

# Technological Catch-up and Geographic Proximity

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## Abstract

This paper examines productivity catch-up as a source of establishment productivity growth. We present evidence that, other things equal, establishments further behind the industry frontier experience faster rates of productivity growth. Geographic proximity to frontier firms makes catch-up faster. Our econometric specification implies a long-run relationship between productivity levels, where non-frontier establishments lie a steady-state distance behind the frontier such that their rate of productivity growth including catch-up equals productivity growth at the frontier. We use our econometric estimates to quantify the implied contribution to productivity growth of catch-up to both the national and regional productivity frontiers.

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# 1 Introduction

Deregulation and the opening of markets to international trade and investment have been widely recognized as major drivers of growth. Recent studies on entry regulation<sup>1</sup> have revived interest in the subject and foreign firms have been identified as important potential conduits of technology transfer. The existing literature on productivity spillovers from foreign firms typically regresses productivity levels or growth rates on a measure of foreign presence in an industry. But any high productivity establishment within the industry, whether it is foreign or domestically-owned, provides a potential source of productivity catch-up.<sup>2</sup> Building on this idea, we use a standard time-series econometric specification to provide evidence on the contribution of productivity catch-up to productivity growth in non-frontier establishments. We also investigate whether geographic proximity matters, in the sense that firms benefit more from frontier establishments that are located nearby. We find that geographic proximity to frontier firms speeds up the process of catch-up. Using our econometric specification, we quantify the implied contribution to productivity growth of catch-up to both the national and regional productivity frontier.

The literature that regresses productivity levels or growth rates on the share of foreign firms in employment, sales or the total number of firms is extensive.<sup>3</sup> While much of this research concentrates on productivity spillovers from inward investment, other recent work has emphasized the importance of “technology sourcing” where firms locate abroad in order to access the latest technologies and repatriate them to their home country.<sup>4</sup> In both

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<sup>1</sup>See, inter alia, Baily *et al.* (1992), Davis and Haltiwanger (1991), Nicoletti and Scarpetta (2002), Djankov *et al.* (2002) and Aghion et al (2009).

<sup>2</sup>For empirical evidence that domestic multinationals frequently have comparable levels of productivity to foreign multinationals, see Doms and Jensen (1998), Girma and Görg (2007), Griffith and Simpson (2004) and Criscuolo and Martin (2005).

<sup>3</sup>See for example Aitken and Harrison (1999), 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 (2007), Girma and Wakelin (2002), Görg and Greenaway (2002), and Harris and Robinson (2002).

<sup>4</sup>Case studies emphasising technology sourcing include von Zedtwitz and Gassman (2002) or Serapio and Dalton (1999) and the references therein. Econometric evidence is contained in Griffith, Harrison and Van

cases, productivity catch-up to high productivity establishments within industries provides a potential source of productivity growth to non-frontier establishments. Our approach incorporates productivity catch-up while at the same time allowing for persistent productivity dispersion within industries. In the long-run relationship implied by our econometric specification, non-frontier establishments lie a steady-state distance behind the frontier such that their rate of productivity growth including catch-up equals productivity growth at the frontier. Our approach thus reconciles productivity heterogeneity, as documented in the micro-econometric literature on firms and plants, with productivity catch-up as emphasized in the macroeconomic literature on convergence.<sup>5</sup> Our paper contributes to an emerging literature that emphasizes the characteristics of both domestic and foreign firms in influencing the extent to which foreign presence contributes towards domestic productivity growth.<sup>6</sup> Our paper also contributes to the regional and urban economics literatures that emphasizes localized knowledge spillovers by providing evidence of regional productivity catchup to the frontier.<sup>7</sup>

The United Kingdom provides a natural context within which to explore the role of productivity catch-up. Throughout the 1970s productivity levels and growth rates in the UK lagged behind those of the US. The 1980s saw a period of rapid growth in the UK that led to a reduction in the aggregate productivity gap with the US. This aggregate picture hides substantial heterogeneity in productivity across establishments.

The structure of the paper is as follows. Section 2 outlines our empirical approach. Section 3 discusses the data and a number of measurement issues. In section 4 we present

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Reenen (2006) and Branstetter (2006).

<sup>5</sup>The micro-econometric literature includes Baily *et al.* (1992), Bartelsman and Doms (2000), Davis and Haltiwanger (1991), Davis, Haltiwanger and Schuh (1996), Disney *et al.* (2003), Dunne, Roberts and Samuelson (1989) and Foster, Haltiwanger and Krizan (2002) among others. For macroeconomic research on productivity convergence, see Acemoglu *et al.* (2002), Aghion and Howitt (1997), Cameron (1996), Cameron *et al.* (2005), Grossman and Helpman (1991), Howitt (2000) and Parente and Prescott (1994, 1999).

<sup>6</sup>See for example Girma, Greenaway and Wakelin (2001), Girma (2005), and Kinoshita (2001).

<sup>7</sup>The literature emphasising localised knowledge spillovers dates back to at least Marshall (1920), as discussed by for example Krugman (1991), Duranton and Puga (2004) and Rosenthal and Strange (2004).

our econometric results. First we present our estimates of productivity catch-up before examining the role of geographic proximity and the contribution to productivity growth of catch-up to the national and regional productivity frontier. A final section concludes.

## 2 Empirical Framework

Our main interest lies in understanding how the distribution of productivity evolves over time and whether we can find evidence consistent with productivity catch-up. We employ a formulation from the macroeconomics literature on convergence (see for example Bernard and Jones 1996 and Cameron 2005), which captures productivity catch-up, but which also encompasses other observed empirical regularities: persistence in productivity levels at the establishment level over time and heterogeneity in productivity levels across establishments. Equation (1) describes our starting point where  $i$  indexes establishments and  $t$  time. We characterize  $\ln A$ , an index of technology or Total Factor Productivity (TFP), as a function of its prior level ( $A_{it-1}$ ) to capture persistence, an individual specific factor ( $\gamma_i$ ) to reflect heterogeneity in innovative capabilities, and the current productivity frontier for industry  $j$  ( $A_{Fjt-1}$ ) to capture convergence:

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

where the parameter  $\gamma_i$  captures an establishment's own rate of innovation through its underlying capabilities; the parameter  $\lambda$  captures the speed of productivity catch-up; and  $u_{it}$  captures the influence of stochastic shocks to productivity growth.

Re-arranging equation (1), taking the first term on the right-hand side over to the left-hand side, we obtain:

$$\Delta \ln A_{it} = \gamma_i + \lambda \ln \left( \frac{A_{Fj}}{A_i} \right)_{t-1} + u_{it} \quad (2)$$

where  $u_{it}$  is a stochastic error. While this provides our baseline specification, we also consider a number of generalizations and robustness tests.

We estimate the specification in equation (2) for all non-frontier establishments (section 3.4 discusses how we identify the frontier). We face a number of specific challenges in doing this. The first is obtaining accurate measures of  $\Delta \ln A_i$  and  $\ln(A_F/A_i)$  and section 3.2 discusses our approach to productivity measurement and the robustness tests that we undertake. The second is that  $A_{it-1}$  appears on both the left and right-side of equation (2), so that shocks to  $A_{it-1}$ , due for example to measurement error, could lead to biased estimates of the speed of technological convergence  $\lambda$ . We address this concern in section 4.2 using a variety of approaches including instrumental variables estimation. Third, we provide evidence that identification of  $\lambda$  is being driven by variation in the position of the frontier  $A_{Fjt-1}$ , and thus indicates productivity catch-up, and is not simply driven by variation in  $A_{it-1}$ , as discussed in section 4.4.

A final issue is that we can only estimate equation (2) on surviving establishments. To control for the non-random survival of establishments, we use a standard Heckman (1976) selection correction, estimating a probit regression for firm survival and augmenting the equation for productivity growth in (2) with an inverse Mills ratio. We model a firm's exit decision as an unknown non-linear function of firm age, log firm investment and log firm capital stock, which have no direct effect on productivity under our assumptions of constant returns to scale and Hicks-neutral productivity differences. These firm characteristics are therefore suitable excluded variables from the productivity equation that affect the probability of firm survival.<sup>8</sup> As the functional form of the non-linear relationship determining a firm's exit decision is unknown, we follow Olley and Pakes (1996) and Pavcnik (2002) in adopting a semi-parametric specification, which approximates the unknown function using a polynomial expansion in firm age, log firm investment and log firm capital stock and their interactions.

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<sup>8</sup>The correlation coefficients between these three variables are as follows: firm age and log investment (0.162), firm age and log capital stock (0.129), log investment and log capital stock (0.756).

Our empirical model for productivity growth in equation (2) permits a general specification of the error term. The specification includes an establishment-specific fixed effect ( $\gamma_i$ ) that we allow to be correlated with other independent variables. For example, establishments which begin far from the frontier and converge rapidly towards it may be precisely those with high levels of innovative capabilities  $\gamma_i$ . We also include a full set of time dummies,  $T_t$ , to control for common shocks to technology and macroeconomic fluctuations, together with an idiosyncratic error,  $\varepsilon_{it}$ :

$$u_{it} = T_t + \varepsilon_{it}. \quad (3)$$

Standard errors are clustered on four-digit industries, which allows the error term to be correlated across time within establishments and across establishments within four-digit industries (see, for example, Bertrand *et al.* 2004).<sup>9</sup>

As a robustness test we consider an augmented version of this specification, which allows for a more flexible specification of the relationship between non-frontier and frontier TFP, and which is derived from the following Autoregressive Distributed Lag ADL(1,1) model for TFP levels:

$$\ln A_{it} = \gamma_i + \alpha_1 \ln A_{it-1} + \alpha_2 \ln A_{Ft} + \alpha_3 \ln A_{Ft-1} + T_t + \varepsilon_{it}. \quad (4)$$

Under the assumption of long-run homogeneity ( $\frac{\alpha_2 + \alpha_3}{1 - \alpha_1} = 1$ ), which ensures that the rate of productivity catch-up depends on relative rather than absolute levels of productivity, we obtain the following Equilibrium Correction Model (ECM) specification (see Hendry 1996):<sup>10</sup>

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<sup>9</sup>Bertrand *et al.* (2004) examine several approaches to allowing for correlated errors and show that clustering performs very well in settings with at least 50 clusters. While clustering on four-digit industries preserves a sufficiently large number of clusters, we also examined the robustness of our results to clustering on two-digit sectors, to allow for example for input-output linkages between industries within the same two-digit sector. While we find a similar pattern of results in this robustness check, we do not adopt it as our preferred specification, because of the relatively small number of clusters using two-digit sectors (around 20).

<sup>10</sup>Under the assumption of long-run homogeneity, doubling  $A_{it-1}$ ,  $A_{Ft}$  and  $A_{Ft-1}$  doubles  $A_{it}$ , ensuring that the rate of productivity catch-up does not depend on units of measurement for output or factor inputs.

$$\Delta \ln A_{it} = \gamma_i + \beta \Delta \ln A_{Ft} + \lambda \ln \left( \frac{A_{Fj}}{A_i} \right)_{t-1} + T_t + \varepsilon_{it}, \quad (5)$$

where equation (2) is a more restrictive version of this expression, with  $\beta = \alpha_2 = 0$  and  $\lambda = (1 - \alpha_1)$ .

## 2.1 Implications for productivity dispersion

Before proceeding to discuss the data and presenting our baseline empirical results, it is useful to examine the implications of our empirical framework for the cross-section distribution of productivity within the industry. This is not central to our empirical strategy, but clarifies the interpretation of the results and makes clear how productivity catch-up is consistent with long-run productivity dispersion.

Returning to our baseline specification for productivity growth in (2), the productivity frontier in industry  $j$  advances at a rate determined by innovative capabilities  $\gamma_{Fj}$  and a stochastic error  $u_{Fj}$ :

$$\Delta \ln A_{Fjt} = \gamma_{Fj} + u_{Fjt}. \quad (6)$$

Combining the expression for the frontier above with the equation for TFP growth in a non-frontier establishment  $i$  in equation (2), yields an expression for the evolution of productivity in establishment  $i$  relative to the industry  $j$  frontier:

$$\Delta \ln (A_{it}/A_{Fjt}) = (\gamma_i - \gamma_{Fj}) + \lambda \ln \left( \frac{A_{Fjt-1}}{A_{it-1}} \right) + (u_{it} - u_{Fj}). \quad (7)$$

Taking expectations in equation (7), the long-run equilibrium level of productivity relative to the frontier implied by our econometric specification is:

$$\mathbf{E} \ln \left( \frac{\widehat{A}_i}{A_{Fj}} \right) = \frac{\gamma_i - \gamma_{Fj}}{\lambda}. \quad (8)$$

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 converge

towards the constantly advancing frontier ( $\lambda$  is finite). In the long-run, the frontier is whichever establishment in the industry has highest  $\gamma_i$  ( $\gamma_{Fj} = \max_i\{\gamma_i\}$ ), while all other establishments lie a distance behind the frontier such that expected productivity growth including catch-up equals expected productivity growth in the frontier.

In our data we find that affiliates of US multinationals frequently lie at the industry productivity frontier. In terms of equation (8), this finding implies that affiliates of US multinationals often have higher values of  $\gamma_i$  than other multinationals and than purely domestic establishments. The higher values of  $\gamma_i$  are consistent with fixed costs of becoming a multinational, so that only the most productive foreign firms are observed in the UK, and with the US having technological leadership in a range of industries.

Equations (1), (7) and (8) 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. 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. The analysis focuses on the relationship over time between an establishment's rate of growth of productivity and its distance from the frontier.

Although the establishment fixed effects are included in an equation for productivity *growth* (2), 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 (our econometric specification is an ECM representation of this long-run relationship in productivity levels). 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 (8).

In summary, our econometric specification captures heterogeneity in productivity within



industries, while allowing for productivity catch-up. Each establishment converges towards its own steady-state level of productivity relative to the industry frontier and there is long-run productivity dispersion.

### 3 Data and measurement issues

#### 3.1 Measuring growth and relative levels of TFP

As emphasized above, one of the main challenges in the productivity literature is obtaining accurate measures of TFP growth and relative TFP levels ( $\Delta \ln A_i$  and  $\ln(A_F/A_i)$  respectively). Two main approaches are taken in the literature - the superlative index number approach and production function estimation. Both make restrictive assumptions in order to obtain measures of productivity. The main advantage of the superlative index number approach, and the reason why we adopt it in our empirical specification, is that by exploiting assumptions about market behavior we can allow a more flexible functional form for the production technology.

The key assumptions behind the superlative index number measures that we employ are a constant returns to scale translog production function and perfect competition.<sup>11</sup> We therefore follow an influential line of research in assuming that the knowledge spillovers captured in our model of productivity catch-up are external to the firm, so that the firm's production technology exhibits constant returns to scale in its own inputs of labor and physical capital (see for example Fujita and Ogawa 1982, Lucas and Rossi-Hansberg 2002, and Combes et al. 2008). Following this line of research, we also assume that knowledge spillovers are disembodied and enter the Hicks-neutral productivity shifter in our model of productivity catch-up.<sup>12</sup> Together our assumptions of constant returns to scale and perfect competition imply that the share of a factor in total costs contains information on

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<sup>11</sup>See for example Caves et al. 1982a,b.

<sup>12</sup>Therefore this line of research abstracts from richer forms of knowledge spillovers that for example are non-neutral across the various factors of production such as capital, skilled and unskilled workers.

its marginal physical productivity, and therefore provides the correct weight for the factor input when measuring productivity. The assumption of a translog production technology provides an arbitrarily close local approximation to any underlying constant returns to scale production technology.

We also report results using augmented superlative index number measures of TFP<sup>13</sup> that allow for some form of imperfect competition where price is a mark-up over marginal cost. More generally, we pay careful attention to measurement issues and we carry out a number of robustness checks designed to deal with measurement error (see section 4.2) that could in principle affect the estimated speed of technological catch-up  $\lambda$ .

The alternative approach of production estimation faces the challenge of estimating the parameters of the production function while also allowing for the endogeneity of factor input choices. Olley and Pakes (1996) and Levinsohn and Petrin (2003) develop methodologies to address this challenge under the assumption that the production technology is Cobb-Douglas.<sup>14</sup> Although we also use the Olley-Pakes methodology as a robustness test, we do not take this as our preferred measure of productivity, because we believe it is important in our application to allow for a more flexible production technology, and because the theoretical model underlying the Olley-Pakes methodology does not incorporate productivity catch-up across establishments, which is a central feature of our empirical framework.

We calculate the growth rate of TFP ( $\Delta TFP_{it}$ , the empirical counterpart to  $\Delta \ln A_{it}$ ) using the following superlative index number:

$$\Delta TFP_{it} = \Delta \ln Y_{it} - \sum_{z=1}^Z \tilde{\alpha}_{it}^z \Delta \ln x_{it}^z, \quad (9)$$

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  $\alpha_{it}^z$  is the share of the factor in output at time  $t$ ),  $Z$  is the

<sup>13</sup>Following the ideas in Hall (1988), Roeger (1995) and Klette (1999).

<sup>14</sup>While other studies in the production function estimation literature consider translog functional forms following Christenson *et al.* (1973), these studies do not typically allow for the endogeneity of factor input choices.

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. This formulation assumes that production technology is homogeneous of degree one and exhibits diminishing marginal returns to the employment of each factor alone. We allow factor shares to vary across establishments and time, which is consistent with the large degree of heterogeneity in technology observed even within narrowly defined industries.<sup>15</sup>

To allow for potential measurement error in the shares of factors of production in output,  $\alpha_{it}^z$ , we exploit the properties of the translog production function following Harrigan (1997). Under the assumption of a translog production technology and constant returns to scale,  $\alpha_{it}^z$  can be expressed as the following function of relative factor input use:

$$\alpha_{it}^z = \xi_i + \sum_{z=2}^Z \phi_j^z \ln \left( \frac{x_{it}^z}{x_{it}^1} \right), \quad (10)$$

where  $\xi_i$  is an establishment-specific constant and where we have imposed constant returns to scale by normalizing 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 (9) and below. While we make this correction to address potential concerns about measurement error, we in fact find a very similar pattern of results using the raw shares of factors of production in output.

The level of TFP in establishment  $i$  relative to the frontier in industry  $j$  ( $TFPGAP_{it}$ , the empirical counterpart to  $\ln(A_j^F/A_i)_t$ ) is measured using an analogous superlative index number. As a first step, TFP in each establishment is evaluated relative to a common reference point - the geometric mean of all other establishments in the same industry (averaged

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<sup>15</sup>We assume here for simplicity that technological change is Hicks neutral, in the sense of raising the marginal productivity of all factors proportionately.

over all years). The measure of relative TFP is,

$$MTFP_{it} = \ln \left( \frac{Y_{it}}{\bar{Y}_j} \right) - \sum_{z=1}^Z \sigma_i^z \ln \left( \frac{x_{it}^z}{\bar{x}_j^z} \right), \quad (11)$$

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. We again allow for measurement error by smoothing the factor shares using the properties of the translog production technology (see equation (10) above), and we impose constant returns to scale so that  $\sum_z \sigma_i^z = 1$ .

Denote the frontier level of TFP relative to the geometric mean  $MTFP_{jt}^F$ . Subtracting  $MTFP_{it}$  from  $MTFP_{jt}^F$ , we obtain our superlative index of the productivity gap between an establishment and the frontier in an industry-year ( $TFPGAP_{it}$ ):<sup>16</sup>

$$TFPGAP_{it} = MTFP_{jt}^F - MTFP_{it}. \quad (12)$$

### 3.2 Data

Our empirical analysis uses 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.<sup>17</sup> We use data at the establishment level.<sup>18</sup> The country of residence of the ultimate owner of the

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<sup>16</sup>Note that equation (11) 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.

<sup>17</sup>Basic 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) and Barnes and Martin (2002).

<sup>18</sup>Establishments correspond to ‘lines of business’ of firms, the level at which production decisions are likely to be 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.

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 our 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 establishments being sampled for at least 5 years.<sup>19</sup> As a robustness check, we examine the sensitivity of our results to alternative thresholds for the minimum number of years for which an establishment is present in the sample. To control for non-random survival of establishments, we include a sample selection correction term. As measurement error is

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<sup>19</sup>We 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.

likely to be larger in smaller establishments, we also weight observations by employment.

### 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.<sup>20</sup> 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.<sup>21</sup> 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 1 and 2 show the distribution of relative TFP (MTFP, as defined by (11)) for two example 2-digit industries. 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 our empirical framework by variation in establishment innovative capabilities, and the fact that it takes time to catch-up with a constantly advancing frontier. The industry in Figure 1, office machinery and computer equipment, shows stronger growth and less dispersion of productivity around the geometric mean than the industry in Figure 2, footwear and clothing. Over time, as industries converge towards steady-state, our empirical framework implies that productivity

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<sup>20</sup>Disney et al (2003) report annual TFP growth of 1.06% between 1980 and 1992. In our sample annual TFP growth averaged 1% over the 1980s.

<sup>21</sup>Cameron, 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.

dispersion may rise or fall, depending on the relationship between the initial distribution of productivity across establishments and the steady-state distribution. Figure 3 summarizes 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 framework discussed above.

These descriptive statistics show that there is substantial variation in growth rates, even within industries. And these differences in growth rates translate, in some cases, into persistently different level of TFP. Our framework 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 productivity frontier**

Before turning to the econometric evidence it is worth considering what we are capturing in our measure of the distance to the frontier. We begin by using the establishment with the highest level of TFP to define the frontier. This approach has the advantages of simplicity and of closely following the structure of the empirical framework. Another attraction is that it potentially allows for endogenous changes in the frontier, as one establishment first

catches up and then overtakes the establishment with the highest initial level of 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 productivity 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 productivity catch-up. What matters for estimating the parameters of interest is the correlation between our measure and true unobserved distance from the productivity 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, allow us to control for many of the sources of measurement error suggested in the existing literature. Nonetheless, it is likely that measurement error remains and we consider a number of robustness tests. To abstract from high frequency fluctuations in TFP due to measurement error, we define the productivity frontier as an average of the five establishments with the highest levels of TFP relative to the geometric mean. As another robustness test, 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. While it may be hard to accurately measure an establishment's exact level of productivity, the decile of the productivity distribution where an establishment lies is likely to be measured with less error. We also address measurement error in TFP using instrumental variables estimation as discussed further below.

Table 1 provides descriptive statistics and 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 ( $\exp(0.548) = 1.73$ ). The table also shows that there is substantial variation in the size of the TFP gap, which we exploit below in estimating the



contribution of productivity catch-up to productivity growth.

## 4 Empirical results

We start by presenting estimates of the relationship between TFP growth and an establishment's distance behind the frontier, and in doing so examine the role of geographic proximity. We then consider a number of robustness tests to address potential econometric concerns. We then use our estimates to quantify the importance of productivity catch-up to both the national and regional frontier in the growth process.

### 4.1 Productivity dynamics

We start by examining the relationship between an establishment's TFP growth rate and distance to the TFP frontier in their 4-digit industry, 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 our basic specification in equation (2). 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 selection equation used to derive the inverse Mills ratio is shown in table A1 in the Appendix). 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. This is consistent with the idea that the affiliates of US multinationals have higher levels of innovative capabilities ( $\gamma_i$ ) in equations (2) and (8).<sup>22</sup> 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, implying that it is only the affiliates of US multinationals that exhibit a

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<sup>22</sup>When we split the US dummy into greenfield and acquisitions we find that the coefficient (standard error) on greenfield is 0.002 (0.002) and on acquisition is 0.007 (0.003). This is in line with other work using UK data, for example, Bloom, Sadun and Van Reenen (2007).

statistically significant difference in innovative capabilities. This pattern of coefficients is consistent with other studies that have found US multinationals are consistently more productive than other foreign-owned multinationals in the United Kingdom (see for example Griffith 1999 and Criscuolo and Martin 2005).<sup>23</sup> 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 allow innovative capabilities ( $\gamma_i$ ) in equation (2) to vary across establishments, and control for unobservable 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 frontier in their 4-digit industry have faster rates of productivity growth than firms closer to the frontier. This is consistent with the idea that there is productivity catch-up.<sup>24</sup> The magnitude of the coefficient increases slightly when we include establishment fixed effects. This makes sense: omitted establishment characteristics that raise the level of productivity (e.g. good management that promotes higher innovative capabilities  $\gamma_i$ ) will be negatively correlated with the productivity gap term (from equation (8) these establishments are 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 fixed effects means that our econometric equation focuses on variation in the time-series relationship between productivity in individual establishments and productivity in the frontier.

While the increase in the coefficient on the productivity gap when fixed effects are

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<sup>23</sup>While US multinationals account for the largest share of foreign-owned firms in the UK (12% of our sample, Table 1), we also included separate dummies for the three next largest inward investors Germany (1.5% of our sample), Canada (1.2%) and Switzerland (1.2%). The Canadian and Swiss dummies were statistically insignificant. The German dummy was negative but only marginally significant (at the 10% level).

<sup>24</sup>As a robustness check, we also re-estimated the specification in Column 3 clustering the standard errors on two-digit sector rather than four-digit industry, which has relatively little impact. For example the standard error on the productivity gap term becomes 0.019 rather than 0.015.

included is consistent with a negative correlation between omitted establishment characteristics that raise the level of productivity and the productivity gap, we note that the inclusion of fixed effects and a lagged dependent variable leads to a downwards bias in the estimated coefficient on the lagged dependent variable (Nickell 1981). Therefore, as  $\ln A_{it} = (1 - \lambda) \ln A_{it-1} + \lambda \ln A_{Fjt-1} + \gamma_i + u_{it}$  can be equivalently represented as  $\ln A_{it} - \ln A_{it-1} = \lambda \ln A_{Fjt-1} - \lambda \ln A_{it-1} + \gamma_i + u_{it}$ , the downwards bias in the estimated value of  $(1 - \lambda)$  implies an upwards bias in the estimated value of  $\lambda$ , which could also account for the rise in the estimated coefficient on the productivity gap between Columns 2 and 3. A comparison of the OLS estimates in Column 2 with the fixed effects estimates in Column 3 provides an indication of the potential magnitude of the bias, which is monotonically decreasing in the number of time-series observations in the panel.

In the fourth column we add in the growth rate of TFP in the frontier, as in the ECM representation (equation 5). 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 empirical model of productivity catch-up ( $\alpha_2 > 0$ ,  $(1 - \alpha_1) > 0$  and  $\alpha_3 = (1 - \alpha_1) - \alpha_2 > 0$  in equation (4)).

## 4.2 The importance of geography

An interesting question is whether geographic proximity matters, in the sense that firms benefit more from frontier establishments that are located nearby. To investigate this we extend our basic model by including a second TFP gap term, defined as an establishment's distance from the regional frontier, where the regional frontier is the establishment with the highest TFP in a particular geographic region, industry and year. We use two measures of

geographic region: one is based on broad Government Administrative Regions (8 regions within England plus Wales and Scotland), and the other is very detailed, covering around 300 Travel to Work Areas (TTWAs). TTWAs represent local labour market areas and are defined using information on individuals' commuting patterns, hence these should reflect better the geographic areas in which localized knowledge transfer might occur. For example, the three largest TTWAs in terms of total manufacturing employment in our data are the cities of London, Manchester and Birmingham.

Table 4 shows details of mean TFP growth, the mean productivity gap with the overall frontier and the mean gap with the regional frontier. The first panel shows a breakdown by Administrative Region, and also provides information on the regional distribution of the overall frontier and all establishments. The second panel uses the TTWA definition of region. As the national frontier is the maximum of the regional frontiers, the average TFP gap with the regional frontier is smaller than that with the national frontier: 0.331 and 0.568 respectively using Administrative Regions and 0.229 and 0.575 respectively using TTWAs. There is however substantial variation in the size of the regional productivity gap.

In Table 5 we provide evidence that productivity catch-up varies with geographic proximity to the TFP frontier. The sample size is smaller than in Table 3 because information on location was only available for a restricted set of establishments (see note to Table 5), and since we also exclude those establishments identified as the regional frontier from the sample. In columns 1 and 4 of Table 5 we replicate the specification from column 3 of Table 3 to ensure that our main results are not substantially affected by the change in sample. In columns 2 and 5 we add in the measure of an establishment's distance to the regional TFP frontier to our main specification, and in columns 3 and 6 we include only the TFP gap with the regional frontier. The results using both the Administrative Region and TTWA definitions imply that establishments exhibit productivity catch-up both to the overall frontier and to the regional frontier. In particular, they are suggestive of faster catch-up to the

regional frontier, consistent with the idea that knowledge spillovers may be to some extent geographically concentrated. Additionally, comparing the two panels of the table, we find that catch-up to the regional frontier is more rapid using TTWAs than Administrative Regions, which is consistent with the smaller size of TTWAs and the geographic localization of knowledge spillovers. Even though catch-up is faster to the regional frontier, we see that the overall national frontier still plays a role, and in section 4.4 we examine the overall contribution to productivity growth of catch-up to each frontier.

### 4.3 Robustness

We present a number of robustness tests to examine potential econometric concerns. We consider three main robustness checks to address concerns about measurement error and endogeneity, parameter heterogeneity, and mean reversion.

#### 4.3.1 Measurement error

As mentioned above, one concern is that  $TFP_{it-1}$  appears on both the right and left hand sides of our regression specification (2). Therefore measurement error in  $TFP_{it-1}$  could induce a spurious correlation between TFP growth and distance to the frontier. We address this concern in a number of ways. First, we control for many sources of measurement error in our TFP indices by using detailed micro data (as described above). Second, rather than using the continuous measure of distance to the frontier we use a discrete version indicating which decile, in terms of distance to the frontier, the establishment is in. While it may be hard to accurately measure an establishment's exact level of productivity, the decile of the productivity distribution to which the establishment belongs is likely to be measured with less error. Although the decile dummies reduce the extent of variation in productivity relative to the frontier, this works against us by making it harder to identify the relationship of interest. The estimates with decile dummies are shown in column 5 of Table 3. We find that, conditional on the other covariates, establishments in the tenth decile (those furthest

away from the 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.<sup>25</sup>

We also take three further approaches. First, in column 1 of Table 6 we include an alternative measure of distance from the frontier, based on the average TFP in the five establishments with the highest measured TFP levels.<sup>26</sup> If measurement error is imperfectly correlated across establishments, averaging will reduce the relative importance of measurement error so that the average TFP of the top five establishments provides a closer approximation to the true productivity frontier. Again we find a positive and significant coefficient on the TFP gap. In column 2 of Table 6 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. The instruments address the concern that contemporaneous measurement error in  $TFP_{it-1}$  will induce a spurious correlation between  $\Delta TFP_{it}$  on the left-hand side of equation (2) and  $TFPGAP_{it-1}$  on the right-hand side of the equation. In the IV specification, we focus solely on variation in  $TFPGAP_{it-1}$  that is correlated with the productivity gap at time t-2 and t-3. 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 induced by the use of information on longer lags.

Second, another concern about measurement error is that TFP is measured under the assumption of perfect competition, as discussed above. In column 3 of Table 6 we adjust the factor shares by an estimate of the markup (calculated at the 2-digit industry-year level).

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<sup>25</sup>We also experimented with quartile dummies, since measuring the quartile of the productivity distribution to which the establishment belongs is likely to be measured with even less error. Again we found a similar pattern of results, with establishments in lower quartiles experiencing statistically significantly higher rates of productivity growth.

<sup>26</sup>This 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 in each industry-year.

The coefficient on the gap term remains positive and significant.

Third, in column 4 of Table 6 we use an alternative measure of TFP. We implement the Olley-Pakes technique to estimate the level of TFP and from this calculate the growth rates and the gap. Again we find a similar pattern of results, with the coefficient on the gap positive and significant.

### 4.3.2 Parameter heterogeneity and sample composition

Our baseline estimation results pool across industries, imposing common slope coefficients, and a possible concern is that there might be parameter heterogeneity across industries - for example, in some industries knowledge may spillover more easily than in others. To allow for this we re-estimated the model separately for each 2-digit industry.<sup>27</sup> 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 productivity 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 estimates lie close to the baseline within groups estimates reported in column 3 of Table 3.<sup>28</sup>

As a further robustness check, we examined the sensitivity of our results to outliers. To do so, we followed the conventional approach of using the residuals to classify observations as influential if they have a DFITS of greater than two multiplied by the square root of the number of regressors / number of observations. Excluding observations classified as influential we find a very similar pattern of results, with an estimated coefficient (standard error) of 0.087 (0.005) on the productivity gap, lying close to our baseline estimate reported

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<sup>27</sup>See, for example, the discussion in Pesaran and Smith (1995).

<sup>28</sup>One concern we might have is that there are industry specific shocks that are correlated with distance to the frontier, yet we only allow for common time shocks. The results in column 6 of Table 3, where the specification is estimated separately for each 2-digit industry, allow for separate time effects for each 2-digit industry. In addition, we ran the specification with deciles (column 5 of Table 3) including 4-digit industry time dummies and the coefficients on the decile dummies remain similar, for example, the coefficient (standard error) on decile 2 is 0.065 (0.006) and on decile 10 is 0.261 (0.017).

in column 3 of Table 3.

Finally, we also examine the sensitivity of our results to alternative thresholds for the minimum number of years for which an establishment is present in the data. Re-estimating our baseline specification requiring establishments to be observed for a minimum of ten years results in a similar estimated coefficient (standard error) on the productivity gap of 0.109 (0.016). This similarity of the results despite a substantial reduction in the sample size suggests that our findings are not highly sensitive to the minimum number of years over which an establishment is observed in the data.

### 4.3.3 Mean reversion

A further concern with our results is whether we are picking up productivity catch-up 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 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 productivity growth and lagged distance from the frontier. Under this interpretation, the identification of the parameters of interest is driven solely by variation in  $A_{it-1}$ . In contrast, according to our productivity catch-up hypothesis, variation in the position of the frontier,  $A_{Fjt-1}$ , also plays an important role.

To address this concern, we test the null hypothesis that each establishment reverts to its own mean level of TFP by examining the statistical significance of the decile dummies used above. Under this null hypothesis, establishment TFP follows an AR(1) process with



reversion to an establishment specific mean:

$$\Delta \ln A_{it} = \gamma_i + \lambda \ln A_{it-1} + u_{it}, \quad |\lambda| < 1. \quad (13)$$

Under the alternative hypothesis that productivity catch-up plays an important role in determining establishment productivity growth, as in equation (2), the location of the frontier should also be important. We test this prediction by including the decile dummies in equation (13) and testing the joint statistical significance of the coefficients on the decile dummies. In column 1 of Table 7, we find that the coefficients on the decile dummies are highly statistically significant. The coefficients on the decile dummies have the expected sign, and the coefficients for the lower deciles are typically larger than those for the higher deciles as predicted by our empirical model of productivity catch-up. As an additional robustness check, we repeat this specification allowing for a more general autoregressive process for establishment productivity than AR(1) by including an additional lag in the level of establishment own productivity in column 2. Again we find a very similar pattern of results.

To further address the concern that contemporaneous measurement error in establishment own productivity at t-1 may induce a spurious correlation between left and right-hand side variables, column 3 returns to the AR(1) specification from column 1, but instruments the lagged level of establishment own productivity with its value at t-2 and t-3. We continue to find correctly signed and statistically significant coefficients on the decile dummies, as implied by our empirical model of productivity catch-up.<sup>29</sup> Taken together, these results provide support for the idea that the location of the productivity frontier influences establishment productivity growth in addition to the establishment's own level of productivity.

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<sup>29</sup>We also experimented with specifications using dummies for the quintiles or quartiles of the productivity distribution where an establishment lies, which are likely to be measured with less error than the decile of the distribution. We continued to find a similar pattern of results.

#### 4.4 Economic importance

What do our results imply about the magnitude of the contribution of productivity catch-up to productivity growth in non-frontier establishments? If we take the coefficient on the productivity gap, multiply this by the gap for each individual establishment, and represent this as a percentage of the establishment's own annual growth rate, our results imply that for the median establishment productivity catch-up accounts for 9% of annual growth, (taking the mean across establishments, rather than the median we find that productivity catch-up accounts for on average 8% of annual productivity growth). If we instead express the contribution of productivity catch-up as a percentage of predicted growth (omitting the idiosyncratic element) our results imply that for the median establishment it accounts for 26% of growth (taking the mean across establishments, productivity catch-up accounts for 98% of annual predicted productivity growth).<sup>30</sup>

We can also use the specifications in columns 2 and 5 of Table 5 to examine the contribution of catch-up to the national versus regional frontier to productivity growth. Using the approach described above, the estimates from column 2 imply that for the median establishment catch-up to the national frontier accounts for 13% of annual productivity growth (43% of predicted growth) and catch-up the Administrative Region frontier 5% of annual productivity growth (18% of predicted growth). Similarly, for column (5) for the median establishment catch-up to the national frontier accounts for 19% of annual productivity growth (44% of predicted growth) and catch-up the Travel to Work Area frontier 3% of annual productivity growth (11% of predicted growth). Hence, while the results in Table 5 demonstrate that geographic proximity to a frontier establishment implies *faster* productivity catch-up, because the productivity gap with the regional frontier is smaller than with the national frontier, (as shown in Table 4), the overall contribution to productivity growth

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<sup>30</sup>If 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.

of catch-up to the regional frontier is smaller.

## 5 Conclusions

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

In this paper we used micro panel data to investigate the correlation between an establishment's TFP growth and its distance from the technological frontier. We did this in a way that also allowed for persistent dispersion as an equilibrium outcome. We found statistically significant and quantitatively important evidence that is consistent with productivity catch-up to the technological frontier. We also found evidence that geographic proximity makes the catch-up process faster. Taken together, our findings suggest a richer process for the dynamics of establishment productivity than implied by many existing models of industry equilibrium where establishment productivities follow independent stochastic processes.

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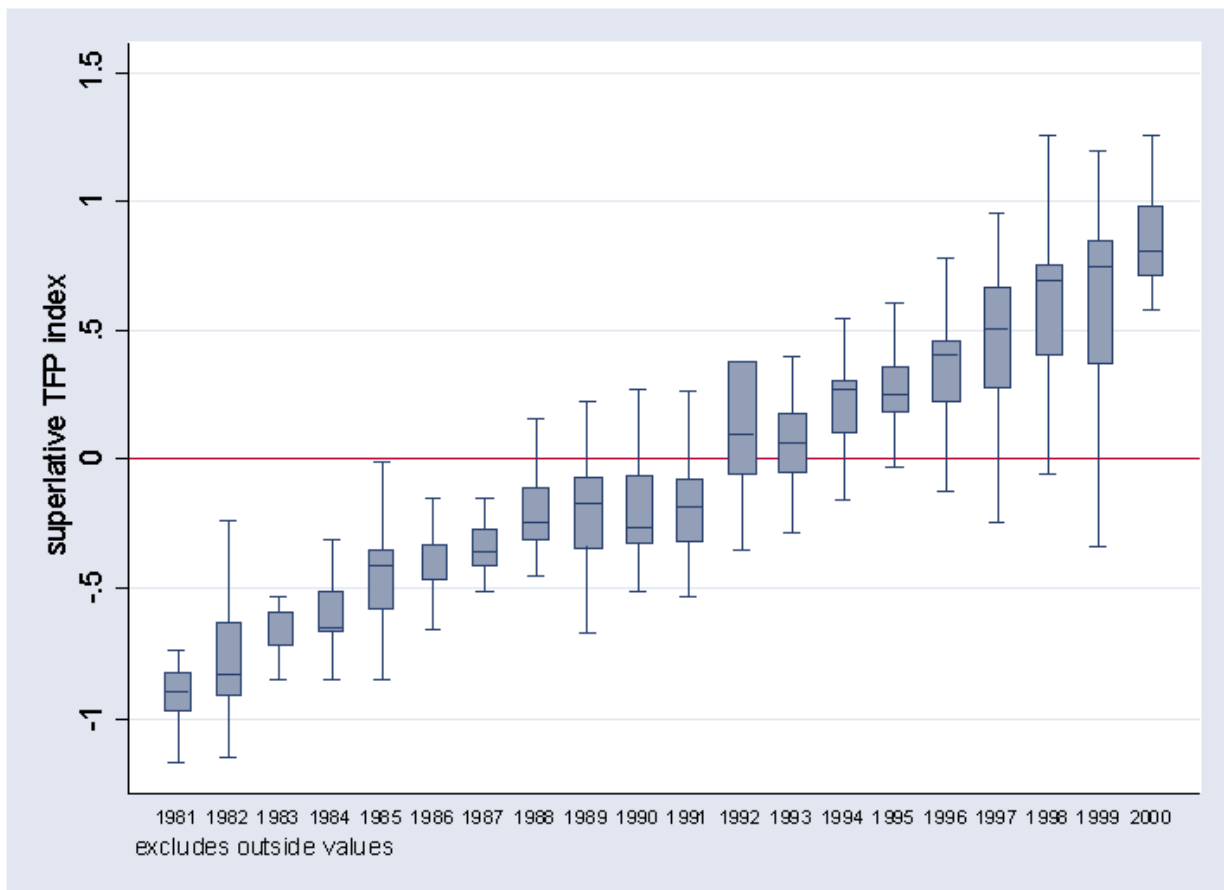
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**Table 1: Descriptive statistics**

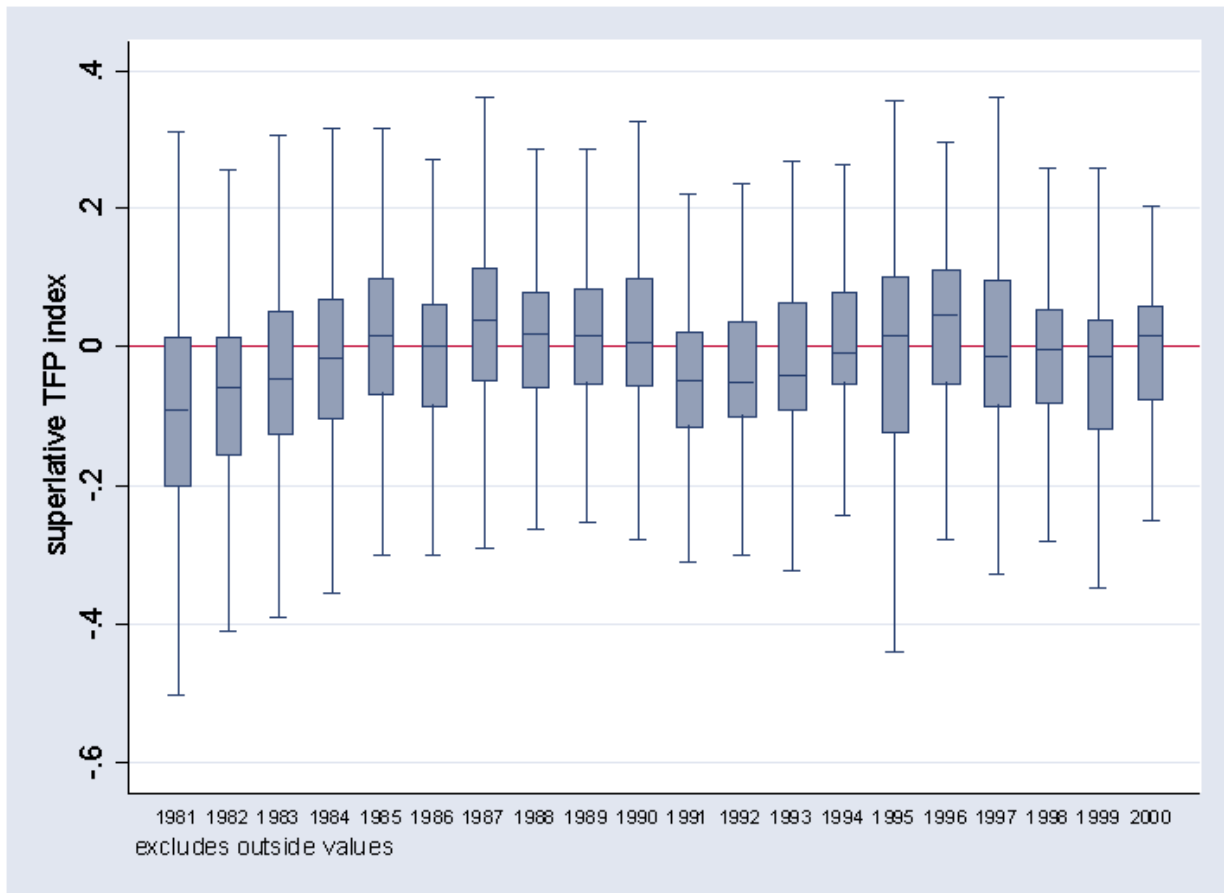
Variable	Mean	Standard deviation
$\Delta TFP_{ijt}$	0.003	0.129
$TFPGAP_{ijt-1}$	0.548	0.317
$\Delta TFP_{Fjt}$	0.003	0.303
Age	8.127	5.122
US dummy	0.120	0.325
Other foreign dummy	0.105	0.306

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.  
Source: authors' calculations using the ARD (Source: ONS).

**Figure 1: Evolution of TFP in the office machinery and computer equipment industry**

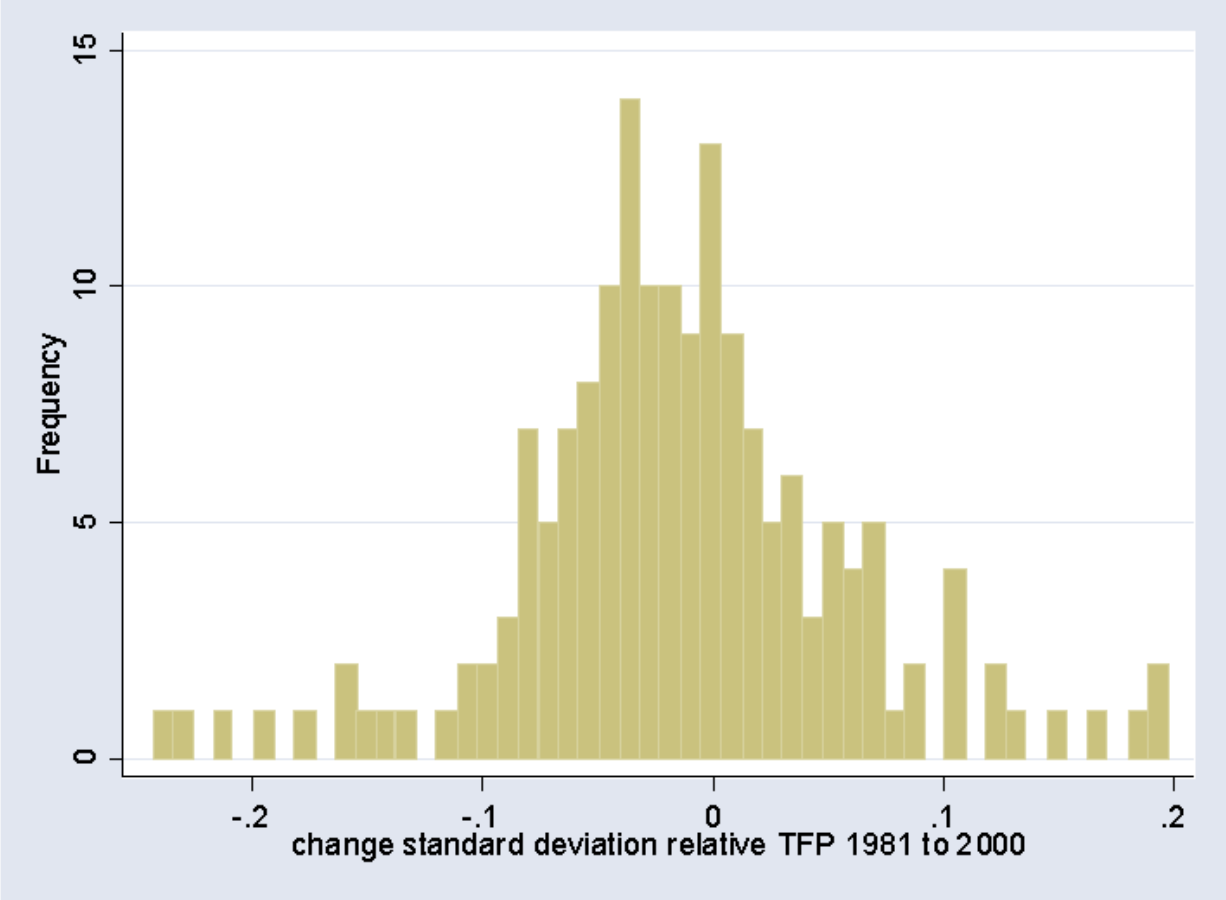
Note: The figure shows the distribution of TFP in 2-digit industry no.33 over time. TFP in each establishment is measured relative to the geometric mean of all other establishments in the same 4-digit industry (averaged over all years). The sample includes 627 observations on non-frontier establishments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

**Figure 2: 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 95<sup>th</sup> and 5<sup>th</sup> percentile respectively. Source: authors' calculations using the ARD (Source: ONS).

**Figure 3: 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.  
Source: authors' calculations using the ARD (Source: ONS).

**Table 2: Transition matrix**

Quintile of TFP distribution, t-5	Quintile of TFP distribution t					Total
	1	2	3	4	5	
1	<b>37.71</b>	29.39	18.27	9.41	5.22	100
2	26.46	<b>28.06</b>	25.16	13.76	6.57	100
3	17.39	26.48	<b>25.13</b>	22.08	8.92	100
4	18.03	20.22	28.58	<b>21.92</b>	11.25	100
5	22.19	23.81	19.81	21.47	<b>12.73</b>	100
<b>Total</b>	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. Source: authors' calculations using the ARD (Source: ONS).

**Table 3: Catch-up model**

Dep var: $\Delta TFP_{ijt}$	(1)	(2)	(3)	(4)	(5)	(6)
Obs	103,664	103,664	103,664	103,664	103,664	103,664
$\Delta TFP_{Fjt}$				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
R <sup>2</sup>	0.073	0.074	0.152	0.194	0.250	

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.

$\Delta TFP_{Fjt}$  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.

Source: authors' calculations using the ARD (Source: ONS).

**Table 4: Descriptive statistics at the regional level**

	Mean TFP growth (standard deviation)	Gap with overall frontier (standard deviation)	Gap with regional frontier (standard deviation)	Number of times overall frontier is in region (% total)	Number establishments (% total)
	(1)	(2)	(3)	(4)	(5)
<b>Administrative Region sample</b>					
South East	0.002 (0.126)	0.549 (0.288)	0.411 (0.269)	731 (25%)	19,879 (25%)
East Anglia	0.008 (0.109)	0.574 (0.301)	0.207 (0.170)	100 (3%)	2,084 (3%)
South West	0.012 (0.149)	0.601 (0.311)	0.283 (0.244)	184 (6%)	5,109 (6%)
West Midlands	0.007 (0.113)	0.534 (0.273)	0.301 (0.213)	313 (11%)	11,973 (15%)
East Midlands	0.007 (0.106)	0.570 (0.293)	0.294 (0.202)	254 (9%)	8,384 (11%)
Yorkshire and Humberside	0.008 (0.105)	0.560 (0.288)	0.297 (0.222)	287 (10%)	9,112 (12%)
North West	0.005 (0.125)	0.547 (0.297)	0.308 (0.244)	419 (15%)	10,337 (13%)
Northern	0.026 (0.170)	0.619 (0.311)	0.265 (0.226)	153 (5%)	2,945 (4%)
Wales	0.016 (0.130)	0.629 (0.310)	0.277 (0.220)	143 (5%)	3,034 (4%)
Scotland	0.018 (0.167)	0.663 (0.345)	0.380 (0.330)	299 (10%)	6,217 (8%)
<b>All</b>	<b>0.008</b> <b>(0.127)</b>	<b>0.568</b> <b>(0.298)</b>	<b>0.331</b> <b>(0.251)</b>	<b>2,883</b> <b>(100%)</b>	<b>79,074</b> <b>(100%)</b>
<b>Travel to Work Area sample</b>					
<b>All</b>	<b>0.011</b> <b>(0.126)</b>	<b>0.575</b> <b>(0.274)</b>	<b>0.229</b> <b>(0.199)</b>	<b>1,656</b> <b>(100%)</b>	<b>22,394</b> <b>(100%)</b>

Note: Columns (1) to (3) are weighted by the inverse of the sampling probability and employment. Column (1) shows mean TFP growth of establishments in each region. Column (2) shows the mean gap with the frontier in the establishments' industry-year. Column (3) shows the mean gap with the frontier in the establishment's region-industry-year, where region is Administrative Region in the first panel and Travel to Work Area in the second panel. Column (4) shows the regional distribution of the national frontier establishments and column (5) shows the distribution of establishments used in the regressions in Table 5. See note to Table 5 for descriptions of each estimation sample.

**Table 5: Catch-up to the regional frontier**

Dep var: $\Delta TFP_{ijt}$	Administrative Regions			Travel to Work Areas		
	(1)	(2)	(3)	(4)	(5)	(6)
Obs	79,074	79,074	79,074	22,394	22,394	22,394
$TFPGAP_{ijt-1}$	0.131 (0.019)	0.082 (0.013)		0.162 (0.032)	0.112 (0.026)	
$TFPGAP\_REG_{ijt-1}$		0.111 (0.017)	0.163 (0.023)		0.173 (0.023)	0.234 (0.033)
Age	0.0002 (0.0007)	0.0002 (0.0006)	0.0003 (0.0006)	-0.003 (0.002)	-0.002 (0.002)	-0.001 (0.002)
US dummy	0.012 (0.007)	0.013 (0.008)	0.013 (0.009)	-0.0002 (0.012)	0.008 (0.011)	0.016 (0.012)
Other foreign dummy	-0.012 (0.009)	-0.011 (0.010)	-0.011 (0.011)	0.011 (0.011)	0.008 (0.011)	0.007 (0.011)
Inverse Mills ratio	0.045 (0.011)	0.040 (0.011)	0.038 (0.011)	0.045 (0.039)	0.032 (0.037)	0.021 (0.035)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Within groups	Yes	Yes	Yes	Yes	Yes	Yes
R <sup>2</sup>	0.20	0.22	0.21	0.38	0.40	0.38

Note: Regressions are estimated on all non-frontier establishments for 1980-2000 (columns (1) to (3)) and for 1984-1996 (columns (4) to (6)). Information on Travel to Work Areas is only available for a shorter period. All columns are weighted by the inverse of the sampling probability and employment. Standard errors in brackets are clustered at the 4-digit industry.  $\Delta TFP_{Fjt}$  is tfp growth in the frontier.  $TFPGAP_{ijt-1}$  is tfp relative to frontier in the previous period.

$TFPGAP\_REG_{ijt-1}$  is tfp relative to the regional frontier (defined for 10 Administrative Regions or 300 Travel to Work Areas) in the previous period. Columns (1) and (4) replicate the specification from column (3) Table 3.

Source: authors' calculations using the ARD (Source: ONS).

**Table 6: Robustness**

Dep var: $\Delta TFP_{ijt}$	(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 (0.000)		
F-statistics (P-value)				
R <sup>2</sup> of reduced form		0.50		
Year dummies	Yes	Yes	Yes	Yes
Within groups	Yes	Yes	Yes	Yes
R <sup>2</sup>	0.244	0.157	0.238	0.146

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.

Source: authors' calculations using the ARD (Source: ONS).



**Table 7: Further Robustness**

	(1)	(2)	(3)
Dependent variable	$\Delta TFP_{ijt}$	$\Delta TFP_{ijt}$	$\Delta TFP_{ijt}$
Obs	103,664	84,232	70,023
TFP <sub>ijt-1</sub>	-0.342 (0.051)	-0.375 (0.034)	-0.271 (0.035)
TFP <sub>ijt-2</sub>		0.068 (0.016)	
Age	0.001 (0.0005)	0.0005 (0.0006)	-0.0004 (0.0008)
US dummy	0.006 (0.005)	0.010 (0.006)	0.010 (0.008)
Other foreign dummy	-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 Mills ratio	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 <sup>2</sup> of reduced form			0.69
Year dummies	Yes	Yes	Yes
Within groups	Yes	Yes	Yes
R <sup>2</sup>	0.307	0.310	0.318

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 (3) we instrument TFP<sub>t-1</sub> with TFP<sub>t-2</sub> and TFP<sub>t-3</sub>. Source: authors' calculations using the ARD (Source: ONS).

## Appendix

**Table A1: First stage selection equation**

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Dependent variable = 1 if establishment survives (remains in sample)	
Obs	166,576
Age	0.332 (0.003)
Age <sup>2</sup>	-0.014 (0.00001)
Ln(real investment)	2.225 (0.402)
Ln(real investment) <sup>2</sup>	0.016 (0.065)
Ln(real investment) <sup>3</sup>	-0.017 (0.006)
Ln(real investment) <sup>4</sup>	-0.00005 (0.00002)
Ln(real capital stock)	0.095 (0.509)
Ln(real capital stock) <sup>2</sup>	-0.011 (0.102)
Ln(real capital stock) <sup>3</sup>	0.003 (0.010)
Ln(real capital stock) <sup>4</sup>	-0.00008 (0.00004)
Ln(real investment)* Ln(real capital stock)	-1.019 (0.184)
Ln(real investment)* Ln(real capital stock) <sup>2</sup>	0.156 (0.028)
Ln(real investment)* Ln(real capital stock) <sup>3</sup>	-0.008 (0.001)
Ln(real investment) <sup>2</sup> * Ln(real capital stock)	0.021 (0.027)
Ln(real investment) <sup>2</sup> * Ln(real capital stock) <sup>2</sup>	-0.007 (0.004)
Ln(real investment) <sup>2</sup> * Ln(real capital stock) <sup>3</sup>	0.001 (0.0002)
Ln(real investment) <sup>3</sup> * Ln(real capital stock)	0.005 (0.002)
Ln(real investment) <sup>3</sup> * Ln(real capital stock) <sup>2</sup>	-0.0004 (0.0002)
Ln(real investment) <sup>3</sup> * Ln(real capital stock) <sup>3</sup>	0.000005 (0.000007)
Year dummies	Yes

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Notes: The inverse Mills ratio is derived from a sample of 166,576 establishments including the 103,664 in our main estimating sample that are observed for at least 5 years.

Source: authors' calculations using the ARD (Source: ONS).