0	YES††
Critical Values						
1%	-13.8	-2.58	0.174	1.78		
5%	-8.1	-1.98	0.233	3.17		
10%	-5.7	-1.62	0.275	4.45		
Intercept and Trend						
Levels						
y_t	-9.77784	-2.1811	0.22306	9.4542	1	NO†
k_t	-3.88823	-1.2975	0.333700	22.2136	1	NO†
$stan_t$	-3.94219	-1.39327	0.35343	22.9819	2	NO†
First Differences						
Δy_t	-38.5591	-4.25139	0.11026	3.11047	0	YES††
Δk_t	-19.6839	-3.10797	0.15789	4.80901	0	YES†††
$\Delta stan_t$	-26.2044	-3.54983	0.13547	3.89186	0	YES††
Critical Values						
1%	-23.8	-3.42	0.143	4.03		
5%	-17.3	-2.91	0.168	5.48		
10%	-14.2	-2.62	0.185	6.67		

notes:

[1] Null hypothesis (H_0): unit root is present

[2] MZα and MZ_t are modified versions of Phillips (1987) and Phillips and Perron (1988); MSB modifies Bhargava's (1986) test; MPT is a modified version of the Elliot et al (1996) point-optimal test

† Only possible to reject the null of a unit root at significance levels considerably greater than 10%; ††all tests unanimously reject unit root at 1% level; ††† all tests reject null of a unit root at 5% level, but not all at the 1% level

Table A2

Lag Length Criteria Test Results

Lag Length	Log-L	LR	FPE	AIC	SC	HQ
0	372.8	NA	2.34×10^{-8}	-9.06	-8.61	-8.88
1	667.6	530.0	1.69×10^{-11}	-16.29	-15.57	-16.01
2	712.6 *	77.4 *	6.81×10^{-12} *	-17.20 *	-16.21 *	-16.81 *
3	719.6	11.7	7.19×10^{-12}	-17.16	-15.90	-16.65
4	727.4	12.2	7.49×10^{-12}	-17.12	-15.60	-16.51
5	732.3	7.3	8.43×10^{-12}	-17.02	-15.22	-16.30
6	741.3	12.8	8.58×10^{-12}	-17.02	-14.95	-16.19

Note:
* indicates lag order selected by the criterion
LR: sequential modified LR test-statistic (each test at 5% level)
FPE: Final Prediction Error
AIC: Akaike Information Criterion
SC: Schwarz Information Criterion
HQ: Hannan-Quinn Information Criterion

Table A3

Lagrange Multiplier (LM) test results for residual autocorelation
(no of observations = 79)

Lag Length	LM statistic	p-value[1]
1	15.976	0.067
2	7.950	0.539
3	16.362	0.060
4	3.425	0.945
5	17.118	0.047
6	4.111	0.904

Note:
test of H_0: residuals are not correlated at stated lag
LM p-values are based upon χ^2_9

Table A4

VAR residual normality test results[1]

Endogenous variable	Skewness	χ^2	df	p
y_{t-1}	-0.085934	0.097231	1	0.7552
k_{t-1}	0.132244	0.230266	1	0.6313
$stan_{t-1}$	-0.299513	1.508656	1	0.2771
Joint			3	0.6803
	Kurtosis	χ^2	df	p
y_{t-1}	3.279188	0.256571	1	0.6125
k_{t-1}	2.828493	0.096823	1	0.7557
$stan_{t-1}$	3.681905	1.530605	1	0.216
Joint		1.884	3	0.5968
	Jarque-Bera		df	p
y_{t-1}	0.353802		2	0.8379
k_{t-1}	0.327089		2	0.8491
$stan_{t-1}$	2.711764		2	0.2577
Joint	3.392656		6	0.7582

[1] H_0: residuals are multivariate normal

Note: Cholesky (Lutkepohl) orthogonlization used. Qualitatively similar results were obtained using the procedures of Doornik-Hansen and Urzua