

The Dynamics of Establishment Productivity: Technology Transfer and Productivity Dispersion

Rachel Griffith,^{*} Stephen Redding,[†] and Helen Simpson[‡]

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Abstract

This paper investigates the dynamics of Total Factor Productivity at the establishment level. We introduce technology transfer into a framework with heterogeneous firms and ongoing entry and exit. We find evidence that convergence to the frontier is statistically and quantitatively important. Foreign multinationals make up a significant proportion of establishments at the technological frontier, and therefore make an important contribution to productivity growth through shifting out the technological frontier and thus allowing greater technology transfer.

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Correspondence: rgriffith@ifs.org.uk; s.j.redding@lse.ac.uk; hsimpson@ifs.org.uk. Institute for Fiscal Studies, 7 Ridgmount Street, London WC1E 7AE UK.

^{*}Institute for Fiscal Studies and University College London

[†]London School of Economics and Institute for Fiscal Studies

[‡]Institute for Fiscal Studies

1 Introduction

Deregulation and the opening of markets to international trade and investment has been widely recognized as a major driver of growth. Recent studies on entry¹ have revived interest in the subject. Three main effects of liberalisation have been identified in the literature. First, the replacement of low productivity plants with high productivity entrants can increase average or aggregate productivity through the reallocation of inputs and output. Second, increased competition or entry may induce incumbent firms to organize work more effectively, to trim fat and reduce slack, and to learn through imitation from new entrants who are utilizing superior technology or organizational structures. Third, competition may spur domestic firms to increase their own efforts and investments in frontier innovation.

In this paper, we develop a framework which encompasses these channels of influence and provides econometric evidence of the importance of technology transfer in driving productivity growth in non-frontier establishments. Our analysis encapsulates firm heterogeneity, ongoing entry and exit, stochastic shocks to productivity, and endogenous technology transfer from leading to lagging establishments. We obtain the somewhat surprising result that technology transfer is consistent with persistent productivity dispersion across establishments within industries. Productivity dispersion emerges in steady-state equilibrium because establishments differ in terms of their underlying innovative capabilities, and it takes time to transfer technology from an advancing frontier. In steady state, the establishment with greatest innovative capability becomes the technology frontier and experiences productivity growth as a result of innovation. All other establishments lie an equilibrium distance behind the technological frontier, such that productivity growth from innovation and technology transfer equals productivity growth from innovation at the frontier. Stochastic shocks to technology provide a source of departure from steady-state levels of productivity

¹See, *inter alia*, Baily *et al.* (1992), Davis and Haltiwanger (1991), Nicoletti and Scarpetta (2002) and Djankov *et al.* (2002).

relative to the frontier and, together with out of steady-state dynamics, generate variation in establishment productivity growth.

We test the predictions from this model using a large-scale comprehensive micro panel dataset. Our analysis provides new empirical evidence on productivity dynamics within industries, the role of technology transfer in driving productivity growth at the establishment level, and the contribution of affiliates of US multinationals to domestic productivity growth through advancing the UK's technological frontier. In addition, our findings show how apparently contradictory strands of existing research can in fact be reconciled. On the one hand, many studies have emphasized the persistence of variation in productivity across establishments, even within narrowly defined industries.² On the other hand, a separate body of research has emphasised the importance of technology transfer as a source of growth, particularly for those behind the technological frontier.³ On the face it, these results appear contradictory. This paper shows that productivity dispersion can be consistent with technology transfer between establishments. Heterogeneous productivity emerges as an equilibrium outcome reflecting a tension between variation in establishments' innovative capabilities (which tends to enhance productivity dispersion) and technology transfer (which tends to reduce productivity dispersion). Technology transfer shapes the process of entry and exit by which high productivity firms are selected and industry productivity raised. Exiting firms continue to have on average low productivity, but the transfer of technology provides a route by which a currently low productivity firm may turn its performance around and prosper.

We empirically test these ideas using data on plants located in the United Kingdom. Throughout the 1970s productivity levels and growth rates in the UK lagged behind those

²See, for example, Baily *et al.* (1992), Bartelsman and Doms (2000), Bernard and Jensen (1995), Davis and Haltiwanger (1991), Davis, Haltiwanger and Schuh (1996), Disney *et al.* (2003), Dunne, Roberts and Samuelson (1989) and Foster, Haltiwanger and Krizan (2002).

³See, for example, Acemoglu *et al.* (2002), Aghion and Howitt (1997), Grossman and Helpman (1991), Howitt (2000) and Parente and Prescott (1994, 1999).

of the US. The 1980s saw a period of rapid growth in the UK that led to a reduction in the aggregate technology gap with the US. This aggregate picture hides substantial heterogeneity in productivity across establishments and a Darwinian process of selection as poor performers exited and were replaced by a new cohort of establishments. 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 factors including capital. This opening up of the UK economy was expected to increase growth through a number of routes, including technology transfer from more technologically advanced economies, facilitated by the presence and entry of foreign-owned multinationals employing superior production techniques within the UK. This historical background makes a UK a natural choice for exploring these effects, although our framework and empirical results are of broader interest.

Foreign firms, and in particular US firms, play an important role in the UK economy and are viewed as conduits of knowledge transfer. Our framework enables us to shed light on the contribution that affiliates of US-owned multinationals make to domestic productivity growth, through their role in advancing the industry technological frontier. The existing literature on foreign ownership and productivity 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.⁴ We use an establishment's distance from the technological frontier as a direct measure of the potential for technology transfer. The affiliates of foreign multinationals are often the technology leaders within in-

⁴Aitken 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), Smarzynska Javorcik (2004) 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).

dustries and expand the frontier from which knowledge may be transferred. This is not to say that domestic firms cannot also play this role, especially domestic-owned multinationals who may be sourcing technologies from abroad.⁵ In our sample the affiliates of US multinationals are frequently the most productive, and we use our framework to quantify their estimated contribution to technology transfer and productivity growth.

The structure of the paper is as follows. Section 2 outlines the model and the econometric specification. Section 3 discusses the data and a number of measurement issues. In section 4 econometric results are presented. In developing the econometric results, we first present the estimates of the model of technology transfer before examining the contribution of foreign firms. A final section concludes.

2 Theoretical Framework

We consider a simple model of industry dynamics which allows for entry, exit, heterogeneous productivity and endogenous productivity growth at the establishment-level. The model implies that each establishment converges to its own equilibrium level of productivity relative to the frontier, which depends on own innovative capabilities and those at the frontier, as well as the speed of technology transfer. There is persistent productivity dispersion within industries, because of the constant advancement of the technological frontier. Establishments differ in innovative capabilities and it takes time to transfer technology from the frontier. In steady-state, the frontier will be whichever establishment has the highest innovative capability. All other establishments will lie an equilibrium distance behind the frontier, such that expected productivity growth as a result of innovation and technology transfer equals expected productivity growth as a result of innovation in the frontier.

Thus, our model features productivity convergence, but this convergence relates to the

⁵See for example Doms and Jensen (1998) and Criscuolo and Martin (2005) for empirical evidence that domestic multinationals frequently have comparable levels of productivity to their foreign-owned counterparts.

time-series relationship between productivity in individual establishments and productivity in the frontier. Persistent dispersion in productivity levels relates to the cross-section distribution of productivity over different establishments. There is cross-section dispersion because different establishments have different steady-state levels of productivity relative to the frontier. Depending on the initial cross-section distribution of productivity, and the steady-state cross-section distribution of productivity implied by our model, the within-industry dispersion of productivity may rise, decline or remain constant over time. We document exactly this sort of variation across establishments and industries below.

2.1 Entry, Exit and Production

There is a competitive fringe of potential entrants into the industry. Currently-active establishments and potential entrants have an outside option, which yields a known return of ρ_{it} that may vary across establishments and time. Assuming costless entry and exit, a new establishment will enter if the expected profits from producing in the industry exceed the return from the outside option, and an existing establishment will exit if the expected profits fall below the return from the outside option.⁶

Profits are uncertain and evolve over time as a result of stochastic productivity shocks. The production technology takes the following neoclassical form:

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

where i indexes establishments; j indexes industries; t indexes time; Y is output; X is a vector of factor inputs including labour, physical capital, and intermediate inputs; and A is an index of technology or Total Factor Productivity (TFP).

The function $F_{jt}(\cdot)$ is assumed to be homogeneous of degree one and to exhibit diminishing marginal returns to the employment of each factor alone. We allow this function to

⁶For currently active establishments, the outside option corresponds to a liquidation value, as in Ericson and Pakes (1995). See also Jovanovic (1982), Hopenhayn (1992), and Melitz (2003) for models of industry dynamics. Costless entry and exit is a simplifying assumption which permits a more general model of productivity dynamics than typically considered.

vary across industries and time to reflect variation in how factor inputs map into output. Productivity A_{it} varies across establishments and time, which is consistent with the large degree of heterogeneity in technology observed even within narrowly defined industries.⁷

Productivity evolves over time as a result of innovation and technology transfer. An establishment's current productivity (A_{it}) depends on its own past level of productivity (A_{it-1}), its underlying innovative capabilities and potential (γ_i), the industry technological frontier in the previous period (A_{Fjt-1}), from which knowledge may be transferred, and stochastic shocks to technology (u_{it}):

$$A_{it} = \Psi(A_{it-1}, \gamma_i, A_{Fjt-1}, u_{it}). \quad (2)$$

Lagged productivity and the lagged level of the technological frontier are both observable to the establishment when it chooses factor inputs in the current period. The same is true for the establishment's underlying capability, which will be captured in our econometric specification with an establishment-specific fixed effect. In the most general case, the stochastic productivity shock may include a component that is observed in the current period before factor inputs are chosen, and a component that is only observed after factor usage decisions have been made.

Establishments choose prices subject to a downward-sloping demand curve under conditions of imperfect competition, which yields the standard result that prices are a mark-up over marginal cost. For simplicity we assume that the demand system takes the Constant Elasticity of Substitution (CES) form, which yields the following expressions for equilibrium establishment prices (p_{it}) and revenue (r_{it}):

$$p_{it} = \left(\frac{\sigma}{\sigma - 1} \right) \frac{b_{jt}(\omega_t)}{A_{it}}, \quad (3)$$

⁷While we assume here for simplicity that technological change is Hicks neutral, in the sense of raising the marginal productivity of all factors proportionately, the model of technology transfer developed below could also be applied to non-neutral technological change.

$$r_{it} = p_{it}^{1-\sigma} R_t P_t^{\sigma-1}, \quad (4)$$

where $\sigma > 1$ is the constant elasticity of demand; $b_{jt}(\omega_t)/A_{it}$ corresponds to the marginal (equals average) cost function, with the total cost function dual to equation (1) equal to $B_{it} = (b_{jt}(\omega_t)/A_{it})Y_{it}$; ω_t is the vector of factor prices; R_t denotes aggregate expenditure on industry output (equals aggregate industry revenue); and P_t denotes the CES industry price index.

Using the pricing rule, equilibrium establishment profits are proportional to equilibrium revenue:

$$\pi_{it} = \frac{r_{it}}{\sigma}, \quad (5)$$

where, substituting the pricing rule (3) into the expression for revenue (4), equilibrium profits are increasing in establishment productivity.

The establishment's entry/exit decision depends on profitability in the industry relative to the outside option:

$$\begin{aligned} \pi_{it} &> \rho_{it} && \text{enter / remain in the industry,} \\ \pi_{it} &\leq \rho_{it} && \text{do not enter / exit the industry.} \end{aligned} \quad (6)$$

Costless entry and exit implies that this decision is made period by period. As productivity evolves over time according to the dynamic process specified in equation (2), some existing establishments will exit and other new establishments will enter. With establishment revenue increasing in firm productivity, equation (6) implicitly defines a threshold level of productivity, A_{it}^* , below which the establishment will exit the industry. Other things equal, exiting establishments will be of lower productivity than those producing within the industry.

2.2 Productivity dynamics

The general specification for the evolution of establishment productivity in equation (2) incorporates a number of important features from the empirical literatures on technology and productivity. First, the dependence of current on past levels of productivity captures persistence in productivity and innovation, which is a pervasive and well-documented empirical regularity.⁸ Second, heterogeneity in establishment productivity partly reflects variation in underlying capabilities, γ_i . These include managerial ability, firm organization, as well as the potential to innovate and advance future technology levels.⁹ Third, we allow for knowledge spillovers, as is consistent with the large theoretical and empirical literature on the role of imitation and technology transfer in determining rates of productivity growth.¹⁰ Technology transfer need not be automatic and instantaneous, but will typically vary with ‘absorptive capacity’ and incentives to adopt superior technologies, which are here absorbed in the function $\Psi(\cdot)$ in equation (2).¹¹

To develop a framework amenable to empirical implementation that enables us to keep track of the evolution of the entire cross-section distribution of productivity, we place some further structure on the function $\Psi(\cdot)$:

$$\ln A_{it} = \ln A_{it-1} + \gamma_i + \lambda \ln \left(\frac{A_{Fj}}{A_i} \right)_{t-1} + u_{it}. \quad (7)$$

This has the following intuitive interpretation: the parameter γ_i captures an establishment’s own rate of innovation through its underlying capabilities; the parameter λ captures the speed at which knowledge is transferred from the technological frontier; and u_{it} captures the influence of stochastic technology shocks on productivity growth. In the analysis that

⁸See, for example, Baily and Chakrabarty (1985) and Geroski *et al.* (1993).

⁹For further discussion of innovative capabilities and their role in determining the pace of technological change, see for example Cohen (1995).

¹⁰Recent theoretical work includes Aghion and Howitt (1997), Eeckhout and Jovanovic (2002), Howitt (2000) and Parente and Prescott (1994). Empirical work includes Bernard and Jones (1996), Griliches (1992) and Keller (2004).

¹¹For theory and empirical evidence on the role of absorptive capacity, see for example Aghion and Howitt (1997) and Griffith, Redding and Van Reenen (2003), (2004).

follows, we also consider a number of generalizations of and robustness tests for this baseline specification.

2.3 Econometric specification

Our baseline econometric equation is derived directly from the theoretical model above. From equation (7), establishment productivity growth conditional on being active in the industry is:

$$\Delta \ln A_{it} = \gamma_i + \lambda \ln \left(\frac{A_{Fj}}{A_i} \right)_{t-1} + u_{it} \quad (8)$$

where γ_i is an establishment-specific fixed effect which captures variation in underlying innovative capabilities, and u_{it} is a stochastic error. We estimate this specification for all non-frontier establishments.

One primary concern we have is the effect that entry and exit will have on our estimates. These are central to our model, and in our data we see substantial amounts of entry and exit. This may lead to selection bias. Establishments that are not able to imitate and benefit from technology transfer will be more likely to exit. Those that are better at this will be more likely to enter. Using the structure of the model, an establishment will be active if and only if productivity is greater than the threshold value, A_{it}^* , defined by the entry and exit condition (6). Defining an indicator variable, d_{it} , equal to 1 if $Z_{it} = \ln A_{it} - \ln A_{it}^* > 0$ and an establishment is active in the industry and equal to 0 otherwise, we control for entry and exit using the standard Heckman (1976) procedure. We estimate a first-stage Probit for the probability that an establishment remains in the sample and include the inverse Mills ratio in the second-stage equation for productivity growth in equation (8). We follow Olley and Pakes (1996) and Pavnick (2002) in including investment, capital stock, their interaction and higher order terms of these variables to identify the selection equation. The fixed effects included in the productivity growth equation also control for selection on time invariant observables and unobservables.

We consider a general specification of the error term. We allow the establishment-specific fixed effect to be correlated with other independent variables, so that, for example, establishments which begin far from the frontier, and converge rapidly towards it, may be precisely those with high levels of innovative capabilities γ_i . We also include a full set of time dummies, T_t , to control for common shocks to technology and macroeconomic fluctuations. Finally, the error term includes an idiosyncratic component, ε_{it} :

$$u_{it} = T_t + \varepsilon_{it}. \quad (9)$$

We also allow a more general relationship between non-frontier and frontier TFP, as is consistent with an Autoregressive Distributed Lag ADL(1,1) model:

$$\ln A_{it} = \gamma_i + \alpha_1 \ln A_{it-1} + \alpha_2 \ln A_{Ft} + \alpha_3 \ln A_{Ft-1} + T_t + \varepsilon_{it}. \quad (10)$$

We assume long-run homogeneity ($\frac{\alpha_2 + \alpha_3}{1 - \alpha_1} = 1$) so that the rate of technology transfer depends on relative, rather than absolute, levels of technology.¹² The cointegrating relationship between non-frontier and frontier TFP above therefore has the following Equilibrium Correction Model (ECM) representation, with many attractive statistical properties:¹³

$$\Delta \ln A_{it} = \gamma_i + \beta \Delta \ln A_{Ft} + \lambda \ln \left(\frac{A_{Fj}}{A_i} \right)_{t-1} + T_t + \varepsilon_{it}. \quad (11)$$

This corresponds to equation (8), where $\beta = \alpha_2 = 0$ and $\lambda = (1 - \alpha_1)$, and the specification is again estimated for all non-frontier establishments.

2.4 Implications for productivity dispersion

Before proceeding to discuss the data and present our baseline empirical results, it is useful to examine the implications for the cross-section distribution of productivity within the industry. This is not central to our empirical strategy, but clarifies the interpretation of the

¹²Under this assumption, doubling A_{it-1} , A_{Ft} and A_{Ft-1} doubles A_{it} , ensuring that the rate of technology transfer does not depend on units of measurement for output or factor inputs.

¹³See Hendry (1996).

results and makes clear how technology transfer is consistent with equilibrium productivity dispersion.

The technological frontier in industry j will advance at a rate determined by innovative capabilities γ_{Fj} and a stochastic error u_{Fjt} :

$$\Delta \ln A_{Fjt} = \gamma_{Fj} + u_{Fjt}. \quad (12)$$

Combining the equation for TFP growth in a non-frontier establishment i with the expression for the frontier above, yields an expression for the evolution of productivity in establishment i relative to the industry j frontier:

$$\Delta \ln (A_{it}/A_{Fjt}) = (\gamma_i - \gamma_{Fj}) + \lambda \ln \left(\frac{A_{Fjt-1}}{A_{it-1}} \right) + (u_{it} - u_{Fjt}). \quad (13)$$

Taking expectations in equation (13) prior to the realization of the stochastic shock to technology, the error terms are equal to zero and the steady-state equilibrium level of technology relative to the frontier is:

$$\mathbf{E} \ln \left(\frac{\widehat{A_i}}{A_{Fj}} \right) = \frac{\gamma_i - \gamma_{Fj}}{\lambda}. \quad (14)$$

Intuitively, there is productivity dispersion within the industry because establishments differ in their underlying potential to innovate ($\gamma_i \neq \gamma_{Fj}$) and it takes time to transfer technology from the frontier (λ is finite). In steady-state, the frontier will be whichever establishment in the industry has highest capability to innovate ($\gamma_{Fj} = \sup_i \{\gamma_i\}$). All other establishments will lie an equilibrium distance behind the frontier, such that expected productivity growth as a result of both innovation and technology transfer equals expected productivity growth as a result of innovation in the frontier.

Equations (7), (13) and (14) are most closely related to the time-series literature on convergence, since they imply a long-run cointegrating relationship between TFP in frontier

and non-frontier establishments.¹⁴ The inclusion of establishment-specific fixed effects in the econometric specification means that the parameters of interest are identified from the differential time-series variation across establishments in the data. We focus on the relationship over time between an establishment's rate of growth of productivity and its distance from the technological frontier.

Although the establishment fixed effects are included in an equation for productivity *growth* (8), the presence of the term in lagged productivity relative to the frontier means that the equation estimated can be interpreted as a dynamic specification for how the *level* of each establishment's productivity evolves relative to the frontier (the equation is an ECM representation of this relationship). Therefore, the fixed effects are capturing information on the steady-state level of each establishment's productivity relative to the frontier, depending on its underlying capabilities, as is revealed by equation (14).

Thus, our approach differs from the literature on β -convergence, which explores the *cross-section* relationship between rates of growth of productivity and initial own levels of productivity. It also differs from the literature on σ -convergence, which examines the *evolution of cross-section* measures of dispersion such as the sample standard deviation of productivity. Depending on the relationship between the initial distribution and the steady-state distribution in equation (14), the sample standard deviation of productivity relative to the frontier may rise, decline or remain constant over time.¹⁵

Figures 1 and 2 display two very different examples of industry productivity dynamics, both of which are consistent with our framework. In Figure 1, establishment I remains the frontier in all periods and establishment II converges to an equilibrium distance behind the frontier. In Figure 2, there is an endogenous change in technological leadership as establishment II catches up with and overtakes establishment I. In Figure 1, the dispersion

¹⁴See for example Bernard and Durlauf (1996).

¹⁵See Barro and Sala-i-Martin (1995) for further discussion of the empirical growth literatures on β and σ -convergence.

of productivity across establishments declines over time, while in Figure 2 it rises. In reality, productivity dynamics will be considerably more uneven than displayed in these figures reflecting stochastic shocks to technology.

The steady-state distribution of productivity in equation (14) is across all establishments (both active and inactive). The observed distribution of productivity will be truncated at the endogenous minimum threshold for productivity within the industry, A_i^* , that is defined by equation (6). In the transition to steady-state, there will be entry and exit of establishments as productivity in some inactive establishments rises above A_i^* and productivity in some active establishments falls below A_i^* . In steady-state equilibrium, there will be ongoing entry and exit as stochastic technology shocks induce establishment productivity to rise above or fall below A_i^* .

In summary, this simple model of industry dynamics captures heterogeneity in productivity within industries, while allowing for endogenous productivity growth at the establishment-level. Each establishment converges towards its own steady-state level of productivity relative to the industry technological frontier. Stochastic technology shocks induce ongoing entry and exit, and mean that establishments' productivities may depart from their steady-state equilibrium values for substantial periods of time. Convergence towards steady-state equilibrium productivity relative to the frontier will occur gradually, depending on realizations of stochastic productivity shocks and the speed of technology transfer.

3 Data and econometric issues

3.1 Data

In order to empirically investigate this model we use a rich and comprehensive micro panel data set. Our main source of data is the Annual Respondents Database (ARD). This is collected by the UK Office for National Statistics (ONS) and it is a legal obligation for firms to reply. These data provide us with information on inputs and output for production

plants located in the UK.¹⁶ We use data at the establishment level.¹⁷ The country of residence of the ultimate owner of the establishment is also contained in the 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. We use data for all of Great Britain from 1980 to 2000 for 189 4-digit manufacturing sectors. In the calculation of TFP we use information on gross output, capital expenditure, intermediate inputs, and on the number of skilled (Administrative, Technical and Clerical workers) and unskilled (Operatives) workers employed and their respective wagebills.

We use price deflators for output and intermediate goods at the 4-digit industry level produced by the ONS. 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.

The ARD contains more detailed information on both output and inputs than is typically available in many productivity studies, and the analysis is undertaken at a very disaggregated level. This enables us to control for a number of sources of measurement error and aggregation bias suggested in the literature on productivity measurement. In addition, because response to the survey is compulsory, there is effectively no bias from non-random responses. We use a cleaned up sample of establishments that conditions on

¹⁶Basic information (employment, ownership structure) is available on all plants located in the UK. Detailed data on inputs and outputs is available on all production establishments with more than 100 employees and for a stratified sample of smaller establishments. The cut off point over which the population of establishments is sampled increases from 100 in later years. All of our results use the inverse of the sampling probability as weights to correct for this. For further discussion of the ARD see Griffith (1999), Oulton (1997) and Barnes and Martin (2002).

¹⁷Establishments correspond 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.

establishments being sampled for at least 5 years.¹⁸ We include a sample selection correction term in the econometric analysis that controls for non-random survival of establishments. 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. TFP growth is measured by a superlative index derived from the translog production function,

$$\Delta TFP_{it} = \Delta \ln Y_{it} - \sum_{z=1}^Z \tilde{\alpha}_{it}^z \Delta \ln x_{it}^z, \quad (15)$$

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 the value of intermediate inputs, the stock of physical capital, and the numbers of 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

¹⁸We 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, and condition on the sum of the shares of intermediate inputs, skilled and unskilled workers in output being between 0 and 1.

expressed as the following function of relative factor input use,¹⁹

$$\alpha_{it}^z = \xi_i + \sum_{z=2}^Z \phi_j^z \ln \left(\frac{x_{it}^z}{x_{it}^1} \right), \quad (16)$$

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 (15) and below.

The level of TFP is measured using an analogous superlative index number, where TFP in each establishment is evaluated relative to a common reference point - the geometric mean of all other establishments in the same industry (averaged over all years). The measure of relative TFP is,

$$MTFP_{it} = \ln \left(\frac{Y_{it}}{\bar{Y}_j} \right) - \sum_{z=1}^Z \sigma_i^z \ln \left(\frac{x_{it}^z}{\bar{x}_j^z} \right), \quad (17a)$$

where a bar above a variable denotes a geometric mean; that is, \bar{Y}_j and \bar{x}_j^z , are the geometric means of output and use of factor of production z in industry j . The variable $\sigma_i^z = (\alpha_i^z + \bar{\alpha}_j^z)/2$ 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 (16) above), and we impose constant returns to scale ($\sum_z \sigma_i^z = 1$).

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 $\ln \left(A_j^F / A_i \right)_t$ in the theoretical section

¹⁹See Caves *et al.* (1982b) and Harrigan (1997).

above,²⁰

$$TFPGAP_{it} = MTFP_{jt}^F - MTFP_{it}. \quad (18)$$

These superlative TFP indices provide very general measures of productivity. Under the assumptions made about market conditions, they avoid problems associated with the endogeneity of factor input choices to productivity shocks that may affect estimates of technical efficiency derived from estimating the production function.

We also use an alternative method for measuring TFP that was introduced by Olley and Pakes (1996), used by Pavnick (2002), which involves directly estimating the production function and explicitly controlling for the simultaneity of input use with respect to productivity shocks. In the first step of the Olley-Pakes procedure a consistent estimate of the labour coefficient (α_l) is obtained using a non-parametric approach to sweep out the correlation of variable inputs with the error term. In the second step the capital parameter (α_k) is obtained using non-linear least squares. Exit is controlled for through an auxiliary equation predicting the probability that a firm remains in business in the next period. Our identification strategy follows Olley and Pakes (1996) and Pavnick (2002) and uses investment, capital stock and their interactions and higher order terms in the first stage equation.

One final consideration about measuring TFP is the impact that changes in the extent and nature of product market competition might have on our measures. The superlative index numbers above are the key benchmarks in the productivity literature, but they assume perfect competition. With imperfect competition each factor's share will not necessarily equal their marginal product. This generally leads to an overestimate of TFP when markets are less competitive (see Hall 1988 and Klette and Griliches 1996). If the extent of competition in markets is changing systematically over time, this could lead to a system-

²⁰Note that equation (17a) 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.

atic under or over-estimate of productivity growth rates. As a robustness test, we report estimation results using productivity measures that control for imperfect competition using the methodology developed by Hall (1988) and Roeger (1995).

3.3 Productivity growth and dispersion

In our data we see substantial variation in rates of productivity growth and convergence across establishments and industries. Table 1 provides summary statistics on our main measures. Growth in TFP in establishments in our estimation sample averaged 0.3% per annum over the period 1980 to 2000. For this set of establishments, many report negative average TFP growth rates during the period. This is largely driven by the recessions in the early 1980s and 1990s, and is consistent with the findings of industry-level studies for the UK and other countries.²¹ Over this same period labour productivity growth in our sample averaged 3.4% per annum across all industries. 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. The standard deviation in TFP growth across the whole sample is 0.129, which shows that there is substantial variation in growth rates.

Figures 3 and 4 show the distribution of relative TFP (MTFP, as defined above) for two example 2-digit industries. Relative TFP is measured relative to the geometric mean across establishments and time within each 4-digit sub-industry. Each year we plot the distribution between the 5th and 95th percentile, with the line in the middle of each grey bar being the median. All industries display persistent productivity dispersion, this is explained in the model by variation in establishment innovative capabilities and the fact it takes time to transfer technology from a constantly advancing frontier. The industry in Figure 3, office

²¹Cameron, 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.

machinery and computer equipment, shows stronger growth and less dispersion of productivity around the geometric mean than the industry in Figure 4, footwear and clothing. Over time, as industries converge towards steady-state, the model implies that productivity dispersion may rise or fall, depending on the relationship between initial and steady-state productivity distributions. Figure 5 summarises changes in productivity dispersion for all 4-digit industries in our sample, by plotting changes in the sample standard deviation of relative TFP using a histogram. In 107 industries the standard deviation of relative TFP declined, while in 82 industries it increased, over the period 1980-2000.

Table 2 shows the proportion of establishments that transit between quintiles of their 4-digit industry TFP distribution. The rows show the quintile at time $t - 5$, while the columns show the quintile at time t . For example, the row marked quintile 5 shows that, of the establishments that were in the bottom quintile of their industry's TFP distribution, five years later 22% of those that survive have moved up to the top quintile, 24% have moved to the second quintile, 20% to the third, 21% to the fourth, and 13% remain in the bottom quintile. This transition matrix shows that persistent cross-section dispersion is accompanied by individual establishments changing their position within the productivity distribution, as implied by the theoretical model.

These descriptive statistics show that there is substantial variation in growth rates, even within industries. And that these differences in growth rates translate, in some cases, into persistently different level of TFP. The model developed above provides one explanation for this, and below we look at how well it describes the variation we see in the data.

3.4 The technological frontier

Before turning to the econometric evidence it is worth considering what we are capturing in our measure of the distance to 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.

For our econometric estimates, it is not important 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.

Year on year fluctuations in measured TFP may be due partly to measurement error and 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 five establishments with the highest levels of TFP relative to the geometric mean. We also report instrumental variables estimates, estimates of the ADL(1,1) representation of the model, and specifications where we replace our measure of distance to the frontier by a series of dummies for the decile of the industry productivity distribution where an establishment lies.

Finally, Table 1 shows that, on average, the log TFP gap is 0.548 which implies that on average the frontier establishment has TFP 73% higher than non-frontier establishments ($\exp(0.548) = 1.73$), and that there is substantial variation in this.

4 Empirical results

We start by presenting evidence that our basic model of technology transfer provides a good description of variation in the data with regards to productivity dynamics. We use these estimates to quantify the importance of technology transfer in the growth process. We then consider the role that foreign firms play in technology transfer.

4.1 Productivity dynamics

We start by correlating an establishment's distance to the technological frontier in their 4-digit industry, the technology gap term, with the establishment's TFP growth rate, controlling for only year effects and industry fixed effects. This is shown in the first column of Table 3. We see that there is a positive and significant correlation. This is close to our basic specification in equation (8). In column 2, we add age, an indicator for whether the establishment is an affiliate of a US multinational or an affiliate of another foreign multinational, and a term to correct for possible bias due to sample selection. The coefficient on age never enters significantly, while the dummy for US-owned establishments enters with a positive and significant coefficient, indicating that the UK-based affiliates of US multinationals experience around a half of one percent faster growth than the average UK establishment. We also include a dummy indicating whether an establishment is an affiliate of a multinational from any other foreign country and find that this is statistically insignificant. These coefficients are in line with the findings in other empirical work.²² As expected, the coefficient on the inverse Mills ratio is positive and significant, indicating that firms that survive have, on average, higher growth rates. In line with this, when we look at exiting firms we see that they are mainly exiting from the lower deciles of the TFP growth distribution.

In the third column we add establishment-specific effects. These control for unobserv-

²² Criscuolo and Martin (2005) provide evidence for the UK showing that the UK affiliates of US multinationals have a productivity advantage over UK and other foreign multinationals (located in the UK).

able characteristics that may be correlated with the TFP gap. We find a positive and significant effect of the TFP gap term - other things equal, establishments further behind the technological frontier in their 4-digit industry experience faster rates of productivity growth than firms that are more technologically advanced. This provides evidence of technological convergence and technology transfer at the establishment-level. The magnitude of the coefficient increases slightly when we include establishment fixed effects in column 3. This makes sense, omitted establishment characteristics that raise the level of productivity (e.g. good management) will be negatively correlated with the technology gap term (these establishments will be more likely to be nearer to the technology frontier than other establishments) and so lead to negative bias in the coefficient on the technology gap. Including establishment effects means that our model of convergence focuses on the time-series relationship between productivity in individual establishments and productivity in the frontier. Persistent dispersion in productivity levels relates to the cross-section distribution of productivity over different establishments. There is cross-section dispersion because different establishments have different steady-state levels of productivity relative to the frontier, as shaped by the fixed effects and the estimated speed of technology transfer (equation (14)).

In the fourth column we add in the growth rate of TFP in the frontier, as in the ECM representation (equation 11). This specification allows for a more flexible long-run relationship between frontier and non-frontier TFP. The frontier growth rate enters with a positive and significant coefficient - establishments in industries where the frontier is growing faster also experience faster growth. The coefficient on the gap term remains positive and significant. This pattern of estimates is consistent with the positive cointegrating relationship between frontier and non-frontier TFP implied by our model of technology transfer ($\alpha_2 > 0$, $(1 - \alpha_1) > 0$ and $\alpha_3 = (1 - \alpha_1) - \alpha_2 > 0$ in equation (10)).

As mentioned above, 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 a number of 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 include dummies indicating which decile, in terms of distance to the frontier, the establishment is in. Using deciles, rather than the actual distance to frontier, means that TFP_{it-1} does not enter directly on the right-hand side, so measurement error can not be driving these results. These estimates are shown in column 5 of Table 3. These show that, conditional on differences that arise due to year and establishment effects, age and being US or other foreign-owned, establishments in the tenth decile (those furthest away from the technological frontier), experience 25% faster TFP growth than those very close to the frontier. The coefficients on the decile dummies are monotonically declining, with those nearest the frontier experiencing the slowest growth rates. We also take two further approaches - we instrument the TFP gap term (column 2 of Table 4) and we use an alternative measure of distance from the technological frontier based on the average of the top five establishments (column 1 of Table 4).

A final concern we deal with in Table 3, before turning to a range of other robustness checks, is potential parameter heterogeneity. Our baseline estimation results pool across industries, imposing common slope coefficients. We re-estimated the model separately for each 2-digit industry.²³ As shown in column 6 of Table 3, this yielded a similar pattern of results. The median estimated coefficients, across 2-digit industries, were 0.134 for distance from the technological frontier, 0.0006 for age, 0.013 for the US dummy and -0.01 for the other foreign dummy. The coefficient on distance to the frontier was positive in all cases, and in 15 out of 17 2-digit industries it was significant at the 5% level. These lie close to the baseline within groups estimates reported in column 3 of Table 3.

We now turn to a number of robustness checks. We start, in column 1 of Table 4, by

²³See, for example, the discussion in Pesaran and Smith (1995).

considering an alternative measure of distance from the technological frontier, based on the average TFP in the five establishments with the highest measured TFP levels.²⁴ This smooths the distance from the technological frontier term, and again we find a positive and significant coefficient on the TFP gap. In column 2 we instrument relative TFP using lagged values of the TFP gap term. We use the t-2 and t-3 lags, both of which are statistically significant with an R-squared in the reduced form regression of 0.50, indicating that the instruments have some power. Again, we find a similar pattern of results. The coefficient on the gap term increases substantially (as does the standard error). This is due to the instrumenting rather than the change in sample. A final concern about measurement error is that TFP is measured under the assumption of perfect competition, as discussed above. In column (3) we adjust the factor shares by an estimate of the markup (calculated at the 2-digit industry-year level). Nonetheless, the coefficient on the gap term remains positive and significant. Finally, in column (4) we use an alternative measure of TFP growth. We implement the Olley-Pakes technique to estimate the level of TFP and from this calculate the growth rates and the gap. The coefficient on the gap remains positive and significant, although the magnitude of the coefficient is somewhat reduced.

A further concern is whether we are picking up technology transfer or mean reversion. The statistical significance of the establishment fixed effects provides evidence against reversion to a common mean value for productivity across all establishments. There remains the concern that each establishment may be reverting to its own mean level of productivity. A negative realization of the stochastic shocks to technology last period, u_{it-1} , leads to a lower value of lagged productivity, A_{it-1} , and a larger value of distance from the technological frontier, A_{Fjt-1} . Reversion to the establishment's mean level of productivity would result in a faster rate of TFP growth, inducing a positive correlation between establishment

²⁴This leads to a smaller sample size because we omit the frontier establishments from our estimating sample, so in this case we are omitting the five top establishments.

productivity growth and lagged distance from the technological frontier. On this interpretation, the identification of the parameters of interest is driven solely by variation in A_{it-1} . In contrast, according to our technology transfer hypothesis, variation in the position of the technological frontier, A_{Fjt-1} , also plays an important role.

As a robustness test, we have estimated the ADL(1,1) representation in TFP levels from equation 10, shown in Table 5. In column (1) we find that the terms for frontier TFP are individually and jointly statistically significant, providing evidence that our results are not exclusively driven by variation in A_{it-1} . As an additional robustness test, we estimated the equation for TFP growth in (8), but include lagged own establishment TFP (rather than distance from the technological frontier) on the right-hand side, together with a set of (0,1) dummies for the decile of the within-industry productivity distribution in which the establishment was present the previous period. Even after conditioning on lagged own establishment TFP, the decile dummies are highly statistically significant and the coefficients on the dummies are larger for deciles further from the frontier. While they are no longer monotonically increasing the dummies for deciles further from the frontier are statistically different from those that are close to the frontier. In the third column we add an additional lag of own TFP and in column (4) we instrument own lagged TFP with lags $t-2$ and $t-3$. The results for the decile dummies hold up to these, providing further evidence of the important role played by distance from the technological frontier.

What do these estimates imply about the economic importance of technology transfer in growth? If we take the coefficient on the gap, multiply this by the gap for each individual establishment, and represent this as a percentage of the establishment's own annual growth rate, we find that for the median establishment technology transfer accounts for 9% of total growth (the mean is 8%). If we take it as a percentage of predicted growth (so omitting the idiosyncratic element) we find that for the median establishment it accounts for 26% of

growth (the mean is 98%).²⁵

Taken together, these estimates imply that the further a firm lags behind the technological leader the greater the potential to realize productivity growth through technology transfer. We now turn to the question - what role is there for foreign-owned establishments within this framework?

4.2 Foreign ownership and productivity dynamics

The existing literature emphasises the importance of foreign-owned firms in driving technology transfer, particularly in technologically less advanced countries. Productivity levels or growth rates are typically regressed 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. But a major concern about this approach is that the entry and presence of foreign-owned establishments may be endogenous to TFP growth rates, and technology transfer may occur not only from foreign to domestic firms, but also between high performing and laggard domestic firms. In this paper, we take an alternative approach to estimating the impact of foreign direct investment on productivity growth of host-country firms. 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).

In many ways, foreign-owned establishments are just like any other. However, a large theoretical and empirical literature finds that they are on average more productive than domestically-owned establishments, and they may have access to superior technology from the source country where the parent firm is based.²⁶ Frequently, foreign-owned establishments may be close to, and may advance, the technological frontier within an industry,

²⁵If we simply take the coefficient on the gap and multiply it by the average gap, we obtain a much larger estimate of the contribution of technology transfer. This is driven by the influence of outlying observations that affect mean productivity growth and levels.

²⁶For empirical evidence on the higher productivity of foreign-owned establishments and multinationals more generally, see Criscuolo and Martin (2003), Doms and Jensen (1998) and Griffith (1999). This evidence is consistent with there being fixed costs to becoming a multinational firm, as formalized in Helpman *et al.* (2004) and Markusen (2002).

thereby providing a source of knowledge spillovers for domestically-owned establishments. In the UK, the majority of foreign investment has come from the US, and many papers have documented the fact that the US is the technological leader in a large number of industries. In addition, Criscuolo and Martin (2005) show that it is specifically US multinationals operating within the UK that have a productivity advantage over UK multinationals. The positive and sometimes significant dummy on US-owned establishments in Tables 3, 4 and 5 suggests that this is also the case in our sample. We also include a dummy to control for foreign affiliates of all other nationalities, but this is never significant. Therefore, in this section we focus our attention on the impact that US multinationals have on productivity growth.

In our model, US-owned establishments influence the productivity growth of non-frontier establishments in so far as they advance the technological frontier. Table 6 quantifies this impact. We first show the extent to which US affiliates are present in the UK. Column 1 shows that, using data on the population of plants, US affiliates account for around 9% of employment, ranging from 30% in the high-tech office machinery and computer equipment sector, to zero in the leather and leather goods sector. Column 2 shows that US affiliates were the frontier establishment around 13% of the time across industries over the period 1980-2000. There is again a large range, from US affiliates being at the frontier around a quarter of the time in non-metallic mineral products to only three percent of the time in textiles. As we would expect, the presence of US-owned establishments in an industry is positively correlated with the likelihood that they are at the technological frontier. US-owned establishments have the highest presence in high-tech industries such as office machinery and computer equipment, chemicals and instrument engineering, and make up the technological frontier over 25% of the time in these sectors.

The third column shows how far foreign-owned establishments advance the technological frontier, where they are the technological leader. Using our relative TFP measure we

calculate the productivity gap between the US-owned frontier and the most technologically advanced non-US-owned establishment. When the frontier is a non-US-owned establishment this figure is zero. This distance averages two percent across all manufacturing industries, and ranges from zero to 5 percent. Looking just at cases where a US affiliate is the frontier, on average it advances it by 19%. To examine how important US establishments are in facilitating technology transfer to non-frontier UK-based establishments, we calculate the proportion of technology transfer ($\delta_1 TFP_{GAP_{it-1}}$) due to US affiliates advancing the frontier ($\delta_1 (TFP_{GAP_{it-1}} - TFP_{GAP_{it-1}}^{*nf})$), where $TFP_{GAP_{it-1}}^{*nf}$ is a measure of what the TFP gap would have been if no US establishments had been present to advance the frontier, holding all else equal. This is equal to

$$\frac{\delta_1 (TFP_{GAP_{it-1}} - TFP_{GAP_{it-1}}^{*nf})}{\delta_1 TFP_{GAP_{it-1}}} = 1 - \frac{TFP_{GAP_{it-1}}^{*nf}}{TFP_{GAP_{it-1}}}.$$

We calculate this for each individual establishment and take the mean over all establishments. This is shown in column 4 of Table 6. We see that this ranges from zero, in industries where no US affiliates are present at the frontier, to 20% in mechanical engineering. The pattern across industries suggests that US affiliates make a larger contribution to technology transfer in high-technology industries such as mechanical engineering, instruments, office machinery and data processing equipment and chemicals.

5 Conclusions

The recent literature has emphasised deregulation and the opening up of markets as a key source of productivity growth. One important mechanism through which this works is technology transfer, both from domestic leaders and from inward investment from more technologically advanced economies. But the importance of technology transfer raises the puzzle of how this can be reconciled with persistent dispersion in productivity levels across establishments within narrowly defined industries.

In this paper we developed a model of technology transfer in which persistent dispersion is an equilibrium outcome. We 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 found statistically significant and quantitatively important evidence of catch-up to the technological leader. Other things equal, establishments further behind the technological frontier experience faster rates of productivity growth. We looked specifically at the role of the affiliates of US multinationals in contributing to productivity growth by raising the potential for technology transfer. The existing literature on the links between foreign presence and productivity growth has not included measures of distance from the technological frontier that we find to be important here. Our findings suggest that US-affiliates make a positive contribution to technology transfer in the UK, and that this is larger in high-technology industries, consistent with priors about US technological advantage.

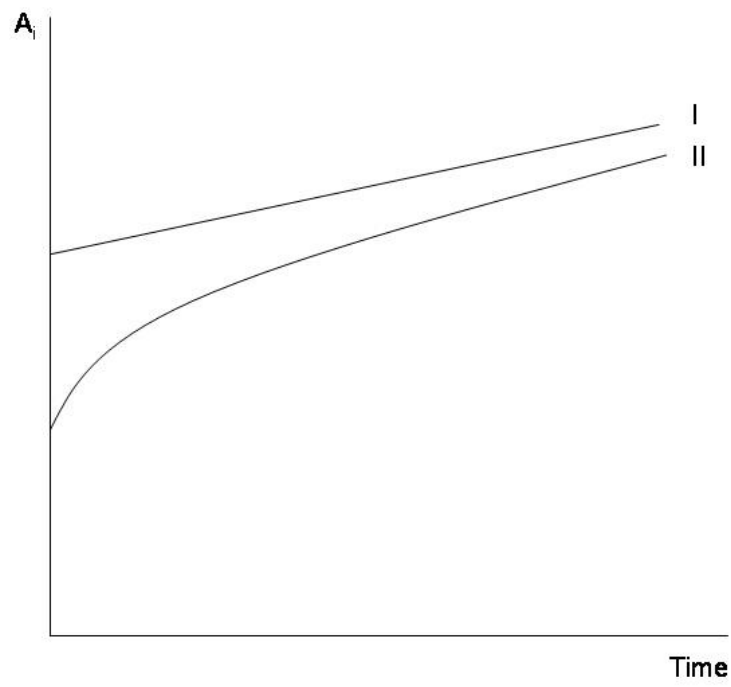


Figure 1: Unchanged Technological Leadership

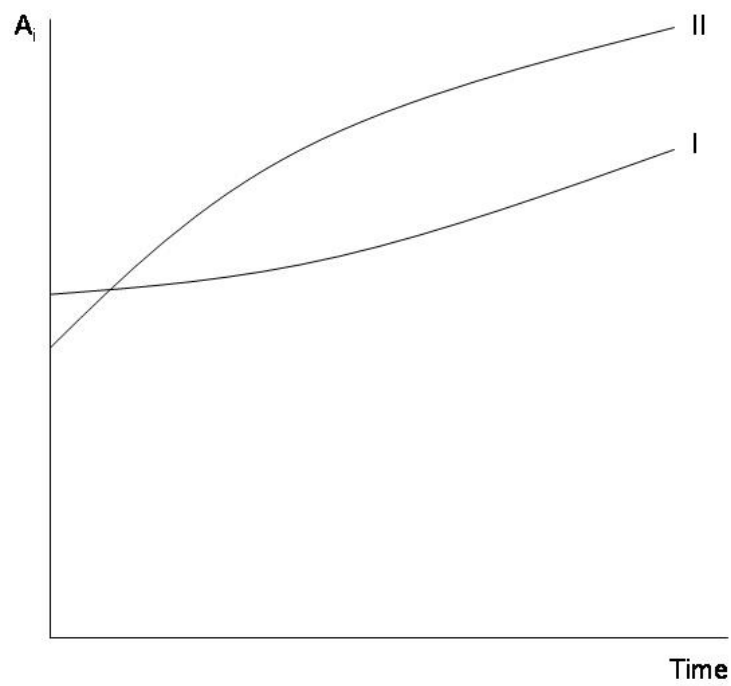


Figure 2: Endogenous Change in Technological Leadership

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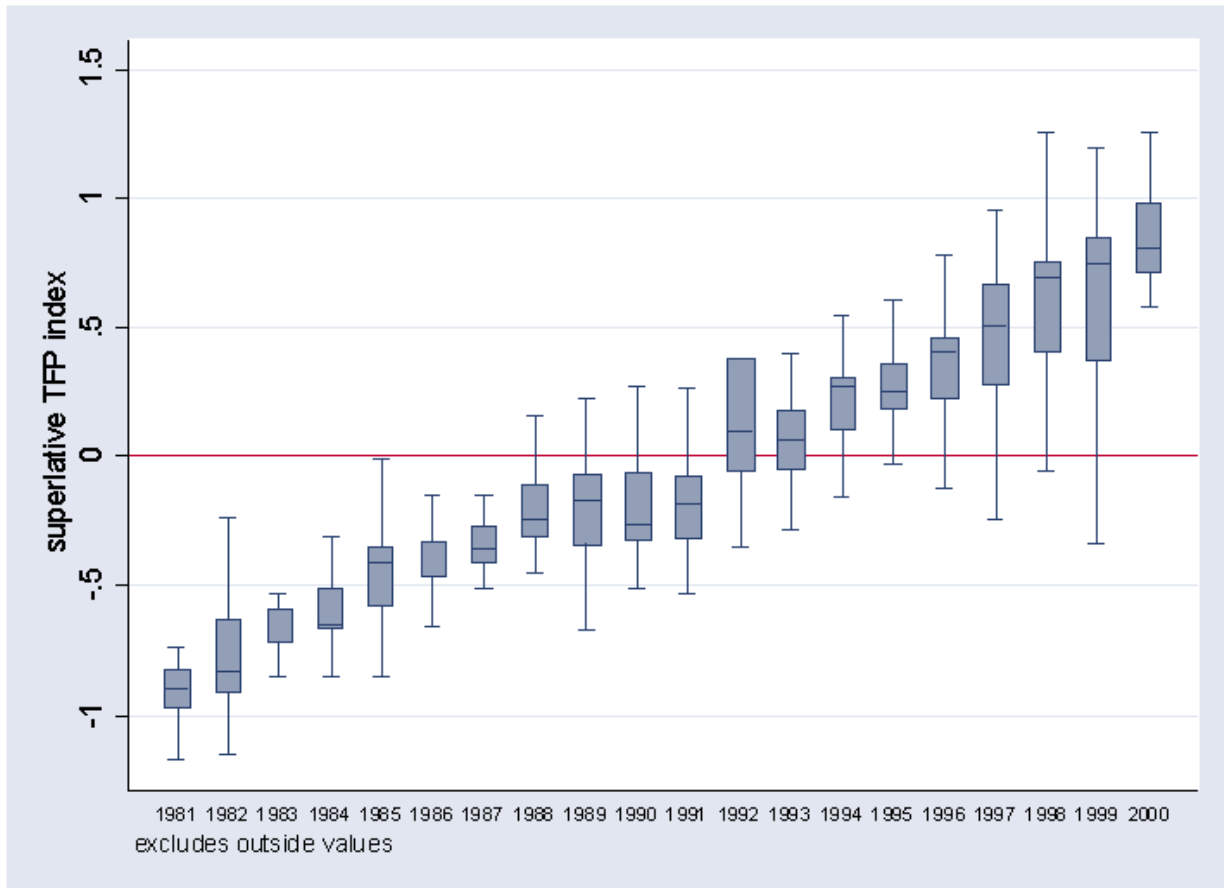
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Table 1: Descriptive Statistics

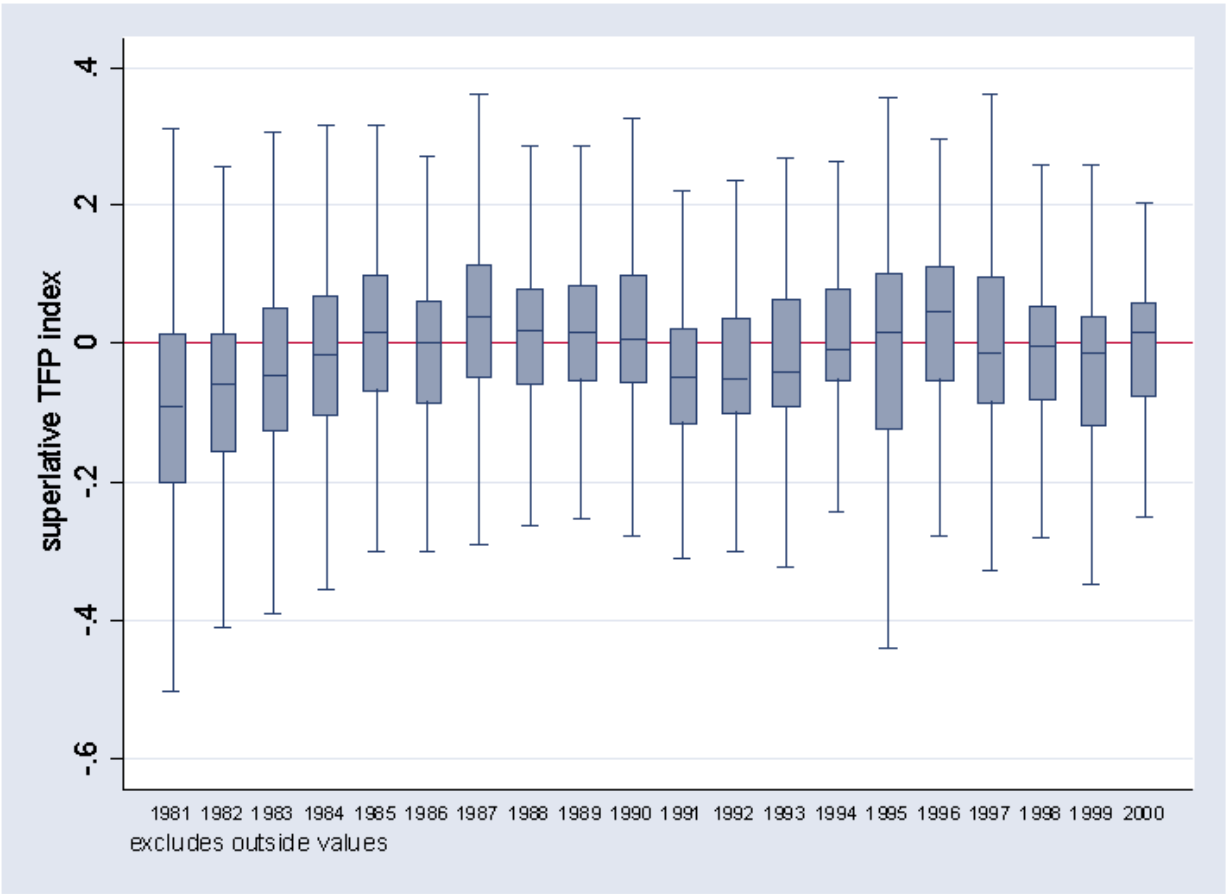
Variable	Mean	Standard deviation
ΔTFP_{ijt}	0.003	0.129
$TFPGAP_{ijt-1}$	0.548	0.317
ΔTFP_{Fjt}	0.003	0.303
Age	8.127	5.122
US dummy	0.120	0.325
Other foreign dummy	0.105	0.306

Note: The sample includes 103,664 observations on all non-frontier establishments over the period 1980-2000. Means are weighted by the inverse of the sampling probability and employment.

Figure 3: Evolution of TFP in the office machinery and computer equipment industry

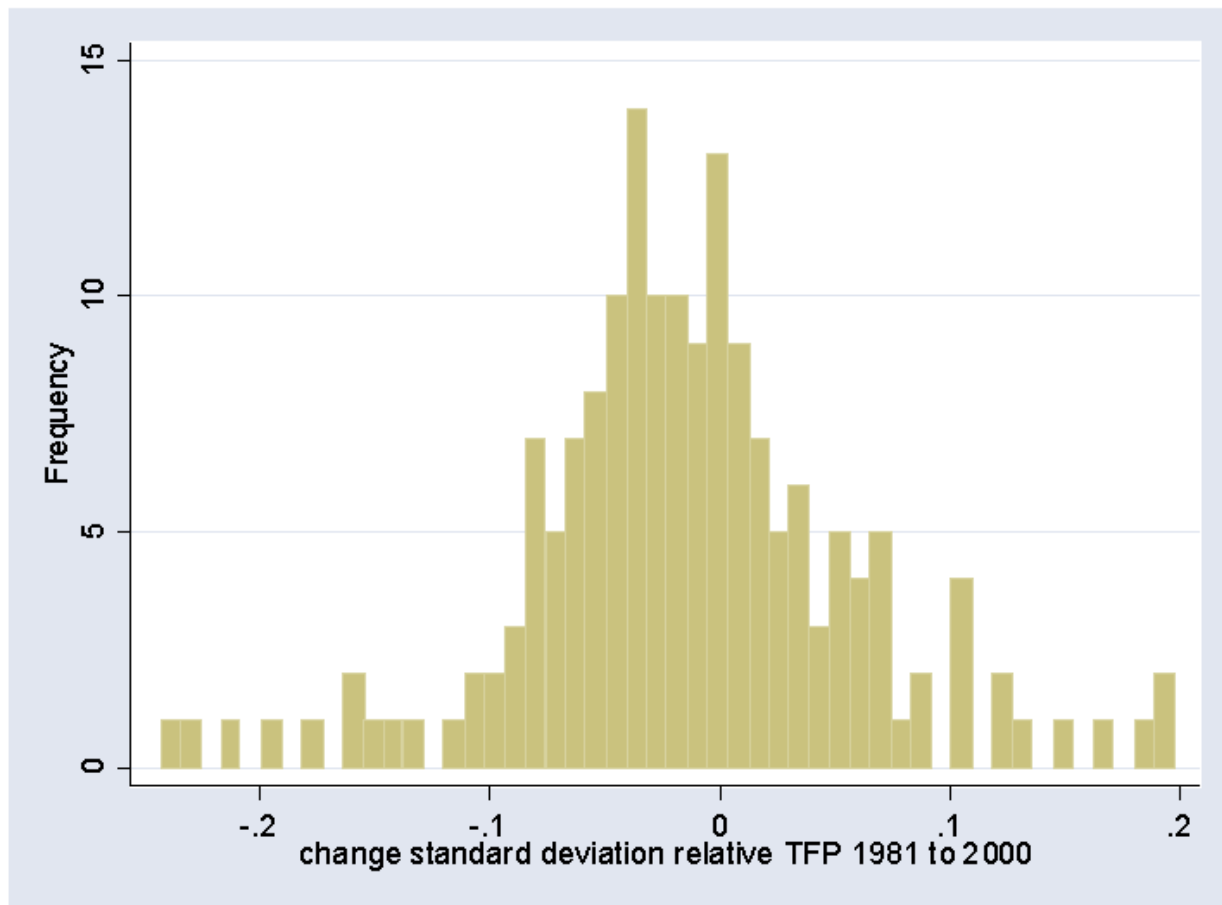
Note: The figure shows the distribution of TFP in 2-digit industry no.33 over time. TFP in each establishment is measured relative to the geometric mean of all other establishments in the same 4-digit industry (averaged over all years). The sample includes 627 observations on non-frontier establishments over the period 1981-2000. The horizontal bar shows the median, the top and bottom of the horizontal lines represent the 95th and 5th percentile respectively.

Figure 4: Evolution of TFP in the footwear and clothing industry



Note: The figure shows the distribution of TFP in 2-digit industry 45 over time. TFP in each establishment is measured relative to the geometric mean of all other establishments in the same 4-digit industry (averaged over all years). The sample includes 6129 observations on non-frontier establishments over the period 1981-2000. The horizontal bar shows the median, the top and bottom of the horizontal lines represent the 95th and 5th percentile respectively.

Figure 5: Change in Standard Deviation of TFP within 4-digit industries, 1981-2000



Note: The figure shows the distribution of the change in the standard deviation over the period 1981-2000 for the 189 4-digit industries in our sample.

Table 2: Transition matrix

Quintile of TFP distribution, t-5	Quintile of TFP distribution t					Total
	1	2	3	4	5	
1	37.71	29.39	18.27	9.41	5.22	100
2	26.46	28.06	25.16	13.76	6.57	100
3	17.39	26.48	25.13	22.08	8.92	100
4	18.03	20.22	28.58	21.92	11.25	100
5	22.19	23.81	19.81	21.47	12.73	100
Total	24.75	25.88	23.36	17.35	8.67	100

Note: The table shows the proportion of establishments by quintile of the TFP distribution within their 4-digit industry in period t-5 and t, averaged over the four five year periods in our sample. The quintiles are defined across all establishments in our sample (including entrants and exitors), while only establishments that are present in both period t-5 and t are included in the table. The figures are weighted by the inverse of the sampling probability and employment.

Table 3: Catch-up model

dep var: ΔTFP_{ijt}	(1)	(2)	(3)	(4)	(5)	(6)
Obs	103,664	103,664	103,664	103,664	103,664	103,664
ΔTFP_{Fjt}				0.111 (0.012)		
$TFPGAP_{ijt-1}$	0.091 (0.012)	0.091 (0.012)	0.117 (0.015)	0.199 (0.022)		0.134
Age		0.0002 (0.0005)	0.0003 (0.0006)	0.0002 (0.0006)	0.001 (0.0004)	0.0006
US dummy		0.005 (0.002)	0.007 (0.005)	0.010 (0.005)	0.007 (0.006)	0.013
Other foreign		-0.009 (0.006)	-0.020 (0.014)	-0.020 (0.014)	-0.022 (0.015)	-0.010
DD2					0.062 (0.006)	
DD3					0.098 (0.008)	
DD4					0.123 (0.008)	
DD5					0.146 (0.010)	
DD6					0.164 (0.009)	
DD7					0.188 (0.011)	
DD8					0.224 (0.013)	
DD9					0.251 (0.013)	
DD10					0.254 (0.017)	
Inverse mills ratio		0.006 (0.004)	0.043 (0.010)	0.038 (0.011)	0.021 (0.012)	0.032
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
4-digit industry dummies	Yes	Yes	-	-	-	-
Within groups	No	No	Yes	Yes	Yes	Yes

Note: Regressions are estimated on all non-frontier establishments for 1980-2000. All columns are weighted by the inverse of the sampling probability and employment. Standard errors in brackets are clustered at the 4-digit industry.

ΔTFP_{Fjt} is tfp growth in the frontier. $TFPGAP_{ijt-1}$ is tfp relative to frontier in the previous period. DD* are dummies representing the decile of the within 4-digit industry year distribution of $TFPGAP_{ijt-1}$ where DD10 is the decile for establishments with the largest gap with the frontier. DD1 the decile for those closest to the frontier is omitted. Column (6) reports the median of the coefficients from 2-digit industry level regressions.

Table 4: Robustness

Dep var: ΔTFP_{ijt}	(1)	(2)	(3)	(4)
Obs	101,328	70,023	52,478	93,825
$TFPGAP_{ijt-1}$		0.400 (0.070)	0.138 (0.021)	0.054 (0.006)
$TFPGAP5_{ijt-1}$	0.327 (0.030)			
Age	0.001 (0.0006)	-0.0009 (0.0008)	0.0005 (0.001)	0.0009 (0.0005)
US dummy	0.004 (0.005)	0.012 (0.006)	-0.007 (0.009)	0.003 (0.005)
Other foreign	-0.021 (0.015)	-0.031 (0.019)	-0.022 (0.013)	-0.015 (0.012)
Inverse mills ratio	0.029 (0.011)	0.040 (0.021)	0.053 (0.018)	0.032 (0.010)
Control function in regression		-0.319 (0.070)		
Significance of instruments in reduced form		324.83		
F-statistics (P-value)		(0.000)		
R ² of reduced form		0.50		
Year dummies	Yes	Yes	Yes	Yes
Within groups	Yes	Yes	Yes	Yes

Note: Regressions are estimated on non-frontier establishments for 1980-2000. All columns are weighted by the inverse of the sampling probability and employment. Standard errors in brackets are clustered at the 4-digit industry. Column (1) uses a measure of distance to the frontier where the frontier is defined by the average level of TFP in the top five establishments. In column (2) the TFP gap term is instrumented using own lags dated t-2 and t-3. In column (3) the measure of TFP is adjusted for variation in markups at the 2-digit industry-year level. In column (4) we use Olley-Pakes/Pavnick estimates of TFP.

Table 5: ADL(1,1) and ECM specifications

	(1)	(2)	(3)	(4)
Dependent variable	TFP_{ijt}	ΔTFP_{ijt}	ΔTFP_{ijt}	ΔTFP_{ijt}
Obs	103,664	103,664	84,232	70,023
TFP_{ijt-1}	0.545 (0.036)	-0.342 (0.051)	-0.375 (0.034)	-0.271 (0.035)
TFP_{ijt-2}			0.068 (0.016)	
$TFPF_{jt}$	0.044 (0.009)			
$TFPF_{jt-1}$	0.021 (0.008)			
Age	0.0012 (0.0005)	0.001 (0.0005)	0.0005 (0.0006)	-0.0004 (0.0008)
US dummy	0.006 (0.005)	0.006 (0.005)	0.010 (0.006)	0.010 (0.008)
Other foreign dummy	-0.019 (0.017)	-0.021 (0.016)	-0.024 (0.019)	-0.025 (0.020)
DD2		0.025 (0.005)	0.026 (0.007)	0.024 (0.007)
DD3		0.039 (0.009)	0.042 (0.009)	0.041 (0.009)
DD4		0.048 (0.010)	0.050 (0.010)	0.047 (0.010)
DD5		0.058 (0.010)	0.060 (0.010)	0.057 (0.010)
DD6		0.062 (0.013)	0.064 (0.011)	0.060 (0.010)
DD7		0.068 (0.015)	0.069 (0.013)	0.065 (0.013)
DD8		0.085 (0.017)	0.085 (0.014)	0.082 (0.013)
DD9		0.087 (0.021)	0.093 (0.016)	0.089 (0.017)
DD10		0.079 (0.023)	0.079 (0.019)	0.075 (0.020)
Inverse mils ratio	0.006 (0.015)	0.006 (0.014)	-0.006 (0.026)	-0.005 (0.030)
Control function in regression				-0.116 (0.032)
Significance of instruments in reduced form				10867.83
F-statistics (P-value)				(0.000)
R ² of reduced form				0.69
Year dummies	Yes	Yes	Yes	Yes
Within groups	Yes	Yes	Yes	Yes

Notes: Regressions are estimated on non-frontier establishments for 1980-2000. All columns are weighted by the inverse of the sampling probability and employment. Standard errors in brackets are clustered at the 4-digit industry. In column 1 frontier TFP ($TFPF_{jt}$) and lagged frontier TFP ($TFPF_{jt-1}$) are jointly significant. Dependent variable in columns 2 to 4 is TFP growth. In column 3 we add in TFP t-2 and in column 4 we instrument TFP t-1 with TFP t-2 and TFP t-3.

Table 6: The contribution of affiliates of US multinationals, 1980-2000

Sector	US affiliates: Share of industry employment %	% of time frontier	Advancement of the frontier	Advancement of the frontier as a proportion of the total gap
22 metal manufacturing	5	17	0.02	0.07
24 non-metallic mineral products	4	24	0.04	0.15
25 + 26 chemicals and man-made fibres	18	23	0.05	0.14
31 metal goods n.e.s.	8	6	0.01	0.08
32 mechanical engineering	15	18	0.04	0.20
33 office machinery and data processing equipment	30	13	0.03	0.15
34 electrical and electronic engineering	10	10	0.01	0.06
35 motor vehicles and parts	16	17	0.05	0.10
36 other transport equipment	3	4	0.00	0.00
37 instrument engineering	20	22	0.02	0.13
41 + 42 food, drink and tobacco	6	14	0.02	0.06
43 textiles	4	3	0.01	0.02
44 leather and leather goods	0	0	0	0
45 footwear and clothing	2	4	0.01	0.03
47 paper, paper products and publishing	8	9	0.02	0.12
48 rubber and plastics	8	21	0.03	0.13
49 + 46 other manufacturing, timber	4	1	0.00	0.01
<i>All manufacturing</i>	<i>9</i>	<i>13</i>	<i>0.02</i>	<i>0.10</i>

Notes: All means are weighted by the inverse of the sampling probability and employment. Column (1) shows the annual average proportion of employment in each 4-digit industry with the 2-digit industry that is in affiliates of US firms, 1980-2000. Column (2) shows the percentage of times an affiliate of a US firm is the most productive establishment in its 4-digit industry. Column (3) shows how far the US affiliate advances the frontier (i.e. the distance between the US affiliate and the nearest non-US-owned establishment) when it is the frontier. This is the mean of $\ln(A_{FUS}/A_{FNon-US})$. Column 4 shows the amount that affiliates of US firms advance the frontier (increase the TFP gap) divided by the total gap, calculated at the establishment level and averaged.