



DEPARTMENT OF ECONOMICS

DISCUSSION PAPER SERIES

**RUNNING TO STAND STILL? – INTELLECTUAL PROPERTY AND
VALUE ADDED IN INNOVATING FIRMS**

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Number 134

December 2002

Manor Road Building, Oxford OX1 3UQ

Running to Stand Still? - Intellectual Property and Value Added in Innovating Firms

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This version October 2002: for presentation at a conference on 'The Future of Manufacturing in the UK', November 1st 2002 at the London School of Economics.

An earlier version of this paper was presented at the 9th Congress of the International Joseph A Schumpeter Society, Gainesville Florida, March 27–30, 2002, and at the Centre for Economic Performance Industrial Economics Workshop, May 1st 2002.

100 word abstract:

We construct a unique panel dataset to examine how R&D and intellectual property (IP), via patents and trade marks, increase firm productivity. Knowledge has public good characteristics of non-depletability and non-excludability. Even with IP, imitation and inventing around other firm's products is possible, so we examine the size and duration of benefits to IP protection. If non-depletion is correct, this implies that absolute R&D, or total IP assets are important. We examine this hypothesis against the alternative of depletability, where innovative intensity relative to the size of the firm matters. The results support rapid depletability and poor ability to exclude.

Key words: Intellectual property, R&D, value added, manufacturing
JEL codes: L11, L60, O33, O34

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October 2002

Abstract

The importance of innovation for firm performance is widely recognised but not frequently quantified, due to the lack of data on the creation and acquisition of intangible knowledge assets. In this analysis we use a unique data set to estimate how far expenditures on R&D and the acquisition of intellectual property (IP), in the form of patents and trade marks, can increase the productivity of firms, measured as the value added by inputs of labour and capital services.

Without IP protection, knowledge is known to have the public good characteristic of non-excludability. Even with the existence of patents and trade marks, imitation and inventing around other firm's products is frequently observed. We examine both the size and the duration of benefits to IP protection for firms. Knowledge assets are also frequently assumed to have the second public good characteristic of being non-depletable; if true this would imply that within firms it is the absolute amount of R&D, or the total number of IP assets, which is important for success. We examine this hypothesis against the alternative, that either or both R&D and IP reflect knowledge stocks which are depletable in use within the firm; on this view it is the intensity of these activities relative to the size of the firm which matters for their increased performance.

We find evidence of productivity gains from doing R&D, for those firms reporting this activity separately within their accounts, and also positive returns from registering patents and trade marks. Evidence from the panel of firms, conditioning on unobserved fixed firm characteristics, shows that the benefits are short-lived and that the intensity of these activities within the firm matters. Firms in high technology sectors register the largest returns from R&D, whereas firms in low technology sectors show more significant returns to IP. However cross section analysis of persistent differences between firms also shows permanent differences between all firms according to the incidence and scope of their R&D and IP activity. These findings indicate that firms, especially those in the most dynamic sectors, have to keep innovating in order to preserve their productivity ranking in relation to their competitors.

Acknowledgements

Mark Longland's time is currently supported by a research grant from The Patent Office under the title 'The Extent and Value of Intellectual Property in UK Firms'. In addition to this financial support, we are grateful to the present Chief Executive, Alison Brimelow, and the former Comptroller General, Paul Hartnack, for access to records of UK patent publications. The database used for this study was developed with the support of two earlier ESRC research grants in collaboration with Derek Bosworth, nos. L 325253005 (Company Performance and the Valuation of Intellectual Property) and L 325253036 (The Economic Role and Value of Trade Marks). We are grateful to St. Peter's College for office accommodation for these various projects.

Introduction - the issues

Innovation proceeds by firms generating and applying knowledge to the design of new products and to improving their processes of production. Firms which undertake R&D are thus seen as flagship developers of new products and processes, which will be the subject of imitation as these inventions become diffused throughout the relevant markets. To achieve these long run social benefits it is necessary to ensure that firms gain some private benefits from innovation. If firms are able to acquire intellectual property (IP) rights, granting them temporary private monopoly rights over their innovations, then they can delay any immediate imitation, or charge fees for any licences offered to other firms during the period of their temporary monopoly.

Following this process of creation and acquisition of private rights in intangible knowledge assets, it is to be expected that research active firms will gain in terms of value added per firm over their rivals. Their gains in productivity will arise from either or both product and process innovation: in the first case by permitting the firm to offer a higher quality product, which will command a better price reflecting its added value to consumers; in the second, by offering savings of input resources used in production. Firms which license their inventions will also achieve direct gains in profits from these contracts.

The rise in value added in firms from R&D and IP is often seen as constituting a lower bound to the social returns to such investment and innovation. Further gains will accrue to final consumers if choice is increased via product variety or if product quality is raised (Grossman and Helpman, 1991). Gains also accrue to firms in the same industry, as well as to intermediate users of the firm's output who may be in other sectors, all of whom may experience an increase in profits or a decrease in their production costs from the transfer of knowledge and the use of better inputs (Griliches, 1995). Additionally, as shown by Van Reenen, (1997) and by Greenhalgh et al., (2001), there will be gains in terms of the preservation and creation of employment, which will constitute a social as well as a private gain, unless there is permanent full employment. All these gains must be added to the productivity gains to calculate total social benefits from R&D and IP, which will exceed private returns, meriting policy intervention to redress the likely under-investment in R&D.

The preservation of the incentives to invent and innovate by means of the offer of intellectual property rights is seen as justifying the social cost of monopoly prices during the period of these rights, with consequent delays in the process of diffusion, even though this is necessarily a second best solution to the incentive problem when knowledge has the principle public good characteristic of non-depletability (Arrow, 1962). The view that knowledge has this feature of non-depletability is also present in models of aggregate growth, where the presence of this factor as a determinant of the state of technology gives rise to increasing returns to scale (see for example Romer, 1986; Barro and Sala-i-Martin, 1995). However it remains to be tested whether increasing returns to input factors including knowledge are present at the firm level, where positive returns are crucial to the incentive process which generates the investment of resources in R&D.

The emphasis on the role of R&D as a creative process offering major breakthroughs for eventual general use contrasts with its role as a learning process, often generating incremental innovation and firm level adaptation of prior inventions and allowing firms to keep up with advances in their sector. Patel and Pavitt (1995 and references therein) have for many years argued that doing R&D is not only directed towards invention, but is also an important activity for being able to imitate and adopt other firms' inventions. This theme is taken up by Griffith et al. (2000) in analysing the 'two faces of R&D', looking at how the rate of catching-up with frontier technology by countries is linked to their domestic R&D effort. By analogy at the firm level, we might expect to see firms which do not engage in R&D falling behind more active firms, which are using part of their research budget to search for and adapt improvements pioneered by others.

Another strand of literature which emphasises the product competition aspects of innovation also highlights the likelihood of rather ephemeral gains to the firm from the introduction of new products into an already crowded spectrum. In his development of consumer theory, Lancaster (1966) considered new products to be competing for a place in the 'characteristics frontier' from which consumers selected their purchases. This approach presumes that consumers are demanding goods for

their consumption activities according to both prices and product characteristics. The frontier consists of products which minimise the cost of achieving desired combinations of consumption characteristics. If innovative products embody higher quantities of the desired characteristics at similar or lower prices, then new products can quickly displace old ones, rendering them redundant in the marketplace.

On this view firms are engaging in a race in which they have to expend R&D effort to keep up with others and, far from enjoying long periods of private monopoly from their IP assets, any advance they make on rivals can be eroded quite quickly by advances made by other firms, displacing their products and processes from the frontier. Seen from the perspective of the firm, its R&D and IP activity is an investment in a depletable private knowledge stock subject to a high rate of obsolescence. Certainly the evidence of studies of the registration and renewal of patents is consistent with the view that, of the many patents which are registered, few are renewed to full term, giving rise to short median durations and to extreme skewness in the implied private value of patents (Shankerman and Pakes, 1986).

So could it be the case that, even with a system of IP protection designed to enhance the rewards to invention, firms have to be continually running to stand still in respect of doing R&D and acquiring IP assets? Hall (1993 and 2000) demonstrates that the stock market's valuation of R&D by firms in the US reached a peak in the early 1980s and declined sharply thereafter, reviving somewhat in the early 1990s but not to the level of the earlier boom years. However on the basis of analysis of the productivity of R&D, Griliches (1995) has questioned any interpretation of Hall's early findings as demonstrating a fall in the overall real returns to R&D. His view, echoed by Hall (1996), is that it may have become harder for private firms to capture their share of the returns, due to greater competition and faster product imitation, but Griliches sees no evidence of a decline in the total returns to R&D as measured by studies of industry-wide total factor productivity.

Another large theme from the historical study of innovation is the question of what is the optimal size of firm and the market structure which is most conducive to innovation. Evidence in past studies has shown that larger firms conduct absolutely

more R&D but the increase is broadly proportional to size and they do not have a higher productivity of R&D than smaller firms (Cohen, 1995). Several studies have shown that the scale of firm which maximises the intensity of innovation is small to medium sized (Pavitt et al., 1987; Acs and Audretsch, 1991). This issue of firm size comes into focus when we consider how a given amount of input factors in the economy might best be arranged into small or large firms, to generate the most innovation and the highest social returns to innovation in the short and long run. Suppose first that the propensity to innovate is uniformly distributed across workers employed in R&D regardless of firm size and that the rate of R&D is proportional to firm employment. The aggregate rate of innovation is then invariant to market structure, which may group the total workforce into a lot of small firms or a few large firms without affecting the overall rate of innovation.

For major innovations which will survive to exhibit long run public goods characteristics, the eventual return to society is unaffected. Even so, if the innovation is only exploited by the innovating firm during its period of reward as owner of the associated IP, the rate of diffusion is effectively slowed by IP ownership if innovation occurs in smaller firms, unless each successful small firm can immediately capture all of the market supplied by the other firms in its sector, or engages in widespread licensing, both of which seem unlikely. However suppose that IP rights are not very effective in preserving the private gains to the firm of its innovation. Then the transfer to full social benefit is speeded up by the processes of imitation and adaptation. Now what matters most for society is which firms offer the highest rate of innovation relative to the resource inputs they are using. If this is genuinely a characteristic of small monopolistically competitive firms, then the preference for large oligopolistic firms as innovators is reversed.

Earlier studies of firm productivity have certainly demonstrated an increase in value added associated with the conduct of R&D and with the acquisition of patents (see Griliches, 1995). Other analysts have chosen to investigate the rise in the stock market value of firms, seeing this as encapsulating the value of the whole present and future gain in productivity, and hence profitability, of the innovating firm (for a survey see Hall, 2000). Even so, most of the prior art in this field uses data for US firms and, as

far as we are aware, none of the US or UK studies has ventured into the analysis of trade marks as a different basis from patents for sustaining monopoly rents, although there is work on the market value of trade marks for Australian firms by Bosworth and Rogers (2001).

The only recent study for British firms is that of Bloom and Van Reenen (2000), which investigates both firm-level productivity and market value. However the measure of productivity used in their study relates to firm sales, proxying gross output, rather than measuring the value added, or net output of firms. Despite this, their empirical model does not include any explanatory variables reflecting the use of intermediate inputs, as would be required for estimating a gross output production function. Work by one of the present authors (Greenhalgh and Gregory, 2000) has shown that the structure of supply chains varies significantly both across sectors and over time, affecting both the ratio of gross sales to value added and the ratio of in-house employment to contracted out purchases of services. Hence the correlation between sales and net output is not, in our view, sufficiently reliable for the first measure to be a good proxy for the second when examining a panel of firms engaged in innovation. Additionally in Greenhalgh et al. (2001) we found that labour and materials are complementary inputs, so that an omitted variable of materials could bias upward the estimated labour contribution to gross output as proxied by sales.

In the analysis which follows we use a unique panel data set for British firms from 1986-95. We estimate how far expenditures on R&D and the acquisition of IP in the form of patents and trade marks, increased the productivity of firms as measured by their value added, or net output and what is the duration of the productivity boost. We also test alternative specifications of this model, pitting a model of R&D investment and IP assets as local public goods within the firm against a model which implies that these are depletable and depreciating knowledge inputs for the firm, even though some part of this effort will have wider social benefits.

The data

The basic data relate to 843 large British companies for which accounts were reported for the years 1987-94 on the Company Analysis database under industrial headings

reflecting mining, manufacturing, consumer goods and utilities (Extel Financial, 1996). Data for R&D spending were included in this source whenever firms had separately reported this type of expenditure; of this sample of companies just under half were reporting R&D expenditure. The acquisition of intellectual property assets by these firms was derived by matching records of patents and trade marks using firm names given in the IP registration documents. As well as matching by the principal parent firm's name, matchings were constructed for all the subsidiary and associate firms which were part of the company reporting its accounts as a group in the Company Analysis database. The ownership structure was derived from a snapshot of listings in Dun and Bradstreet International, (1994). The resulting panel data set containing both financial and IP variables relates to 740 firms. Firms in this sample were observed with principal products in a wide range of sectors of industry (see Table A2 below for details).

To calculate the amount of annual net output using the firm's group accounts, we took the reported profits before tax (which are net of depreciation) and added back total staff costs (wages plus other labour costs). This is equivalent to the alternative (which is more tricky in terms of the accounts) of deducting depreciation of capital and all intermediate inputs (including raw materials and energy) from gross output or sales. After deflation by the GDP price deflator, it provides a measure of the real net value added by the labour and capital factors, which have been used to transform the intermediate goods into finished goods for sale. Value added also measures the size of the firm's output contribution to the Net Domestic Product 'cake', to be distributed in three ways: to owners of capital (including intangible assets) as profits (either distributed as dividends or retained for reinvestment), to workers as wages, and to government as taxes.

In earlier papers (Greenhalgh et al., 2000; Greenhalgh and Longland, 2001) we document trends in patents and trade marks in Britain, Europe and the US and we compare the attributes of the sample of firms in this panel with those for all applicants. Our findings are that, for all applicants of any nationality, rising trends in levels of patenting in Europe and the US were in sharp contrast to a falling trend in patenting directly in the UK. Trends in UK trade marks were more similar to those in

the US and rising. For the panel of production firms the same divergent trend for UK patents is demonstrated and overall the net rise in patenting via Europe was not sufficient to compensate for the fall in UK patenting. Of particular concern is the evidence that patenting rates per firm fell in high technology sectors, while in trade marks the increased activity was most evident in mature technology product areas.

We also investigated the characteristics of the panel firms in regard to their size distribution and their rates of innovation by size. We found that whether size was measured by sales or employment, smaller firms had a higher intensity of new UK patents and trade marks both in 1986 and 1995 (Greenhalgh et al. 2000, Figs. 8-11 and Table 14; Greenhalgh and Longland, 2001, Figs 5-8). The superior intensity in smaller firms was less evident for patents taken out in Europe and the US where patenting was more broadly proportional to size. Nevertheless the variation of IP intensity makes it important to investigate whether the firm's value added is affected by its absolute level of IP assets, following the 'within-firm public good' model, or by the rate of innovation relative to size as well as to determine which types of IP assets are the most effective. It is also imperative to discover how long is the duration of private benefit from the IP assets before private depreciation arises and either the invention becomes extinct, or external agents take hold of the benefits through positive spillovers.

The value added model

To relate our measure of firm net output to the stocks of labour, tangible capital and intangible knowledge, which are supplying input services, we use a standard production function, which assumes all input factors are acting interactively, but with different powers of impact. These coefficients are estimated via a natural logarithmic transformation which gives a linear estimating equation. The specification of the production function is thus:

$$\ln Y_{it} = \ln A_{it} + a \ln L_{it} + b \ln K_{it} + f_i + e_t + u_{it} \quad (1)$$

where Y is net output, A is the technology shift parameter, L is labour stock and K is capital stock, f is a firm fixed effect, e is a time dummy and u is a random error.

Subscripts depict firms (i) and years (t) respectively. Labour and capital services are assumed to flow smoothly from the utilisation of the stocks of these factors, as we do not have any measures of either annual worker hours or capacity utilisation to correct for variations in the flow of services. However the estimation of model variants with time dummies partitions out cyclical and trend factors, reflecting temporary macroeconomic shocks which are common to all firms. The use of firm fixed effects is designed to partition out persistent differences between firms which are attributable to firm specific characteristics which are not directly measurable. These would include such things as higher resource quality including management, but they would also take account of *permanent* differences in average product quality and technological performance. Thus in modelling the impact of both R&D activity and intellectual property acquisition on value added and including firm fixed effects we are forced to consider what is the impact effect of either increased R&D or new IP assets. Nevertheless it is possible to investigate further the relationship between the estimated

fixed effects and the firm's history of technological activity and we outline this below after considering the dynamic models.

The technology parameter, or total factor productivity, A , reflects the state of technology and product design in current commercial production. In the first variant of the model we substitute for $\ln A_{it}$ as follows:

$$\ln A_{it} = c + d \sum_k (1 - \delta_k) IP_{i,t-k} \quad (2)$$

where IP is one of the intellectual property assets (not logged because frequently zero in any given year) used to create a partial stock variable for a limited number of k years, with depreciation assumed to occur at rate δ . Model (2) can include more than one IP stock variable using separate but similar terms for each IP variable. As we did not have a very long series of data the full changes in stocks could not be constructed. Even so we experimented with current and lagged values, exploring a number of single variable and weighted average measures to investigate the timing and persistence of the impact of new intangible assets on value added. This model reflects

the view that IP protected knowledge is a local public good within the firm, affecting all aspects of the firm's production without being used up in the process.

The alternative variant is:

$$\ln A_{it} = c^* + d^* \sum_k [(1 - \delta_k) IP_{it-k}/FS_{it-k}] \quad (3)$$

where FS is a scaling factor for firm size. This formulation reflects the view that IP assets are specific inputs or outputs within the firm, which cannot affect all types of activity equally. Thus they appear to be effectively depleted in use as are private goods, by influencing only some specific aspects of the firm's production or product range. The alternative scaling factors used to test this hypothesis were sales, employment and capital stock.

As noted above, not all firms were reporting R&D accounts separately. To investigate the impact of R&D we had two options. We could either cut the sample to those firms reporting R&D separately in their accounts, or we could retain the whole sample and parameterise the reporting of separate R&D accounts using separate intercept effects for those reporting R&D, entering the level of R&D only for those firms reporting its value. In this latter case the two variants of the model now become:

$$\ln A_{it} = c + d \sum_k (1 - \delta_k) IP_{i,t-k} + f \ln RD_{it} + e_{RD} \quad (4)$$

$$\ln A_{it} = c^* + d^* \sum_k [(1 - \delta_k) IP_{it-k}/FS_{it-k}] + f \ln (RD_{it}/FS_{it}) + e^*_{RD} \quad (5)$$

where RD is expenditure on R&D if reported, e_{RD} is the shift parameter for R&D reporting firms and we explore the same range of potential scaling factors in (5) as in (3) above.

Of necessity, the use of a dummy for R&D reporting firms in the presence of firm fixed effects begins to reveal the extent to which such firms are persistently different from other firms in their permanent position in the hierarchy of value added, as combining (4) and (5) with (1) essentially allows each firm two components to its

firm specific effect, $(e_{RD} + f_i)$. To explore more fully whether intellectual property appears to be associated with persistently higher value added, we also saved the estimated fixed effects from a number of model variants and perform supplementary cross section analysis on these using the following regression:

$$f_i = c + \sum_x g_x D_{xi} + \sum_x h_x Dev_{xi} + v_i \quad (6)$$

where the D s are zero/one dummies reflecting the presence or absence of any intellectual property assets of type ‘ x ’ and the Dev variables reflect the deviation of each firm’s IP performance from the grand sample means, again for each IP type, over the period of panel observation.

Results - value added model for all firms

The first important finding to report is that the models of A as in (3) and (5), reflecting intensities of activity within the firm, clearly dominate models (2) and (4), modelling absolute activity, for both IP and R&D variables. Surprisingly no impact of IP on value added can be found using models (2) or (4), whereas all variants of models (3) and (5) yield some positive impacts. These results were entirely stable with regard to the inclusion or exclusion of time dummies, which only influenced the constant terms in the equations and gave rise to a very small increase in the fit of the model by absorbing general cyclical variation in productivity.

For the IP variables, the ‘best fit’ firm size scaling factor, choosing among sales, employment and capital stock, is to scale by employment. Seemingly it is the intensity of good ideas, resulting in the creation of additional IP assets relative to the number of workers in the firm, which matters most for adding to the value of output. In comparison, the R&D variable demonstrates ‘best fit’ when R&D is measured relative to capital stock. In addition to portraying the characteristic of depletion in use across the firm, the length of time that these assets continued to impact on value added was very short (high δ and small k values). Thus local knowledge stocks appear to embody one characteristic of public goods in being non-excludable from competitors and another characteristic of private goods, appearing to be depleted by use within the firm. A better way to explain the latter effect may be to think of the knowledge as

truly non-depletable, but limited to a small range of specific applications. We comment below on a further possible interpretation of the short duration of impact of IP and R&D.

Table 1 shows estimates of the value added production function for the whole sample of firms. The results quoted here all include firm fixed effects, but not time dummies. A key to variable names and definitions is given in Table A1. Rows 1 and 2 show that the net output elasticities of labour (0.55 to 0.64) and physical capital (0.19 to 0.21) imply the expected positive marginal returns to each factor, but they also reveal diminishing returns to scale (of the order of 0.76 to 0.85) in these conventional inputs. It is notable that these coefficient estimates for conventional factor inputs are not influenced by the inclusion of time dummies (results not shown). However they are influenced by the inclusion of the firm fixed effects, which allow total factor productivity to vary persistently between firms due to unmeasured factors such as the quality of management. When these firm fixed effects are suppressed, the output elasticities of labour and capital rise to values for which constant returns to scale would not be rejected (results not shown). This points to a positive correlation between firm size and total factor productivity, which can bias upward the apparent returns to input factors.

Table 1, cols. 2 to 5, reveals that most types of intellectual property assets show positive returns when entered singly. The exception is US patents, which has no significant impact in the range of lags investigated, which ranged from current variables to those two years previously. Experimenting with lagged variables and partial stock measures suggests quite short lags are appropriate and the choice between alternative weighted stocks imply high rates of depreciation of the positive returns to both UK and EPO patents. The 3-year weighted stock of patents used is declining at around 35% p.a. for EPO and 65% p.a. for UK patents, thus showing a more rapid depreciation of the gains from UK patents. There is some degree of multicollinearity between these two different measures of IP assets, which leads to unstable coefficients when both of these IP variables are entered simultaneously. Both the size of the coefficients and the relative rates of depreciation indicate a stronger impact on value added of EPO than of UK patents. This is to be expected given the

wider geographical coverage of most EPO patent applications designating the UK as one among several countries.

Trade marks are also associated with gains in value added and, as this variable is not very highly correlated with patents across firms in the total sample, the result is quite robust to variations in the specification for patents. Here it is current flows of trade marks which matter and not lagged stocks. For both patents and trade marks the finding is that it is the intensity of the flow of IP acquisitions relative to the number of employees which is important for keeping ahead of the crowd, rather than the accumulated long run stock of IP assets acting in a more persistent way. The underlying cause may be thought of as the quality of the human capital engaged in generating the continuous flow of innovations.

Models (2) and (3) include firm fixed effects, which average to zero around the general constant but, as noted above, will proxy persistent differences in productivity. In moving to consider the effects of R&D in models (4) and (5), the R&D reporting dummy effectively tells us whether there is a common difference in firm fixed effects between reporting and non-reporting firms; interestingly there is a positive permanent differential for R&D reporting firms. Moving to consider changing levels of R&D, whether we use the full sample with the dummy or the reduced sample of only R&D reporters, the findings are of significant positive returns to R&D spending. R&D is most highly correlated with output when measured as a ratio to tangible fixed assets; this reflects the flow of inputs into R&D compared to the services drawn from capital.

For both IP and R&D the lack of persistence in the net output gains could be due to the forces of product obsolescence or to the competitive erosion of monopoly rents as discussed above. However a further feature of these data, which we have demonstrated in Greenhalgh et al. (2001), is that firms raising their R&D become more labour intensive and that firms which acquire UK patents create more jobs with a two year time lag. If these extra workers are being hired to pursue more product development and not to engage in immediately productive work, then there is an endogenous rise in measured labour input. Persisting gains in output due to earlier innovation would then be attributed to the rise in labour input in this simple model,

whereas in fact the number of workers engaged in production will not have risen, but their increased productivity is sustaining the hiring of more non-production workers. Unfortunately we have no data on the workforce split between workers directly engaged in production and those employed in R&D and marketing, so we cannot explore these dynamics further.

Nevertheless the main finding is strikingly clear: given that all the innovation variables are scaled by firm size, the increasing returns model for knowledge assets, familiar from the literature on economic growth, is firmly rejected here for individual firms. Firms cannot escape from diminishing marginal returns to capital, nor from diminishing returns to scale, by expanding their R&D and IP assets in absolute terms, nor by expanding their innovation rate *pro rata* to labour and capital. Rather it is the case that they have to *increase* their intensity of IP and R&D relative to their human and physical capital to feel any benefit. Even this benefit may be rather short-lived for the firm, but note these results are *ceteris paribus* on the firm fixed effects which we explore further below.

Results for high and low technology firms

The division of the sample is possible using the SIC of the principal product of the firm to designate it as either ‘high’ or ‘low’ technology, (henceforth referred to as H and L firms, although perhaps ‘fast’ and ‘slow’ technology would be more meaningful descriptions given our findings of the need for continuous innovative activity). The sample division yields further insights into the returns to R&D and different forms of IP protection according to the sector in which the firm is located. Tables 2 and 3 show the comparable estimates to Table 1 for the two sub-samples of firms. Details of the industrial split are given in Table A2.

The output elasticities of labour and capital differ somewhat, with a slightly higher elasticity with regard to labour in L firms. This is conformable with the view that low technology is intrinsically more labour intensive in production; in fact the capital-labour ratio in H firms averages around three times that of L firms. Calculation of the implied marginal productivity (MP) of labour and capital shows that both factors have higher MP in H firms; it is plausible that this reflects some factor quality differences,

as well as possibly some temporary disequilibrium as between expanding H and contracting L firms. Despite the variation in output elasticities, summing these gives very little difference between the two sub-sectors of manufacturing in their returns to scale, which are slightly higher in L firms, but still diminishing.

Acquiring intellectual property assets and conducting R&D show positive impacts in at least one sub-sample, but there are some large differences to note. A very striking result is that UK patents, EPO patents and UK trade marks have an impact for L firms but none are significant for H firms. In contrast, neither R&D incidence or R&D intensity are significant for L firms, but they remain strongly significant for H firms. Thus the IP results in the total sample are driven by their impact in L firms whereas the R&D result is driven by strong returns for H firms. These differences may reflect variation in market destinations for output, with H firms being more likely to compete in the global market place, requiring continuous effort in R&D, but difficulties in retaining the private benefits of innovation in the face of a greater range of active competitors. Yet there is also a tendency to immediately reinvest the gains by hiring more non-production labour, causing labour input to rise: in our employment analysis (Greenhalgh et al. 2001) it was specifically the high technology firms which showed this characteristic of creating new jobs when undertaking more R&D or following the acquisition of patents.

In order to put the regression results into context, Table 4 gives some simulated changes in real value added which could result from changes in the typical amounts of R&D and IP acquisition. Adding one extra patent and one trade mark per firm per year would increase value added permanently by a quarter of one per cent. Raising all firms IP levels by one standard deviation would raise real value added by 6% for UK patents and trade marks, whilst for EPO patents and UK trade marks this would raise it by 8%. For the L firms which are smaller on average these percentage effects are correspondingly larger. Raising average R&D by one standard deviation would increase the average net output in the R&D reporting firms by 7% and in high tech firms this effect is 11%.

Given the very different dynamic effects in the two sub-samples, do the observed trends in patents and trade marks per firm show rational behaviour by H and L firms? It appears that this may be so: in the case of high technology firms, patenting in the UK and via Europe has been neglected, although some of these firms have increased their patenting in the US (Greenhalgh and Longland, 2001). Several low technology sectors have demonstrated higher EPO patenting as well as a rise in trade marks per firm, consistent with a recognition of the marginal value of these kinds of IP assets.

Analysis of persistent differences between firms

To investigate the persistent differences between firms we estimated model (6), which relates the estimated firm fixed effects to the presence or absence of any IP assets (dummy variables D_{ik}) and to the deviation of the average IP performance of the firm compared to others over the period of observation (variables Dev_{ik}). In interpreting these findings we note that causality between IP and performance is not proven, given that we are now ceasing to control for unobserved differences between firms, which could reflect such things as managerial competence or the level of technological opportunity offered by new scientific developments to their industry.

Table 5 gives the results for the full panel and the two sub-groups of high and low technology sector firms. For each case we have analysed two sets of predicted fixed effects, estimated from panel analyses which were conducted firstly without R&D and IP variables and then with these variables being included, using the preferred specifications from Tables 1 to 3 above. For the whole sample of firms, each of the dummy variables has a positive and significant relationship with the firm fixed effects but, as in the panel analysis, there are some differences by sector. The high technology firms show persistent positive associations with all types of patents but not trade marks, while the low technology group shows positive association with trade marks but not for all kinds of patents when all variables are included together. Even so, each separate pair of dummy and deviation variables is significantly positive when entered without the other explanatory variables, indicating again some difficulties due to multicollinearity between the types of IP, as occurred with the panel analysis.

One way of interpreting the magnitude of these coefficients is to look at the maximum gap which is implied between a firm with all types of IP assets and a firm with none. This is given in the bottom row using the sum of the dummy coefficients; this is the cumulative log. difference, hence these values imply large differences in absolute value added per firm between the best and the weakest over the long run. Overall the cross-section results support the view that doing R&D and introducing new products and processes is essential for keeping firms at the frontier of production technology, and maintaining their product market shares in the medium term. Demand for their products will fall, and they will suffer excess capacity and X-inefficiency due to lower demand for output, if they do not sustain their R&D expenditure and their rates of IP acquisition.

Conclusions

The intangible assets of firms are forged by undertaking R&D and by registering intellectual property rights in their inventions and innovations. In estimating the contribution of these assets to the creation of value added, we have quantified an important source of increased real net output in the knowledge based economy. However we find that there are twin problems for firms in sustaining their returns to intangible assets: first there is no absolute advantage to knowledge-based assets, which would provide evidence of their replicability within firms, but rather R&D and IP intensity matters. Furthermore there is either rapid evaporation of the private firm gains to these assets, or rapid re-investment in the form of extra workers, which leads to a masking of the returns as measured total labour input rises. Even so, both the panel and the cross section analysis using dummy variables suggests that the long term productivity rankings of firms depend on their maintaining positive rates of R&D and acquisition of intangible assets. Benefits may also flow through to their customers, whether firms or final consumers, if they are passed through in the form of price reductions for rising quality products.

There is also evidence of diseconomies of scale to conventional inputs of labour and capital operating against expanding firms. Thus in all the dimensions of IP and R&D, it seems that firms have to run to stand still and they have to run faster to grow their business. Nevertheless, even if the best practice frontier (for production techniques)

and the best product frontier (for consumer products) are densely populated and continually changing, as these findings suggest, there is still every reason to encourage UK firms to be represented in each frontier, rather than leaving them to be populated by processes and products invented and produced abroad. There is no reason to suppose that a marginal improvement in the rate of patenting and trade mark registration by UK firms would be likely to increase the total amount of market distortion due to IP rights in manufactured products. With low rates of innovation by domestic firms, customers will simply be paying the higher prices of superior products protected by foreign firms if these embody the characteristics they seek.

Our findings also have a bearing on the question of what is the optimal sized firm for generating technological progress. The evidence that the productivity of R&D and IP is not magnified by its occurrence in a large firm adds weight to the view that the optimal sized firm for maximising the rate of innovation within the aggregate economy is rather modest. To maximise the average intensity of IP per firm, resources should be employed in smaller-sized firms (but note that all of the sample firms are quite large in respect of both sales and employment relative to the typical SME).

From our findings we can conclude that the UK Chancellor of the Exchequer is right to have widened the R&D tax credit beyond that initially introduced for very small firms in order to benefit all innovating firms (HM Treasury and Inland Revenue, 2001). Even so, taking together the positive returns to patenting presented here with the overall negative time trends in patenting by UK firms, our findings suggest that British business must also be encouraged to generate such IP rights. This raises a question for policy design - should the rate of R&D tax credit contain any multiplier for firms which increase their rates of patent registration, particularly for patenting in Europe? Such a policy could be justified not only as a monitoring device (that R&D inputs were being successfully used), but also on the grounds that this helps to redirect the rents from innovation protected by IP towards British firms and displaces foreign competitors from the product frontier.

Also given the substantial revenue costs to the Exchequer of the new tax credit (Griffith et al. 2001), consideration might be given to rebalancing corporate taxes and

credits to permit the design of a budget-neutral R&D credit. Much advertising is designed to enhance brand image and to sustain returns to brands linked to trade marks. Although we have demonstrated the importance of trade marks as an intangible asset for low technology firms, it seems unlikely that this emphasis on consumer product variety will generate the same level of broad social benefits (via better product quality and more employment) as would more patented inventions in high technology firms (for evidence of variation in R&D intensities and the transmission of R&D between industrial sectors, see Greenhalgh and Gregory, 2000). One possibility for policy, given the negative trends in patents, could be to tax firm-level advertising, by partially reducing the tax offsets for this expenditure, in order to finance more generous R&D tax credits leading to higher rates of patent registration. This could encourage the creation of a more balanced portfolio of intangible assets in the firm as between patents and trade marks, to increase social spillovers from R&D in high technology industries.

Table 1: production function regressions for all "production" (pnlmemb == 1) firms

All reported regressions employ fixed effects and have the dependent variable `r_cake1`, t-statistics have been reported in parentheses.

Ln_employ	0.55 (32.78)	0.63 (28.31)	0.58 (31.90)	0.63 (28.53)	0.59 (32.10)	0.63 (28.41)	0.64 (28.61)	0.63 (28.64)	0.55 (32.68)	0.63 (28.39)	0.64 (28.58)	0.63 (28.60)
r_tfa	0.21 (14.75)	0.19 (10.71)	0.20 (13.30)	0.19 (10.81)	0.20 (13.46)	0.19 (10.77)	0.19 (10.87)	0.19 (10.88)	0.21 (15.13)	0.20 (11.29)	0.21 (11.38)	0.21 (11.39)
UKP65dL		7.67 (6.28)				7.70 (6.30)	2.09 (1.07)			7.88 (6.46)	2.35 (1.20)	
USPprEMP			2.65 (0.54)									
EP35dL				18.56 (7.17)			15.23 (3.68)	18.69 (7.22)			14.99 (3.62)	18.89 (7.31)
UKTprEMP					2.54 (2.51)	3.99 (2.55)	4.10 (2.62)	4.12 (2.63)		4.07 (2.60)	4.18 (2.67)	4.20 (2.69)
rnd_perk									0.043 (4.10)	0.048 (3.97)	0.047 (3.89)	0.046 (3.84)
RNDsome1									0.13 (3.37)	0.14 (2.93)	0.13 (2.82)	0.13 (2.76)
constant	6.09 (45.84)	5.74 (31.34)	5.97 (40.12)	5.70 (31.18)	5.91 (39.32)	5.70 (31.07)	5.65 (30.72)	5.66 (30.89)	6.02 (44.94)	5.57 (30.00)	5.52 (29.69)	5.54 (29.88)
R^2	0.37	0.33	0.37	0.33	0.37	0.33	0.33	0.33	0.37	0.33	0.34	0.34
F	1674.88	694.22	983.77	700.16	986.94	522.96	422.31	527.59	843.99	352.87	305.20	355.79
Chow F	13.48	11.82	12.25	11.76	12.38	11.73	11.64	11.67	12.74	11.11	11.08	11.11
Firms	843	739	740	739	740	739	739	739	843	739	739	739
Obs	6511	4957	5754	4957	5754	4957	4957	4957	6511	4957	4957	4957

Table 2: production function regressions for high-tech (high_t_2 == 1) "production" (pnlmemb == 1) firms
All reported regressions employ fixed effects and have the dependent variable r_cake1, t-statistics have been reported in parentheses.

Ln_employ	0.55 (20.20)	0.62 (18.45)	0.55 (20.19)	0.62 (18.36)	0.55 (20.16)	0.62 (18.36)	0.62 (18.22)	0.62 (18.27)	0.55 (19.91)	0.61 (17.99)	0.61 (17.85)	0.61 (17.88)
r_tfa	0.23 (10.50)	0.17 (6.52)	0.23 (10.68)	0.17 (6.52)	0.23 (10.66)	0.17 (6.51)	0.17 (6.50)	0.17 (6.52)	0.25 (11.14)	0.21 (7.53)	0.21 (7.51)	0.21 (7.52)
UKP65dL		-0.71 (-0.29)				-0.71 (-0.29)	-0.71 (-0.29)			-0.022 (-0.009)	-0.016 (-0.006)	
USPprEMP			0.76 (0.14)									
EP35dL				-0.17 (-0.026)			-0.054 (-0.008)	-0.17 (-0.026)			-0.29 (-0.043)	-0.29 (-0.044)
UKTprEMP					-0.071 (-0.031)	0.21 (0.083)	0.21 (0.083)	0.19 (0.077)		0.37 (0.15)	0.37 (0.15)	0.37 (0.15)
rnd_perk									0.064 (4.38)	0.067 (4.17)	0.067 (4.17)	0.067 (4.19)
RNDsome1									0.20 (4.07)	0.19 (3.42)	0.19 (3.42)	0.19 (3.43)
constant	5.94 (26.96)	6.26 (22.64)	5.96 (25.52)	6.25 (22.27)	5.97 (25.40)	6.26 (22.53)	6.26 (22.05)	6.25 (22.15)	5.74 (25.28)	5.88 (20.26)	5.89 (19.88)	5.89 (20.03)
R^2	0.36	0.33	0.38	0.33	0.38	0.33	0.33	0.33	0.37	0.34	0.34	0.34
F	650.01	280.24	412.06	280.19	412.05	210.06	167.95	210.03	332.36	144.28	123.60	144.28
Chow F	10.70	9.98	9.40	9.85	9.61	9.96	9.81	9.83	9.74	8.99	8.93	8.94
Firms	336	297	297	297	297	297	297	297	336	297	297	297
Obs	2613	2009	2325	2009	2325	2009	2009	2009	2613	2009	2009	2009

Table 3: production function regressions for low-tech (low_t_2 == 1) "production" (pnlmemb == 1) firms

All reported regressions employ fixed effects and have the dependent variable r_cake1, t-statistics have been reported in parentheses.

ln_employ	0.56 (25.90)	0.64 (21.76)	0.61 (24.74)	0.64 (21.82)	0.61 (24.87)	0.65 (21.84)	0.64 (21.62)	0.64 (21.91)	0.56 (25.91)	0.65 (21.89)	0.64 (21.68)	0.64 (21.97)
R_tfa	0.19 (10.46)	0.20 (8.42)	0.17 (8.33)	0.21 (8.51)	0.18 (8.55)	0.21 (8.54)	0.21 (8.62)	0.21 (8.64)	0.19 (10.57)	0.21 (8.61)	0.21 (8.69)	0.21 (8.70)
UKP65dL		10.12 (6.93)				10.17 (6.98)	0.81 (0.21)			10.23 (7.02)	0.76 (0.19)	
USPprEMP			7.95 (0.83)									
EP35dL				21.57 (7.37)			20.22 (2.57)	21.73 (7.44)			20.45 (2.60)	21.87 (7.49)
UKTprEMP					3.06 (2.68)	5.98 (2.98)	6.09 (3.04)	6.09 (3.04)		5.99 (2.99)	6.11 (3.05)	6.11 (3.05)
rnd_perk									0.014 (0.79)	0.022 (1.07)	0.024 (1.17)	0.024 (1.18)
RNDsome1									0.0062 (0.080)	0.036 (0.41)	0.045 (0.51)	0.0460 (0.51)
constant	6.17 (37.10)	5.38 (22.21)	6.02 (31.00)	5.40 (22.49)	5.93 (30.09)	5.33 (21.98)	5.34 (22.06)	5.35 (22.24)	6.15 (36.92)	5.30 (21.84)	5.32 (21.92)	5.32 (22.10)
R^2	0.38	0.33	0.37	0.34	0.37	0.34	0.34	0.34	0.38	0.34	0.34	0.34
F	1028.02	419.61	574.80	422.71	578.21	317.92	256.23	320.40	515.31	212.67	183.67	214.36
Chow F	13.29	11.48	12.51	11.47	12.50	11.32	11.31	11.31	12.97	11.08	11.07	11.08
Firms	507	442	443	442	443	442	442	442	507	442	442	442
Obs	3898	2948	3429	2948	3429	2948	2948	2948	3898	2948	2948	2948

Table 4: Actual and predicted value added levels (in £m, at 1999-2000 prices) of firms with specified characteristics

	All firms (739 firms)	All firms (739 firms)	All R&D reporting firms (355 firms)	All R&D reporting firms in high-tech (218 firms)	Firms in low-tech sectors (442 firms)	Firms in low-tech sectors (442 firms)
<u>Actual</u>						
All firms and years	204.17	204.17	463.08	486.36	142.54	142.54
All firms which had no UK, EPO (designating the UK) or US patents during 1986-94, and no UK trade marks during 1988-94	21.49	21.49	45.36	33.57	18.29	18.29
All firms which had at least one UK, EPO (des. UK) or US patent during 1986-94, or at least one UK trade mark during 1988-94	237.60	237.60	486.51	507.97	172.72	172.72
<u>Predicted</u>						
Sum of UK patents decreased by 1 standard deviation (SD) and UK trade marks decreased by 1 SD	202.62	-	-	-	141.37	-
Sum of UK patents increased by 1 SD, and UK trade marks increased by 1 SD	216.77	-	-	-	155.71	-
Sum of EPO (des. UK) patents decreased by 1 standard deviation (SD) and UK trade marks decreased by 1 SD	-	201.56	-	-	-	140.93
Sum of EPO (des. UK) patents increased by 1 standard deviation (SD) and UK trade marks increased by 1 SD	-	220.98	-	-	-	156.56
R&D intensity decreased by 1 SD	-	-	430.98	437.21	-	-
R&D intensity increased by 1 SD	-	-	497.56	541.04	-	-

Table 5: Cross-section analysis of firm fixed effects

Panel:	All firms	All firms	High tech	High tech	Low tech	Low tech
Specification :	Table 1	Table 1	Table 2	Table 2	Table 3	Table 3
	Col. 1	Col. 12	Col. 1	Col. 9	Col. 1	Col. 8
D(UKP)	0.12	0.11	0.09	0.08	0.13	0.11
D(USP)	0.17	0.14	0.13	0.12	0.15	0.11
D(EPP)	0.14	0.10	0.22	0.20	(0.01)	(0.01)
D(UKT)	0.07	0.07	(0.03)	(0.03)	0.12	0.09
D(UKTH)	0.10	0.08	(-0.03)	(-0.03)	0.17	0.14
Dev(UKP)	0.005	0.005	0.004	0.003	0.017	0.015
Dev(USP)	0.003	0.003	0.001	0.001	0.021	0.015
Dev(EPP)	-0.003	-0.005	0.002	0.001	-0.014	-0.010
Dev(UKT)	0.008	0.006	0.005	0.005	0.015	0.009
Dev(UKTH)	0.0002	0.0002	0.0004	0.0004	(-0.0000)	(0.0001)
Constant	-0.34	-0.28	-0.27	-0.25	-0.33	-0.26
Panel has IP variables	No	Yes	No	No	No	Yes
Panel has RD variables	No	Yes	No	Yes	No	No
No. of firms	740	739	297	297	443	443
Sum of the D coefficients	0.60	0.51	0.44	0.40	0.58	0.54

Notes to Table 5:

1. The dependent variable is the firm fixed effect saved from the indicated panel analysis in which the dependent variable was the log. of real value added.
2. Parentheses denote coefficients which are not statistically significant at 90% confidence levels; all other coefficients are significant.
3. D (X) equals 1 if some, and 0 if none, of the IP assets of type X were recorded for the firm. Dev(X) is the firm's mean minus the whole sample mean for type X assets over the sample period. UKTH relates to the firm's cumulative trade mark history up to the start of the panel observation period.
4. The sum of the D coefficients gives the maximum predicted gap in fixed effect between a firm with all types of IP asset and a firm with no IP assets.

Table A1: Variable names and their definitions as used in Tables 1 – 3

r_cake1	log. of real value added, where real value added is sum of profit before tax and staff costs, deflated using GDP price deflator with year 1999-2000 = 100
ln_employ	log. of number of employees
r_tfa	log. of real tangible fixed assets, deflated as for r_cake1
UKPprEMP	publications of UK patents per employee
UKP65dL	weighted stock of UKPprEMP values for years t-2, t-1 and t with depreciation at 65% per year
USPprEMP	publications (on grant) of US patents per employee
EPOprEMP	publications of EPO patents (designating the UK among the list of countries) per employee
EP35dL	weighted stock of EPOprEMP values for years t-2, t-1 and t with depreciation at 35% per year
UKTprEMP	UK trade mark applications per employee
rnd_perk	log. of R&D expenditure divided by tangible fixed assets
RNDsome1	dummy variable set to 1 for those firms reporting R&D in that year
R^2	within groups R^2 ; proportion of variation explained by regressors after firm fixed effects have been excluded
F	F test of all the regressors (other than firm fixed effects) being jointly zero
Chow F	Test of significance of firm fixed effects

Table A2: Number of Firms by Technology Group and Sector

SIC Description	UK80 SIC Code	Full Panel	IP Panel
High Technology Panel			
Aerospace & shipping etc	36	19	15
Business services	83	26	24
Chemicals	25	62	57
Electrical & Electronic	34	78	72
Extraction-Oil & gas	13	27	21
Fibres manufacture	26	1	1
Instrument Engineering	37	19	15
Mechanical Engineering	32	64	56
Mineral oil processing	14	3	3
Motor vehicle manufctr	35	21	19
Office machinery	33	11	10
Research & development	94	2	2
Telcomms & Post	79	3	2
	Sub-total	336	297
Low Technology Panel			
Brewing Wines & spirits	42	31	27
Building & Construction	50	65	59
Electricity & Gas prodn	16	2	1
Extraction-Coal	11	3	3
Extraction-metal ores	21	6	5
Extraction-other	23	9	8
Food manufacturing	41	49	43
Footwear & clothing	45	18	17
Forestry	1	9	8
Furniture	46	24	16
Hotels & Catering	66	9	7
Jewellery Toys etc	49	2	1
Leather goods	44	1	1
Medical services	95	9	5
Metal manufacture	22	23	21
Non metals manufacture	24	25	22
Other metals manufacture	31	37	31
Other retailers	65	2	1
Printing Publishing & Paper	47	33	33
Property	85	7	7
Rental & Hire	84	8	5
Rubber & Plastic	48	35	33
Textiles	43	33	31
Transport other	77	1	1
Wholesale distribution	61	66	56
	Sub-total	507	443
	Total	843	740

Notes to Table A2:

The full panel consists of all firms satisfying two conditions. First, they had to be detailed by “Company Analysis” (Extel Financial, 1996) as satisfying Industry = Mineral Extraction or General Manufacturing or Consumer Goods or Utilities. Second, their accounts given on “Company Analysis” needed to permit the creation of calendar estimations/observations for the period 1987-1994. We did not insist that all variables of interest had to be available throughout this period, and so the resulting panel was unbalanced in respect of some variables. This sample was used for regressions not involving IP, but including R&D.

The high and low technology panels consisted of those firms detailed by the variable ‘SIC industry sector’ {SIC_Indy} of “Company Analysis” (Extel Financial, 1996) as being predominantly active in certain UK80 two digit SICs. The designation of high technology industries was made with reference to OECD conventions: all other sectors were designated as low technology.

The IP panel consists of firms for which it was possible to trace the ownership of subsidiaries and associates using Who Owns Whom (Dun & Bradstreet International, 1994). For these firms the full ownership of the IP assets, including those of subsidiaries and associates could be measured. This sample was used for regressions involving IP variables.

Table A3: Descriptive statistics for all firms and for high and low tech. samples

	All	High	Low
No. of firms	740	297	443
No. of observations	5754	2325	3429
Real value added per firm at 1999-2000 prices	£203.5m	£296.6m	£140.4m
Employment per firm	6,671	8,271	5,585
Real R&D per firm, 1999-2000 prices, if any (sample)	£34.1m (1802)	£45.3m (1129)	£15.4m (673)
Proportion reporting R&D at least once 1986-94	0.3132	0.4856	0.1963
Proportion reporting UK patents 1986-94	0.6246	0.7557	0.5357
Proportion reporting US patents 1986-94	0.3994	0.5449	0.3007
Proportion reporting EPO patents 1986-94	0.4607	0.6095	0.3599
Proportion reporting UK trade marks 1986-94	0.7680	0.8043	0.7434
Proportion reporting UK trade marks pre-1986	0.7569	0.8025	0.7257
UK patents p.a. per firm if any (sample)	4.69 (3594)	6.75 (1757)	2.71 (1837)
US patents p.a. per firm if any (sample)	7.33 (2298)	11.18 (1267)	2.60 (1031)
EP patents p.a. per firm if any (sample)	3.75 (2651)	4.98 (1417)	2.34 (1234)
UK trade marks p.a. per firm if any (sample)	5.60 (4419)	6.39 (1870)	5.02 (2549)
UK trade mark	96.05	110.44	85.28

stock at 1985 per (4355) (1866) (2489)
 firm if any
 (sample)

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