IT AIN'T WHAT YOU DO IT'S THE WAY THAT YOU DO I.T. INVESTIGATING THE PRODUCTIVITY MIRACLE USING MULTINATIONALS

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Abstract

Productivity growth in sectors that intensively use information technologies (IT) appears to have accelerated much faster in the US than in Europe since 1995, leading to the US "productivity miracle". If this was partly due to the superior management or organization of US firms (rather than simply the advantages of being located in the US geographically) we would expect to see a stronger association of productivity with IT for US multinationals (compared to non-US multinationals) located in Europe. We examine a large panel of UK establishments and provide evidence that US owned establishments do indeed have a stronger relationship between productivity and IT capital than either non-US multinationals or domestic establishments. Indeed, the differential effect of IT appears to account for almost *all* the difference in total factor productivity between US-owned and all other establishments. This finding holds in the cross section, when including fixed effects and even when we examine a sample of establishments taken over by US multinationals. We find that the US multinational effect on IT is particularly strong in the sectors that intensively use information technologies (such as retail and wholesale): the very same industries that accounted for the US-European productivity growth differential since the mid 1990s.

Key words: *Productivity, IT, multinationals, organization.*

JEL classification: *E22, O3, O47, O52*

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I. INTRODUCTION

> "The 1995-2001 acceleration [in US productivity] may be plausibly accounted for by a pickup in capital services per hour worked and by increases in *organizational capital*, the investments businesses make to reorganize and restructure themselves, in this instance in response to newly installed information technology"
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> *Economic Report of the President, February 2006, p.26*

One of the most startling economic facts of the last decade has been the reversal in the long-standing catch-up of European countries' productivity with the US. After slowing down after 174, American Labour productivity growth accelerated after 1995 whereas Europe's did not (see Figure 1). Decompositions of US productivity growth show that the great majority has occurred in those sectors that either intensively use or produce IT (information technologies)[1]. Figure 2 shows that US IT intensity appears to be consistently higher in the US than Europe and this gap has widened over time. Closer analysis has shown that European countries had a similar productivity acceleration as the US in IT *producing* sectors but failed to achieve the spectacular levels of productivity growth in the sectors that *used* IT intensively (predominantly market service sectors include retail, wholesale and financial intermediation). We show this in Figure 3. Given the common availability of IT throughout the world at broadly similar prices, it is a major puzzle to explain why these IT related productivity effects have not been more widespread.

Assuming that the difference in Europe's relative productivity performance is not simply mis-measurement[2], then at least two explanations are possible. First, there are some "natural advantages" to the environment in which US plants operate that enables them to take better advantage of the opportunity of rapidly falling IT prices. These natural advantages could be tougher product market competition, lower regulation in the product and labour markets, better access to

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[1] See, for example, Stiroh (2002). Jorgenson (2001), Oliner and Sichel (2001). In the 2002-2004 period Oliner and Sichel (2004) find that the US productivity growth remained strong, but there was a more widespread increase in productivity growth across sectors. See Gordon (2004) for a general discussion.

[2] One explanation is simply differences in the way we measure productivity across countries (Blanchard, 2004). This is possible, but the careful work of O'Mahony and Van Ark (2003) and others who focus on the same sectors in the US and EU, use US-style adjustments for hedonic prices, software capitalization and aggregate demand conditions, still find a difference.

risk capital, more educated workers, larger market size, more geographical space or a host of other factors. A second class of explanations stresses that it is not the US environment *per se* that matters but rather the internal organization (the depth of "organizational capital") of US firms that has enabled better exploitation of IT. For example, US firms may be simply better managed or they have adopted features that are better at exploiting IT (e.g. more decentralization or flatter hierarchies)[3].

Although these explanations are not mutually exclusive, one way to test whether "US firm organization" hypotheses has any validity is to *examine the IT performance of American owned organizations in a non-US environment*. Assuming that US multinationals at least partially export their business models outside the US – and a walk into McDonalds or Starbucks anywhere in Europe suggests that this is not an entirely unreasonable assumption – then analyzing the IT performance of US multinational establishments in Europe should be informative. If we still observe a systematically better use of IT in a non-US environment then this is consistent with the "US firm organization" model. We return to the origins of differences in European vs. US organizational forms in the conclusion.

In this paper we examine the productivity of IT in a panel of establishments located in the UK, examining the differences in IT intensity and productivity between plants owned by US multinationals, plants owned by non-US multinationals and domestic plants. The UK poses a useful testing ground because (a) it has not experienced a US-style productivity acceleration since 1995 (as Basu et al (2003) show); (b) it is a large recipient of foreign direct investment so we are able to compare across many types of ownership; and (c) it has high levels of mergers and acquisition activity producing frequent establishment ownership change. A key comparison group for US multinationals are "statistically similar" non-US multinationals (i.e. establishments in the same industry, of a similar age, size and factor intensity). We report evidence that the key difference in understanding productivity differences is the ability of US multinationals to gain a higher productivity impact from IT than non-US multinationals (and domestic plants). This effect is strongest in precisely those industries that experienced the largest relative productivity gains in the

[3] Bresnahan, Brynjolfsson and Hitt (2002) and Caroli and Van Reenen (2001) both find that internal organization and other complementary factors such as skills are important in generating significant returns to ICT.

US after 1995 (the sectors that intensively used IT). This finding is robust to a number of tests including examining British plants before and after they have been taken over by a US multinational compared to US takeovers (compared to being taken by a non-US multinational or other kind of firm). In short, we conclude that the higher productivity of IT in the US is not just the US environment, but also has something to do with the internal organization of US firms.

Some preliminary evidence on the importance of different internal organization of US firms can be seen in Figures 4 and 5. This uses data on the internal organizational of over 700 firms in the US and Europe. Figure 4a shows that, on average, firms operating in the US are more decentralized than those operating in Europe[4]. In Figure 4b, we break down the latter into purely Domestic European firms, subsidiaries of European multinationals and subsidiaries of US multinationals. Interestingly, the degree of decentralization of US multinational subsidiaries in Europe is similar to US firms as a whole and is significantly higher than the degree of decentralization of European multinationals (and domestic European firms). In Figure 5 we use a composite measure of management best practices (see Bloom and Van Reenen, 2006, for details). A similar picture emerges – management quality is higher in the US and higher for US multinational subsidiaries in Europe than European subsidiaries.

Although our focus is in accounting for the difference in macro productivity trends using micro data, our paper related to three other literatures. First, there is a large literature on the impact of IT on productivity, but most of this is based on data aggregated to the industry or macro-economic level. Even the pioneering work of Brynjolfsson[5] and his co-authors focuses at the firm level which may conceal much heterogeneity between plants *within* firms. In this paper we provide, for the first time, estimates for the level and the productivity impact of IT capital stocks for a panel of around 11,000 establishments, probably the largest micro-based sample in the world for this kind of exercise. Our database, unlike the US LRD, also covers the non-manufacturing sector, which is important as the majority of sectors that use IT intensively are in services.

[4] Decentralization was measured in the same way as Bresnahan et al (2002) using questions related to task allocation and pace setting in order to indicate the degree of employee autonomy. See notes to the Figures for details.

[5] Brynjolfsson and Hitt (1995, 2003), Brynjolfsson, Hitt and Yang (2002). Brynjolfsson and Yang (1996) or Stiroh (2004) survey the evidence.

Second, in a reversal of the Solow Paradox, the firm level productivity literature has found returns to IT that are *larger* than one would expect under the standard growth accounting assumptions. Brynjolfsson and Hitt (2003) argue that this is due to complementary investments in "organizational capital" that are reflected in the coefficients on IT capital. Almost all of these studies are on US firms, however, and the data used is generally prior to the post 1995 acceleration in productivity growth. Examining UK firms that may have made fewer complementary investments we might expect to see lower returns (Basu et al, 2003).

Thirdly, there is a literature on the productivity of multinationals compared to similar non-multinational establishments. The first wave of research that compared domestic plants with multinationals was clearly misleading as multinationals are a self-selected group that have some additional efficiency as signaled by their ability to operate overseas. But comparing across different multinationals it appears that US plants are more productive whether based geographically in the US (Doms and Jensen, 1998) or in other parts of the world such as the UK (e.g. Criscuolo and Martin, 2005). Our paper suggests that the major reason for this American multinational productivity advantage is the way in which US multinationals are able to use new technologies more effectively than other multinationals.

In summary, we do find significant impacts of IT on productivity. We also find that we can account for almost all of the higher productivity of US multinationals by the higher productivity impact of their use of IT. Furthermore, this US advantage is strongest in the sectors that intensively use IT: precisely those sectors that account for the faster productivity growth in the US than Europe since 1995. This suggests that at least some of the differential performance of productivity between the US and the EU since the mid 1990s is due to the internal organization of US firms. Drawing on some of our other work we show that there is evidence for significant differences in the "organizational capital" of US firms relative to British and other European firms, even when these US firms operate in Europe.

The structure of this paper is as follows. Section II discusses the empirical framework, section III the data and section IV gives the main results. In section V we sketch a simple model that can account for the stylized facts we see in the data. Finally, section VI offers some conclusions.

II. EMPRICIAL MODELLING STRATEGY

II.A. Basic Approach

We assume that the basic production function can be written as follows

$$\tilde{q}_{it} = \tilde{a}_{it} + \alpha_{it}^{M}\tilde{m}_{it} + \alpha_{it}^{L}\tilde{l}_{it} + \alpha_{it}^{K}\tilde{k}_{it} + \alpha_{it}^{C}\tilde{c}_{it} \tag{1}$$

where $\tilde{x}_{it} \equiv \ln X_{it} - \ln X_{t}$ is the logarithmic deviations from the year-specific industry mean (which control for input and output prices).[6] Q is gross output, A is an establishment specific productivity factor, M is materials, L is labor, K is non-IT fixed capital and C is computer/IT capital.

We are particularly interested in the role of IT capital and whether the impact of computers on productivity is systematically higher for the plants belonging to US firms in the sectors that intensively use IT and that appear to have been responsible for the bulk of the US productivity acceleration since the mid 1990s. Consider parameterizing the output elasticities in equation (1) as:

$$\alpha_{it}^{J} = \alpha_{h}^{J,0} + \alpha_{h}^{J,USA} D_{it}^{USA} + \alpha_{h}^{J,MNE} D_{it}^{MNE} \tag{2}$$

where D_{it}^{USA} denotes that the establishment is owned by a US firm in year *t* and D_{it}^{MNE} denotes that the establishment is owned by a non-US multinational enterprise (the base case is that firm is a non-multinational purely domestic firm), the sub-script *h* denotes sector (e.g. industries that use IT intensively vs. non-IT intensive sectors) and the super-script *J* indicates a particular factor of production (*M, L, K, C*). We further assume that total plant specific efficiency can be written as:

$$\tilde{a}_{it} = a_{i} + \delta_{h}^{0} + \delta_{h}^{USA} D_{it}^{USA} + \delta_{h}^{MNE} D_{it}^{MNE} + \gamma_{h}'\tilde{z}_{it} + u_{h,it} \tag{3}$$

[6] See Klette (1999) for a detailed discussion of this approach.

where z are other observable factors influencing productivity such as establishment age, region, whether the establishment is part of a multi-plant group, etc. So the general form of the production function that we will estimate is (combining equations (1) through (3)):

$$\begin{aligned}\tilde{q}_{it} = &\sum_{M,L,K,C\in J}\alpha_h^{J,0}\tilde{x}_{it}^J + \sum_{M,L,K,C\in J}\alpha_h^{J,USA}D_{it}^{USA}\tilde{x}_{it}^J + \sum_{M,L,K,C\in J}\alpha_h^{J,MNE}D_{it}^{MNE}\tilde{x}_{it}^J \\ &+ a_i + \delta_h^{USA}D_{it}^{USA} + \delta_h^{MNE}D_{it}^{MNE} + \delta_h^0 D_{it}^0 + \gamma_h{}'\tilde{z}_{it} + u_{h,it}\end{aligned} \tag{4}$$

where $x^M = m$, etc.

Although we will estimate equation (4) in some specifications, most of the interactions between factor inputs and ownership status are insignificantly different from zero. One interaction that will stand out is that between the US ownership dummy and IT capital: the coefficient on computer capital is significantly higher for US firms than for other multinationals and/or domestic firms. Consequently our preferred specifications are usually of the form:

$$\begin{aligned}\tilde{q}_{it} = &\alpha_h^M\tilde{m}_{it} + \alpha_h^L\tilde{l}_{it} + \alpha_h^K\tilde{k}_{it} + \alpha_h^{C,0}\tilde{c}_{it} + \alpha_h^{C,USA}D_{it}^{USA}\tilde{c}_{it} + \alpha_h^{C,MNE}D_{it}^{MNE}\tilde{c}_{it} \\ &+ a_i + \delta_h^{USA}D_{it}^{USA} + \delta_h^{MNE}D_{it}^{MNE} + \delta_h^0 D_{it}^0 + \gamma_h{}'\tilde{z}_{it} + u_{h,it}\end{aligned} \tag{5}$$

where the key hypotheses are whether $\alpha_h^{C,USA}D_{it}^{USA} = 0$ and/or $\alpha_h^{C,USA}D_{it}^{USA} = \alpha_h^{C,MNE}D_{it}^{MNE}$.

II.B. Takeover Sub-sample

A concern with our strategy is that US firms may cherry pick the best UK establishments. In other words, it is not US multinational's internal organization that helps improve the productivity of IT but the ability to recognize UK plants that are better at utilizing IT capital. To tackle this issue we focus on a sub-sample of UK establishments that have been taken over by another firm at some point in the sample period. We then estimate equation (5) before and after the takeover to investigate whether the IT coefficient changes if a US multinational takes over a UK plant relative to a non-US multinational. We also investigate the dynamics of change: since organizational changes are costly we should expect to see change happening slowly over time (so we examine how the IT coefficients change one year after the takeover compared to two year, and so on).

The identification assumption here is not that establishments who are taken are the same as establishments who are not taken over (the taken over tend to be less productive). Rather, we are assuming that US multinationals are not systematically better than non-US multinationals at successfully predicting (pre-takeover) the higher productivity of IT two or three years hence for statistically identical British establishments. We regard this as a plausible assumption, but if US managers *did* possess such foresight (and we will show that it is only for IT that the US takeovers appear to be different than non-Us multinationals), it is not identified from the more general organizational superiority of American firms.

II.C. Unobserved Heterogeneity

In all specifications we allow for a general structure of the error term that allows for arbitrary heteroscedacity and autocorrelation over time. But there could still be establishment specific unobserved heterogeneity. So we also generally include a full set of establishment level fixed effects (the "within groups" estimator). The fixed effects estimators are more rigorous as there may be many unobservable omitted variables correlated with IT that generate an upwards bias to the coefficient on computer capital. On the other hand, attenuation bias (caused by measurement error in IT and other right hand side variables) will be exacerbated by including fixed effects generating a bias towards zero[7].

II.D. Endogeneity of the Factor Inputs

We also want to allow for endogeneity of the factor inputs and take several approaches to dealing with this issue. Our preferred measure is to use the "System GMM" estimator of Blundell and Bond (1998) but we also compare this to a version of the Olley Pakes (1996) estimator. These methods are detailed in Appendix A.

III. DATA

[7] See Griliches and Mairesse (1998) for a general discussion of this problem with production functions and Brynjolfsson and Hitt, 1995, 1996, 2003) for a discussion specifically on IT.

Our dataset is a panel of establishments covering almost all sectors of the UK private sector called the ABI, which is similar in structure to the US Longitudinal Research Database (LRD). The UK poses a useful testing ground because: (a) it has not experienced a US-style productivity acceleration since 1995 (as Basu et al (2003) show) and (b) it is a large recipient of foreign direct investment so we are able to compare across many types of ownership. In addition, unlike the LRD the ABI contains detailed IT data and also covers the non-manufacturing sector from the mid 1990s onwards, which is important because the majority of the sectors that intensively use IT are outside manufacturing. A full description of the datasets used is in Appendix A.

We build up IT capital stocks from the IT expenditures using the perpetual inventory method following Jorgenson (2001) keeping to US assumptions over depreciation rates and hedonic prices. We report several ways of dealing with the problem of initial conditions[8]. Our dataset runs from 1995 through 2003, but there are many more observations in each year post 1999. After cleaning we are left with 22,736 non-zero observations. There are many small and medium sized establishments in our sample - the median establishment employs 238 workers and the mean establishment employs 796. Nevertheless, the sampling frame of the IT surveys means that our sample on average contains more larger establishments than the UK economy as a whole. At rental prices average IT capital is about 1% of gross output at the unweighted mean (1.5% if weighted by size) or 2.3% of value added. These are similar to the economy wide means in Basu et al (2003).

We have large numbers of multinational establishments in the sample. About 8% of establishments are US owned, 29% are non-US owned and 63% are purely domestic. Multinationals share of employment is even higher and their share of output higher still (see Table A3). US and non-US establishments have about 48% and 46% more employees and about 64% and 51% more value-added than the industry average respectively.[9] This US productivity advantage is partially linked to greater use of inputs: US plants use about 10% more materials/intermediate inputs, 10% more non

[8] Essentially we exploit the fact that we have a long time series of industry level estimates of IT flows and stocks from other studies that use the input-output matrices (e.g. O'Mahony and Van Ark, 2003 ; Basu et al, 2003). We impute an estimate of an establishment's initial IT stock based on its observed flow of IT expenditure and the industry information. Because we have a short time series for many firms we are careful to check the robustness of the results under different assumptions over the treatment of the initial year of the IT stock.

[9] This is consistent with evidence that the plants of multinational US firms are more productive both on US soil (Doms and Jensen, 1998) and on foreign soil (Criscuolo and Martin (2005), Griffith, Simpson and Redding (2002)).

IT capital and 27% more IT capital than non-US multinationals. Hence, US multinationals are notably more IT intensive than other multinational subsidiaries.

We started by running a wide range of investigative OLS, GMM system and Olley-Pakes production function estimations, displayed in full in Appendix A4. In summary, the different estimators produced estimates of the elasticity of output with respect to IT in the range of 0.02 to 0.04. It is reassuring that productivity does indeed have a positive and significant association with IT capital, consistent with the findings from several micro studies in the US and elsewhere. Although the coefficient is larger than the share of IT capital in output (which is about 1% for our firms) the difference is not as dramatic as has been found in other studies such as Brynjolfsson and Hitt (2003)[10]. We will discuss possible reasons for this below, but an obvious reason is that IT impacts may be heterogeneous between US firms and non-US firms.

We also considered several experiments changing our assumptions concerning the construction of the IT capital stock. First, there is uncertainty over the exact depreciation rate for IT capital, so we experimented with a number of alternatives including the extreme case of 100% depreciation and just working with the flows. Second, we do not know the initial IT capital stock for ongoing firms the first time they enter the sample. Our base method is to impute the initial year's IT stock using as a weight the firm's observed IT investment relative to the industry IT investment. An alternative is to assume that the plant's share of the industry IT stock is the same as its share of employment in the industry. In both cases this affected the magnitude of the coefficient on IT, but it always remained positive and significant. In the results section below we analyze a third method where we use an entirely different measure of IT use based on the number of workers in the establishment using computers (from a different survey). This also gives similar results.

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[10] There are a number of possible reasons for the differences. Most obviously, Brynjolfsson's data is from the US whereas ours is from the UK- we show that there appears to be larger IT coefficients for US firms than for UK firms. Other differences include (a) we are using more disaggregated data (establishments rather than worldwide accounts of firms); (b) our measure of IT capital is constructed in the standard way from flows of expenditure whereas Brynjolfsson and Hitt use a measure based on pricing different pieces of IT equipment; (c) our sample is much larger and covers a more recent time period and (d) our estimation techniques are different. We investigate some of these below.

IV. RESULTS

IV.A. US Multinationals, IT and productivity

Table 1 contains the key results for the paper which is the productivity advantage of US multinationals is linked to the use of IT. Column (1) estimates the basic production function including a dummy variables for whether or not the plant was owned by a US multinational ("USA") or a non-US multinational ("MNE") with plants who are domestic being the omitted base. US establishments are 8.5% more productive than UK domestic establishments and non-US multinationals are 4.8% more productive. The difference between the US and non US MNE coefficients is also significant at the 1% level (p-value =0.001).

The second column of Table 1 includes the IT hardware measure which enters significantly and reduces the coefficients on the ownership dummies. US plants are more IT intensive than other plants and this explains some of the productivity gap. But it only accounts for about 12% of the initial gap, i.e. about one percentage point of initial 8.5% productivity gap. Column (3) includes two interaction terms: one between IT capital and the US dummy and the other between IT capital and the non-US multinational dummy. These turn out to be very revealing. The interaction between the US dummy and IT capital is positive and significant at conventional levels. According to column (3) doubling the hardware stock is associated with an increase in productivity of 5.2% for a US MNE but only 4.1% for a domestic firm. Non-US multinationals are insignificantly different from domestic UK firms in this respect: we cannot reject that the coefficients on IT are equal for domestic UK firms and non-US multinationals. It is the US firms that are distinctly different. In fact, the linear US dummy is now insignificantly different from zero. Interpreted literally, this means that we can "account" for all of the US MNE advantage by their superior use of IT. Hypothetically, US plants that have less than about £1,000 of IT capital (i.e. $\ln(C) = 0$) are no more productive than their UK counterparts (no US plants in the sample have IT spending this low, of course).

To investigate the industries that appear to account for the majority of the productivity acceleration in the US we split the sample into "highly IT using intensive sectors" in column (4) and "low IT using intensive sectors" in column (5). Sectors that use IT intensively includes retail, wholesale and printing/publishing.[11] The US interaction with IT capital is much stronger in the IT intensive sectors, being insignificantly different from zero in the less IT intensive sectors (even though there are twice as many firms in these industries). The final three columns include a full set of establishment fixed effects. The earlier pattern of results is repeated with a higher value of the interaction than in the non-fixed effects results. In particular, column (7) demonstrates that US plants appear to have significantly higher productivity of their IT capital stocks than domestic firms or other multinationals[12]. A doubling of the IT capital stock is associated with 2% higher productivity for a domestic plant, 2.5% for a non-US multinational but 5% higher productivity for a plant owned by a US multinational.

The reported US*IT interaction tests for significant differences in the IT productivity impact between US multinationals and UK domestic firms. However, note that in our key specifications the IT coefficient for US multinationals is significantly different from the IT coefficient for other multinationals. The last row of Table 1 reports the p-value of a tests on the equality between the US*IT and the MNE*IT coefficient.

IV.B. Robustness Tests

Table 2 presents a series of tests showing the robustness of the main results - we focus on the fixed effects specification in the IT intensive sectors which are the most demanding specifications. The first column represents our baseline results from column (7) in Table 1. Column (2) simply re-iterates what we have already observed in Table 1 by estimating the production function with a full set of interactions between the US dummy and *all* the factor inputs. None of the additional non-IT factor input interactions are individually significant and the joint test at the base of the column of the additional interactions shows that they are insignificant (for example the joint test of the all the US interactions except the IT interaction has a p-value of 0.73). We cannot reject the specification in column (1) as a good representation of the data against the more general interactive models of

[11] See Appendix Table A1 for a full list, which are the same as those in Figure 2. We follow the same definitions of the sectors that intensively use IT as Van Ark et al (2002) who follow Stiroh (2002). Table A5 presents the results of the fixed effects regressions on the separately for wholesale, retail and the rest of the IT intensive sectors.

[12] The p-value on the test of the coefficients US*IT = MNE*IT is 0.02 for the specification in column (7).

Table 1.[13] If, for example, the productivity advantage of the US was due to differential mark-ups then we would expect to see significantly different coefficients on *all* the factor inputs, not just on the IT variable (Klette and Griliches, 1996).

A concern is that we may be underestimating the true IT stock of US multinationals in the initial year generating our interaction term due to greater measurement error of IT capital for the US establishments. We approach this issue in two ways. First, we use an alternative measure of IT capital (built from our data using employment weights to build the initial condition for the IT capital stocks), and we still find a positive and significant interaction (column 3). Second, we turn to an alternative IT survey (the E-commerce Survey, described in the Appendix) that has data on the proportion of workers in the establishment who are using computers. This is a pure "stock" measure so is unaffected by the initial conditions concern[14]. In Column (4) we replace our IT capital stock measure with this proxy. Reassuringly we still find a positive and significant US ownership interaction. The fifth column of Table 2 implements an alternative way of examining whether the IT productivity impact is higher for US multinationals by aggregating IT and non-IT capital into total capital and including an additional variables for the proportion of IT capital in the total capital stock and its interactions with the ownership dummies. All terms are positive and the US interaction with IT is significantly different from zero at the 1% level. Another concern is that the US*IT interaction reflects some other non-linearity in the production function. We tried including a much fuller set of interactions and higher order terms (a "translog" specification), but these were insignificant. Column (6) shows the results of including all the pairwise interactions of materials, labour, IT capital and non-IT capital and the square of each of these factors. The additional terms are jointly insignificant (p-value = 0.29) and the US interaction with the linear IT term remains basically unchanged. Column (7) presents a value added based specification instead of an output based specification. The results are similar to using gross output (although the coefficients are larger of course).

[13] We also investigated whether the coefficients in the production function regressions differ by ownership type and sector (IT intensive or not). Running the 6 separate regressions (3 ownership types by two broad sectors) we found the F-test rejected at the 1% pooling of the US multinationals with the other firms in the IT intensive sectors. In the non-IT intensive sectors, by contrast, the pooling restrictions were not rejected. Details on request from the authors.

[14] Our IT stock measure is more appropriate theoretically as it is built in an entirely analogous way to the non-IT stock and comparable to best practice existing work. The E-Commerce Survey is available for three years (2001 to 2003), but the vast majority of the sample is observed only for one period, so we do not control for fixed effects.

Another possible explanation for the higher productivity of IT in US firms is that US multinationals may be disproportionately represented in specific industries in which the IT coefficient is particularly high. The interaction of IT capital with the US dummy would then capture omitted industry characteristics rather than a "true" effect linked to US ownership. To test for this potential bias we included in our regression as an additional control the percentage of US multinationals in the specific four-digit industry ("USA_IND")[15]. We also construct a similar industry level variable for the non-US multinationals ("MNE_IND"). The IT elasticity is higher in sectors with a larger US MNE presence (see column (8)) and this is significant at the 10% level, but the coefficient on the IT*US interaction remains largely unchanged. Next, we considered the role of skills. Our main control for labour quality in Table 1 is the inclusion of establishment specific fixed effects which, so long as the labour quality does not change too much over time, should control for the omitted human capital variable. As an alternative, we assume that wages reflect marginal products of workers so that conditioning on the average wage in the firm is sufficient to control for human capital[16]. The average wage is highly significant, but the interaction between the average wage and IT capital was positive but insignificant. The interaction between the US dummy and average wages in the plant were also insignificant (p-value =0.512)[17].

We also implemented a large number of other robustness tests including alternative econometric estimation techniques, different versions of dealing with measurement error in the capital stocks and more flexible specifications of the production function. One issue is that US firms may be more productive in the UK because the US is geographically further away than the other multinationals (mainly European countries) and only the most productive firms are able to overcome the fixed costs of distance. To test this we divided the non-US multinational dummy into European vs. non-European firms. Under the distance argument, the non-European firms would have to be more

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[15] The variable is constructed as an average between 1995 and 2003 and is built using the whole ARD population.

[16] The problem is that wages may control for "too much" as some proportion of wages is almost certainly related to other factors apart from human capital. For example, in many models, firms with high productivity will reward even homogenous workers with higher wages (see Van Reenen (1996) on rent sharing).

[17] As an alternative we matched in education information at the industry-region level from an individual level survey, the Labor Force Survey. In the specifications without fixed effects, there was some evidence for a positive and significant interaction between skills and IT consistent with complementarity between technology and human capital. The US*IT capital interaction remained significant. Including fixed effects, however, renders the skills variables and

productive to be able to set up plant in the UK. In the event, the European and non-European multinationals were statistically indistinguishable from each other – it was again the US multinationals that appeared different[18]. We were also concerned that the US firm advantage may simply be due to their larger size. We did not find that the US firms were larger at the median compared to non-US multinationals, however. Furthermore, interactions of total firm (or toal establishment) size with IT were insignificant.

IV.C. US Multinational Takeovers of UK establishments

One possible explanation for our results is that US firms "cherry pick" the best establishments with the highest potential productivity impact from IT. This would generate the positive interaction we find but it would be entirely due to selection on unobserved heterogeneity rather than higher IT productivity due to US ownership. To look at this issue we examined the sub-sample of establishments who were, at some point in our sample period taken over by another firm, considering both US and non-US acquirers. Because of the high rate of M&A activity in the UK, this is a large sample (5,718 observations). In columns (1) and (2) of Table 3 we start by estimating our standard production functions (with and without IT respectively) for all establishments that are eventually taken over in their *pre-takeover* years (this is labeled "before takeover). The coefficients on the observable factor inputs are very similar to those for the whole sample in columns (1) and (2) of Table 1. Unlike the full sample, however, the US and non-US ownership dummies are also insignificant, suggesting the establishments that multinationals take over are not *ex ante* more productive than those acquired by domestic UK firms.

In column (3) of Table 3 we interact the IT capital stock with a US and a non-US multinational ownership dummy, again estimated on the *pre-takeover* data. We see that neither interaction is significant – that is *before* establishments are taken over by US firms they do not show a

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their interactions insignificant (even though US*IT interaction remains significant). Interactions between the US dummy and skills were insignificant in all specifications.

[18] In specifications of column (2) Table 1 the European dummy was 0.042 compared to 0.040 for the non-European, non-US multinational dummy (the US dummy was 0.075). All were significantly more productive than domestic establishments. The interactions of these extra dummies with IT capital were always insignificant (e.g. In the specification of Table 1 column (3) the coefficient on the non-US non-EU multinational interaction with IT capital was 0.006 with a standard error of 0.006 whereas the US interaction was 0.011 with a standard error of 0.005).

significantly higher IT productivity impact. So, US firms also do not appear to be selecting establishments which provide a higher IT productivity. In columns (4) and (5) we run a similar production function check on the *post-takeover* sample and again observe very similar coefficients to columns (1) and (2) in Table 1, suggesting that these *post* takeover establishments are also similar to the rest of the sample. This time, however, the non-US and US multinational ownership coefficients are positive and significant. Thus, a transfer of ownership from domestic to multinational production is associated with an increase in productivity, particularly for a move to US ownership.

Column (6) is a key result for Table 3. It estimates a specification allowing the IT capital stock coefficient to vary by ownership for the *post* takeover sample. In this group we do indeed see a higher IT productivity impact for US firms, which is significant at the 10% level, but not for non-US owned establishments. Hence, after a takeover by a US MNE establishments significantly increase their IT productivity impact, but not after a takeover by a non-US MNE. The inclusion of this US interaction also drives the coefficient on the linear US multinational term into insignificance, suggesting the main reason for the improved performance of establishments after a US takeover is linked to the increased IT productivity.

The final column of Table 3 breaks down the post takeover period into the first year after the takeover and the subsequent years (throughout the table we drop the takeover year itself as there is likely to be restructuring in that period). The greater productivity of IT capital in establishments taken over by US multinationals is only revealed two and three years after takeover (the interaction is significant at the 5% level whereas the interaction in after the first year is insignificant). This is consistent with the idea that US firms take a couple of years to get the organizational capital of the firm in place before obtaining higher productivity gains from IT. Domestic and other multinationals again reveal no pattern with all dummies and interactions remaining insignificant.

Table 4 explores this idea further by running IT investment equations for the establishments that have been taken over at some point. The first column focuses on the pre-takeover period and shows that the establishments who were subsequently taken over by US firms were no more IT intensive than other establishments taken over by non-US multinationals or domestic UK firms. The second column contains the results from the post-takeover period. Again, there is evidence that US establishments invest significantly more in IT than other statistically similar establishments taken over by other firms. The final column splits the takeover period into the first year post-takeover and then the second and third. As with productivity, the boost to IT in US takeovers takes more than just one year to occur with the increase in IT capital being a gradual process.

As another cut on the cherry-picking concept we ran a probit of US takeovers where the dependent variable is equal to unity for establishments who are taken over by a US firm and otherwise. We find that IT intensity is insignificant in this regression. Hence, US firms do not appear to target establishments that are particularly IT intensive prior to the takeover, but instead increase the IT intensity of these establishments post-takeover. [19]

Finally Table 5 investigates a little further the sectors driving the higher returns to IT for US firms in the IT intensive sector by breaking out its two largest sectors groups – Retail and Wholesale - and comparing these to the remaining sectors. In column (1) we simply represent the results from column (7) in table 1 to provide the baseline of all IT intensive sectors. In columns (2), (3) and (4) we see that the coefficients on the US interaction are remarkably similar across Retail, Wholesale and all other IT intensive sectors. It also highlights the role that Retail and Wholesale play given their large share of total output in the IT intensive sector.

IV.D. Further Investigations

Could the higher IT coefficient simply be due to greater software intensity in US firms? We have some information of software expenditure that we can use to build analogous measures of the software IT stock. When included in the specifications these stocks are positive and significant, but the hardware coefficient is only slightly reduced. Using the same specification as Table 1 column (2) when the software stock is included it has a coefficient of 0.0138 and a standard error of 0.0038. Conditional on this software stock the hardware coefficient is 0.0284 with a standard error of 0.0049. The hardware interaction with the US remains positive and significant when software is included. For example in column (3) of Table 1 the hardware interaction has a coefficient of 0.0.370

[19] After a take-over by a US multinational establishments increase their IT capital per head by 30%, which is significantly different from takeovers by non-US multinational establishments at the 5% level.

with a standard error of 0.0166. One concern with comparing software data for multinationals versus domestic firms may be that some multinational software development happens in the home country, which is not fully measured through transfer pricing, so that multinational subsidiary software expenditure under-reports total software inputs. This emphasizes the importance, however, of comparing US multinationals to non-US multinationals that should have similar "underreporting" issues to the extent these occur. As noted above, whether or not we include these software measures, US multinationals still obtain a significantly higher productivity from IT inputs than either domestic firms or other non-US multinationals.

V. A SIMPLE THEORETICAL MODEL OF IT AND PRODUCTIVITY

In this section we consider a formal model that can rationalize the macro stylized facts and the results that we see in the empirical analysis. We base this theory on the costs of making organizational changes as this seems to be consistent with a range of information from case studies and other papers. We readily concede that this is not the only model that could rationalize some of the facts (see sub-section V.B below), but we think that it is a compelling model to fit the general facts in our empirical study and the more general literature.

V.A. Basic Model

Consider two representative firms, one in the US and one in the EU. To keep things as simple as possible we assume that technology, prices and all parameters (except organizational adjustment costs) are globally common in the two regions. Firms in the US and EU are always optimizing - i.e. European firms are not making systematic "mistakes" by choosing a different organizational form, but reacting optimally given their different adjustment costs.

The firms produces output (*Q*) by combining IT (*C*) inputs, non-IT physical capital inputs (K) and labor inputs (*L*), with all other inputs assumed zero for simplicity, and is defined as follows:

$$Q = A\, C^{\alpha+\sigma O}\, K^{\beta-\sigma O}\, L^{1-\alpha-\beta}$$

Organizational structure is denoted *O* and is normalized on a scale from zero as Taylorist "centralized" production to unity as modern re-organized (or "decentralized") production[20]. The α, β and σ are production function parameters where $0 < \alpha + \beta < 1$ and $0 < \sigma < \beta$. This specification of the production function is a simple way of capturing the notion that IT and re-organized production are complementary as $\sigma > 0$.[21] Second, we have modeled *O* as having only adjustment costs, there is no "price" of a level of organizational capital nor is there always a positive marginal product of output with respect to *O*. This implies that the optimal organizational form will depend on the relative prices of the factor inputs and technology. In earlier eras the higher price of IT meant that firms were more intensive in physical capital (*K*), which gave no advantage to positive levels of *O*.

The firm sells its output into a market with iso-elastic demand elasticity *e* (>1) so that $P = BQ^{-1/e}$ where *P* is the output price and *B* is a demand shock parameter.

Combining the production and demand functions together we can write revenue as

$$PQ = Z(C^{\alpha+\sigma O} K^{\beta-\sigma O} L^{1-\alpha-\beta})^{1-1/e}$$

where $Z = BA^{1-1/e}$ is an arbitrary constant (since A and B are arbitrary sizing constants), defining $\omega = \alpha(1-1/e)$, $\mu = \beta(1-1/e)$, $\gamma = (1-\alpha-\beta)(1-1/e)$ and $\lambda = \sigma(1-1/e)$ we combine together the production function parameters and the demand parameters to re-write revenue as[22]

$$PQ = C^{\omega+\lambda O} K^{\mu-\lambda O} L^{\gamma}$$

Flow profits can then be defined as follows:

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[20] We choose centralization/decentralization based on some of the case study evidence, but to some extent this is just labelling. What matters is that the optimal organizational form changes with IT and that there are costs associated with making this change.

[21] The restriction that $\sigma > 0$ does not guarantee that C and O will be Hicks-Allen complements, but it certainly makes this more likely. Although we label O as an index of decentralization it obviously captures a much broader notion of organization that are better for increasing the relative productivity of IT.

[22] For simplicity we have not allowed O to also enter in the exponent of L. Nothing fundamental would change from allowing– what matters is the strength of the positive interaction between lnC and O is stronger than it is with the other two factors.

$$\Pi = C^{\omega+\lambda O} K^{\mu-\lambda O} L^{\gamma} - g(\Delta O) - WL - p^C I^C - p^K I^K$$

where W is the wage rate, p^C is the price of IT investment goods (denoted I^C), p^K is the price of non-IT investment goods (denoted I^K) and Δ is the first difference operator (e.g. $\Delta O_t = O_t - O_{t-1}$). We assume that both IT and non-IT capital can be represented by the perpetual inventory formulas, $C_t = I^C + (1-\delta^C)C_{t-1}$ and $K_t = I^K + (1-\delta^K)K_{t-1}$ where δ^C and δ^K are the depreciation rates of IT and non-IT capital respectively.

As appears to be true in the data (e.g. Jorgensen, 2001) we assume that the cost of IT investment goods, p_t^C were falling exponentially at 15% per year until 1995 and at 25% per year from 1995. Non-IT capital prices and wages rates in comparison have been relatively more stable and for simplicity in the model are assumed to be constant.

We assume that the organizational adjustment cost term g(ΔO) has a quadratic component and a fixed disruption component and is borne as a financial cost. Our critical assumption is that the quadratic component is higher in Europe (possibly reflecting tougher labor laws that make it expensive to rapidly hire and fire workers in any organizational change). The fixed component reflects the business disruption from any organizational change[23].

$$g(\Delta O) = \omega_k(\Delta O)^2 + \eta PQ|\,\Delta O \neq 0| \qquad \text{where } k=\{EU,US\} \text{ and } \omega_{EU} > \omega_{US}$$

Firms maximize their present discounted value of profits given a discount rate r. Introducing explicit time sub-scripts and given the structure of the problem we can write the deterministic value function for a firm as:

$$V_t(O_{t-1}, p_t^C) = \max_{C_t, K_t, L_t, O_t} \{C_t^{\omega+\lambda O_t} K_t^{\mu-\lambda O_t} L_t^{\gamma-\lambda O_t} - g(\Delta O_t) - W_t L_t - p_t^C I_t^C - p_t^K I_t^K + \frac{1}{1+r} V_{t+1}(O_t, p_{t+1}^C)\}$$

Applying standard results from Stokey and Lucas (1988) it can be shown that this value function is continuous, strictly decreasing in p_t and has an almost everywhere unique solution in C_t, K_t, L_t and

[23] We assume this to be common in Europe and the US for modeling simplicity – allowing this to be higher in the EU would tend to reinforce the qualitative results reported below.

O_t. Given any initial conditions for p_0^C and O_0 the policy correspondence functions can be used iteratively to solve the time path of C_t, K_t, L_t and O_t .

The long-run qualitative features are reasonably obvious. As the price of IT continues to fall the steady state optimal organizational form is complete decentralization for all firms (O equal to unity). The interesting question, however, is the transitional dynamics and how this differs between the US and Europe. Although the model has a well-behaved analytical solution in order to derive numerical values for any particular set of parameter values, however, we need to use numerical methods.

To do this we defined the parameter values as follow. We set: $\alpha = 0.025$ reflecting a 2.5% revenue share for IT, $\beta = 0.3$ reflecting a 30% revenue share for non-IT capital, and e = 3 reflecting a 50% mark-up over marginal costs, *mc*, ((P-mc)/mc = 1/(1-e)). The parameter λ has no obvious value, so we set this at $\lambda = \omega$ so that full "decentralization" (moving from *O* equal zero to *O* equal unity) doubles the value or the marginal product of IT and reduces the value of the marginal product of capital by just under 10% . Picking larger or smaller values of λ while holding the scaling on *O* constant increases or reduces the degree of complementarity between *O* and λ. The discount rate is set at r = 10%, the IT depreciation rate at $\delta^C = 30\%$ (Basu et al, 2003), the non-IT depreciation rate of $\delta^K = 10\%$ and the wage rate is normalized to unity (W = 1). The fixed cost of adjustment are set at $\eta = 0.2$ percent of sales selected on the evidence for the fixed costs of capital investments (see Bloom, 2006) given the lack of any direct evidence on the cost of organizational adjustment costs. The quadratic adjustment cost parameter is set so adjustment costs are four times as high in Europe as in the US (i.e. $\omega_{US}/\omega_{EU} = 4$, roughly similar to the differences in the OECD's labor regulation indices in Nicoletti et al, 2000). The starting values for p_0^C and O_0 are taken as $p_0^C = 0.075$ and $O_0 = 0$ in 1965, with the price process then exponentially decaying (as outlined above) until 2025 at which point prices stop falling any further. The first and last ten years of the simulation are then discarded to abstract from any initial and terminal restrictions[24].

[24] The code is written in MATLAB and is available on request from the authors.

The model has several intuitive predictions that are consistent with the stylized facts and also contains some novel predictions. First, we trace out the decentralization decisions of firms in Figure 6. We see that US firms start to decentralize first (in the late 1980s in the baseline case) and are on average more decentralized than European firms throughout the period under consideration (the representative EU firm begins to decentralize about 19 years after the American firm). The US decentralizes first because of its lower adjustment costs. The fixed costs implies that firms always change *O* in discrete "chunks" and the cost of making any given jump will always be greater for European firms because of their higher adjustment costs[25].

Figure 7 examines the pattern of IT per unit of capital in logarithms (ln(C/K)). Unsurprisingly this is rising in both regional blocs due to the global fall in IT prices. IT intensity grows at an identical rate in the two regions until the US starts to decentralize and at this point American firms start to become more IT intensive than European firms. This is because of the complementarity underlying the production function (higher O implies higher optimal IT investment). Labour productivity (Q/L) is shown in Figure 8. Unsurprisingly, the higher IT intensity translates through into higher labor productivity which accelerates from the mid 1990s.

These findings are consistent with the broad macro facts as discussed earlier. We now discuss extensions to fit the micro data results.

V.B. Extensions to the basic model

(a) Multinationals

We now consider multinational companies who operate several plants at least one of which is on foreign soil. We extend the modeling framework to consider an additional cost in maintaining different organizational forms in different plants. Multinationals appear to operate globally similar management and organizational structures (e.g. Bartlett and Ghoshal, 1999) as this makes it much easier to integrate senior managers, human resource systems, software, etc. At different ends of the

[25] Without any fixed costs, O will be changed in infinitesimally small increments due to the quadratic adjustment costs. In this case the higher quadratic adjustment costs of European firms gives them an incentive to smooth adjustment more than US firms which will mean that European firms start to decentralize first. In the limit when US adjustment costs are zero, US firms will adjust in a single period when optimal C/K = 1. Before this point European firms will be more decentralized, more IT intensive and have higher labor productivity. After this point the opposite is true. This shows the importance of allowing for fixed adjustment costs in matching the stylized facts.

skills spectrum both McKinsey and Starbucks are recognizably similar in Cambridge, Massachusetts and Cambridge, England. To formalize this we allow an additional quadratic adjustment cost which has to be born if there is a difference between the organization of the plant *i* (O_i) and its parent (O^k), $\phi(O_i - O^k)^2(PQ)_i$

Consider the case of a US firm purchasing a European plant (in the period after US firms have started to decentralize). The purchased plant will start to become more decentralized than identical plants owned by domestic firms (or European multinationals operating solely in Europe). It will also start increasing IT intensity and labor productivity at a faster rate than European owned plants. The degree to which the plant resembles its American parent will depend on the size of ϕ relative to the adjustment cost differential ω_{EU}. The larger is ϕ the more the establishment will start to resemble its US parent[26]. Note that the presence of adjustment costs, however, suggests that this change will not be immediate so after an American firm takes over a European establishment the IT intensity and productivity will be, for some periods, below than of longer-established US affiliates.

The middle line in Figure 9 shows the simulation results for a hypothetical British plant taken over by a US multinational in 2003. The calibration assumes ϕ_i =1. Under this scenario, the taken over firm initially converges to within 0.1 of the organizational structure of the US parent company five years after the take over year.

These are the key testable predictions that we take to the micro data – is it the case that US multinationals not only perform more IT than EU multinationals but also appear to obtain higher productivity from their IT capital stock? When US firms takeover European establishments do we see these patterns emerge in the data?

(b) Industry Heterogeneity

[26] This raises questions about the reasons for takeovers. Why should a US firm ever take over a European plant if it has to bear greater adjustment costs than a European multinational? One reason is that the US parent may have higher TFP from some firm-specific advantage that it can diffuse to the affiliate (such as better technology or management).

The fall in the price of IT has opened up the possibility of IT-enabled innovations to a greater extent in some industries than others. Baker and Hubbard (2004) for example describe how on-board computers have altered business methods in the trucking industry. In our model we can capture this by allowing a different degree of complementarity between IT and organization in some industries than others (i.e. a higher σ). Those sectors in Figure 2 that Stiroh and others have labeled "intensive in IT using" would have a higher σ and therefore follow the patterns analyzed above. Other sectors with low σ would not and for these industries US and EU productivity experience should be similar as both regions enjoy the benefits of faster productivity growth. This is what we find in the micro data – the differences between US and EU firms are much stronger in the intensive IT using sectors.

(c) Adjustment Costs for IT capital

For simplicity we abstracted away from adjustment costs in IT capital and other factors of production. Consider a simple extension of the model where we also have quadratic adjustment costs in IT capital, but assume that these are the same across countries. Obviously this will slow down the accumulation of IT and O, but the qualitative findings discussed above will still go through[27]. One difference, however, is that measured TFP will grow more quickly in the US than in the EU as decentralization occurs under this model. Under the baseline model the share of IT capital in revenue is still equal to $\omega + \lambda O$ in every period so the "weight" on IT capital in the measured TFP formula will be correct. Once we allow for adjustment costs in IT, by contrast, the empirical share of IT in revenues will always be below its steady state level (in the period when O is greater than zero and less than unity). This will mean that measured TFP will exceed actual TFP (A) and that measured TFP in the US will exceed that of the EU in the transition.

(d) Permanent Differences in Management Quality?

An alternative model to the one we have presented could be one were US firms have always been better managed/organized than European firms *and* that this better management is complementary with IT. This could be due to tougher competition, culture, less family run firms, etc. Under this

[27] For an analysis of mixed fixed and quadratic adjustment costs with two factors see Bloom, Bond and Van Reenen (2006) or Bloom (2006).

model “O” would enter as an additional factor input in the production function with an exogenously lower price in the US than in Europe. For example,

$$Q = A\,O^{\chi}C^{\alpha+\sigma O}\,K^{\beta-\sigma O}\,L^{1-\alpha-\beta-\chi}$$

This set-up would rationalize most of the findings presented in the paper except one. We found in Table 1 and elsewhere that the linear US multinational dummy was insignificantly different from zero once we have accounted for the higher coefficient on IT capital for US firms. In the extended equation above, then, we find $\sigma>0$ but $\chi = 0$. Consequently, we have some preference for the more parsimonious model presented here. It is the *flexibility* of the US economy in adapting to the challenges of major changes (such as the IT revolution) that gives it productivity advantage, not its permanent superiority in all states of the world. Of course, if we have moved into a stage of development where turbulence is inherently greater, then the US will retain an edge over Europe for the foreseeable future.

VI. CONCLUSIONS

Using a large and original establishment level panel dataset we find robust evidence that IT has a positive and significant correlation with productivity even after controlling for many factors such as fixed effects. We estimate that a doubling of the IT stock is associated with an increase in productivity of between 2% and 4%. The most novel result is that we can account for the US multinational advantage in conventionally measured TFP by their higher productivity impact of IT capital. Furthermore, the stronger association of IT with productivity for US firms is confined to the same “IT using intensive” industries that largely accounted for the US “productivity miracle” since the mid 1990s. US firms in the UK were able to get significantly more productivity out of their IT than other multinational (and domestic British) firms, even in the context of a UK environment. This suggests that part of the IT-related productivity gains in the US may be due to the management/organizational capital of firms rather than simply the “natural advantages” (geographical, institutional or otherwise) of the US environment.

A major research tasks remain in understanding *why* US firms are able to achieve these "IT friendly" organizational forms and their European counterparts cannot. It could be due to timing – US firms where closer to the development of the new wave of IT producers and so were the first to learn about them. In this scenario European firms will quickly catch up (although there is little evidence of this happening so far). A second explanation is that US firms are "leaner and meaner" than their European counterparts due to tougher competitive conditions in their domestic markets and are therefore intrinsically quicker to adapt to revolutionary new technologies. Alternatively, US firms may be more organizationally devolved for historical reasons due to their greater supply of college levels skills, relative absence of family owned firms and/or their history of technological leadership (see Acemoglu et al, 2006), rendering them better equipped to adopt new IT technologies. Under these scenarios Europe will resume the catching up process with a much longer lag than is conventionally thought.

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TABLE 1 – ALLOWING THE I.T. COEFFICIENT TO DIFFER BY OWNERSHIP STATUS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**
Sectors	All Sectors	All Sectors	All Sectors	IT Using Intensive Sectors	Non IT Using Intensive Sectors	All Sectors	IT Using Intensive Sectors	Non IT Using Intensive Sectors
Fixed effects	**NO**	**NO**	**NO**	**NO**	**NO**	**YES**	**YES**	**YES**
Ln(C)	-	0.0434***	0.0414***	0.0356***	0.0442***	0.0293***	0.0206***	0.0272***
IT capital		(0.0023)	(0.0025)	(0.0032)	(0.0033)	(0.0031)	(0.0045)	(0.0037)
USA*ln(C)	-	-	0.0108**	0.0190**	0.0067	0.0084	0.0294***	0.0009
USA ownership*IT capital			(0.0047)	(0.0075)	(0.0060)	(0.0065)	(0.0106)	(0.0076)
MNE*ln(C)	-	-	0.0037	-0.0004	0.0073*	-0.0016	0.0044	-0.0017
Non-US multinational *IT capital			(0.0028)	(0.0037)	(0.0040)	(0.0035)	(0.0056)	(0.0045)
Ln(M)	0.5472***	0.5383***	0.5385***	0.6137***	0.5013***	0.4662***	0.5598***	0.4115***
Materials	(0.0081)	(0.0080)	(0.0080)	(0.0139)	(0.0100)	(0.0135)	(0.0189)	(0.0186)
Ln(K)	0.1295***	0.1176***	0.1178***	0.1024***	0.1342***	0.1638***	0.1398***	0.2109***
Non-IT Capital	(0.0066)	(0.0063)	(0.0063)	(0.0082)	(0.0085)	(0.0107)	(0.0155)	(0.0156)
Ln(L)	0.3151***	0.2864***	0.2858***	0.2334***	0.3030***	0.3170***	0.2528***	0.3391***
Labour	(0.0062)	(0.0062)	(0.0062)	(0.0099)	(0.0076)	(0.0138)	(0.0180)	(0.0172)
USA	0.0847***	0.0745***	0.0155	-0.0554	0.0503	-0.0174	-0.1656***	0.0144
USA Ownership	(0.0109)	(0.0106)	(0.0257)	(0.0397)	(0.0337)	(0.0390)	(0.0639)	(0.0449)
MNE	0.0478***	0.0414***	0.0234	0.0313	0.0078	0.0436**	-0.0064	0.0444*
Non-US multinational	(0.0067)	(0.0066)	(0.0148)	(0.0197)	(0.0202)	(0.0208)	(0.0356)	(0.0254)
Observations	22736	22736	22736	7876	14860	22736	7876	14860
Test USA*ln(C)=MNE*ln(C), pvalue	-	-	0.14	0.01	0.92	0.14	0.02	0.74

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit SIC mean in the same year. The estimation method in all columns is OLS. All columns include age, foreign ownership and region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. Columns (6) to (8) include firm level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedacity and autocorrelation of unknown form). See Appendix B for definition of IT using intensive sectors.

TABLE 2 – ROBUSTNESS TESTS ON PRODUCTION FUNCTIONS

Experiment	(1) Baseline Specification	(2) All Inputs Interacted	(3) Alternative IT Initial Conditions	(4) Alternative IT Measure	(5) Alternative functional form	(6) Full "Translog" interactions	(7) US FDI in SIC-4 industry	(8) Average Wage
Dependent variable	**ln(GO)**	**ln(GO)**	**ln(GO)**	**Ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**
Ln(C)	0.0206***	0.0184***	0.0412***	0.0385***	-	0.0181***	0.0170***	-0.0028
IT capital	(0.0045)	(0.0046)	(0.0086)	(0.0062)		(0.0042)	(0.0047)	(0.0130)
USA*ln(C)	0.0294***	0.0441***	0.0242*	0.0311*	-	0.0292***	0.0260**	0.0163*
USA ownership*IT capital	(0.0106)	(0.0151)	(0.0129)	(0.0163)		(0.0104)	(0.0108)	(0.0090)
MNE*ln(C)	0.0044	0.0059	0.0004	0.0014	-	0.0002	0.0024	0.0033
Non-US multinational *IT capital	(0.0056)	(0.0066)	(0.0082)	(0.0077)		(0.0051)	(0.0058)	(0.0053)
ln(Wage)*ln(C)	-	-	-	-	-	-	-	0.0048
Average Wage*IT capital								(0.0045)
USA*[C/(Total Capital)]	-	-	-	-	0.9532***	-	-	-
USA ownership*Fraction of IT Capital in Total K					(0.2033)			
MNE*[C/(Total Capital)]	-	-	-	-	0.2900	-	-	-
Non-US multinational *Fraction of IT Capital in Total Capital					(0.2047)			
Ln(M)	0.5598***	0.5577***	0.5563***	0.6100***	0.5592***	0.2618	0.5594***	0.5045***
Materials	(0.0189)	(0.0203)	(0.0193)	(0.0164)	(0.0187)	(0.1340)	(0.0190)	(0.0200)
Ln(K)	0.1398***	0.1482***	0.1235***	0.1191***	-	0.2497***	0.1398***	0.0962***
Non-IT Capital	(0.0155)	(0.0155)	(0.0141)	(0.0131)		(0.0614)	(0.0156)	(0.0144)
Ln(Total_K)	-	-	-	-	0.1702***	-	-	-
Non IT capital + IT capital					(0.0152)			
Ln(L)	0.2528***	0.2520***	0.2496***	0.2234***	0.2496***	0.3938***	0.2547***	0.3845***
Labour	(0.0180)	(0.0196)	(0.0176)	(0.0117)	(0.0169)	(0.1303)	(0.0182)	(0.0206)
USA	-0.1656***	0.1433	-0.1342	-0.1156	-0.0320	-0.1641***	-0.1469	-0.1148**
USA Ownership	(0.0639)	(0.2341)	(0.0829)	(0.0879)	(0.0261)	(0.0599)	(0.0646)	(0.0577)
MNE	-0.0064	0.0754	0.0235	0.0230	0.0111	0.0099	0.0044	-0.0069
Non-US multinational	(0.0356)	(0.1381)	(0.0555)	(0.0420)	(0.0148)	(0.0319)	(0.0367)	(0.0338)
USA*ln(M)	-	0.0017	-	-	-	-	-	-

USA ownership*materials		(0.0324)						
MNE*ln(M)	-	0.0040	-	-	-	-	-	-
Non-US multinational *materials		(0.0190)						
USA*ln(K)	-	-0.0341	-	-	-	-	-	-
USA ownership*Non IT capital		(0.0400)						
MNE*ln(K)	-	-0.0175	-	-	-	-	-	-
Non-US multinational *Non IT capital		(0.0137)						
USA*ln(L)	-	-0.0108	-	-	-	-	-	-
USA ownership*Employment		(0.0425)						
MNE*ln(L)	-	0.0072	-	-	-	-	-	-
Non-US multinational *Employment		(0.0217)						
C/(Total Capital)	-	-	-	-	0.3151	-	-	-
Fraction of IT Capital in Total Capital					(0.1382)			
USA_IND*ln(C)	-	-	-	-	-	-	0.6359*	-
[% of US Multinationals in industry]*IT capital							(0.3443)	
ln(Wage)	-	-	-	-	-	-	-	0.2455***
Average wage								(0.0299)
Observations	7876	7876	7716	2859	7876	7876	7876	7872
Test on joint significance of all the interaction terms, excluding IT interactions (p-value)	-	*0.91*	-	-	-	-	-	-
Test on joint significance of all the US interaction terms, excluding IT (pvalue}	-	*0.73*	-	-	-	-	-	-
Test on all the other MNE's interaction terms, excluding IT (p-value)	-	*0.84*	-	-	-	-	-	-
Test on the other omitted "translog" terms (p-value)	-	-	-	-	-	0.29	-	-
Test USA*ln(C)=MNE*ln(C), pvalue	0.02	0.01	0.08	0.07	0.003	0.01	0.03	0.16

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit SIC mean in the same year. The estimation method in all columns is OLS. All columns except (4) include firm level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedacity and autocorrelation of unknown form). All columns are for the sectors that use IT intensively only. The IT measure in columns (3) is the percentage of people using computers*total number of employees.

TABLE 3. PRODUCTION FUNCTIONS BEFORE AND AFTER TAKEOVERS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sample	**Before takeover**	**Before takeover**	**Before takeover**	**After takeover**	**After takeover**	**After takeover**	**After takeover**
Dependent Variable	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**	**Ln(GO)**
USA USA Takeover	0.0444 (0.0361)	0.0472 (0.0355)	0.1697 (0.1040)	0.0971*** (0.0316)	0.0869*** (0.0300)	-0.0352 (0.0781)	-
MNE Non-US multinational Takeover	-0.0096 (0.0250)	-0.0117 (0.0244)	0.0009 (0.0629)	0.0524** (0.0218)	0.0479** (0.0212)	-0.0166 (0.0446)	-
Ln(C) IT capital	-	0.0553*** (0.0075)	0.0560*** (0.0077)	-	0.0444*** (0.0068)	0.0398*** (0.0072)	0.0404*** (0.0071)
USA*ln(C) USA Takeover*IT capital	-	-	-0.0224 (0.0179)	-	-	0.0230* (0.0131)	-
MNE*ln(C) Non-US multinational Takeover*IT capital	-	-	-0.0025 (0.0113)	-	-	0.0133 (0.0086)	-
USA*ln(C) one year after takeover	-	-	-	-	-	-	-0.0051 (0.0143)
USA*ln(C) two and three years after takeover	-	-	-	-	-	-	0.0378** (0.0168)
MNE*ln(C) one year After takeover	-	-	-	-	-	-	0.0088 (0.0109)
MNE*ln(C) two and three years after takeover	-	-	-	-	-	-	0.0137 (0.0095)
USA one year after takeover	-	-	-	-	-	-	0.1066 (0.0857)
USA two and three years after takeover	-	-	-	-	-	-	-0.1131 (0.1003)
MNE one year	-	-	-	-	-	-	-0.0438

after takeover							(0.0581)
MNE two and three Years after takeover	-	-	-	-	-	-	0.0044 (0.0503)
Ln(M) Materials	0.5096*** (0.0301)	0.4977*** (0.0297)	0.4972*** (0.0298)	0.5494*** (0.0205)	0.5380*** (0.0204)	0.5380*** (0.0204)	0.5350*** (0.0204)
Ln(K) Non-IT Capital	0.1624*** (0.0247)	0.1454*** (0.0234)	0.1455*** (0.0234)	0.1193*** (0.0162)	0.1096*** (0.0156)	0.1165*** (0.0156)	0.1141*** (0.0156)
Ln(L) Labor	0.3140*** (0.0185)	0.2794*** (0.0183)	0.2799*** (0.0184)	0.3143*** (0.0164)	0.2869*** (0.0166)	0.2852*** (0.0165)	0.2851*** (0.0164)
Observations	2365	2365	2365	3353	3353	3353	3353

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The sample is of all establishments who were taken over at some point over the sample period (the omitted base is “domestic takeovers” - UK firms taking over other UK firms). The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 3 digit industry mean in the same year. The estimation method is OLS. Columns include age, foreign ownership and region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedasticity and autocorrelation of unknown form). A takeover is defined as a change in the foreign ownership marker or - for UK domestic firms - as a change in the enterprise group marker. The "before" period is defined as the interval between one and three years before the takeover takes place. The "after" period is defined as the interval between one and three years after the takeover takes place. The year in which the takeover takes place is excluded from the sample.

TABLE 4: INVESTMENT IN INFORMATION TECHNOLOGY BEFORE AND AFTER TAKEOVERS BY MULTINATIONAL STATUS

	(1)	(2)	(3)
Sample	**All firms before takeover**	**All firms after takeover**	**All firms after takeover**
Estimation Method	**OLS**	**OLS**	**OLS**
Dependent Variable	**ln(Investment in IT$_t$)**	**ln(Investment in IT$_t$)**	**ln(Investment in IT$_t$)**
USA –Before USA Takeover	0.0396 (0.1393)	-	-
USA –After USA Takeover	-	0.4239*** (0.1367)	-
USA one year after takeover	-	-	0.5189*** (0.1862)
USA two and three years after takeover	-	-	0.3589** (0.1629)
MNE–Before Non-USA Takeover	0.0660 (0.1167)	-	-
MNE–After Non-USA Takeover	-	0.2221*** (0.0858)	-
MNE one year after non-US takeover	-	-	0.3357*** (0.1116)
MNE two and three years after non-US takeover	-	-	0.1549 (0.0979)
Ln(L) Labor	1.1100*** (0.0311)	1.0109*** (0.0321)	1.0100*** (0.0321)
USA USA Takeover	0.0444 (0.0361)	0.0472 (0.0355)	0.1697 (0.1040)
MNE Non-US multinational Takeover	-0.0096 (0.0250)	-0.0117 (0.0244)	0.0009 (0.0629)
MNE Non-US multinational Takeover	-0.0096 (0.0250)	-0.0117 (0.0244)	0.0009 (0.0629)
Observations	2149	2928	2928

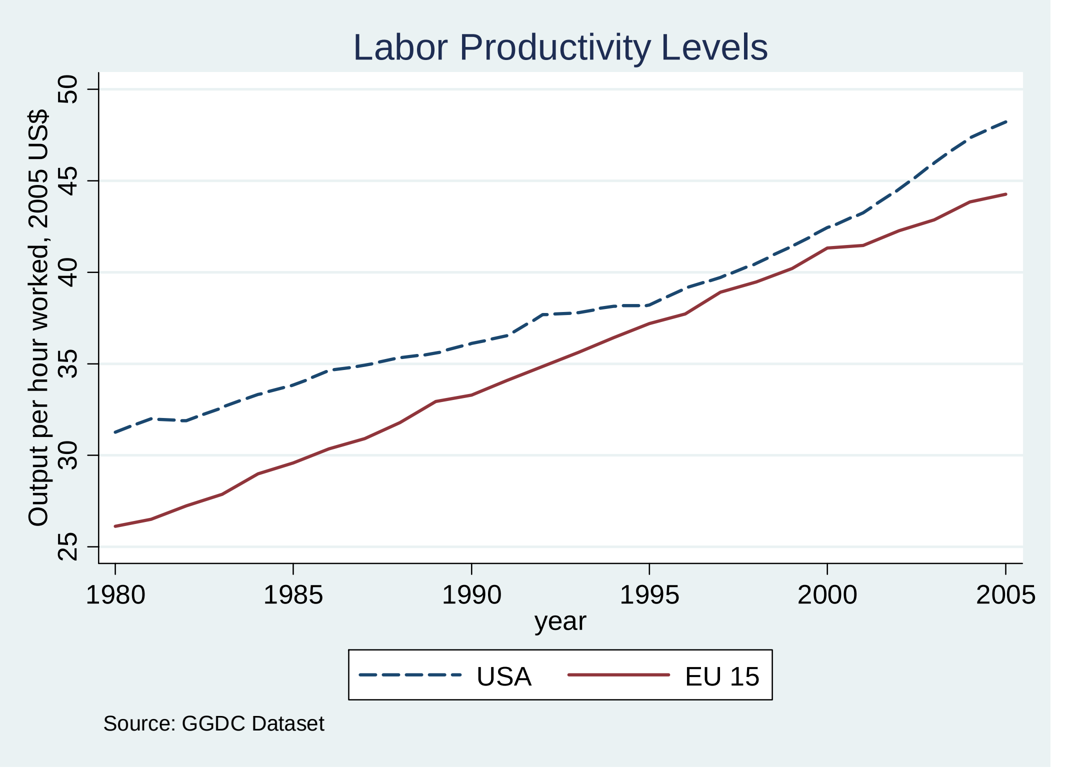
Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. (the omitted base is "domestic takeovers" - UK firms taking over other UK firms).The dependent variable in all columns is the log of investment in IT. The time period is 1995-2003. All variables are expressed in deviations from the 3 digit industry mean in the same year. The estimation method is OLS. Regressions include age, region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedasticity and autocorrelation of unknown form). A takeover is defined as a change in the foreign ownership marker or - for UK domestic firms - as a change in the enterprise group marker. The "before" period is defined as the interval between one and three years before the takeover takes place. The "after" period is defined as the interval between one and three years after the takeover takes place. The year in which the takeover takes place is excluded from the sample.

TABLE 5 – IT INTENSIVE SECTORS IN DETAIL

	(1)	(2)	(3)	(4)
Dependent variable	**ln(GO)**	**ln(GO)**	**ln(GO)**	**ln(GO)**
Sectors	**All IT Intensive (baseline)**	**Wholesale**	**Retail**	**All other IT Intensive**
Fixed effects	**YES**	**YES**	**YES**	**YES**
Ln(C) **IT capital**	0.0206*** (0.0045)	0.0177*** (0.0062)	0.0132*** (0.0049)	0.0241*** (0.0080)
USA*ln(C) **USA ownership*IT capital**	0.0294*** (0.0106)	0.0289 (0.0181)	0.0304** (0.0141)	0.0254* (0.0154)
MNE*ln(C) **Non-US multinational *IT capital**	0.0044 (0.0056)	-0.0005 (0.0070)	-0.0118 (0.0094)	0.0030 (0.0088)
Ln(M) **Materials**	0.5598*** (0.0189)	0.6796*** (0.0286)	0.6376*** (0.0345)	0.4453*** (0.0253)
Ln(K) **Non-IT Capital**	0.1398** (0.0155)	0.1002*** (0.0270)	0.1064*** (0.0215)	0.2175*** (0.0265)
Ln(L) **Labour**	0.2528*** (0.0180)	0.1767*** (0.0294)	0.2197*** (0.0293)	0.3109*** (0.0302)
USA **USA Ownership**	-0.1656*** (0.0639)	-0.0717 (0.0944)	-0.2970*** (0.1070)	-0.1625* (0.0881)
MNE **Non-US multinational**	-0.0064 (0.0356)	0.0789* (0.0432)	0.0912 (0.0683)	-0.0302 (0.0544)
Observations	7876	2620	1399	3857
Test USA*ln(C)=MNE*ln(C), pvalue	0.11	0.11	0.0021	0.16

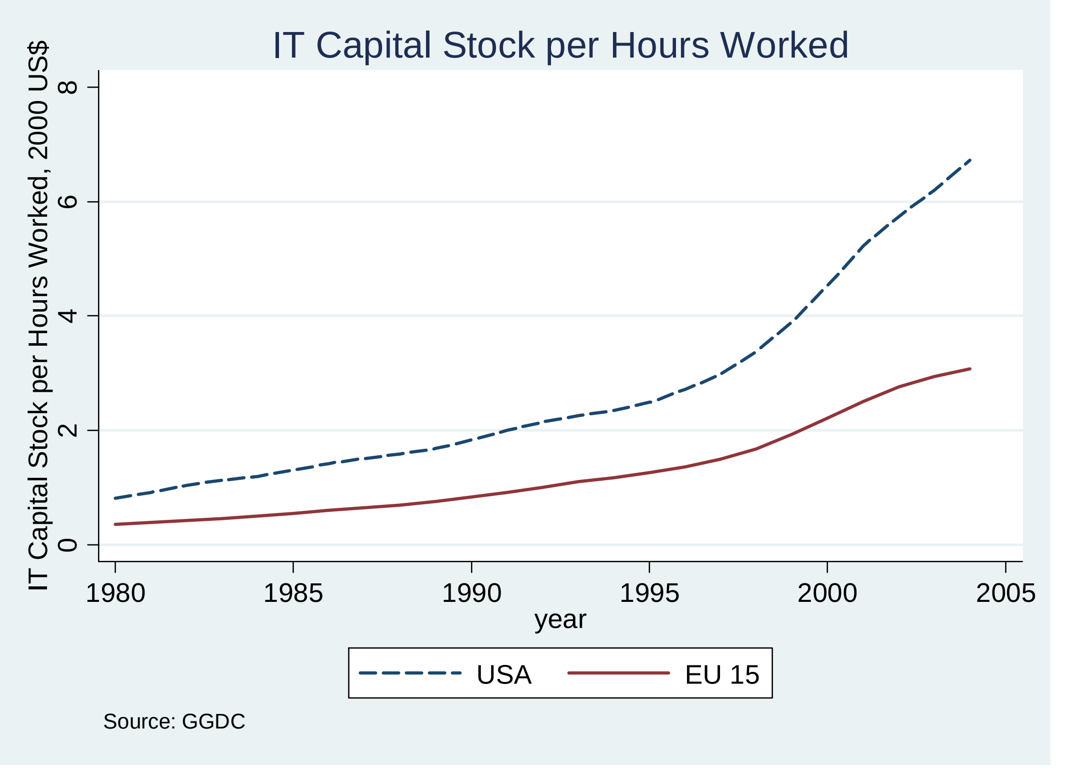
Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit SIC mean in the same year. The estimation method in all columns is OLS. All columns include age, foreign ownership and region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. Columns (6) to (8) include firm level fixed effects. Standard errors in brackets under coefficients in all columns are clustered by firm (i.e. robust to heteroskedacity and autocorrelation of unknown form). See Appendix B for definition of IT using intensive sectors.

Figure 1: Output per hour in Europe and the US, 1980-2005



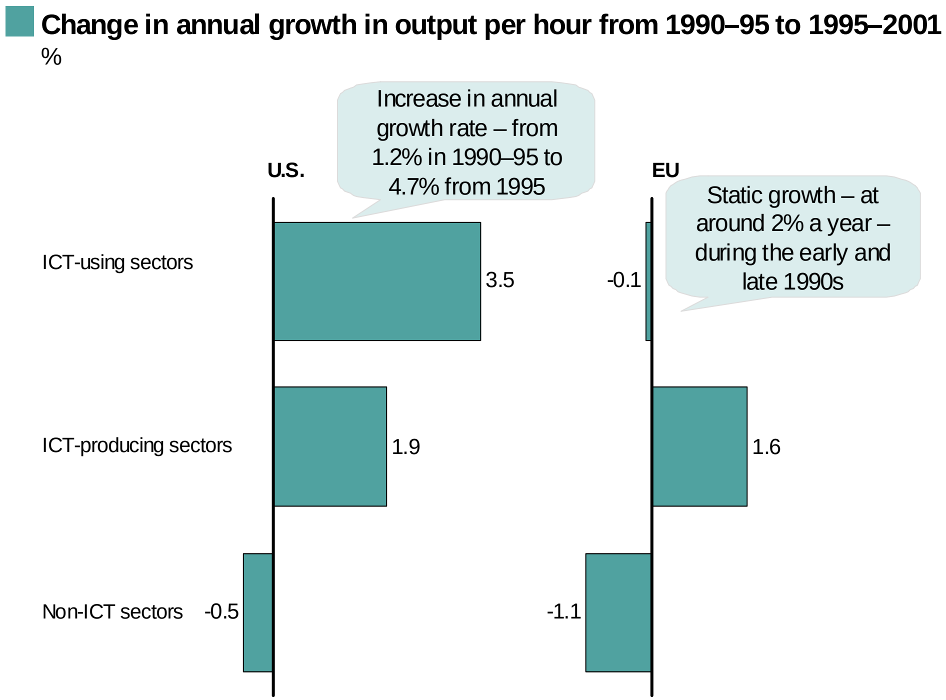
Notes:
Source: The Conference Board and Groningen Growth and Development Centre, Total Economy Database, January 2006, http://www.ggdc.net. The countries included in the "EU 15" group are: Austria, Belgium, Denmark, Finland, France, Germany, Uk, Greece, Italy, Ireland, Luxembourg, Portugal, Spain, Sweden, Netherlands. Labour productivity per hour worked in 2005 US$ (converted to 2005 price level with updated 2002 Euklems PPPs).

Figure 2: IT capital per hour in EU and US



Notes:
Source: Marcel P. Timmer, Gerard Ypma and Bart van Ark, IT in the European Union: Driving Productivity Convergence?, Research Memorandum GD-67, Groningen Growth and Development Centre, October 2003, Appendix Tables, updated June 2005. Downloadable at http://www.ggdc.net/pub/online/gd67(online).pdf. The countries included in the "EU 15" group are: Austria, Belgium, Denmark, Finland, France, Germany, Uk, Greece, Italy, Ireland, Luxembourg, Portugal, Spain, Sweden, Netherlands

Figure 3: Acceleration in productivity growth in EU and US



Notes:
Source: O'Mahony and Van Ark (2003)

Figure 4a: Organizational devolvement, firms by country of location

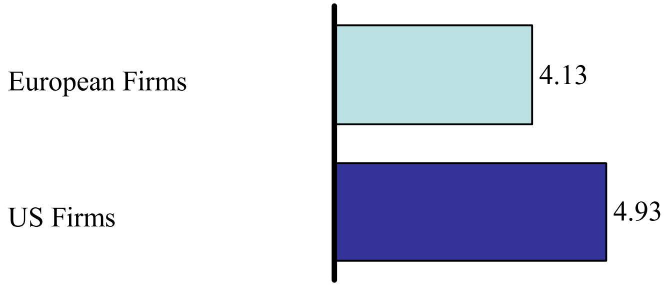


Figure 4b: Organizational devolvement, firms by country of ownership

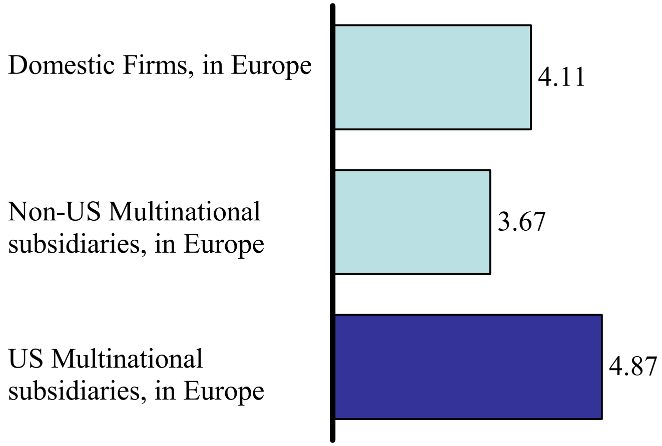


Figure 5a: Management practices, firms by country of location

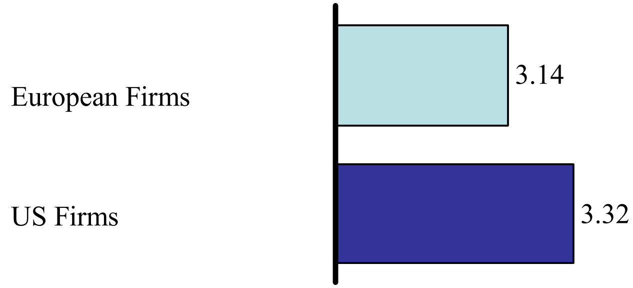
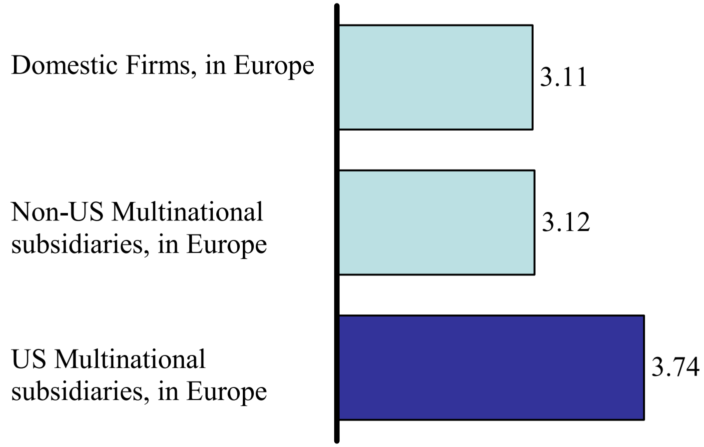
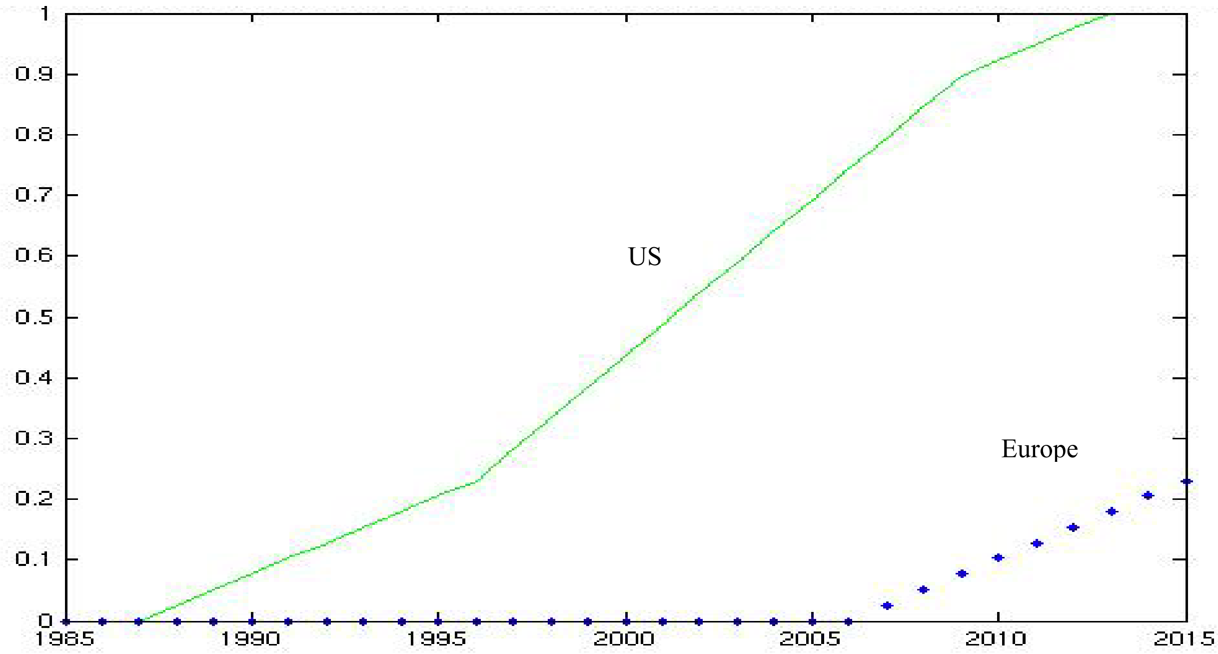


Figure 5b: Management practices, firms by country of ownership



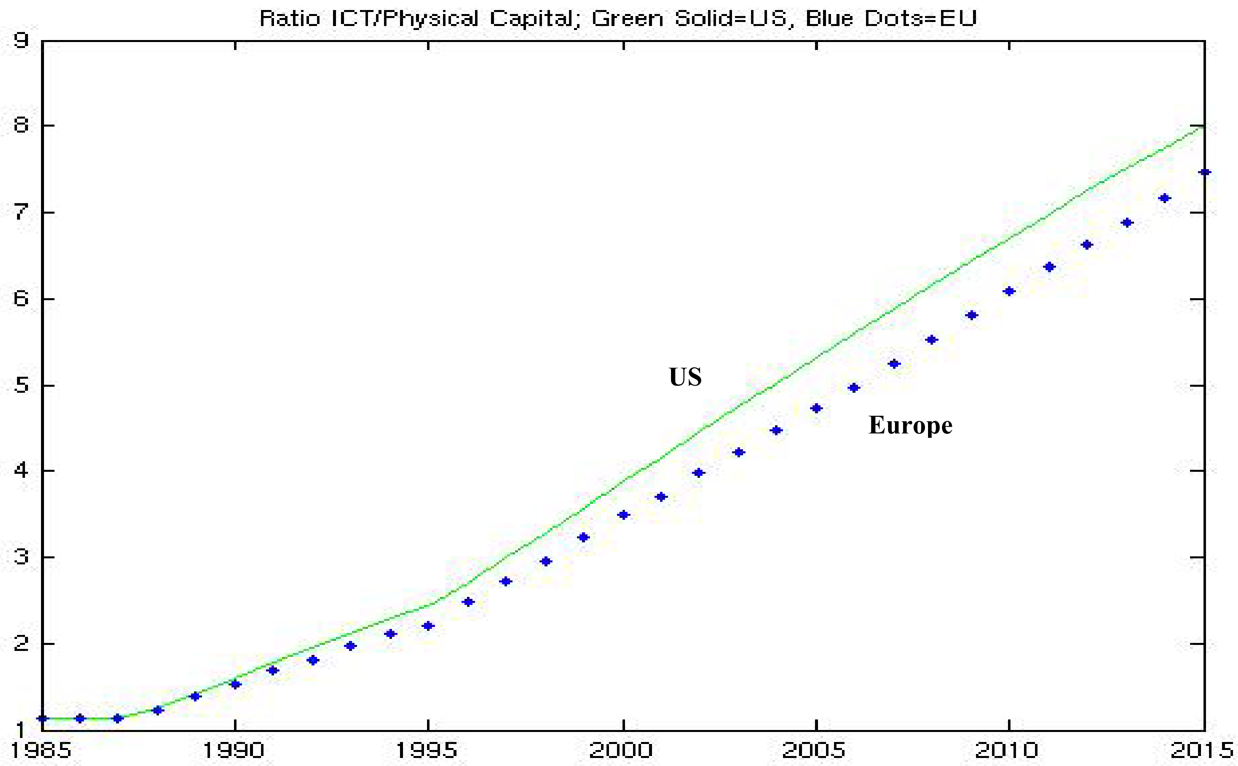
Notes: In Figures 1a and 1b the "Organizational devolvement" score is the average score for the 2 organizational questions for 548 firms in the US (219), UK (98) and France and Germany (231). The questions are taken exactly from Bresnahan et al. (2002) covering "Task allocation" and "Pace setting" where a higher scores indicate greater worker autonomy. Full survey details in Bloom and Van Reenen (2005). In Figures 2a and 2b the "Management Practice" score is the average score for 18 questions on management practices where 1 is "*worst practice*" and 5 is "*best practice*" for 733 firms from the US (290), UK (151) and France and Germany (292). Full survey details in Bloom and Van Reenen (2005). In Figure 1a the differences between "European" and "US" firms is significant at the 1% level with a standard error of 0.143. In Figure 1b the difference between the "US Multinational subsidiaries" and the "Domestic Firms" is significant at the 10% level with a standard error of 0.084. In Figure 2a the difference between the "European" and "US" firms is significant at the 1% level with a standard-error of 0.057. In Figure 2b the difference between the "US Multinational subsidiaries" and the "Domestic Firms" is significant at the 1% level with a standard error of 0.169.

Figure 6: Decentralization (O) by US and European firms, model results



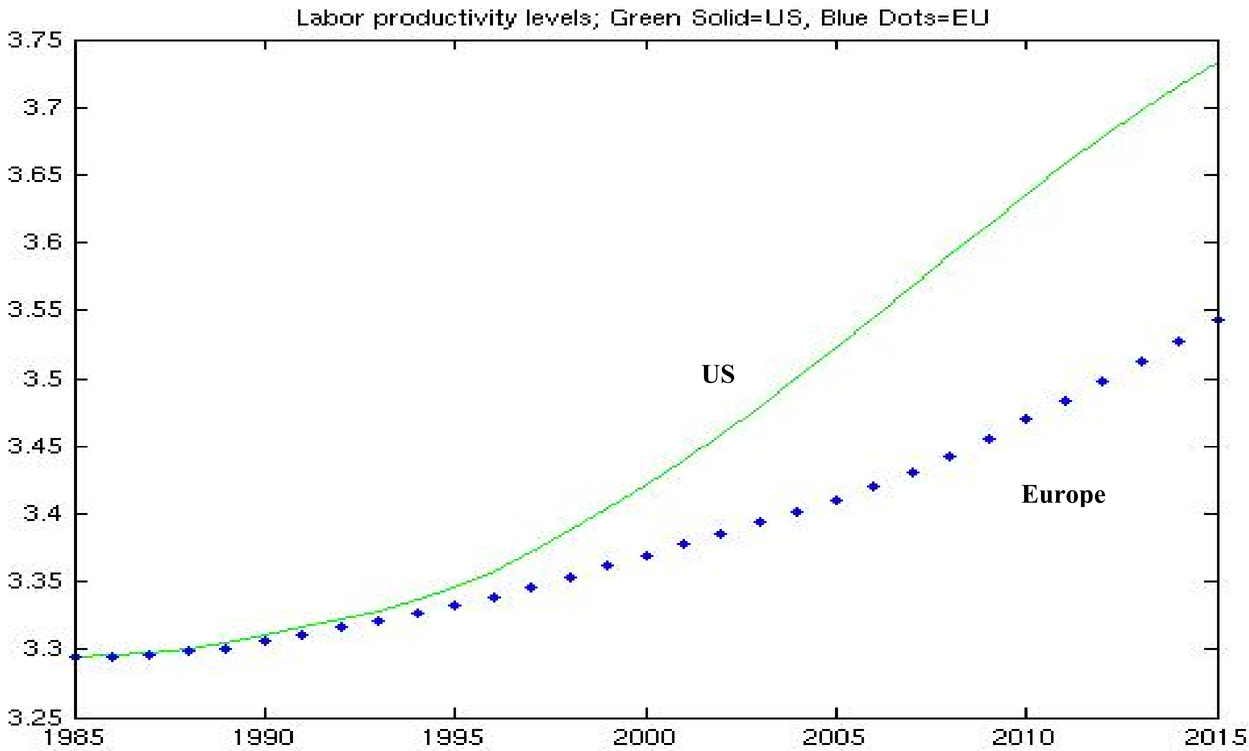
Notes: These are the results from the numerical simulation of the theoretical model 1980-2015 (with fifteen years before and after). See Appendix and texts for details. Decentralization is the value of O.

Figure 7: IT per unit of capital (C/K) in US and European firms, model results



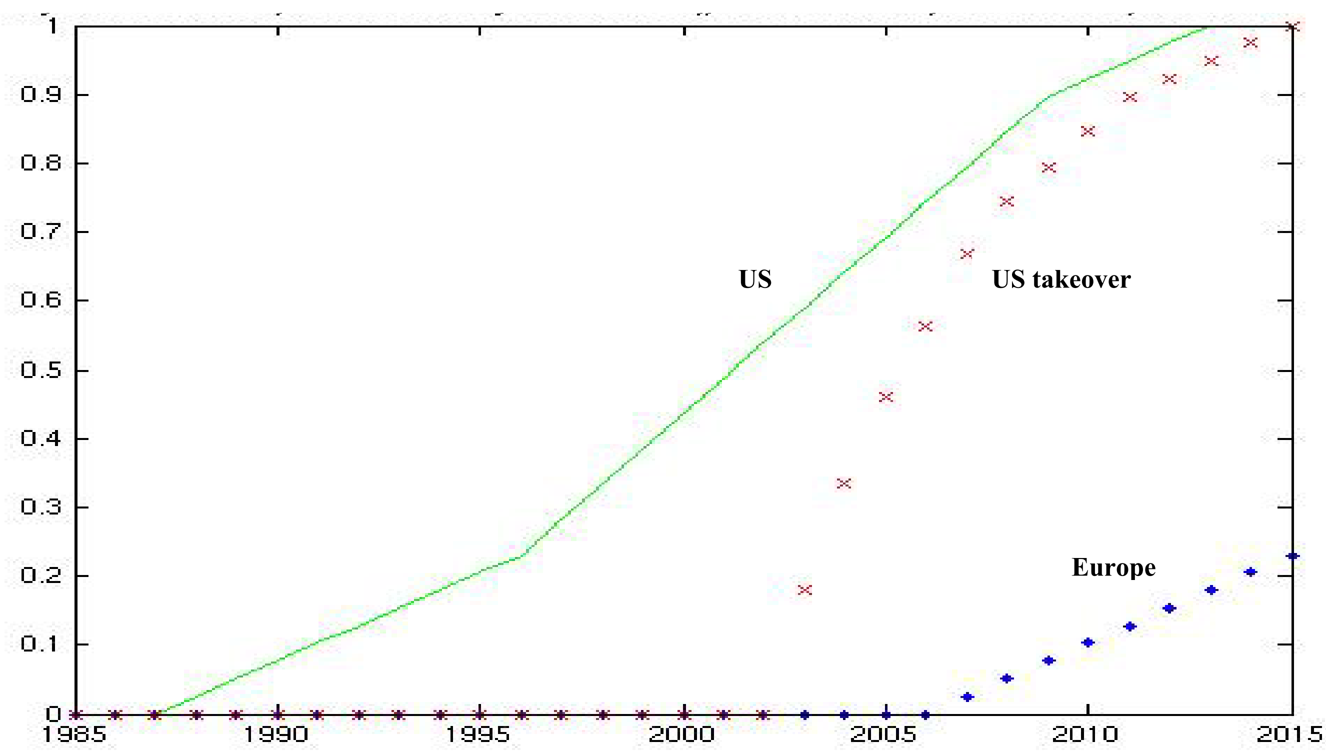
Notes: These are the results from the numerical simulation of the theoretical model 1985-2015 (with ten years before and after). See Appendix and texts for details.

Figure 8: Labor productivity (Q/L) in US and European firms, model results



Notes: These are the results from the numerical simulation of the theoretical model 1985-2015 (with ten years before and after). See Appendix and texts for details.

Figure 9: Decentralization (O) by firms taken over by US multinationals: model results



Notes: These are the results from the numerical simulation of the theoretical model 1985-2015 (with ten years before and after). See Appendix and texts for details. Decentralization is the value of O.

APPENDIX A: DATA AND ADDITIONAL RESULTS

A1 ESTABLISHMENT DATASET ABI

The Annual Business Inquiry (ABI) is the major source of establishment level data in the UK. It underlies the construction of aggregate output and investment in the national accounts and is conducted by the Office of National Statistics (ONS) the UK equivalent of the US Census Bureau. The ABI is a stratified random sample: sampling probabilities are higher for large establishments (e.g. 100% for all establishments with more than 250 employees). Each establishment has a unique "reporting unit reference number" (RUREF) which does not change when a plant is taken over by a new firm. Data on the production sector (including manufacturing) is in the ABI which has a long time series element (from 1980 and before in some cases). Data on the non-production sector (services) is available for a much shorter time period (from 1997 onwards). The sample is large: in 1998 there are 28,765 plants in the production sector alone.

The questionnaire sent out on the ABI is extensive and covers all the variables needed to estimate basic production functions. In particular it includes have gross output, value added, employment, wage bill, investment and total materials (this includes all intermediate inputs – energy, materials, etc.). The response rates to the ABI are high because it is illegal not to return the forms to the Office of National Statistics.

A2 INFORMATION TECHNOLOGY DATASETS

Overview

Working closely with statisticians and data collectors at ONS we combined the four major IT surveys and matched this into the ABI establishment data using the common establishment code (the Inter-Departmental Business Register, or IDBR). The three IT hardware surveys were not designed to cover exactly the same establishments as contained in the ABI survey, but because there is over-sampling of the larger establishments in all surveys the overlap is substantial, especially for the larger plants.

The main IT surveys include the Business Survey into Capitalized Items (BSCI), the Quarterly Inquiry into Capital Expenditure (QICE) and the Fixed Asset Register (FAR). The ABI also has additional questions on software included since 2000. These surveys are compiled at the reporting unit level, and contain information on the value (in thousands of pounds) of software and hardware acquisitions and disposals. Once the stocks are built within each different survey, we combine them across surveys and, for hardware and software separately, we build across-surveys stocks.[28] We have some concerns about the accuracy of the plant reports of software expenditure (we are currently investigating these), so we focus in the main part of the paper on the IT hardware stocks.

[28] We are careful to check for differences in coefficients due to the IT measures coming from different surveys. We could not reject the assumption that there were no significant differences in the IT coefficients arising from the fact that the IT stocks were built from different surveys.

In the following paragraphs we first describe the different surveys; we then illustrate the details of the Perpetual Inventory Method used for the construction of the capital stocks and the procedure followed to build across-surveys variables.

Data Sources

Business Survey into Capitalized Items (*BSCI).* The BSCI asks for detail of acquisitions and disposals of capital in more than 100 categories, including computer hardware and software. The survey is annual and runs between 1998 and 2003; we dropped the 1998 cross section due to concerns over reliability expressed by the data collectors. There is 100% sampling frame for the businesses with more than 750 employees and a stratified random sample of medium sized businesses (between 100 and 750 workers). The BSCI contributes about 1,500 to 2,000 observations for each year between 1999 and 2003.

Quarterly Inquiry into Capital Expenditure (QICE). The QICE provides information on hardware and software investments from 2000Q1 until 2003Q4. The inquiry selects 32,000 establishments each quarter. Of these 32,000 companies, all establishments with over 300 employees are selected each quarter. Businesses with fewer employees are selected for the inquiry randomly. Each quarter one fifth of the random sample is rotated out of the sample and a new fifth is rotated in. The quarterly data have been annualized in several alternative ways and we checked the robustness of the results across these. First, we extrapolated within year for establishments with missing quarters[29]. As a second alternative, we constructed an indicator that gives the number of non-missing values that exist for each year and establishment and included this as an additional control in the regressions. Third, we dropped observations constructed from less than four full quarters. The results were quite robust across all three methods and the Tables report results based on the first method.

Fixed Asset Register (FAR). The FAR asks for the historic cost (gross book value) of the fixed assets held on the firms' asset register, broken down by the years of acquisition. The survey provides information on IT hardware assets only, and covers the years 1995 up to 2000. The survey provides information for about 1,000 hardware observations.

Annual Business Inquiry (ABI). The ABI contains a question on software expenditures from 2000 onwards. There are approximately 20,000 non-zero returned values for software investments in each year.

Estimation of IT capital stocks

We build stocks of IT capital applying the Perpetual Inventory Method (PIM) to the IT investment data (and the non-IT investment data) described above. The basic PIM equation is:

$$K_{it}^{h} = I_{it}^{h} + \left(1-\delta^{h}\right)K_{it-1}^{h} \qquad \text{(B1)}$$

where I_t^h represents real investment of asset type *h* (e.g. computer hardware, I_t^C) and δ_t^h is the asset specific depreciation rate. To construct real investment we deflate nominal investments using the economy-wide (asset specific) hedonic price indices for software and hardware

[29] The extrapolation was done by simple averaging, but we also tried more sophisticated quarterly models taking into account the quarter surveyed. This made practically no difference.

provided by the NIESR (which are based on Jorgensen's US price deflators). We rebased to the year 2000 for consistency with the other PPI deflators (see below).

Estimation of TFP and capital services

To calculate the user cost (e.g. ρ^C is the rental price of IT capital) we use the Hall-Jorgensen formulation:

$$\rho_t^h = \frac{1 - A^h{}_t}{1 - T_t^h}[r_t + \delta_t^h - ((p_t^h - p_{t-1}^h)/p_{t-1}^h)]p_t^h \quad \text{(B2)}$$

where ρ^h is the rental price of asset class h, r is the nominal interest rate, δ is the depreciation rate of the asset, and p^h is the asset price. The tax parameters are given by A which is the present-discounted value of depreciation allowances, and T which is the rate of corporate profits tax. We obtained user costs from the data underlying Oulton and Srinivasan (2004) kindly provided by the authors. These are economy wide

We can then calculate total profits as[30]

$$\Pi_{it} = \sum_h \rho_t^h K^h{}_{it} \quad \text{(B3)}$$

The share of each asset class in revenue is then

$$s_{it}^h = \frac{\rho_t^h K^h{}_{it}}{\sum_h \rho_t^h K^h{}_{it}} \frac{\sum_h \rho_t^h K^h{}_{it}}{pY} = \frac{\rho_t^h K^h{}_{it}}{\Pi_{it}} \frac{\Pi_{it}}{p_t Y_{it}} \quad \text{(B4)}$$

that is used in calculating measured TFP in equation (7) and elsewhere.

Zeros

Both the BSCI and the QICE code missing values as zeros. While in the BSCI we are able to identify actual zero investments through a specific coding, for the QICE this is not possible. In the construction of the capital stocks we treated the zero investments observations as actual absence of IT investments. In the regressions we drop observations with zero IT capital stocks

Interpolations

In order to maximize the number of observations over which we could apply the PIM, we interpolated net investment observations for a single year of data if we observed investment the year before and the year afterwards. This affected only 2.8% of the observations in the regression sample and results are robust to dropping these observations.

Initial Conditions

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[30] Note that empirically there are alternative ways to approach equation (B3). Our preferred method is to calculate $s_{it}^h = \frac{\rho_t^h K^h{}_{it}}{\Pi_{it}} \frac{\hat{\Pi}_{it}}{p_t Q_{it}}$ where Π_{it} is taken from equation (B3) and $\hat{\Pi}_{it}$ is taken as the residual of revenues less materials and the wage bill.

In order to apply the PIM methodology, we need to approximate a starting value to start the recursion. We apply a similar methodology as the one devised by Martin (2005) to construct establishment level capital stocks in the ARD. For each firm, we first build two digit industry-specific IT Investment/Capital ratios using the NISEC02 industry level data-set provided by the NIESR, which contains separate time-series data on hardware and software capital stocks and runs up to 2001 (these are based on the input-output tables starting in 1975). We then use the ratio of the establishment's IT investment flow to the industry investment flow (denoted w_{it}^{A} for method "A") to impute the IT capital stock (i.e. we are assuming that the establishment's share of the IT capital stock in the industry is equal to the establishment's share of IT investment in the industry in the initial year). More precisely, we assume that for $t = 0$ only the initial plant level IT capital stock C_{i0}^{A} is:

$$C_{i0}^{A} = \mathrm{w}_{\mathrm{it}}^{\mathrm{A}}\,\mathrm{C}_{jt} \;\forall\; i \in j\,;\mathrm{w}_{\mathrm{it}}^{\mathrm{A}} = \left(\frac{I_{it}^{C}}{I_{jt}^{C}}\right)$$

where j represents an industry so a j sub-script represents an industry total – i.e. I_{jt}^{C} is total industry IT investment and C_{jt} is the total IT capital stock in time t. We apply this approximation to determine our initial condition in the first year that the establishment appears in our sample. For greenfield sites this is not an issue as their capital stock is zero. After the first year, we simply apply the PIM method.

Some of the establishments that we observe only for the first time may be investing systematically at a different rate from the industry average. To check whether our results were driven by the methodology used to build the initial conditions, we considered an alternative methodology based on employment weights (method "B"). For the first time we observed a plant in our sample we assumed that:

$$C_{i0}^{B} = w_{it-1}^{B} C_{jt-1}(1-\delta) + I_{it}^{C}$$

$$w_{it-1}^{B} = \frac{L_{it-1}}{L_{j-1}} \qquad \forall\, i \in j$$

So this is assuming that the establishment's share of the industry IT stock in the initial period is equal to the establishment's share of employment. Results are presented in Table A5 below and are consistent with the baseline method.

Depreciation

For all IT capital (software and hardware) we chose a depreciation rate of 36%. This choice is consistent with the analysis by methodology followed by the BEA which, in turn, derives from the study by Doms, Dunn, Oliner and Sichel (2004). In this study, the depreciation rate for PC's is estimated at approximately 50%, this value including both obsolescence and reevaluation effects. Since – as the BEA - we use real IT investments we have to use a lower depreciation rate to avoid double counting of the revaluation effect, included in the price deflators.

Basu et al (2003) argue that the true geometric rate of depreciation should be, in fact, approximately 30%. The significance and the magnitude of the coefficient obtained for both hardware and software are not affected by the exact choice of the alternative depreciation rate.

We also experimented with the extreme assumption of 100% depreciation rate for IT, thus working directly with the flows. Results are in Table A5 which shows a significant coefficient with a lower point estimate than in the main table (discussed below).

Across-Survey Stocks

Following the steps described above, we obtain hardware and software stocks within each different survey. We then matched our IT dataset with the ABI sample with non missing observations on other inputs and outputs (value added and gross output). In order to simplify the empirical analysis, we combined all the information of the different the surveys constructing overall across-surveys IT stocks for both hardware and software. Our strategy is to use the BSCI measure as the most reliable observation (as recommended by the data collectors). We then build our synthetic measure using the QICE stocks if the BSCI observation is missing or equal to zero and the QICE is different from zero. We finally use the FAR if both QICE and BSCI are missing and/or equal to zero and the FAR is not. For the software capital stock we also use the ABI information, following the same order described above. The sources of the aggregate capital stocks are summarized in the following table:

Source	**Hardware Capital**	**Software Capital**
BSCI	3,704	2,387
QICE	17,517	13,049
FAR	686	881
ABI	-	43,735

In order to keep track of the possible measurement error introduced using this procedure, we introduce in all the IT regressions a dummy that identifies the provenience of the observation for both the hardware and the software stocks. These dummies and their interactions with the IT coefficients are not significantly different from zero.

A small portion of the firms included in our dataset responded to more than one survey. We use some of this overlapping sample to get a better understanding of the measurement error in the data. By comparing the reports from the same establishments we calculate that there is much more measurement error for software than for hardware, which is why we currently focus on hardware. We did not find any evidence that the measurement error for hardware was different for US firms than other firms, however, which is reassuring.

A3 OTHER DATA

PPI deflators

We deflate gross output using the PPI deflators 2000 based provided by the ONS. For the manufacturing sector, the deflators are usually available at the 4 SIC digits level (MM17 PPI deflators). Whenever this was not the case, we used a general deflator for the 2 digit industry or a deflator relative to the overall manufacturing sector. For the service sector we used a set of experimental deflators generated by the ONS. These deflators refer to a limited number of 5 SIC digits industries. For all the other industries we use the general deflator for the overall service sector.

Skills

In our analysis we use industry and/or region and/or year specific skills measures built using the Labour Force Survey data set. Our preferred measure of skills is the proportion of people in the sample having as a highest qualification a degree or equivalent and/or a title defined as "higher education" by the standard LFS classifications (post GSE A levels), even though the results are not qualitatively different once we use only the proportion of people with a degree.

We use LFS data from 1993 to 2003. First, we keep only observations referring to people between 24 and 64 years. We drop observations for which no information is available on education. The cells over which the proportion is computed are defined by two digit industry, one digit region and year (we also considered four and three digit industry and area-only definitions). For each index, we drop observations that are based on less than 50 observations. We use the number of observations of the LFS cells as weights for the skills regressions. We also constructed similar datasets, containing information on education as well as wages and hours worked. These indexes are built only for observations having non-missing values for these additional variables.

Alternative IT measure from the E-Commerce Survey

The E-Commerce Survey was conducted in 2001, 2002 and 2003 with around 2,500 establishments in each cross section. Unfortunately these were random cross-sections so the overlap between years is minimal (preventing us from performing serious panel data analysis) Plant managers were directly asked "What proportion of your employees use a computer, workstation or terminal". To construct an estimate of the number of employees using IT we multiplied this proportion by the number of workers in the establishment. Although this is conceptually much cruder than the IT capital stock, it has the advantage that we do not have to rely so much on assumptions concerning the initial conditions. In Table 2 we discuss the results from this measure, showing very similar results to those obtained from using the IT capital measure.

A4 CLEANING

We used standard procedures to clean the ABI and the IT data. First, we dropped all observations with negative value added and/or capital stock. Secondly we dropped the top and bottom percentile of the distribution of $\frac{\Delta X}{X}$ for employment and gross value added. Thirdly, we dropped extreme values of total capital stock per employee and gross value added per employee. This step of the cleaning procedure was performed on the overall ARD sample.

We applied a similar cleaning procedure also to our across surveys IT variables. For hardware IT variables (investments and capital stocks) we dropped the top and bottom percentiles of the ratio of the variables on gross value added[31].

[31] The results of the regression are qualitatively similar if the IT data are cleaned using the ratio of investments per employee or stocks per employee.

A5 DEFINITION OF I.T. INTENSIVE USING INDUSTRIES

We focus on "IT intensive" sectors that are defined to be those that use IT intensively according to (Van Ark et al, 2002) who base their definitions on Stiroh (2002). The basic splits between industries that are intensive in "IT use" are based on the proportion of IT capital services in total capital services. This uses US data to calculate the service flows as these are more accurate than service flow calculations based on UK data. The industries are split based on the median proportion of IT capital service flows in total capital service flows.

The IT intensive using sectors are listed in Table A1. Note that the other "non-IT intensive" sectors include the sectors that produce IT intensively. We also considered these as a separate category but found in relation to their IT coefficients they were significantly different from the sectors that used IT intensively. All industries are based on ISIC Revision 3.

A6. TAKEOVERS

The identification of takeovers consists of three basic steps. First, for all the available years (1980-2003 for manufacturing and 1997-2003 for services) we combine all the raw ARD data relative to selected and non selected firms. We thus create a register file that allows us to keep track of the whole history of each firm, and exploit the uniqueness of the reporting unit reference number to correct for obvious reporting problems (i.e. firms that disappear in one year, and appear again after some time). Second, for each firm we keep track of changes in the foreign ownership information and the enterprise group reference number to identify foreign and domestic takeovers[32]. Third, to control for measurement error in the takeover identification, we drop from the sample firms that are subject to more than three takeovers during their whole history and firms that experience consecutive takeovers within a three year time period.

A7 ADDITIONAL ECONOMETRIC RESULTS

Table A4 gives some additional production function results comparing alternative econometric techniques. These alternative methods attempt to control for endogeneity of the regressors in the presence of correlated unobserved heterogeneity (the within group estimates in the main text treat the inputs as strictly exogenous). The econometric methods are System GMM (GMM-SYS) of Blundell and Bond (2000) and the Olley Pakes (1996) method.

Column (1) of Table A4 presents the results without fixed effects, but all other columns control for fixed effects. Across all specifications, all the factor inputs, including IT capital are positive and significant. In column (1) the sum of the coefficients on the factor shares is 0.99, very close to constant returns to scale. Column (2) includes a full set of 11,000 establishment specific fixed effects. The coefficients all remain significant at conventional levels. The coefficient on IT capital falls from 0.04 to 0.03, the coefficient on materials falls from 0.54 to 0.47. By contrast the coefficient on non-IT capital increases from 0.12 to 0.16 and the

[32] Foreign takeovers are observed if a firm experiences a change in the foreign ownership marker. Domestic takeovers are observed if a UK firm changes its enterprise reference number. See Griffith et al (2002) for more details on the methodology.

coefficient on labor rises from 0.29 to 0.32. Compared to many other results in the micro production function literature[33] the results here are reasonably stable when including fixed effects[34].

To implement the GMM system estimates we need to condition on a sample where we have at least three continuous time series observations (the OLS estimates keep all observations, even if we only observe an establishment for a single period). Column (3) conditions on the same sub-sample that we will estimate our GMM results on and re-runs the within groups estimate of column (2). The estimates are stable even after throwing away about three quarters of the sample. Column (4) presents the equivalent specification using GMM-SYS. The absence of higher order serial correlation and the failure of the Hansen-Sargan test to reject are consistent with the hypothesis that the instruments are valid. The coefficients on materials and non-IT capital fall and the coefficients on labour and IT capital rise compared to column (3). Column (5) implements a general dynamic model including lags of all the independent variables and the dependent variable. We then impose the common factor (COMFAC) restrictions by minimum distance and present these restricted estimates in the final column (note that we cannot reject the COMFAC restrictions as indicated by the diagnostics at the base of column (6)). The coefficient on IT (and the other factors) remains positive and significant with a coefficient of about 0.04 (similar to OLS levels in fact). Finally, column (6) implements a version of the Olley Pakes method. Although all the variables are significant at conventional levels this produces the lowest coefficient on IT capital in Table A4: 0.02.

[33] Griliches and Mairesse (1997), Olley and Pakes (1996) or Levinsohn and Petrin (2003)

[34] The transformation of variables into deviations from the industry mean helps stability and it may be that there is much less measurement error in this mandatory establishment survey than the typical firm study using accounting data.

TABLE A1: BREAKDOWN OF INDUSTRIES

We concentrate on sectors that had a higher than median ICT capital services proportion of total capital services. We denote these the "IT intensive using sectors" (Group 1) and choose an identical typology to those in Van Ark et al (2002) who follow Stiroh (2002). These can be sub-divided into manufacturing and services (we found similar results in both IT intensive manufacturing and IT intensive services). The other two broad sectors are IT producing sectors (Group 2) and non-IT intensive sectors (Group 3).

(Group 1) Sectors that intensively use ICT ("IT intensive using sectors")

IT-using manufacturing
18 Wearing apparel, dressing and dying of fur
22 Printing and publishing
29 Machinery and equipment
31, excl. 313 Electrical machinery and apparatus, excluding insulated wire
33, excl. 331 Precision and optical instruments, excluding IT instruments
351 Building and repairing of ships and boats
353 Aircraft and spacecraft
352+359 Railroad equipment and transport equipment
36-37 miscellaneous manufacturing and recycling

IT-using services
51 Wholesale trades
52 Retail trade
71 Renting of machinery and equipment
73 Research and development
741-743 Professional business services

(Group 2) Sectors that intensively produce ICT

IT-producing manufacturing
30 Office Machinery
313 Insulated wire
321 Electronic valves and tubes
322 Telecom equipment
323 radio and TV receivers
331 scientific instruments

IT producing services
64 Communications
72 Computer services and related activity

(Group 3) Non- IT Intensive Sectors)

Non-IT intensive manufacturing
15-16 Food drink and tobacco

17 Textiles
19 Leather and footwear
20 wood
21pulp and paper
23 mineral oil refining, coke and nuclear
24 chemicals
25 rubber and plastics
26 non-metallic mineral products
27 basic metals
28 fabricated metal products
34 motor vehicles

Non-IT Services
50 sale, maintenance and repair of motor vehicles
55 hotels and catering
60 Inland transport
61 Water transport
62 Air transport
63 Supporting transport services, travel agencies
70 Real estate
749 Other business activities n.e.c.

Non-IT intensive other sectors
10-14 Mining and quarrying
50-41 Utilities
45 Construction

Notes
This is the same three way division underlying Figure 2. Not all industries are represented because the ABI does not cover the public sector and the financial sector. Due to the dominance of state provision we also drop all industries relating to health and education.

TABLE A2 - SUMMARY STATISTICS SAMPLE (2001 CROSS SECTION)

All Firms

Variable	Frequency	Mean	Median	Standard Deviation
Employment	7495	795.91	238.00	3943.87
Gross Output	7495	84,475.46	20,053.00	445,039.30
Value Added	7495	28,440.95	6,765.64	167,510.40
Capital per worker	7495	84.03	46.97	112.70
Value Added per worker	7495	38.92	28.26	52.69
Gross Output per worker	7495	118.89	81.08	132.32
Total Materials per worker	7495	79.37	44.47	102.60
IT Capital/ Gross Output	7495	0.0103	0.0041	0.02
IT expenditure per worker	7495	0.39	0.14	0.87
IT capital	7495	989.65	76.55	10,548.86
Materials as a share of gross output	7495	0.57	0.59	0.24
Labor costs as a share of gross output	7495	0.32	0.28	0.22
ln(IT Capital)	7495	4.44	4.34	2.02

Notes: All monetary amounts are in sterling in year 2000 prices, deflated using ONS four SIC digit producer price indexes; firm level value added is constructed as the sum of turnover, variation of total stocks, work of capital nature by own staff, insurance claims received minus purchases; total stocks are constructed as described in the Appendix. All variables in units of 1000s except ratios and employment.

TABLE A3 - DESCRIPTIVE STATISTICS BROKEN DOWN BY MULTINATIONAL STATUS

Normalized to 100 for the SIC4 year mean							
		Employment	Value added per Employee	Gross output per Employee	Capital per Employee	Materials per Employee	IT Capital per Employee
US Multinationals							
	Mean	148.29	123.56	123.20	127.12	123.54	144.26
	St. Deviation	238.77	122.52	101.75	124.89	118.41	196.77
	Observations	569	569	569	569	569	569
Other Multinationals							
	Mean	145.83	111.97	113.00	117.28	113.09	117.89
	St. Deviation	216.97	93.35	75.47	112.72	98.48	155.57
	Observations	2185	2185	2185	2185	2185	2185
UK domestic							
	Mean	73.08	91.66	91.22	88.78	91.14	86.44
	St. Deviation	121.59	97.95	96.68	120.19	122.82	177.78
	Observations	4741	4741	4741	4741	4741	4741

Notes: These are 2001 values from our sample of 7495 establishments (4741 UK domestic establishments, 569 US multinationals and 2185 non-US multinationals.

TABLE A4 –PRODUCTION FUNCTIONS: ALTERNATIVE ECONOMETRIC ESTIMATORS

Estimation Method	(1) OLS, No FE	(2) OLS, FE	(3) OLS, FE	(4) GMM-SYS, Static	(5) GMM-SYS, Dynamic (Unrestricted)	(6) GMM-SYS COMFAC (Restricted)	(7) OLLEY-PAKES
				Dependent variable: ln(Gross Output)			
Ln(C_t) IT capital	0.0440*** (0.0023)	0.0299*** (0.0040)	0.0265*** (0.0063)	0.0391*** (0.0171)	0.0656* (0.0373)	0.0430** (0.0211)	0.0204*** (0.0030)
Ln(C_{t-1}) IT capital, lagged	-	-	-	-	-0.0343 (0.0242)	-	-
Ln(M_t) Materials	0.5384*** (0.0080)	0.4665*** (0.0193)	0.4702*** (0.0283)	0.3998*** (0.0402)	0.3293*** (0.0750)	0.3595*** (0.0494)	0.5562*** (0.0102)
Ln(M_{t-1}) Materials, lagged	-	-	-	-	-0.0715 (0.0534)	-	-
Ln(K_t) Non-IT Capital	0.1193*** (0.0063)	0.1650*** (0.0153)	0.1953*** (0.0234)	0.1584*** (0.0410)	0.3618*** (0.0869)	0.2937*** (0.0526)	0.1511*** (0.0115)
Ln(K_{t-1}) Non-IT Capital, lagged	-	-		-	-0.1815*** (0.0592)	-	
Ln(L_t) Labour	0.2868*** (0.0062)	0.3177*** (0.0198)	0.2979*** (0.0209)	0.4158*** (0.0479)	0.2981*** (0.0829)	0.3524*** (0.0560)	0.2611*** (0.0080)
Ln(L_{t-1}) Labour, lagged	-	-		-	0.0091 (0.0624)	-	
Ln(Y_{t-1}) Gross Output, lagged	-	-	-	-	0.2330*** (0.0581)	-	-
Rho, ρ	-	-	-	-	-	0.3488*** (0.0291)	-
Observations	22,736	22,736	6,763	6,763	6,763	6,763	12,069
Fixed effects	**NO**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1st order serial correlation test (p value)	-	-	-	-3.634 *(0.000)*	-5.223 *(0.000)*	-	-
2nd order serial correlation test (p value)	-	-	-	-0.239 *(0.811)*	0.953 *(0.341)*	-	-
Sargan-Hansen Test (p value)	-	-	-	34.38 *(0.354)*	24.65 *(0.852)*	-	
COMFAC (p value)	-	-	-	-	-	6.7474 *(0.1500)*	-

NOTES: * significant at 10%; ** significant at 5%; *** significant at 1%. The dependent variable in all columns is the log of gross output. The time period is 1995-2003. All variables are expressed in deviations from the 4 digit industry mean in the same year. Firm level value added is constructed as the sum of turnover, variation of total stocks, work of capital nature by own staff, insurance claims received minus purchases; total and IT capital stocks are constructed using the perpetual inventory method as described in the text. The estimation method in columns (1) through (3) is OLS (with fixed efefcts in columns (2) and (3); in columns (4) to (6) we use System-GMM (Blundell and Bond, 1998) and in column (7) we use Olley Pakes (1996). Standard errors in brackets under coefficients in all columns are clustered by establishment (i.e. robust to heteroskedacity and autocorrelation of unknown form). One step GMM results reported. All columns include age, foreign ownership and region dummies and a dummy taking value one if the firm belongs to a multi-firm enterprise group as additional controls. In columns (4) to (6) instruments are all plant level factor inputs lagged t-2 and before (when available) in the differenced equation (i.e. m_{t-2}, n_{t-2} ,k_{t-2},$c_{t-2,}$ q_{t-2}) and lagged differences in the levels equation (Δm_{t-1}, Δn_{t-1} , Δk_{t-1}, $\Delta c_{t-1,}$). Serial correlation tests are LM tests of the first differenced residuals (See Arellano and Bond, 1991). Sargan-Hansen Test of instrument validity is a test of the over-identification restrictions. Olley Pakes uses a fourth order series expansion to approximate the phi function. Standard errors in Olley-Pakes are block bootstrapped with 200 replications.

APPENDIX B: ECONOMETRIC MODELS

B.1 BASIC APPROACH

Re-consider the basic production function in equation (1) suppressing the tildas for simplicity

$$q_{it} = a_{it} + \alpha_{it}^{M} m_{it} + \alpha_{it}^{L} l_{it} + \alpha_{it}^{K} k_{it} + \alpha_{it}^{C} c_{it} \tag{A1}$$

We can exploit the fact that we have panel data on our plants and attempt to control for unobserved heterogeneity more rigorously. We attempt to deal with the endogeneity of the time varying inputs (IT capital, non-IT capital, labour and materials) through various panel data techniques for production functions (specifically System GMM and versions of Olley Pakes, 1996).

B.2 SYSTEM GMM

The basic equation we wish to estimate can be written in simplified form as

$$y_{it} = \theta x_{it} + u_{it} \tag{A2}$$

Where θ is the parameter of interest. Assume that the stochastic error term, u_{it}, takes the form

$$\begin{aligned} u_{it} &= \eta_i + \tau_t + \omega_{it} \\ \omega_{it} &= \rho \omega_{it-1} + \upsilon_{it} \end{aligned} \tag{A3}$$

The τ_t represent macro-economic shocks captured by a series of time dummies, η_i is an individual effect, and υ_{it} is a serially uncorrelated mean zero error term. The other element of the error term, ω_{it} is allowed to have an AR(1) component (with coefficient ρ) which could be due to measurement error or slowly evolving technological change. Substituting (A3) into (A2) gives us the dynamic equation

$$y_{it} = \pi_1 y_{it-1} + \pi_2 x_{it} + \pi_3 x_{it-1} + \eta^*{}_i + \tau^*{}_t + \upsilon_{it} \tag{A4}$$

The common factor restriction (COMFAC) is $\pi_1 \pi_2 = -\pi_3$. Note that $\tau^*{}_t = \tau_t - \rho \tau_{t-1}$ and $\eta_i^* = (1-\rho)\eta_i$.

In the main results section we present several econometric estimates of production functions (OLS, within groups and GMM). Blundell and Bond (1998) recommend a system GMM approach to estimate equation (A4) and impose the COMFAC restrictions by minimum distance. If we allow inputs to be endogenous we will require instrumental variables. In the absence of any obvious natural experiments we consider moment conditions that will enable us to construct a GMM estimator for equation (A4). A common method would be to take first differences of (A4) to sweep out the fixed effects:

$$\Delta y_{it} = \pi_1 \Delta y_{it-1} + \pi_2 \Delta x_{it} + \pi_3 \Delta x_{it-1} + \Delta \tau_t + \Delta \upsilon_{it} \tag{A5}$$

Since υ_{it} is serially uncorrelated the moment condition

$$E(x_{it-2} \Delta \upsilon_{it}) = 0 \tag{A6}$$

ensures that instruments dated t-2 and earlier[35] are valid and can be used to construct a GMM estimator for equation (4) in first differences (Arellano and Bond, 1991). A problem with this estimator is that variables with a high degree of persistence over time (such as capital) will have very low correlation between their first difference (Δx_{it}) and the lagged levels being used an instrument (e.g. x_{it-2}). This problem of weak instruments can lead to substantial bias in finite samples. Blundell and Bond (1998) point out that under a restriction on the initial conditions another set of moment conditions are available[36]:

$$E(\Delta x_{it-1}(\eta_i + \upsilon_{it})) = 0 \tag{A7}$$

This implies that lags of the first differences of the endogenous variables can be used to instrument the levels equation (A4) directly. The econometric strategy is then to combine the instruments implied by the moment conditions (A6) and (A7). We stack the equations in differences and levels (i.e. (A4) and (A5)). We can obtain consistent estimates of the coefficients and use these to recover the underlying structural parameters in (A2).

The estimation strategy assumes the absence of serial correlation in the levels error terms (υ_{it})[37]. We report serial correlation tests in addition to the Sargan-Hansen test of the over-identifying restrictions in all the GMM results[38].

This GMM "system" estimator has been found to perform well in Monte Carlo simulations and in the context of the estimation of production functions. The procedure should also be a way of controlling for transitory measurement error (the fixed effects control for permanent measurement error).

B.3 OLLEY PAKES

Reconsider the basic production function[39]

$$q_{it} = \alpha^L l_{it} + \alpha^M m_{it} + \alpha^K k_{it} + \alpha^C c_{it} + \omega_{it} + \eta_{it} \tag{A8}$$

The "efficiency term", ω_{it}, is the unobserved productivity state that will be correlated with both output and the variable input decision and η_{it} is an i.i.d. error term (either measurement error

[35] Additional instruments dated t-3, t-4, etc. become available as the panel progresses through time.

[36] The conditions are that the initial change in productivity is uncorrelated with the fixed effect $E(\Delta y_{i2} \eta_i) = 0$ and that initial changes in the endogenous variables are also uncorrelated with the fixed effect $E(\Delta x_{i2} \eta_i) = 0$

[37] If the process is MA(1) instead of MA(0) then the moment conditions in (A6) and (A7) no longer hold. Nevertheless $E(x_{it-3} \Delta \upsilon_{it}) = 0$ and $E(\Delta x_{it-2}(\eta_i + \upsilon_{it})) = 0$ remain valid so earlier dated lags could still be used as instruments. This is the situation empirically with the wage equations.

[38] These are based on the first differenced residuals so we expect significant first order serial correlation but require zero second order serial correlation for the instruments to be valid. If there is significant second order correlation we need to drop the instruments back a further time period.

[39] For notational simplicity we abstract from plant age, but this we consider this in the implement this in the estimation routine along the same lines as Olley and Pakes (1996).

or an unforecastable shock to productivity). We assume that both capital stocks are predetermined and current investment (which will react to productivity shocks) takes one period before it becomes productive, i.e. $I_{it}^{K} = I_{t-1}^{K} + (1-\delta^{K})K_{it-1}$ and $I_{it}^{C} = I_{t-1}^{C} + (1-\delta^{C})C_{it-1}$.

It can be shown that the investment policy functions for IT and non-IT are monotonic in non-IT capital, IT capital and the unobserved productivity state.

$i_{it}^{K} = i^{K}(k_{it}, c_{it}, \omega_{it})$

$i_{it}^{C} = i^{C}(k_{it}, c_{it}, \omega_{it})$

The investment policy rule can therefore be inverted to express ω_{it} as a function of investment and capital. We choose to focus on the non-IT investment policy function which is inverted to obtain the proxy:

$\omega_{t}^{K}(i_{it}^{K}, k_{it}, c_{it})$

The first stage of the OP algorithm uses this invertibility result to re-express the production function as:

$$y_{it} = \alpha^{L} l_{it} + \alpha^{M} m_{it} + \alpha^{K} k_{it} + \alpha^{C} c_{it} + \omega_{t}^{K}(i_{it}^{K}, k_{it}, c_{it}) + \eta_{it} = \alpha^{L} l_{it} + \alpha^{M} m_{it} + \phi(i_{it}^{K}, k_{it}, c_{it}) + \eta_{it}$$

where $\phi(i_{it}^{K}, k_{it}, c_{it}) = \phi_{t} = \omega_{t}^{K}(i_{it}^{K}, k_{it}, c_{it}) + \alpha^{K} k_{it} + \alpha^{K} c_{it}$

We approximate this function with a series estimator that previous applications have shown to be close to the fully non-parametric approximation. We can use this first stage results to get estimates of the coefficients on the variable inputs. The second stage of the OP algorithm is

$$y_{it}* = y_{it} - \alpha^{L} l_{it} - \alpha^{M} m_{it} = \alpha^{K} k_{it} + \alpha^{C} c_{it} + \omega_{it} + \eta_{it}$$

Note that the expectation of productivity conditional on last period's information set (denoted Ω_{t-1}) is

$$\omega_{it} |_{\chi_{it}=1} = E[\omega_{it} \mid \omega_{it-1}, \chi_{it} = 1] + \xi_{it}$$

where $\chi_{it} = 1$ indicates that the firm has chosen not to shut down (in the empirical results we experiment with also allowing for a selection stage over the decision to exit). This expression for the productivity state follows from the assumption that unobserved productivity evolves as a first order Markov process. Again we assume that we can approximate this relationship with a high order series approximation g(ω_{it-1}).

Substituting this in to the "second stage" and taking expectations conditional on last period's information set gives us

$$E(y_{it}* \mid \Omega_{t-1}) = \alpha^{K} k_{it} + \alpha^{C} c_{it} + g[\phi(i_{it-1}^{K}, k_{it-1}, \alpha^{C} c_{it-1}) - \alpha^{K} k_{it-1} - \alpha^{C} c_{it-1}]$$

Since we already have in hand estimates of the ϕ_{t-1} function this amounts to estimating by Non-Linear Least Squares (NLLS). This now gives us all the relevant parameters of the production function.

There are numerous extensions to the basic Olley-Pakes methodology that have been suggested. One we considered was the additional selection correction originally suggested by the authors, but this made little difference to the results so the tables report the non-selectivity corrected results.