

Abstract

This paper investigates whether there is convergence in Total Factor Productivity towards the technological frontier at the establishment level. We find convergence to the frontier is statistically and quantitatively important, suggesting the existence of technology spillovers. Foreign multinationals make up a significant proportion of establishments at the technological frontier, and therefore make a contribution to productivity growth through technology transfer. We also find evidence that increased foreign presence within an industry raises the speed of convergence to the technological frontier.

JEL Classification: F23, O33, O47

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Productivity Convergence and Foreign Ownership at the Establishment Level

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Introduction	2
2. The Model	6
2.1 TFP growth and technology transfer	6
2.2 The role of foreign firms	8
3. Data and Econometric Issues	10
3.1 Data	10
3.2 Measuring growth and relative levels of TFP	12
3.3 The technological frontier	15
3.4 Econometric specification	18
4. Empirical Results	19
4.1 Productivity dynamics	19
4.2 The role of foreign firms	20
5. Conclusions	23
References	25
Figure	29
Tables	30

1 Introduction

Throughout the 1970s productivity levels and growth rates in the UK lagged behind those of the US. The 1980s in the UK saw a period of rapid growth and led to a reduction in the technology gap with the US (see Figure 1). The 1970s and 1980s were also a time when the British economy was becoming increasingly open to international competition. By 1980 the British government had removed exchange controls and had joined the European Economic Community. By the late 1980s Britain was embarking on the EU Single Market Program which aimed to improve the international mobility of capital. This opening up of the UK economy was expected to bring increased growth through a number of routes, one of which was technology transfer from the US and other more technologically advanced economies, facilitated by the presence and entry of foreign-owned multinationals employing superior production techniques within the UK. In this paper we investigate the role foreign firms played in the productivity growth of domestic establishments using a model derived from the new growth literature and apply it to panel data on UK production establishments from 1980-1992.

From the early literature of Vernon (1966), Dunning (1977) and Caves (1974) it has been suggested that multinational firms may be an important source of technology diffusion. The endogenous growth and new trade literatures focus on the role multinational firms play in transferring technology from the frontier to technologically less advanced economies. Empirical work, largely at the aggregate level, has identified correlations between the openness of an economy and growth in Total Factor Productivity (TFP).¹ Empirical literature using cross-country data at the industry level suggests that less technologically advanced countries catch up to the technological

¹See, *inter alia*, Barrell and Pain (1997); Cameron, Proudman and Redding (1998); studies using micro-data include Blomstrom and Persson (1983), Davies and Lyons (1991), Globerman (1979).

frontier. Various metrics have been identified including trade, R&D, patent citations and FDI. But most authors have remained agnostic as to the precise mechanism by which these affect TFP.² In this paper we use a model derived explicitly from theory to investigate the dynamics of productivity growth in UK manufacturing establishments over the period 1980 to 1992 and the role played by foreign multinationals.

The predominant model of the multinational firm focuses on the role played by intangible assets.³ It is typically more costly for firms to operate abroad than domestically. Local firms have superior knowledge of local markets, consumer preferences and business practices. Foreign firms must therefore have some other advantage over domestic firms in order to compete. This can be in the form of higher productivity levels, or through greater market power, for example through owning a patent. In addition, the firm must have some incentive to internalize the technology and not license it to foreign producers, for example due to the moral hazard problem arising from asymmetric information between the owner of the technology and the licensee and the inability to write an enforceable contract.⁴ Further, the firm must have an incentive to locate production in the host country rather than supplying foreign markets through international trade.⁵

There are several mechanisms by which inward foreign investment can affect either the level or growth rate of domestic productivity. Here we focus on two. First, foreign firms may introduce new technologies into the UK. Demonstration effects mean that domestic firms may be able to imitate the technology used by foreign firms more

²Examples of cross-country work are Coe and Helpman (1995), Jaffe and Trajtenberg (1998), and Eaton and Kortum (1999). Industry-level studies include Bernard and Jones (1996a,b), Cameron (1996), Cameron, Proudman, and Redding (1998), Griffith, Redding, and Van Reenen (2001a), and Keller (2000).

³As well as the early literature mentioned above, more recent work includes Helpman and Krugman (1985), Grossman and Helpman (1993), Caves (1996), Markusen (2002) and Markusen and Venables (1998, 2000).

⁴See, in particular, Hart (1995).

⁵See, for example, Brainard (1997).

easily once the foreign firm is located in the domestic market. Second, foreign firms may increase competitive pressure in the domestic product market, and may broaden the market by opening up access to foreign markets.

Empirical work looking at the impact of foreign-owned establishments on the productivity of domestic-owned establishments has yielded mixed results. The existing literature typically regresses productivity levels or growth rates on a measure of foreign presence in an industry, such as the share of foreign firms in employment, sales, or the total number of firms.⁶

In this paper, we take an alternative approach to estimating the impact of foreign direct investment on productivity growth of domestic firms that uses an establishment's distance from the technological frontier as a direct measure of the potential for technology transfer. This allows for knowledge spillovers from both foreign-owned multinationals and highly productive domestic firms (including domestic multinationals which may be sourcing technologies from abroad). We apply techniques and ideas from the literature on knowledge spillovers at the country and industry-level to establishment-level data, and extend the approach to analyze the effects of foreign ownership.

Careful attention is paid to issues of productivity measurement and the robustness of results across a variety of econometric specifications. We measure relative total factor productivity (TFP) using the superlative index of Caves et al (1982a,b) which is consistent with a translog production function. This allows us to measure the growth rate of TFP or to measure the relative level of TFP across establishments within

⁶Aitken and Harrison (1999) use panel data on Venezuelan firms and find that there are no externalities to domestic firms from foreign investment; gains from foreign investment are fully captured by joint ventures. Other empirical studies include Blomstrom (1989), Globerman (1979), Görg and Strobl (2001), Keller and Yeaple (2002), and Teece (1977). Work that has looked at this issue in the context of the UK includes Haskel, Pereira and Slaughter (2002), Girma and Wakelin (2000), Görg and Greenaway (2002), and Harris and Robinson (2002).

four-digit industries. The technological frontier is defined by the establishment with the highest level of relative TFP within an industry in Great Britain, although we experiment with alternative definitions. Across all these definitions, we find strong evidence of convergence in productivity towards the technological frontier.

While cross-country evidence has shown that UK manufacturing industries lag behind the international technological frontier in many sectors (as shown in Figure 1), the picture is somewhat different when we look within Great Britain. In our sample, the frontier is a foreign-owned establishment in around a fifth of 4-digit industry-year observations, (see column 2 of Table 2 below for more detail). The fact that both foreign and UK-owned establishments are found to be technological leaders accords with recent work that has shown that UK-owned multinationals have equally high productivity as foreign multinationals when operating in the UK.⁷

Our findings suggest that foreign multinationals do play a role in the convergence process, as do other high productivity UK-owned firms. In addition to the role played by foreign-owned firms as technological leaders, we find that increased foreign presence within an industry is correlated with productivity growth in domestic-owned establishments through an increased speed of technology transfer. This is consistent with foreign presence stimulating competition and increasing incentives to adopt new technologies.

The structure of the paper is as follows. Section 2 outlines the model and some methodological issues involved in measuring total factor productivity. Section 3 discusses the data and a number of measurement and econometric issues. It then presents some descriptive statistics on TFP growth and the presence of foreign-owned firms in British manufacturing industries. In section 4 econometric results are presented.

⁷See Criscuolo and Martin (2002) and Griffith, Simpson and Windmeijer (2002) for the UK and Doms and Jensen (1998) for the US and Globerman (1979) for Canada.

We begin by showing that the model of technological convergence describes establishment level productivity dynamics well, and then turn to a consideration of the role of foreign multinationals in host country productivity growth. A final section concludes.

2 The Model

We begin by developing a general model of technological convergence and productivity growth, in which the distance an establishment is from the technological frontier is used as a direct measure of the potential for technology transfer.⁸ The framework is then extended to examine the role of foreign ownership. Foreign firms may have direct effects on productivity growth in so far as they advance the technological frontier within industries. Using our framework, it is also possible to examine whether the presence of foreign firms has an additional direct effect on rates of productivity growth (through, for example, stimulating innovation or eliminating X-inefficiency) or an indirect effect through raising the speed of technology transfer (an effect that depends on an establishment's distance from the technological frontier).

2.1 TFP growth and technology transfer

Consider a general neoclassical production technology,

$$Y_{it} = A_{it}F_{jt}(X_{it}) \tag{1}$$

where i indexes establishments, j indexes industry, t indexes time, Y is output, X is a vector of inputs including numbers employed, physical capital, and intermediate inputs, and A is an index of technical efficiency or Total Factor Productivity (TFP).

$F_{jt}(\cdot)$ is assumed to be homogeneous of degree one, to exhibit diminishing marginal

⁸Here, we build on a literature that has used models of this form at the country and industry-level (see, for example, Bernard and Jones 1996a, 1996b; Cameron 1996; Cameron, Proudman, and Redding 1998; and Griffith, Redding, and Van Reenen 2001b). Despite the rich sources of information available, there has been little research using models of this form with establishment-level data.

returns to the accumulation of each factor alone, and is allowed to vary across four-digit industries and time.

We begin by considering a very general specification of knowledge spillovers. Denote the technological frontier in sector j at time t by A_{jt}^F . TFP in a non-frontier establishment i is assumed to be related to the frontier according to the following ADL(1,1) cointegrating relationship,

$$\ln A_{it} = \alpha_1 \ln A_{it-1} + \alpha_2 \ln A_{jt}^F + \alpha_3 \ln A_{jt-1}^F + u_{it} \quad (2)$$

where u_{it} is a stochastic error (including establishment and time effects). This specification has many attractive statistical properties.⁹ Under the assumption of long-run homogeneity ($\alpha_2 + \alpha_3 = 1 - \alpha_1$), the relationship has the following Equilibrium Correction Model (ECM) representation,

$$\Delta \ln A_{it} = \beta \Delta \ln A_{jt}^F + \delta \ln \left(\frac{A_j^F}{A_i} \right)_{t-1} + u_{it} \quad (3)$$

where $\beta = \alpha_2$ and $\delta = (1 - \alpha_1)$.

Intuitively, the terms on the right-hand side of (3) capture technology transfer.¹⁰ The first term ($\Delta \ln A_{jt}^F$) allows TFP growth in the frontier to have a direct effect on TFP growth in non-frontier establishments. This provides a flexible specification of the TFP growth process.¹¹ The second term $\left(\ln (A_j^F/A_i)_{t-1} \right)$ corresponds to the distance a non-frontier establishment lies behind the technological frontier (the size of the technology gap). The further behind the frontier, the larger the value of $\ln(A_j^F/A_i)_{t-1}$, and the greater the potential for technology to be transferred. Hence, technology transfer implies a positive estimated coefficient on the technology gap

⁹See, for example, Hendry (1996).

¹⁰Griffith, Redding, and Van Reenen (2001b) show that an equation of this form can be derived from a general equilibrium model of endogenous growth through increasing productivity following Aghion and Howitt (1992, 1997).

¹¹As a robustness test, we also re-estimated the model without the $\Delta \ln A_{jt}^F$ term. This corresponds to a special case of the ADL(1,1) specification where $\alpha_2 = 0$.

(δ). The parameter δ captures the speed of technology transfer, while β captures the strength of the direct link between TFP growth in non-frontier establishments and growth in the frontier.

Within this framework, what is important is not the *identity* of the technological frontier *per se* but the measure of *distance from the technological frontier* that is used to capture the potential for technology transfer. In steady-state, all non-frontier establishments will lie an equilibrium distance behind the technological frontier such that their rate of productivity growth exactly equals the frontier's. There is thus a steady-state distribution of heterogeneous productivities across establishments, and the model allows for endogenous changes in the technological frontier over time.¹²

2.2 The role of foreign firms

The model above provides a structural framework within which to look at the dynamics of productivity growth and the role played by technology transfer. To look at the role played by foreign firms in this process we extend this framework in a number of dimensions.

The first is to note that, to the extent that foreign establishments located within the UK have higher levels of TFP than domestic-owned establishments, they will push the frontier out, and thereby raise the potential for productivity growth in non-frontier establishments through technology transfer. That is, the technology gap $\ln(A_j^F/A_i)$ will be larger than in the absence of foreign-owned establishments within the UK. As noted above, this is the case in 19 percent of observations. One way to quantify the importance of this effect is to calculate how much lower productivity growth rates

¹²The steady-state distribution of productivities will depend, in part, on the unobserved characteristics of establishments captured in the establishment fixed effect. The model is thus consistent with the empirical literature which has documented heterogeneity in productivity within industries. See, for example, Bernard and Jensen (1999) for the US; Disney et al. (2000) for the UK; and the survey by Bartelsman and Doms (2000).

would have been if foreign establishments had not been present, assuming that foreign firms have no other impact on TFP growth rates. Let A_j^{F*} denote the frontier in the absence of foreign firms, then the benefit to growth in domestic firms from foreign firms pushing the frontier out is

$$\begin{aligned} & \delta \left[\ln \left(\frac{A_j^F}{A_j} \right) - \ln \left(\frac{A_j^{F*}}{A_j} \right) \right] \\ &= \delta \ln \left(\frac{A_j^F}{A_j^{F*}} \right). \end{aligned}$$

Second, we allow for the possibility that the presence of foreign firms within an industry may have additional effects on UK productivity growth. For example, foreign presence may stimulate competition and enhance incentives to innovate, to eliminate X-inefficiency, or to adopt existing technologies, leading to productivity improvements in domestic-owned firms.¹³ To explore the potential importance of these effects, we augment the model introduced above with a measure of foreign presence and with foreign presence interacted with the distance from the technological frontier:

$$\Delta \ln A_{it} = \beta \Delta \ln A_{jt}^F + \gamma Fo_{jt-1} + (\delta_1 + \delta_2 Fo_{jt-1}) \ln \left(\frac{A_j^F}{A_i} \right)_{t-1} + u_{it} \quad (4)$$

where Fo denotes the proportion of employment in foreign firms in the industry.¹⁴ A positive value of γ implies a positive direct effect of foreign presence on TFP growth, while a positive value of δ_2 implies that increased foreign presence raises the rate of technology transfer from the frontier.

The first of these terms (Fo) is comparable with those included in the existing literature and captures a direct effect of foreign presence on the productivity growth

¹³Kinoshita (2000) argues that the effect of foreign presence may depend on domestic firms R&D activity. Other studies emphasizing ‘absorptive capacity’ include Griffith, Redding, and Van Reenen (2001a) and Girma (2002).

¹⁴We also experiment with the proportion of sales accounted for by foreign firms and the total number of foreign firms. These alternative measures of foreign presence within an industry are highly correlated and yield similar results.

of domestic-owned host country establishments, for example through increased rates of innovation or the elimination of X-inefficiency. However, this literature omits the terms in distance from the technological frontier and distance from the technological frontier interacted with foreign ownership, which we show empirically to be important as determinants of productivity growth.

3 Data and Econometric Issues

3.1 Data

We use establishment level data from the ARD dataset made available by the Office of National Statistics (ONS). There are two parts to the ARD. Basic information (employment, ownership structure) is available on all plants located in the UK. More detailed data is available on all production establishments with more than 100 employees and for a stratified sample of smaller establishments.¹⁵ All of our results use sampling weights to correct for this. The smallest entity reported in the ARD is called a local unit, which is effectively a plant (it is a single address). However, only the basic information listed above is available at the local unit level. We, therefore, work with data at the establishment level where the more detailed information is available. Establishments correspond roughly to ‘lines of business’ of firms, the level at which it is plausible economic decisions are made. An establishment can be a single plant or a group of plants operating in the same four-digit industry; the number of plants accounted for by each establishment is reported. Establishments can be linked through common ownership, and there is an enterprise code with this information.¹⁶ The country of residence of the ultimate owner of the establishment is also listed in the

¹⁵The cut off point over which the population of establishments is sampled increases from 100 in later years. For further discussion of the ARD see Griffith (1999), Oulton (1997) and Barnes and Martin (2002).

¹⁶The ARD data are on production activity, and only production activity undertaken in the UK is reported.

data. This is collected every year by the ONS from the Dun and Bradstreet publication Who Owns Whom. Output, investment, employment and wages by occupation, and intermediate inputs are reported in nominal terms for each establishment.

The detailed data is available on a sample of over 13,000 establishments per year and covers over 200 four-digit production industries. We use data for Great Britain from 1980 to 1992 for the manufacturing sector. In the calculation of TFP we use information on gross output, capital expenditure, intermediate inputs, and on skilled (Administrative, Technical and Clerical workers) and unskilled (Operatives) workers and wages. From other sources price deflators for output and intermediate goods are available at the 4-digit industry level. Price indices for investment in plant and machinery are available at the 2-digit level and for investment in buildings, land and vehicles at the aggregate level. Capital stock data is constructed using the perpetual inventory method with the initial value of the capital stock estimated using industry level data.

There are several important advantages of the ARD for analyzing the effects of foreign-owned firms on domestic productivity growth. One is that direct information on the production activity of foreign firms is available. A number of existing studies analyze the effects of foreign ownership using data on financial flows of foreign direct investment (FDI). These are subject to a number of problems including the repatriation of profits and transfer-pricing (see for example the discussion in Griffith, 1999). The availability of direct information on production activity in foreign-owned firms located in the UK avoids these problems. Second, in the ARD we observe the population of both foreign and domestic-owned manufacturing plants in Great Britain, which can be used to create measures of foreign-presence. Third, the ARD contains more detailed information on both outputs and inputs than typically available in many productivity studies, and the analysis is undertaken at a more disaggregated

level than the two or three-digit sectors often considered in industry-level studies. This enables us to control for a number of sources of measurement error and aggregation bias suggested in the literature on productivity measurement. Finally, response to the survey is compulsory and therefore there is effectively no bias from non-random responses. We use a cleaned up sample of establishments that conditions on establishments being sampled for at least 5 consecutive years.¹⁷ Measurement error is likely to be larger in smaller establishments, and therefore we also weight observations by employment.

3.2 Measuring growth and relative levels of TFP

We calculate the growth rate of TFP (ΔTFP_{it} , the empirical counterpart to $\Delta \ln A_{it}$) and the level of TFP in establishment i relative to the frontier in industry j ($TFPGAP_{it}$, the empirical counterpart to $\ln(A_j^F/A_i)_t$) using the superlative index number approach of Caves et. al. (1982a,b), which allows for a flexible specification of the production technology. A standard benchmark TFP measure in the productivity literature uses value-added for output with employment and the stock of physical capital for inputs. We consider a number of extensions and adjustments to this benchmark measure in order to control for a variety of potential sources of measurement error. As noted above, one of the strengths of the ARD dataset is the large amount of disaggregated information available on output and factor inputs. Our preferred TFP measure controls for measurement error in the share of labour, for intermediate inputs, and for establishment-specific variation over time in the skill composition of the workforce.

¹⁷We drop very small 4-digit industries (with less than 30 establishments) in order to implement our procedure for smoothing factor shares (described in the next section), and drop small establishments (with less than 20 employees). We also apply some standard data cleaning procedures. We drop plants with negative value added, remove the top and bottom percentile of plants by the growth rate of output, employment, intermediate inputs and capital stock, and condition on the sum of the shares of intermediate inputs, skilled and unskilled workers in output being between 0 and 1.

TFP growth is measured by a superlative index derived from the translog production function,

$$\Delta TFP_{it} = \Delta \ln Y_{it} - \sum_{z=1}^Z \tilde{\alpha}_{it}^z \Delta \ln x_{it}^z \quad (5)$$

where Y denotes output, x^z is use of factor of production z , $\tilde{\alpha}_t^z$ is the Divisia share of output ($\tilde{\alpha}_{it}^z = (\alpha_{it}^z + \alpha_{it-1}^z)/2$ where α_{it}^z is the share of the factor in output at time t), Z is the number of factors of production, and we impose constant returns to scale ($\sum_z \tilde{\alpha}_{it}^z = 1$). The factors of production included in Z are intermediate inputs, the stock of physical capital, and skilled and unskilled workers.

One problem we face in measuring TFP is that the shares of factors of production in output α_{it}^z are quite volatile. This is suggestive of measurement error, and we therefore follow Harrigan (1997) in exploiting the properties of the translog production function to smooth the observed factor shares. Under the assumption of a translog production technology, constant returns to scale, and standard market-clearing conditions, α_{it}^z can be expressed as the following function of relative factor input use,¹⁸

$$\alpha_{it}^z = \xi_i + \sum_{z=2}^Z \phi_j^z \ln \left(\frac{x_{it}^z}{x_{it}^1} \right) \quad (6)$$

where ξ_i is an establishment-specific constant and where, when imposing constant returns to scale, we have normalized relative to factor of production 1. If actual factor shares deviate from their true values by an i.i.d. measurement error term, then the parameters of this equation can be estimated by fixed effects panel data estimation, where we allow the coefficients on relative factor input use to vary across 4-digit industries j . The fitted values from this equation are used as the factor shares in our calculation of (5) and below.

The level of TFP is measured using an analogous superlative index number where

¹⁸See Caves *et al.* (1982b) and Harrigan (1997).

TFP in each establishment is evaluated relative to a common reference point - the geometric mean of all other establishments in the same industry-year. The measure of relative TFP is,

$$MTFP_{it} = \ln \left(\frac{Y_{it}}{\bar{Y}_{jt}} \right) - \sum_{z=1}^Z \sigma_{it}^z \ln \left(\frac{x_{it}^z}{\bar{x}_{jt}^z} \right) \quad (7a)$$

where a bar above a variable denotes a geometric mean; that is, \bar{Y}_{jt} and \bar{x}_{jt} , are the geometric means of output and use of factor of production z in industry j at time t respectively. The variable $\sigma_{it}^z = (\alpha_{it}^z + \bar{\alpha}_{jt}^z)/2$ is the average of the factor share in establishment i and the geometric mean factor share. The properties of the translog production function are again exploited to smooth observed factor shares (see equation (6) above), and we impose constant returns to scale ($\sum_z \sigma_{it}^z = 1$).

Denote the frontier level of TFP relative to the geometric mean $MTFP_{jt}^F$. Subtracting $MTFP_{it}$ from $MTFP_{jt}^F$, we obtain a superlative index number measure of an establishment's distance from the technological frontier in an industry-year. This is denoted by $TFPGAP_{it}$ and is the empirical counterpart to $\ln(A_j^F/A_i)_t$ in the theoretical section above,¹⁹

$$TFPGAP_{it} = MTFP_{jt}^F - MTFP_{it}. \quad (8)$$

Table 1 provides information on productivity growth in establishments in our estimation sample by industry. Column 3 shows the mean annual growth rate of TFP across domestic-owned, non-frontier establishments observed in at least five consecutive time periods, over the period 1980 to 1992. For this set of establishments, some industries report negative average TFP growth rates during the period. This is largely driven by the recession at the end of our sample period, and is consistent

¹⁹Note that equation (7a) may be used to obtain a bilateral measure of relative TFP in any two establishments a and b . Since we begin by measuring TFP compared to a common reference point (the geometric mean of all establishments), these bilateral measures of relative TFP are transitive.

with the findings of industry-level studies for the UK and other countries.²⁰ We find that average annual TFP growth is fastest over the period 1980 to 1988 at 0.9%, as shown in column 4 of the same table. Labour productivity growth averages 2.7% per annum over the whole period, as shown in column 2. In our econometric specification, we explicitly control for the effects of the two recessions over this period and macroeconomic shocks on TFP growth by including a full set of time dummies.

3.3 The technological frontier

We begin by using the establishment with the highest level of TFP to define the technological frontier. This approach has the advantages of simplicity and of being close to the structure of the model. Another attraction is that it potentially allows for endogenous changes in the technological frontier, as one establishment first catches up and then overtakes the establishment with the highest initial level of measured TFP.

One problem is that year on year fluctuations in measured TFP may be in part due to measurement error. This could lead to mis-measurement in the location of the frontier. The rich source of information that we have on establishments in the ARD and the series of adjustments that we make in measuring TFP should eliminate many of the sources of measurement error suggested in the existing literature. Nonetheless, it is likely that measurement error remains. Since we wish to abstract from high frequency fluctuations in TFP due to measurement error, we also consider defining the technological frontier as an average of the top $s > 0$ establishments with the highest levels of TFP relative to the geometric mean. Estimation with a variety of

²⁰Cameron, Proudman, and Redding (1998) report negative estimated rates of TFP growth for some UK industries during 1970-92, while Griliches and Lichtenberg (1984) report negative rates of TFP growth for some US industries during an earlier period. Average TFP growth rates are positive during 1982-88, and re-estimating the model for this sub-period yields similar results.

different values of s yielded similar results, and we report estimates below averaging across the top three establishments.

As discussed above, it is not important for our econometric estimates whether we correctly identify the precise establishment with the highest level of true TFP or, more generally, whether we correctly measure the exact position of the technological frontier. The TFP gap between establishment i and the establishment with the highest TFP level is being used as a measure of the *potential* for technology transfer. What matters for estimating the parameters of interest is the correlation between our measure and true unobserved distance from the technological frontier. We present empirical evidence below of statistically significant and quantitatively important findings of technology transfer using a variety of measures of distance from the technological frontier, each linked directly to the structure of the model.

Of course, as in any econometric estimation, measurement error remains a potential concern. In addition to undertaking the series of adjustments to the TFP measures and to averaging across establishments close to the frontier, we also estimate the model using instrumental variables and estimate an alternative representation of the model that requires more structure to be placed on the production technology but is less sensitive to measurement error. The econometric results are robust across these approaches, suggesting that measurement error is not driving the results.

We now turn to some descriptive statistics before estimating the model. The final column of Table 1 reports the mean distance to the technological frontier among domestic-owned establishments within 2-digit industries (we measure the distance to the frontier at the 4-digit industry level, but here report the mean across 4-digit industries within a 2-digit industry). On average non-frontier establishments have productivity levels that are 64% of frontier TFP, although this varies by sector with the smallest gap observed in instrument engineering (mean TFP in non-frontier es-

establishments is 76% of frontier TFP), and the largest gap in office machinery and computers (mean TFP in non-frontier establishments is only just over half of frontier TFP).

Table 2 looks at the role of foreign-owned establishments. The first column shows the extent to which foreign-owned establishments advance the technological frontier. That is for each 4-digit industry-year observation where a foreign-owned establishment is the technological leader we calculate the productivity gap between the foreign-owned frontier and the most technologically advanced domestic-owned firm. When the frontier is a domestic-owned establishment this figure is zero. This distance averages three percentage points across all manufacturing industries. In only two of the 2-digit sectors do we never observe a foreign-owned establishment to be the technological leader. The third column shows the frequency with which foreign-owned establishments are observed to be the technological leader. Foreign establishments are the frontier in approximately 19 per cent of the 4-digit industry-year observations in our sample. Finally, in the fourth column, we show the proportion of employment that is in foreign-owned establishments by industry. We calculated this measure from information on the *population* of manufacturing plants in each 4-digit industry year, which means that it is a more accurate measure of the extent of foreign-owned activity in an industry than would be obtained from the sample of establishments. The proportion of industry employment is a common measure of foreign presence used in the empirical literature on spillovers, which we also use in estimation. As is to be expected the presence of foreign-owned establishments in an industry is positively correlated with the likelihood that they are at the technological frontier. Foreign-owned establishments have the highest presence in high-tech industries such as office machinery and data-processing equipment, chemicals and instrument engineering, and make up the technological frontier in over 25% of industry-year observations in

these sectors.

3.4 Econometric specification

Our basic econometric specification of the relationship between TFP growth and distance from the technological frontier is (3), reproduced below

$$\Delta \ln TFP_{it} = \beta \Delta \ln TFP_{jt}^F + \delta \ln TFP_{GAP_{it-1}} + u_{it} \quad (9)$$

where TFP growth and levels are measured using the superlative index numbers described above. We consider a general specification of the error term u_{it} . We allow for unobserved characteristics that affect rates of TFP growth and may be correlated with our explanatory variables; these are captured by an establishment fixed effect (η_i). There may also be common macroeconomic shocks which affect rates of TFP growth across all establishments; we therefore allow the error term to include a full set of time dummies (T_t),

$$u_{it} = \eta_i + T_t + \varepsilon_{it}$$

where ε_{it} is a serially uncorrelated error.

In this basic specification, foreign presence only affects TFP growth in domestic establishments in so far as foreign-owned firms are the technological frontier in a 4-digit industry. As discussed above, we also consider an augmented version of this basic econometric specification where we include level and interaction terms in the proportion of employment accounted for by foreign-owned firms in a 4-digit industry, as specified in equation (4).

4 Empirical Results

4.1 Productivity dynamics

Table 3 shows the results of the basic specification of the technology transfer model (equation 9). We estimate the model including only non-frontier, domestic-owned establishments. Our baseline estimation results pool across industries, imposing common slope coefficients. In the first column we include 4-digit industry dummies and in the second establishment-specific effects, to control for unobservable characteristics that may be correlated with inputs. We find a positive and significant effect of the growth in the frontier establishment on non-frontier establishments' productivity growth. We also find a positive and significant effect of the relative TFP or TFP gap term. This provides evidence of technological convergence and technology transfer at the establishment-level. Other things equal, establishments further behind the technological frontier experience faster rates of productivity growth. These estimates imply that the further a firm lags behind the technological leader the greater the potential to realize productivity growth through technology transfer, or alternatively the greater incentive there is to make technological improvements as a result of greater competitive pressure.

One concern is measurement error. If we measure TFP with error then this could induce spurious correlation as measured TFP_{it-1} appears in both the right and left hand sides of our regression. We address this potential problem using three complementary approaches. First, we control for many sources of measurement error in our TFP indices by using detailed micro data (as described above). Second, we take an instrumental variables approach and instrument relative TFP using lagged values. Column (3) instruments the TFP gap term using 2 and 3 year lags of an establishment's distance from the technological frontier. Again, we find a similar pat-

tern of results. Third, in column (4), we consider an alternative measure of distance from the technological frontier, based on average TFP in the 3 establishments with the highest measured TFP levels. This smooths the distance from the technological frontier term, and again we find positive and significant coefficients on frontier TFP growth and the TFP gap.²¹

Another potential concern is parameter heterogeneity, and to address this we re-estimated the model separately for 2-digit sectors.²² As shown in the final column of Table 3 this yielded a similar pattern of results, with industries displaying positive and statistically significant values of the frontier growth and TFP gap coefficients. The median estimated coefficients across the 18 2-digit industries were 0.077 for the frontier growth term and 0.262 for distance from the technological frontier. These lie close to and are not statistically different from the baseline within groups estimates reported in Table 3, suggesting that parameter heterogeneity is not driving our results.

4.2 The role of foreign firms

As discussed above, our structural model implies that foreign firms make a contribution to productivity growth in so far as they are the technological frontier within an industry. Existing empirical work regresses productivity growth on measures of foreign presence without controlling for distance from the technological frontier. In Table 4 we examine whether the presence of foreign-owned multinationals has any additional effects besides their role as the technological frontier.

²¹We also estimated the Autoregressive Distributed Lag (ADL) representation of the model (equation 2). An advantage of the ADL representation is that, because TFP_{t-1} only appears on the right-hand side of the equation, measurement error does not give rise to the same spurious correlation. A disadvantage is that this specification requires a measure of the *absolute* level of TFP (rather than simply the relative level), which requires more restrictive assumptions concerning the production technology (Cobb-Douglas). Estimating the ADL(1,1) representation, we again found evidence of a statistically significant long-run relationship between non-frontier and frontier TFP.

²²See, for example, the discussion in Pesaran and Smith (1995).

We begin in column 1 by including the proportion of employment in foreign-owned plants, measured at the 4-digit industry level, on its own and find that this is positively correlated with productivity growth in domestic-owned establishments. In column 2 we include this term in our basic growth model and see that the positive correlation remains. In column 3 we turn to the results of estimating the specification in (4), and investigate whether the presence of foreign-owned establishments has a direct effect on productivity growth or whether it enhances the speed of technology transfer. We find evidence that a greater presence of foreign-owned establishments speeds up the rate of convergence to the technological leader, and that including this interaction term drives the level measure of foreign presence Fo_{jt-1} into insignificance. By including a measure of distance to the technological frontier and the interaction of this term with a measure of foreign-presence, we consider a more general model of the effects of foreign multinationals on technology transfer than the existing literature. In doing so, we find that it is the interaction between foreign presence and relative TFP that is important for productivity growth in domestic-owned establishments.

The presence of foreign-multinationals may increase the speed of technological catch-up in domestic firms by increasing competitive pressures and therefore inducing faster adoption of new technology or the elimination of X-inefficiency. Alternatively, if foreign-owned firms have access to superior technology in their home country that is not fully reflected in the TFP of UK based affiliates, then the frontier may be understated, and hence in the presence of foreign-owned firms the potential technological gap may be larger and the speed of catch-up faster, as captured by the interaction term. It is likely that the true technological know-how of foreign affiliates, and the true potential for technology transfer, is understated to the greatest extent in industries where the UK lags furthest behind internationally in terms of productivity.

A major concern about this approach is that the entry and presence of foreign-

owned establishments may be endogenous to TFP growth rates. For example, it is well known that foreign-owned establishments are concentrated in more R&D intensive industries. Thus the correlation between foreign presence and TFP growth may be spurious. This problem has not been tackled in the literature. In the final column of Table 4 we instrument foreign presence with a number of variables reflecting the state of technology in the US and France, two of the countries from which a large amount of foreign investment into the UK originates, and where data was available. The instruments include labour productivity, investment per worker, wages and the capital-labour ratio in the same 4-digit industry in the US (from the NBER productivity database) and R&D intensity and the level of exports (to all countries) from the US and France in the same 2-digit level (from OECD data). These instruments capture characteristics of the industry that are likely to be correlated with FDI into the UK, but which do not directly affect TFP growth in the UK. They are informative, as indicated by the test of significance in the reduced form. The IV estimation yields a similar pattern of estimates. Surprisingly, the test of the significance of the control function suggests that endogeneity is not an issue.

Finally we quantify the contribution of foreign-owned firms in technological convergence. The first column of Table 5 shows the contribution made by the presence of high productivity foreign-owned establishments through pushing out the technological frontier. This is given by $\delta_1 \ln(A_j^F/A_j^{F*})_{t-1}$ expressed as a percentage of total convergence $(\delta_1 + \delta_2 F_{O_{jt-1}}) \ln(A_j^F/A_i)_{t-1}$. The second column shows the contribution that the extent of foreign presence in an industry makes by raising the speed of convergence, given by $\delta_2 F_{O_{jt-1}} \ln(A_j^F/A_i)_{t-1}$, again expressed as a percentage of total convergence. There is substantial variation by industry. In the first column this variation is driven by the degree to which foreign-owned establishments advance the frontier, which is shown in column 1 of Table 2. Foreign-owned establishments

contributed to over a third quarter of total convergence among domestic non-frontier establishments in the instrument engineering sector through their role as technological leaders. The second column also accounts for the contribution of foreign-owned firms through speeding up the rate of convergence. In total, as shown in column 3, foreign-owned establishments contributed most to technological convergence in the instrument engineering, chemicals and metal manufacturing sectors. Their role as technological leaders is found to be the most important factor, particularly in the metal manufacturing sector where, as shown in column 1 of Table 2, foreign-owned establishments advanced the frontier the most.

5 Conclusions

Policy debate in the UK has emphasised the productivity gap between the UK and other OECD countries. One mechanism by which that gap might be closed is through technology transfer from more technologically advanced economies. The presence of foreign-multinationals in the UK might be expected to facilitate this process. Indeed many governments use fiscal incentives to attract multinational firms in order to capitalise on these technological spillovers. In this paper we investigated the effects of the presence of foreign-multinationals on productivity growth in host country establishments.

We first estimated a structural model of technological convergence at the micro level, that included the technological distance between an establishment and the frontier as a measure of the potential for technology transfer. We find statistically significant and quantitatively important effects of catch-up to the the technological leader. Other things equal, establishments further behind the technological frontier experience faster rates of productivity growth. We then looked specifically at the role

of foreign-owned firms.

We measured relative TFP across establishments within 4-digit industries. In doing so we paid careful attention to potential measurement error in the disaggregated data, and to productivity measurement. Over the period 1980 to 1992 we found that foreign-owned establishments are the technological leader in around a fifth of cases. High productivity foreign-owned establishments are found to make an important contribution to productivity growth by pushing out the technological frontier, but high productivity UK-owned firms, to the extent that they are also technological leaders in some industries, are also important sources of technology transfer.

The existing literature that has focussed on the effects of foreign-presence on productivity growth has not included measures of distance from the technological frontier that we find to be so important here. We examined whether the presence of foreign-owned firms had additional effects on productivity growth beyond their role as technological leaders. We find that a greater foreign presence within an industry increases the speed of technological convergence to the frontier. This is consistent with foreign-owned increasing the rate of technology adoption by increasing competitive pressures and inducing productivity improvements in domestic establishments.

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Figure 1: Total Factor Productivity UK manufacturing relative to US

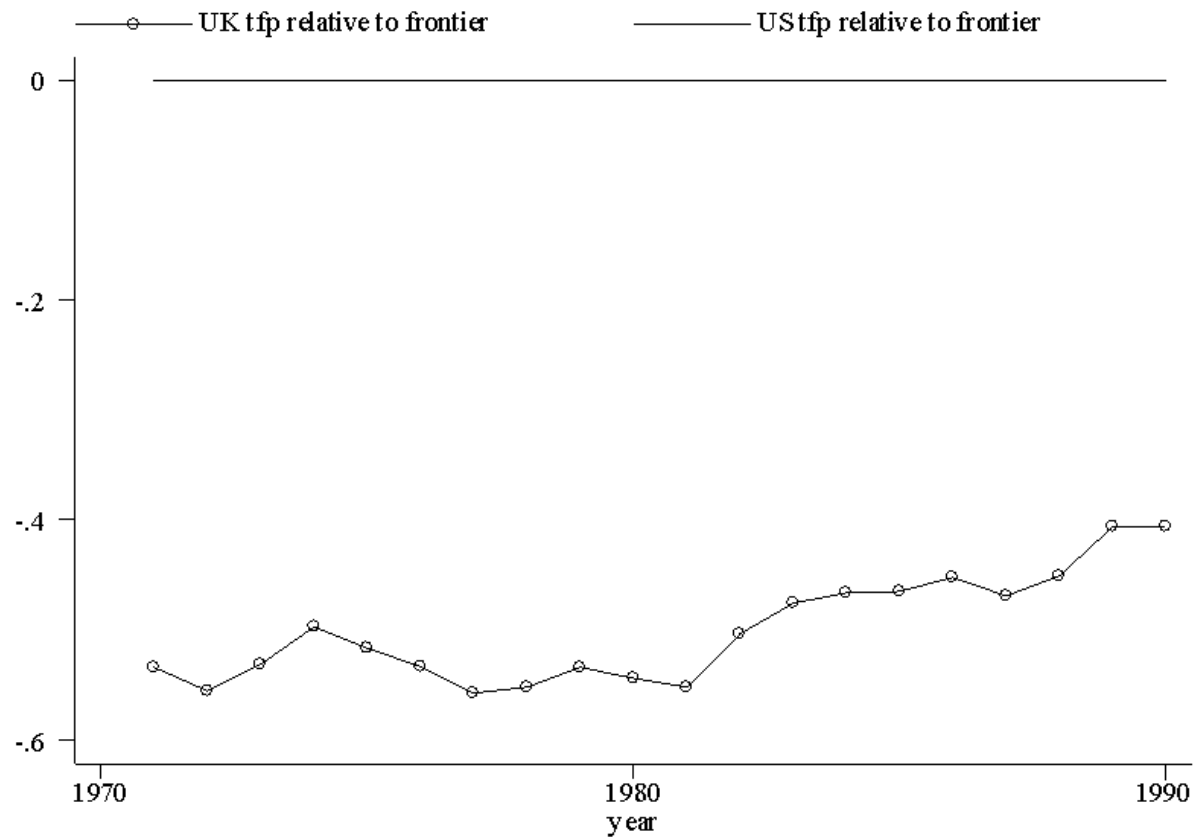


Table 1: Productivity growth and distance to the technological frontier

Sector	Annual average share employment %	Annual average labour productivity growth 1980–1992 %	Annual average TFP growth 1980-1992 %	Annual average TFP growth 1980-1988 %	Mean productivity non-frontier establishment Index, frontier =100
22 metal manufacturing	2.5	2.1	-0.3	1.4	67.1
23 extraction of minerals n.e.s.	0.1	1.8	-2.6	0.3	52.3
24 non-metallic mineral products	6.1	2.3	-0.4	1.5	62.2
25 + 26 chemicals and man-made fibres	6.6	2.6	-0.2	1.7	66.4
31 metal goods n.e.s.	5.9	2.8	0.3	1.4	67.4
32 mechanical engineering	9.8	2.5	-0.1	0.7	62.3
33 office machinery and data processing equipment	0.3	-0.4	-2.6	-1.8	52.2
34 electrical and electronic engineering	14.1	2.8	-0.6	0.4	66.0
35 motor vehicles and parts	6.4	3.9	0.8	1.3	65.4
36 other transport equipment	4.5	3.9	-1.6	-0.5	58.1
37 instrument engineering	0.4	3.9	0.1	0.8	76.5
41 + 42 food, drink and tobacco	14.9	2.3	-0.7	0.1	66.9
43 textiles	6.4	1.8	0.8	1.9	57.5
44 leather and leather goods	0.2	3.7	0.0	0.4	70.4
45 footwear and clothing	6.8	1.9	0.1	1.0	61.2
47 paper, paper products and publishing	7.0	3.8	0.6	1.9	54.7
48 rubber and plastics	4.9	2.8	0.1	1.2	66.5
49 + 46 other manufacturing, timber	3.3	1.4	-0.4	1.0	67.1
<i>All manufacturing</i>	<i>100.0</i>	<i>2.7</i>	<i>-0.2</i>	<i>0.9</i>	<i>63.5</i>

Notes: 2-digit industry codes based on the sic80 classification. Means are across observations in sample of domestic establishments with at least five consecutive observations, 1980-1992 unless otherwise stated. Columns 2-4 are weighted by the inverse of the sampling probability and employment.

Table 2: Technological frontier and foreign-owned establishments

Sector	Advancement of the frontier Mean $\ln \frac{A_j^F}{A_j^{F*}}$	% times frontier is foreign	% employment in foreign establishments
22 metal manufacturing	0.086	42.9	17.7
23 extraction of minerals n.e.s.	0.000	0.0	0.9
24 non-metallic mineral products	0.039	20.8	7.2
25 + 26 chemicals and man-made fibres	0.058	33.9	34.7
31 metal goods n.e.s.	0.018	18.1	12.9
32 mechanical engineering	0.057	24.6	21.1
33 office machinery and data processing equipment	0.043	38.1	47.3
34 electrical and electronic engineering	0.022	22.8	21.2
35 motor vehicles and parts	0.012	10.0	15.4
36 other transport equipment	0.023	12.3	4.7
37 instrument engineering	0.040	25.0	28.9
41 + 42 food, drink and tobacco	0.021	13.6	10.4
43 textiles	0.003	5.3	5.9
44 leather and leather goods	0.000	0.0	1.1
45 footwear and clothing	0.009	6.6	3.9
47 paper, paper products and publishing	0.038	18.3	18.8
48 rubber and plastics	0.036	32.6	22.2
49 + 46 other manufacturing, timber	0.001	3.2	9.2
<i>All manufacturing</i>	<i>0.031</i>	<i>18.9</i>	<i>15.9</i>

Notes: 2-digit industry codes based on the sic80 classification. All columns are means across 4-digit industry years, 1980-1992. The first column shows the extent to which foreign-owned establishments advance the frontier beyond the highest productivity domestic-owned establishment. When the frontier is a domestic-owned establishment it is set to zero.

Table 3: Basic catch-up model

dep var: ΔTFP_{ijt} (domestic firms only)	(1)	(2)	(3)	(4)	(5)
Obs	43,989	43,989	29,549	39,982	43,989
ΔTFP_{Fjt}	0.040 (0.016)	0.062 (0.015)	0.077 (0.031)		0.077
$TFPGAP_{ijt-1}$	0.135 (0.013)	0.224 (0.021)	0.229 (0.089)		0.262
$\Delta TFP3_{Fjt}$	-	-		0.156 (0.015)	
$TFPGAP3_{ijt-1}$	-	-		0.363 (0.013)	
Control function in regression	-	-	0.005 (0.082)	-	
Significance of instruments in reduced form			642.96		
F-statistics (P-value)	-	-	(0.00)	-	
R ² of reduced form	-	-	0.764	-	
Year dummies	yes	yes	yes	yes	yes
Within groups		yes	yes	yes	yes

Note: Regressions are estimated on all non-frontier domestic establishments for 1980-1992. All columns are weighted by inverse of sampling probability and employment. Standard errors in brackets are clustered at 4-digit industry. ΔTFP_{Fjt} is tfp growth in the frontier. $TFPGAP_{ijt-1}$ is tfp relative to frontier in the previous period. $\Delta TFP3_{Fjt}$ is tfp growth in the frontier – measured as the average growth in TFP over the three establishments with the highest measured TFP. $TFPGAP3_{ijt-1}$ is tfp relative to frontier in period $t-1$ where the frontier is measured as the average over the three establishments with the highest measured TFP within 4-digit industry year. Instruments in column 3 are $TFPGAP_{t-2}$, $t-3$. Column (5) reports the median of the coefficients from 2-digit industry level regressions.

Table 4: Catch-up and foreign presence

dep var: ΔTFP_{irjt} (domestic firms only)	(1)	(2)	(3)	(4)
Obs	43,989	43,989	43,989	36,796
ΔTFP_{Fjt}	-	0.063 (0.014)	0.064 (0.014)	0.063 (0.018)
$TFPGAP_{ijt-1}$	-	0.224 (0.021)	0.202 (0.021)	0.208 (0.026)
Fo_{jt-1}	0.058 (0.030)	0.083 (0.041)	0.012 (0.051)	-0.486 (0.421)
$TFPGAP_{ijt-1} * Fo_{jt-1}$	-	-	0.186 (0.077)	0.151 (0.082)
Control function in regression				0.524 (0.442)
Significance of instruments in reduced form				37.76
F-statistics (P-value)				(0.00)
R ² of reduced form				0.909
Year dummies	yes	yes	yes	yes
Within groups	yes	yes	yes	yes

Note: Regressions are estimated on all non-frontier domestic establishments for 1980-1992. All columns are weighted by inverse of sampling probability and employment. Standard errors in brackets are clustered at 4-digit industry. Fo_{jt-1} is the proportion of employment in the 4-digit industry in the previous year that was in foreign-owned firms. ΔTFP_{Fjt} is tfp growth in the frontier. $TFPGAP_{ijt-1}$ is tfp relative to frontier in the previous period. $\Delta TFP3_{Fjt}$ is tfp growth in the frontier – measured as the average growth in TFP over the three establishments with the highest measured TFP. $TFPGAP3_{ijt-1}$ is tfp relative to frontier in period $t-1$ where the frontier is measured as the average over the three establishments with the highest measured TFP within 4-digit industry year. Instruments in the final column are described in the main text.

Table 5: Impact of foreign establishments on productivity convergence, by industry

Sector	Advancing the frontier % of total convergence	Raising the speed of catch-up % of total convergence	Total %
22 metal manufacturing	27.4	9.2	36.6
23 extraction of minerals n.e.s.	0	1.4	1.4
24 non-metallic mineral products	14.0	6.0	20.0
25 + 26 chemicals and man-made fibres	22.1	20.6	42.7
31 metal goods n.e.s.	3.2	7.2	10.4
32 mechanical engineering	13.1	13.6	26.7
33 office machinery and data processing equipment	3.6	28.4	32.0
34 electrical and electronic engineering	5.9	12.8	18.7
35 motor vehicles and parts	4.8	17.0	21.9
36 other transport equipment	12.5	3.0	15.5
37 instrument engineering	36.0	18.3	54.3
41 + 42 food, drink and tobacco	8.3	5.7	13.9
43 textiles	0.4	2.8	3.2
44 leather and leather goods	0	1.1	1.1
45 footwear and clothing	1.8	2.7	4.5
47 paper, paper products and publishing	7.1	13.0	20.1
48 rubber and plastics	10.6	13.1	23.7
49 + 46 other manufacturing, timber	0.2	2.8	3.0
<i>Total manufacturing</i>	<i>8.7</i>	<i>9.7</i>	<i>18.4</i>

Note: Column 1 shows $\delta_1 \ln \left(\frac{A_j^F}{A_j^{F*}} \right)_{t-1} / (\delta_1 + \delta_2 Fo_{jt-1}) \ln \left(\frac{A_j^F}{A_i} \right)_{t-1}$. Column 2 shows $\delta_2 Fo_{jt-1} \ln \left(\frac{A_j^F}{A_i} \right)_{t-1} / (\delta_1 + \delta_2 Fo_{jt-1}) \ln \left(\frac{A_j^F}{A_i} \right)_{t-1}$.

Calculated using $\delta_1 = 0.2$, $\delta_2 = 0.186$, using employment and sampling probability weights, and both expressed as percentages.

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