Like Father like Son: Technology Transfers and Productivity Effects from Firm Ownership*

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Abstract

The literature documents a scarcity of firms transferring tangibles within ownership structures. This is suggestive of the theoretical argument that firm ownership is primarily used to facilitate the efficient transfer of intangibles. In this paper, we analyse the validity of this alternative explanation. We use a carefully constructed European panel of majority owned parent-affiliate relationships with full information on both sides and extend a typical production function estimator to account for transfers of intangibles between ownership-linked firms. We find that the productivity of the linked firm is both a) a significant intangible input in the firm's production technology and b) a key determinant of the firm's productivity dynamics. Firms with foreign ownership-links experience larger transfers of intangible technology from their linked firm and foreign owned affiliates benefit more from productivity increases induced by learning mechanisms.

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1 Introduction

Questions revolving around the meaning of firm ownership have generated a considerable amount of research. On the one hand, the literature suggests that ownership structures accommodate the efficient transfer of tangibles. On the other hand, ownership is seen as facilitating the efficient transfer of intangibles.

The flow of physical goods within ownership groups is concentrated in a small number of large affiliates that are owned by large parent firms, both domestically (Atalay et al. 2014) and internationally (Ramondo et al. 2016; Blanas and Seric 2017a). This provides suggestive evidence that ownership structures are primarily used to facilitate the efficient transfer of intangibles. As considered theoretically by Arrow (1975) and Teece (1982), common ownership allows the firm to transfer intangible inputs across its vertically integrated production units, since the alternative of the market is most likely a non-viable substitute.

Since the transfer of tangibles can only explain a small fraction of ownership structures in the economy, we need to examine the existence and prevalence of the alternative explanation, i.e. transfer of intangibles, in depth.[1] However, any relevant empirical research provides only suggestive evidence of this possibility.[2] Likely, this is due to data restrictions which make it difficult to explicitly measure intangible inputs. In most cases, researchers rely on proxies or incomplete measures, e.g. R&D, royalties paid to parents by affiliates, corporate transferees, etc. To our knowledge, there are no micro-level panel datasets that contain information on the full set of intangibles for both the parent and affiliate on top of standard balance sheet information. Such datasets would allow researchers to fully specify the production function of each parent and affiliate, and hence quantify any transfers of intangibles.

A notable exception is the work of Bilir and Morales (2016). They show, based on a panel of US parents and foreign affiliate(s) with information on output, inputs and R&D investment, that expected affiliate productivity increases with parent innovation. However, R&D spending captures[3] only a specific subset (i.e. proprietary knowledge) of a broad range of intangibles that are potentially transferred within ownership structures. These include but are not limited to: tacit

[1] The existence of one explanation does not mutually exclude the other. To become productive, transfers of tangibles can also be found vis-a-vis to transfers of intangibles, i.e. parental assistance and coordination (Keller and Yeaple 2013; Blanas and Seric 2017b).

[2] Atalay et al. (2014) document that, despite the lack of shipments of physical goods within multi-plant firms in the United States, newly vertically integrated affiliates start resembling their parent along the production and trade activities. Ramondo et al. (2016) confirm this lack of shipments across affiliates of U.S. multinationals. Arnold and Javorcik (2009) and Guadalupe et al. (2012) find that foreign acquisition of domestic firms leads to improvements in: sales; productivity; investment; wages; employment; and innovation. For further documentation on the existence of international technology transfers within the boundaries of the firm see Branstetter et al. (2006); Keller and Yeaple (2013) and Gumpert (2015).

[3] We use the word 'captures' since, similar to physical investment, R&D investment contributes to the periodic accumulation of an 'intangible' input under an (unobserved) stochastic accumulation process. Therefore, lagged R&D spending is actually a proxy for current proprietary knowledge used in the production of the final output. See Griliches (1998) for an extended discussion on this modelling approach.

knowledge; know-how; marketing techniques; managerial practices; and organisational practices. Furthermore, their analysis is silent about domestic ownership structures which, according to our data, represent a relatively larger share of firms which are smaller in size. As such, these firms are also less intensive in R&D spending (OECD 2017). Finally, it is not possible to infer whether the effect they estimate comes through the channel of technology transfers, i.e. input in the production function of the affiliate, or is a pure effect on the affiliate's productivity dynamics, i.e. learning. Overall, there is ample space to validate or provide further empirical support to ownership theories arguing that firm boundaries exist in order to facilitate the transfer of intangibles.

In this paper we do so by identifying transfers of intangible inputs and demonstrating how they determine a firm's production technology and the evolution of its productivity. We use a carefully constructed European panel of majority owned parent-affiliate groups with full balance sheet information on both sides for the period 2004-2015 and extend a typical production function estimation procedure. In response to data limitations on intangible inputs, we devise a method to characterise the full set of intangibles that are potentially transferred between parent and affiliate firms.

Specifically, we exploit information from the balance sheet of the parent and the affiliate to identify their productivities, respectively. These productivities capture both disembodied technological change (e.g. innate characteristics of workers, know-how, etc.) and any potential intangible inputs used in the production of the final output that are not observed in the data (e.g. management practices, acquired characteristics of workers, innovation, etc.).

On the one hand, as theory suggests, if firm boundaries accommodate the transfer of such inputs, we expect firms to tap into and use them in the production of their final output. As such, parent productivity (which is now measurable) is introduced as a 'composite' intangible input in the production function of the affiliate and vice versa. The extent to which parent (affiliate) productivity contributes to the final output of the affiliate (parent) is defined as an intangible technology transfer from one firm to the other. Similar to other tangible inputs, i.e. labour, capital and material, this intangible input is measured as the firm's output elasticity of linked firm productivity. Intuitively, one may think of the impact of having, for example, a corporate transferee from the parent firm at the site of the affiliate.

This modelling approach is similar to Griliches and Mairesse (1999) and Bloom et al. (2016) where a proxy for the stock of knowledge and a score for management practices, respectively, is introduced as an input in the production function technology of the firm. However, our empirical approach provides, instead of an incomplete proxy, an internally consistent composite measure of intangible inputs transferred within the boundaries of the firm.

On the other hand, transfers of intangible technology are potential determinants of the firms's productivity evolution. The mechanism we have in mind is any type of learning, where over

time the firm absorbs/embodies any intangible technological transfer from the ownership-linked firm that affects its overall productivity level in its own intangible technology. Therefore, our empirical methodology allows for technological transfers from one firm to affect the productivity dynamics of the other firm. Intuitively, one may think of a lasting imprint on the affiliates processes after a corporate transferee has left. The modelling approach we follow is similar to Doraszelski and Jaumandreu (2013), De Loecker (2013), and Bilir and Morales (2016) where firms actively learn and assimilate from their actions or changes in their operating environment.

The following findings emerge. First, we show that the productivity of the ownership-linked firm is a significant intangible input in the firm's production technology. In addition, such transfers of intangible technology are important determinants of the firm's future productivity. Exploiting richness of the data, we find that foreign owned firms experience larger technology transfers from their linked-firms, while foreign owned affiliates benefit more from productivity increases induced by learning mechanisms. To support the validity of our methodological approach, we also extend the empirical model by introducing a specific form of intangible that is reported in the data, i.e. patent applications. Overall, we identify, at the firm level, the importance of productivity transfers from various types of ownership structures and confirm the theoretically based argument that firm boundaries exist to facilitate the transfer of intangibles.

The remainder of this paper is organised as follows: in Section 2 we present the empirical methodology. In Section 3 we describe the data. Section 4 presents the main results from applying the proposed methodology to the relevant data, discusses the importance of cross-border barriers in the flow of intangible inputs within the boundaries of the firm and uses observed information on patent applications to support the validity of our methodological approach. Finally, Section 5 offers concluding remarks.

2 Empirical Methodology

We extend a typical production function estimation procedure to capture potential transfers of intangible technology and productivity effects between ownership-linked firm-types, i.e. parent and affiliate. By exploiting information from the balance sheet of each firm-type we can identify their productivities. This way we can introduce them both as an 'intangible' input in the production function of their respective ownership-linked firm-type and as a potential determinant of the ownership-linked firm-type's future productivity. This section describes the empirical model of intangible transfers and productivity effects in majority owned firms.

We consider a set of ownership groups $i = 1,\dots,I$ over periods $t = 1,\dots,T$. In each ownership-group-i, the set of active manufacturing firms in t includes firms indexed by $j = 0,\dots,J$, where $j = 0$ denotes the parent firm that has the majority control of its affiliate(s) $j > 0$. The information set of the firm in t is denoted by $\mathscr{I}_t$ and includes any type of information that the firm uses to make its periodic input decisions.

We consider a flexible gross-output production function for the parent:

$$Y_{i0t} = H(K_{i0t}, L_{i0t}, M_{i0t})(\Omega_{ijt})^{\pi_\omega} \mathrm{e}^{\omega_{i0t}+\varepsilon_{i0t}} \tag{1}$$

with Hicks-neutral total factor productivity (TFP) ω_{i0t}, where

$$H(K_{i0t}, L_{i0t}, M_{i0t}) = \left(\tilde{H}(K_{i0t}, L_{i0t}, M_{i0t})\right)^{\tilde{\pi}} \tag{2}$$

and

$$\Omega_{ijt} = \mathrm{e}^{\omega_{ijt}} \tag{3}$$

In logs, equation (1) takes the following form:

$$y_{i0t} = h(k_{i0t}, l_{i0t}, m_{i0t}) + \pi_\omega \omega_{ijt} + \omega_{i0t} + \varepsilon_{i0t} \tag{4}$$

where y_{i0t}, k_{i0t} and m_{i0t} are log values of deflated (at the country-industry-year level) sales, tangible fixed assets and material costs, respectively. l_{i0t} is the log of the total number of employees of parent 0 in ownership-group-i at time t. The parent's joint output of capital (k_{i0t}), labour (l_{i0t}) and material (m_{i0t}), is combined with the affiliate's TFP (ω_{ijt}) according to a Cobb-Douglas technology.[4,5] The TFP of the affiliate is now introduced as an input in the parent's production technology. All factors captured in the TFP measure of the affiliate are allowed to shift the production frontier of the parent. This is an input assumed to be exogenously given from the affiliate to its parent within the group. Therefore, it is known to the parent at the time of making its decisions in period t. TFP is unobserved to the econometrician but known to the firm. Ex-post shocks, i.e. after the firm's decision about its input use, are picked up by ε_{i0t} and are mean independent of all variables known to the parent in t, i.e. $E[\varepsilon_{i0t}|\mathscr{I}_t] = E[\varepsilon_{i0t}] = 0$.

Capital and labour are predetermined inputs and thus chosen one period prior to the TFP realisation. Specifically, firms have information on these inputs and take them into account in the period's production process $\{l_{i0t}, k_{i0t}\} \in \mathscr{I}_t$. The only flexible input is material that freely adjusts in each period, i.e. $m_{i0t} \notin \mathscr{I}_t$. As such, it has no dynamic implications, i.e. $\frac{\partial}{\partial m_{i0t-1}} m_{i0t} = 0$. We assume that both parent and affiliate firms take output and input prices as given.

It is important to emphasise that TFP is not identical to disembodied technological change, known as the 'Solow Residual' (Solow 1957). This refers to everything that the firm observes but cannot quantify with scientific objectivity, e.g. innate characteristics of workers, know-how, etc. Instead, in our case, TFP also includes the impact of inputs that are quantifiable with scientific

[4]For expositional purposes we allow for general substitution effects by not restricting the elasticity of substitution between capital, labour and materials. However, for our estimations we will focus on a Cobb-Douglass functional form of h. Since we are interested in the average firm behaviour we believe that this specification should suffice.

[5]Keep in mind that, as we will explain in detail below, the log-additivity in the affiliate's TFP is a key assumption that allows us to identify the parameters of interest. More specifically, we do not want the the affiliate's TFP to be interacted with any of the flexible inputs, as defined below.

objectivity from the firm, but not available in the data for the researcher, e.g. management practices, acquired characteristics of workers, innovation etc.

In this same spirit, we consider the production function of the affiliate:

$$Y_{ijt} = F(K_{ijt}, L_{ijt}, M_{ijt})(\Omega_{i0t})^{\alpha_\omega} \mathrm{e}^{\omega_{ijt}+\varepsilon_{ijt}} \tag{5}$$

where

$$F(K_{ijt}, L_{ijt}, M_{ijt}) = \left(\tilde{F}(K_{ijt}, L_{ijt}, M_{ijt})\right)^{\tilde{\alpha}} \tag{6}$$

and

$$\Omega_{i0t} = \mathrm{e}^{\omega_{i0t}} \tag{7}$$

In logs, the production function is of the following form:

$$y_{ijt} = f(k_{ijt}, l_{ijt}, m_{ijt}) + \alpha_\omega \omega_{i0t} + \omega_{ijt} + \varepsilon_{ijt} \tag{8}$$

where the affiliate's joint output of capital (k_{ijt}), labour (l_{ijt}) and material (m_{ijt}), is combined with the parent's TFP according to a Cobb-Douglas technology. The TFP of the parent is now introduced as an input in the affiliate's production technology. All factors captured in the TFP measure of the parent are allowed to shift the production frontier of the affiliate. This is an input assumed to be exogenously given from the parent to its affiliate(s) within the group. Therefore, it is known to the affiliate at the time of making its decisions in period t. Similar to the case of the parent, ex-post shocks are picked up by ε_{ijt} and are mean independent of all variables known to the affiliate in t, i.e. $E[\varepsilon_{ijt}|\mathscr{I}_t] = E[\varepsilon_{ijt}] = 0$, and the timing assumptions for the choice of inputs remain the same.

Equations (4) and (8) are now augmented by the log-additive terms $\pi_\omega \omega_{ijt}$ and $\alpha_\omega \omega_{i0t}$, respectively. The former, captures the relative importance of measured parent TFP in the affiliate's production technology. The latter, in complete symmetry, captures the relative importance of measured affiliate TFP in the parent's production technology. These terms allow for the separation of the firm's TFP from any potential intangible technology transfers from their linked firm(s). Intuitively we consider them as 'intangible inputs' in the production functions of the firms. Therefore, α_ω measures affiliate-j's output elasticity of its parent-0's TFP and π_ω the parent-0's output elasticity of its affiliate-j's TFP.

This setup imposes no restrictions on the direction of the intangible technology transfers between linked firms within the same ownership group. Overall, we extend a production function (standard in the literature) by allowing for technology transfers between parent and affiliate firms in the form of intangibles.

In equations (4) and (8), we come across a 'double identification' challenge: on top of the firm's TFP we do not observe the linked firm's TFP. To circumvent this problem we exploit information from the balance sheet of both the firm and its linked firm, respectively. Estimation

of the production functions is based on the flexible estimator proposed by Gandhi, Navarro, and Rivers (2016) (herein GNR). In addition to the transmission bias, i.e. firms observing their TFP when choosing their inputs, this estimator controls for the value-added bias that arises from estimating a value-added rather than a gross-output production function. A detailed description of the assumptions, steps followed, and dominance over competing estimators can be found in GNR.[6]

This case considers the classic environment of perfect competition in both the input and output market. Conditional on the state variables and other firm characteristics, the static profit maximisation problem yields the first order condition with respect to the flexible input for the parent:

$$P_t^M = P_t \frac{\partial}{\partial M_t} H(K_{i0t}, L_{i0t}, M_{i0t}) (\Omega_{ijt})^{\pi_\omega} \mathrm{e}^{\omega_{i0t}} \mathscr{E}_p \tag{9}$$

and the affiliate:

$$P_t^M = P_t \frac{\partial}{\partial M_t} F(K_{ijt}, L_{ijt}, M_{ijt}) (\Omega_{i0t})^{\alpha_\omega} \mathrm{e}^{\omega_{ijt}} \mathscr{E}_a \tag{10}$$

where P_t^M and P_t are the price of material and output respectively. Under perfect competition in input and output markets, they are constant across parent and affiliates within the same country and industry, but can vary across time. By the time firms make their annual decisions, ex-post shocks ε_{i0t} and ε_{ijt} are not in their information sets. Hence, all firms form similar expectations, $\mathscr{E}_p = E(\mathrm{e}^{\varepsilon_{i0t}})$ and $\mathscr{E}_a = E(\mathrm{e}^{\varepsilon_{ijt}})$.[7] It is important to account and correct for this term since ignoring it, i.e. $\mathscr{E}_p = \mathscr{E}_a = 1$, inherently implies that we move from the mean to the median central tendency of $\mathrm{e}^{\varepsilon_{ijt}}$ (see Goldberger 1968).

We retrieve a material costs share equation for the parent by combining (9) with (4) and re-arranging terms:

$$s_{i0t} = ln\Big(\tilde{\mathscr{H}}(L_{i0t}, K_{i0t}, M_{i0t})\Big) + ln\mathscr{E}_p - \varepsilon_{i0t} \tag{11}$$

Similarly, we retrieve a material costs share equation for the affiliate by combining (10) with (8):

$$s_{ijt} = ln\Big(\tilde{\mathscr{F}}(L_{ijt}, K_{ijt}, M_{ijt})\Big) + ln\mathscr{E}_a - \varepsilon_{ijt} \tag{12}$$

In the above, s_{i0t} and s_{ijt} are the log of the nominal share of material costs for the parent and the affiliate, respectively. $\tilde{\mathscr{H}}(K_{i0t}, L_{i0t}, M_{i0t}) = \frac{\partial}{\partial m_{i0t}} h(k_{i0t}, l_{i0t}, m_{i0t})$ and $\tilde{\mathscr{F}}(K_{ijt}, L_{ijt}, M_{ijt}) = \frac{\partial}{\partial m_{ijt}} f(k_{ijt}, l_{ijt}, m_{ijt})$ are the output elasticities of material, i.e. the flexible input. Notice that in both share equations, in addition to firm's TFP, the 'extra' intangible input from the linked firm is also eliminated. This follows the identification insight of GNR where the TFP term inducing the transmission bias is eliminated from the share equation due to the assumed Hicks-neutrality, i.e. additive. For the same reason, in our augmented model, we also need to assume that the

[6] See GNR for an exposition of the sizeable effects of value-added bias on TFP heterogeneity. Merlevede and Theodorakopoulos (2018) show the impact of such a misspecification when estimating learning by doing effects.

[7] We inherently assume that the existence of any measurement error is symmetric across firms and thus does not affect our results.

'extra' intangible input from the linked firm enters (log-)additively.[8]

In line with most proxy variable methods, the GNR procedure follows two-steps. In the first step, a Non Linear Least Squares (NLLS) estimation for each of the share equations (11) and (12) is applied, with:

$$\tilde{\mathscr{H}}(K_{i0t}, L_{i0t}, M_{i0t})\mathscr{E}_p = \sum_{r_k + r_l + r_m \leq r} \gamma'_{r_k, r_l, r_m} k_{i0t}^{r_k} l_{i0t}^{r_l} m_{i0t}^{r_m}, \; with \; r_k, r_l, r_m \geq 0 \tag{13}$$

and

$$\tilde{\mathscr{F}}(K_{ijt}, L_{ijt}, M_{ijt})\mathscr{E}_a = \sum_{r_k + r_l + r_m \leq r} \delta'_{r_k, r_l, r_m} k_{ijt}^{r_k} l_{ijt}^{r_l} m_{ijt}^{r_m}, \; with \; r_k, r_l, r_m \geq 0 \tag{14}$$

approximated by a polynomial series estimator of order r. This step identifies ε_{i0t} and ε_{ijt} (hence $\mathscr{E}_p$ and $\mathscr{E}_a$) and the output elasticity of the flexible input, i.e. material, for both the parent and affiliate.

By integrating up the output elasticity of the flexible input for the parent:

$$\int \frac{\tilde{\mathscr{H}}(K_{i0t}, L_{i0t}, M_{i0t})}{M_{i0t}} dM_{i0t} = ln\Big(H(K_{i0t}, L_{i0t}, M_{i0t})(\Omega_{ijt})^{\pi_\omega}\Big) + \mathscr{H}(K_{i0t}, L_{i0t}) + \pi_\omega \omega_{ijt} \tag{15}$$

and the affiliate:

$$\int \frac{\tilde{\mathscr{F}}(K_{ijt}, L_{ijt}, M_{ijt})}{M_{ijt}} dM_{ijt} = ln\Big(F(K_{ijt}, L_{ijt}, M_{ijt})(\Omega_{i0t})^{\alpha_\omega}\Big) + \mathscr{F}(K_{ijt}, L_{ijt}) + \alpha_\omega \omega_{i0t} \tag{16}$$

we identify the production function of the parent and the affiliate up to an unknown constant of integration $\mathscr{H}(k_{i0t}, l_{i0t}) + \pi_\omega \omega_{ijt}$ and $\mathscr{F}(k_{ijt}, l_{ijt}) + \alpha_\omega \omega_{i0t}$, respectively. By subtracting the production functions (4) and (8) from equations (15) and (16), respectively, we retrieve the following equations for parent TFP:

$$\omega_{i0t} = \hat{\mathscr{Y}}_{i0t} + \mathscr{H}(k_{i0t}, l_{i0t}) + \pi_\omega \omega_{ijt} \tag{17}$$

and affiliate TFP:

$$\omega_{ijt} = \hat{\mathscr{Y}}_{ijt} + \mathscr{F}(k_{ijt}, l_{ijt}) + \alpha_\omega \omega_{i0t} \tag{18}$$

where $\hat{\mathscr{Y}}_{i0t}$ and $\hat{\mathscr{Y}}_{ijt}$ are the log of the expected output net of the computed integral of the output elasticity of materials for the parent (15) and affiliate (16), respectively, as estimated from the first stage. $\mathscr{H}(k_{i0t}, l_{i0t})$ and $\mathscr{F}(k_{ijt}, l_{ijt})$ represent the remaining part of the combined output of capital, labour and material of the production function to be identified for the parent and affiliate,

[8]Note that there is also scope for this term to enter more flexibly by interacting it to a certain extent with some of the non-flexible tangible inputs under the condition that it cancels out from the share equation. However, since we are interested in the average effect, we believe that the proposed specification suffices.

respectively, and are approximated by a polynomial of degree ν both for the parent:

$$\mathscr{H}(k_{i0t}, l_{i0t}) = \sum_{\nu_k+\nu_l \leq \nu} \pi_{\nu_k,\nu_l} k_{i0t}^{\nu_k} l_{i0t}^{\nu_l}, \; with \;\; \nu_k, \nu_l > 0 \tag{19}$$

and the affiliate:

$$\mathscr{F}(k_{ijt}, l_{ijt}) = \sum_{\nu_k+\nu_l \leq \nu} \alpha_{\nu_k,\nu_l} k_{ijt}^{\nu_k} l_{ijt}^{\nu_l}, \; with \;\; \nu_k, \nu_l > 0 \tag{20}$$

Combining equations (17)-(20), we express parent TFP:

$$\omega_{i0t}(\alpha_\nu, \pi_\nu) = \frac{1}{1-\pi_\omega \alpha_\omega} \left(\hat{\mathscr{Y}}_{i0t} + \sum_{\nu_k+\nu_l \leq \nu} \pi_{\nu_k,\nu_l} k_{i0t}^{\nu_k} l_{i0t}^{\nu_l} \right) + \frac{\pi_\omega}{1-\pi_\omega \alpha_\omega} \left(\hat{\mathscr{Y}}_{ijt} + \sum_{\nu_k+\nu_l \leq \nu} \alpha_{\nu_k,\nu_l} k_{ijt}^{\nu_k} l_{ijt}^{\nu_l} \right) \tag{21}$$

and affiliate TFP:

$$\omega_{ijt}(\alpha_\nu, \pi_\nu) = \frac{1}{1-\pi_\omega \alpha_\omega} \left(\hat{\mathscr{Y}}_{ijt} + \sum_{\nu_k+\nu_l \leq \nu} \alpha_{\nu_k,\nu_l} k_{ijt}^{\nu_k} l_{ijt}^{\nu_l} \right) + \frac{\alpha_\omega}{1-\pi_\omega \alpha_\omega} \left(\hat{\mathscr{Y}}_{i0t} + \sum_{\nu_k+\nu_l \leq \nu} \pi_{\nu_k,\nu_l} k_{i0t}^{\nu_k} l_{i0t}^{\nu_l} \right) \tag{22}$$

as functions of variables observed in the data (l and k), variables generated ($\hat{\mathscr{Y}}$), and parameters to be estimated $\alpha_\nu = (\alpha_k, \alpha_l, \ldots, \alpha_{\nu_k,\nu_l}, \alpha_\omega)$ and $\pi_\nu = (\pi_k, \pi_l, \ldots, \pi_{\nu_k,\nu_l}, \pi_\omega)$.

We proceed in the second step by exploiting the assumption over the law of motion of TFP. We assume that ω_{i0t} and ω_{ijt} evolve over time according to the following stochastic processes:

$$\omega_{i0t} = E[\omega_{i0t}|\mathscr{I}_{t-1}] + \xi_{i0t} \tag{23}$$

and

$$\omega_{ijt} = E[\omega_{ijt}|\mathscr{I}_{t-1}] + \xi_{ijt} \tag{24}$$

where ξ_t's capture, unanticipated at $t-1$, exogenous shocks that affect firm's TFP in t, i.e. $E[\xi_t|\mathscr{I}_{t-1}] = 0$. Similar to the seminal work of Olley and Pakes (1996), an 'exogenous' first order Markov process can be assumed, i.e. $\omega_{it} = E[\omega_{it}|\omega_{it-1}] + \xi_{it}$. However, exogeneity should be relaxed in order to accommodate the fact that TFP evolves endogenously in response to the firm's actions. This has been shown for the case of R&D by Aw et al. (2008) and Doraszelski and Jaumandreu (2013); the case of importing by Kasahara and Rodrigue (2008); the case of exporting by De Loecker (2013); and the case of changes in firms' operating environment, i.e. removing trade barriers, by De Loecker (2011). Taking this into account, we use the controlled Markov process in both (24) and (23) to explicitly allow for certain elements of $\mathscr{I}_{t-1}$ to affect TFP. For the baseline specification of our application, conditional on the information at $t-1$ the expectations of parent and affiliate TFP are:

$$\omega_{i0t} = \rho_{cp} + \rho_{pp}\omega_{i0t-1} + \rho_{pa}\omega_{ijt-1} + \psi_t + \psi_{sa} + \psi_{sp} + \psi_{ca} + \psi_{cp} + \xi_{i0t} \tag{25}$$

and

$$\omega_{ijt} = \rho_{ca} + \rho_{aa}\omega_{ijt-1} + \rho_{pa}\omega_{i0t-1} + \phi_t + \phi_{sa} + \phi_{sp} + \phi_{ca} + \phi_{cp} + \xi_{ijt} \tag{26}$$

where, in addition to lagged firm TFP, lagged linked firm TFP is allowed to affect current firm TFP (in expectation).[9] Also, ψ's and ϕ's are unobserved terms reflecting shocks/characteristics that vary over time (t), across industries of the affiliate (sa), industries of the parent (sp), country of the affiliate (ca) and country of the parent (cp), respectively.[10]

We can now express the 'innovations' of parent (ξ_{i0t}) and affiliate TFP (ξ_{ijt}) as functions of all of the production function parameters introduced in the system (α_v, π_v) by regressing current firm TFP on lagged firm TFP, lagged linked firm TFP and a battery of fixed effects controlling for the unobserved terms following equations (25) and (26), respectively. Note that, as in the case of current and lagged firm TFP our variables of interest, i.e. lagged linked firm TFPs, are also expressed as functions of the production function parameters in the system. Therefore, their effects on future TFP, i.e. ρ_{pa} and ρ_{ap}, are directly estimated within the second step (described below).

The second step proceeds with a standard iterative Generalised Method of Moments (GMM). To estimate the parameters of interest, (α_v, π_v), we form a GMM criterion function that is based on the following moment conditions:

$$E\left[\begin{pmatrix} \mathscr{Z}_v^p & \hat{\mathscr{Y}}_{ijt} & 0 & 0 \\ 0 & 0 & \mathscr{Z}_v^a & \hat{\mathscr{Y}}_{i0t} \end{pmatrix}' \begin{pmatrix} \xi_{i0t}(\alpha_v, \pi_v) \\ \xi_{ijt}(\alpha_v, \pi_v) \end{pmatrix}\right] = 0 \tag{27}$$

where $\mathscr{Z}_v^p = \left(k_{i0t}, l_{i0t}, \ldots, k_{i0t}^{v_k} l_{i0t}^{v_l}\right)$ and $\mathscr{Z}_v^a = \left(k_{ijt}, l_{ijt}, \ldots, k_{ijt}^{v_k} l_{ijt}^{v_l}\right)$ are the 'instrument sub-matrices' with their column space dimensions depending on the degree v of the polynomials used to approximate the constants of integration in (19) and (20).[11] The orthogonality conditions directly depend on the timing assumptions of the inputs. Capital and labour, for both the parent and the affiliate, are predetermined and thus orthogonal to the productivity innovations.[12] These instruments are typical in the literature and allow us to identify the π's and α's for capital and labour. However, in order to identify π_ω and α_ω we use current values of $\hat{\mathscr{Y}}_{i0t}$ and $\hat{\mathscr{Y}}_{ijt}$ (generated from the first stage), respectively, since they are assumed to be exogeneously given to the firm and thus uncorrelated with the unanticipated innovation to productivity at time $t-1$.

By minimising the sample analogue of (27), we retrieve estimates for parameters of the production technology of the parent (π_v) and the production technology of the affiliate (α_v).We

[9] With lagged values, we inherently assume that it takes one period for actions to affect TFP. Such an assumption can be relaxed and tested for robustness against alternative specifications with deeper lags.

[10] One can consider a more general functional form for equations (25) and (26) by introducting a sieve of the relevant controls. However, this case should be considered with caution since non-linearities in the fixed-effects would saturate the model, resulting in the incidental parameters problem.

[11] One can also estimate each set of equations separately. However, joint estimation allows cross-equation restrictions for the same parameters.

[12] However, if labour is assumed to be a dynamic input then current labour and productivity are correlated and thus the instruments should contain lagged values of labour.

also retrieve estimates for the persistence of firms' TFP (ρ_{pp} and ρ_{aa}), the learning by the linked firm's TFP (ρ_{pa} and ρ_{ap}) and all of the fixed-effects in equations (25) and (26).

For the baseline specification we apply industry-specific Cobb-Douglass specifications for $H(\cdot)$ and $F(\cdot)$ in (4) and (8), respectively, to control for growth differentials across industries. This is equivalent to a polynomial of degree zero for the elasticities of material, $r = 0$, i.e. industry dummies in the share equation regression, and a first order polynomial for the constants of integration, $\nu = 1$. Based on estimates of the production function coefficients, we can now compute other relevant variables, i.e. TFP, output elasticities of inputs and returns to scale (RTS), for both the parent and affiliate, using equations (4) and (8), respectively

Finally, note that our TFP estimates are revenue based since we do not observe physical output, but only monetary values deflated at the industry level. Results should be interpreted bearing this in mind (Klette and Griliches 1996).[13]

3 Data

We construct a firm-level panel of manufacturing firms from 19 EU countries[14] for the period 2004 to 2015. Data come from the Amadeus database by Bureau van Dijk Electronic Publishing (2011) (BvDEP). BvDEP regularly updates the information set in Amadeus and releases a version containing the latest information on ownership on a monthly basis. However, firms that exit are dropped fairly rapidly. In order to have a complete set of financial and ownership information over time, we use a time series of (annual) versions to construct a consistent database. In particular, we build a dataset with nearly full financial and administrative information, i.e. balance sheet, profit and loss account activities, location, ownership, entry and exit. To argue over the representatives of the data, Table 9 in Appendix A contains the number of firms and employees covered by our dataset both in levels and as a share of inward Foreign Affiliates Statistics (FATS) provided by Eurostat for the year 2012 (Eurostat 2018). For both measures, our dataset covers close to 60 percent of what is reported in FATS. Merlevede et al. (2015) describe the construction and representativeness of the data at length.

We focus on the sample of affiliate firms. Of these firms, more than 50% of their shares are owned by a domestic or foreign parent firm. Each affiliate can have only one majority controlling parent, while parent firms can control multiple affiliates. We keep the active manufacturing[15] firms that file unconsolidated accounts.[16] We retain firms reporting sales, tangible fixed assets,

[13]A future extension of the empirical model will control for unobserved variation in output prices, by introducing more structure and assumptions. This includes an iso-elastic demand system coupled with monopolistic competition, similar to Klette and Griliches (1996) and De Loecker (2011).

[14]This includes Austria, Belgium, Bulgaria, Croatia, Czech Republic, Estonia, Finland, France, Germany, Hungary, Italy, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.

[15]Table 8 in Appendix A provides an overview of the NACE Rev.2 2-digit industries.

[16]This refers to accounts not integrating the statements of possible controlled subsidiaries or branches of the concerned company. Note that this does not control for the case of multi-plant companies.

number of employees, material costs, NACE Rev.2 2-digit industry classification and ownership information. We remove outliers using the BACON method proposed by Billor et al. (2000).[17] This results in an unbalanced European panel of 12849 parent and 17921 affiliate firms with full balance sheet information on both sides for the period 2004-2015 (see Table 1).

Table 1: Summary Statistics

Affiliates' ...	Obs.	Mean	St.Dev.	p25	p50	p75
Output†	72112	33	264	2	6.3	20
Capital†	72112	7.4	150	.18	1.1	4.3
Material†	72112	22	202	.82	3.1	11
Labour	72112	112	454	13	36	100
Wages	71992	40338	49974	24026	36752	47907
Parents' ...						
Output†	54849	148	1190	7.8	24	74
Capital†	54849	25	145	1	4	14
Material†	54849	95	910	3.6	12	40
Labour	54849	386	2093	39	105	286
Wages	54790	48178	530579	32065	42380	53544
Affiliates	54849	1.3	.84	1	1	1

Notes: † monetary variables in million Euro. BvDEP database for manufacturing firms in 19 EU countries for the period 2004 to 2015.

All monetary variables are deflated using the appropriate country-NACE Rev.2 2-digit output deflator from the EU KLEMS database. (Real) *Output* (Y) is sales deflated with producer price indices. *Capital* (K) is tangible fixed assets deflated by the average of the deflators of various NACE Rev.2 2-digit industries (Javorcik 2004).[18] (Real) *Material* (M) is material inputs deflated by an intermediate input deflator constructed as a weighted average of output deflators, where country-time-industry specific weights are based on intermediate input uses retrieved from input-output tables. *Labour* (L) is the number of employees. *Wages* is the cost of employees divided by the number of employees and *Affiliates* refers to the number of majority controlled affiliates from each parent.

4 Results

In this section we first assess the extent to which linked firm TFP contributes to the final output of the firm. We measure this as the firm's output elasticity of linked firm TFP – similar to

[17] BACON stands for block adaptive computationally efficient outlier nominators. It is a multiple outlier detection method. The variables considered in the method are material costs share and the log of output, labour, capital and material.

[18] Electrical equipment (27); machinery and equipment n.e.c. (28); motor vehicles, trailers and semi-trailers (29); and other transport equipment (30).

other tangible inputs, i.e. labour, capital and material. We then analyse in detail whether such transfers of intangible technology constitute potential determinants of the firm's TFP evolution via learning mechanisms. Finally, to support the validity of our methodological approach, we extend our model by introducing a specific form of intangible reported in our dataset, i.e. dummy for the existence of patent stock applications at the firm-level.

4.1 Intangible Technology Transfers

In Table 2 we report estimates for the production function of affiliate (column 1-3) and parent firms (column 4-6). In columns 1 and 4, we consider the sample of affiliates and parents, respectively, from any type of ownership structure. Capital, labour and material contribute significantly to the production technology of the affiliate and parent, as shown from their respective output elasticities in the first three rows of column 1 and 4. Note that the estimates between affiliates and parents are very similar, pointing to the relatively similar production technologies within industries. Also, the relative importance of each factor is in line with the extensively reported estimates of output elasticities in the production function literature.

Table 2: Production Function Estimates

	(1)	(2)	(3)		(4)	(5)	(6)
	Affiliates				*Parents*		
	All	*Domestic*	*Foreign*		*All*	*Domestic*	*Foreign*
$\bar{\alpha}_m$	0.431***	0.417***	0.501***	$\bar{\pi}_m$	0.471***	0.469***	0.488***
	(0.002)	(0.002)	(0.006)		(0.002)	(0.002)	(0.004)
$\bar{\alpha}_l$	0.341***	0.353**	0.248***	$\bar{\pi}_l$	0.341***	0.357***	0.262***
	(0.014)	(0.144)	(0.075)		(0.014)	(0.078)	(0.043)
$\bar{\alpha}_k$	0.083***	0.084***	0.069***	$\bar{\pi}_k$	0.087***	0.091***	0.092***
	(0.006)	(0.014)	(0.020)		(0.007)	(0.017)	(0.026)
α_ω	0.381***	0.383***	0.404***	π_ω	0.171***	0.163***	0.258***
	(0.039)	(0.059)	(0.085)		(0.011)	(0.023)	(0.044)
$R\bar{T}S_\alpha$	1.236***	1.237***	1.222***	$R\bar{T}S_\pi$	1.070***	1.079***	1.101***
	(0.041)	(0.193)	(0.118)		(0.018)	(0.102)	(0.070)
$R\bar{T}S_\alpha - 1$	0.236***	0.237	0.222*	$R\bar{T}S_\pi - 1$	0.070***	0.079	0.101
	(0.041)	(0.193)	(0.118)		(0.018)	(0.102)	(0.070)
Observations	49269	38721	10542	Observations	49269	38721	10542

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Each column is estimated using all manufacturing firms. The $\bar{\alpha}'s$ and $\bar{\pi}'s$ are averages of the estimated output elasticities (of each relevant input) for affiliate and parent firms, respectively. α_ω and π_ω are point estimates of the output elasticities of the parent and affiliate productivity, respectively. All estimates include additive year, industry-affiliate, industry-parent, country-affiliate and country-parent fixed effects. Standard errors are block-bootstrapped with 500 replications over the GNR two-step estimation procedure and reported in parenthesis below point estimates.

The estimates of α_ω and π_ω show that linked firm TFP is a significant input in the firm's production technology. However, affiliates appear to rely on such transfers of intangible

technology almost two times more than the parents. In column 1, a one percentage point increase in the TFP of the parent leads to a 0.38% increase in the affiliate's output. Similarly, a one percentage point increase in the TFP of the affiliate leads to a 0.17% increase in the parent's output. The extent to which linked firm TFP contributes to the final output of the firm is: for the affiliates comparable to the contribution from labour (0.34%); and for the parents roughly more than half of the contribution from physical capital (0.11%). If we were to ignore such transfers, our results imply that the term $\alpha_\omega \omega_{i0t}$ from equation (8) and $\pi_\omega \omega_{ijt}$ from equation (4) would be falsely subsumed in the affiliate and parent TFP, respectively. In turn, the productivities would be overestimated on average by 46% for the affiliate and 27% for the parent firms. This underscores the fact that linked firm TFP captures important transfers of intangible technology to the firm that should be modeled accordingly.

By adding up all output elasticities we retrieve the average RTS for the production function of affiliate (RTS_α) and parent firms (RTS_π). In both cases, contrary to what has been reported in the literature so far,[19] we reject constant RTS in the last row. This result favors our previous statement where absence of intangible inputs from the production technology of the firm can lead to significantly different estimates, e.g. overestimated TFP and unrealistically low RTS.

In columns 2 and 3 for the affiliate and 5 and 6 for the parent firms, we split the sample in firms with domestic and foreign ownership links, respectively. We find a larger estimated firm output elasticity of linked firm TFP for foreign relative to domestic ownership, both for parents and affiliates. This is in line with suggestive evidence that institutional environments, e.g. with less intellectual property rights (Branstetter et al. 2006), can have a significant effect in the transfer of knowledge, know-how and technology wihtin multinationals (Moran 2007). More specifically, based on a theoretical model of optimal knowledge, Gumpert (2015) shows that higher cross-border communication costs would make multinational firms assign more knowledge to their foreign plants than to the domestic plants.[20] Through the lenses of the same theoretical model, such costs would make the communication between the foreign affiliate and its parent less frequent, and force the foreign affiliates to depend more on learning practices. Our results confirm the former part of the argument, and test the latter in the following subsection.

Overall, we see that linked firm TFP, used as a measure of intangible input accessed by the firm within its ownership group, is a significant determinant of the firm's production technology.

[19] The literature has consistently reported low output elasticities and thus decreasing returns to scale. This has been reconciled as a direct outcome of the fact that they estimate revenue production functions and, as such the coefficients of the production function, would be downward biased in the presence of output-price differences across firms (Klette and Griliches 1996; De Loecker 2011). In this case, we would also expect the parameters estimated for both the intangible technology transfers, i.e. α_ω and π_ω, and the firm's tangible production function to be 'under-under-estimated.' This is because the estimated productivity of the linked firm would already be downward biased from any price differences in the output market of the linked firm.

[20] The parent avoids such communication costs by assigning more knowledge to their foreign affiliates. This helps to explain why foreign affiliates have higher wages and sales relative to domestic ones. We confirm that such differences are prevalent in our data and also exist across other dimensions of the firm, i.e. labour, capital and materials, when comparing Tables 10 and 11 in Appendix A.

4.2 Learning

In Table 3, we report estimates for the affiliate's (columns 1-3) and parent's markov process (columns 4-6) proposed in equation (26) and (25), respectively. As before, the table has two panels and each panel consists of three columns where results cover all, domestic and foreign ownership links, respectively. Fixed effects used in the estimations are not reported in the tables due to space considerations and their non-relevant economic interpretation in this context.

Table 3: Markov Process Estimates

	(1)	(2)	(3)		(4)	(5)	(6)
		Affiliates				*Parents*	
	All	*Domestic*	*Foreign*		*All*	*Domestic*	*Foreign*
ρ_{aa}	0.923***	0.919***	0.937***	ρ_{pp}	0.941***	0.940***	0.945***
	(0.004)	(0.009)	(0.028)		(0.004)	(0.015)	(0.017)
ρ_{ap}	0.025***	0.022***	0.027***	ρ_{pa}	0.016***	0.014***	0.004
	(0.004)	(0.004)	(0.010)		(0.002)	(0.002)	(0.008)
Observations	49269	38721	10542	Observations	49269	38721	10542

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Each column is estimated using all manufacturing firms. All estimates include additive year, industry-affiliate, industry-parent, country-affiliate and country-parent fixed effects, if applicable. Standard errors are block-bootstrapped with 500 replications over the GNR two-step estimation procedure and reported in parenthesis below point estimates.

In the bottom row of column 1 and 4, we see that firm-linked TFP is a significant determinant of future firm TFP. On the one hand, the coefficient estimate of ρ_{ap} suggests that a one standard deviation increase in lagged parent TFP increases current affiliate TFP by 0.36%. On the other hand, the coefficient estimate of ρ_{pa} suggests that a one standard deviation increase in lagged affiliate TFP increases current parent TFP by 0.29%. Due to the assumed Hicks-neutrality in TFP, these effects can also be interpreted as an equivalent increase in firm's output. In the short-run these learning effects are directly comparable and roughly account for one fifteenth and one eleventh of the importance of intangible technology transfers from the parent and affiliate respectively (estimated in the previous section). However, in the long-run, these effects become prevalent and allow affiliates and parents to experience TFP increases that amount to an average 32% and 27% of any increase in parent TFP. In other words, the affiliate's learning capacity is on average roughly one third of the parent TFP growth while the parent's learning capacity is on average roughly one fourth of the affiliate TFP growth.[21]

In columns 2 and 3 we find that this learning effect is larger for foreign versus domestic affiliates. In the long-run, foreign affiliates appear to learn/absorb 15% more from the intangible technology transferred from the parent than domestic affiliates. This result supports the theoretical view that foreign affiliates master a higher share of the production process by themselves,

[21] A one standard deviation increase in the linked firm TFP leads to a 4.61% and 4.90% increase in affiliate and parent TFP, respectively, in the long-run.

due to the presence of high cross-border communication costs(Gumpert 2015). Interestingly, for the case of parent firms only the ones with domestic links learn from transfers of intangible technology from their affiliates. There is no such effect both in terms of magnitude and significance for parents with foreign links. This could reflect the fact that these firms dominate along various dimensions (see Tables 10 and 11) and as such rely relatively more on internal learning processes, as it might be suggested by the higher persistence term (ρ_{pp}).

4.3 Patents

To support the validity of our methodological approach, we extend the empirical model by introducing a specific form of intangible that is reported in the data. The information that we observe is on patent applications at the firm-year level. Following Stiebale (2016), we use this information to construct a patent application stock dummy variable that takes unit values if a firm has positive (not yet depriciated) stock of patent applications and zero otherwise. In Table 4, we see that the majority of patent applications are concentrated at the parent (24%) with affiliates accounting for only a small fraction (7%).

Table 4: Summary Statistics of Patent Application Stock

Patent Application Stock for ...	Obs.	Mean	St.Dev.	p25	p50	p75
Affiliate	72112	.072	.26	0	0	0
Parent	54849	.24	.43	0	0	0

Notes: Patent application stock is a dummy variable taking unit values if a firm has positive (not yet depriciated) stock of patent applications and zero otherwise. The stock of patent applications is constructed following Stiebale (2016).

Table 5 reports simple correlations between the observed (in the data) patent application stock and the unobserved (but estimated from our methodology) TFP for both parent and affiliate firms. As expected, we find a positive association and low strength. This suggests that our estimated TFP measures contain meaningful information for patent applications that can safely be considered as intangibles. In addition, the low strength of the correlation points out that: patent applications are possibly not the most significant determinants in the intangible space; and that our TFP measure contains meaningful information for other intangible inputs.

Table 5: Correlation of TFP and Patents

	ω_{ijt}	ω_{i0t}	$Patents_{ijt}$	$Patents_{i0t}$
ω_{ijt}	1.000			
ω_{i0t}	0.764	1.000		
$Patents_{ijt}$	0.134	0.091	1.000	
$Patents_{i0t}$	0.130	0.093	0.221	1.000

We now extend our empirical methodology by allowing the patent application dummy both as an input in the firms production technology and as a potential determinant of its future productivity. Table 6 presents the estimates from the production function and Table 7 from the markov process for both the affiliate (upper panel) and parent firms (lower panel). Both tables contain 7 columns with the first one reporting the baseline estimates of the previous section. The rest of the columns present estimates for different model specifications when considering the pattern application stock variable.

Table 6: Production Function Estimates with Patents

Affiliates' ...	(1)	(2)	(3)	(4)	(5)	(6)	(7)
α_{ω}	0.381***				0.373***	0.376***	0.368***
	(0.039)				(0.039)	(0.039)	(0.039)
α_{PATa}		0.030**		0.029**	0.028*		0.034**
		(0.015)		(0.014)	(0.016)		(0.015)
α_{PATp}			0.014	0.014		0.004	0.009
			(0.011)	(0.011)		(0.010)	(0.012)
Parents' ...							
π_{ω}	0.171***				0.169***	0.168***	0.166***
	(0.011)				(0.012)	(0.011)	(0.011)
π_{PATp}		0.015		0.015	0.014		0.015
		(0.016)		(0.015)	(0.015)		(0.016)
π_{PATa}			0.020	0.020		0.012	0.016
			(0.019)	(0.019)		(0.019)	(0.019)
Observations	49269	49269	49269	49269	49269	49269	49269

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Each column is estimated using all manufacturing firms. The $\bar{\alpha}'s$ and $\bar{\pi}'s$ representing the averages of the estimated output elasticities (of each relevant input) for affiliate and parent firms, respectively, are not presented in this table for space considerations. α_{ω} and π_{ω} are point estimates of the output elasticities of the parent and affiliate productivity, respectively. All estimates include additive year, industry-affiliate, industry-parent, country-affiliate and country-parent fixed effects. Standard errors are block-bootstrapped with 500 replications over the GNR two-step estimation procedure and reported in parenthesis below point estimates.

The main take-away from both tables is that whenever we introduce the linkedtype patent application stock variable the magnitude of the estimated effect from the linked firm TFP becomes smaller. Overall, this result provides supportive evidence that linked firm TFP contains/controls for variation in intangible inputs and thus can be considered as a meaningful composite index for intangible inputs that are transferred within ownership groups.

Table 7: Markov Process Estimates with Patent Stock Indicator

Affiliates' ...	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ρ_{aa}	0.923***	0.926***	0.926***	0.926***	0.923***	0.923***	0.923***
	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
ρ_{ap}	0.025***				0.025***	0.025***	0.025***
	(0.004)				(0.004)	(0.004)	(0.004)
ρ_{PATaa}		0.003		0.002	0.002		0.002
		(0.004)		(0.004)	(0.005)		(0.005)
ρ_{PATap}			0.003	0.003		0.001	0.001
			(0.003)	(0.003)		(0.003)	(0.003)
Parents' ...							
ρ_{pp}	0.941***	0.943***	0.943***	0.943***	0.941***	0.941***	0.941***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
ρ_{pa}	0.016***				0.016***	0.015***	0.015***
	(0.002)				(0.002)	(0.002)	(0.002)
ρ_{PATpp}		0.004**		0.004	0.005**		0.005**
		(0.002)		(0.002)	(0.002)		(0.002)
ρ_{PATpa}			0.009**	0.008**		0.007*	0.006
			(0.004)	(0.003)		(0.004)	(0.004)
Observations	49269	49269	49269	49269	49269	49269	49269

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Each column is estimated using all manufacturing firms. All estimates include additive year, industry-affiliate, industry-parent, country-affiliate and country-parent fixed effects, if applicable. Standard errors are block-bootstrapped with 500 replications over the GNR two-step estimation procedure and reported in parenthesis below point estimates.

5 Conclusion

A large literature has tried to understand the role of firm boundaries. Suggestive empirical evidence point to the theoretically based argument that firm boundaries exist to facilitate the transfer of intangible inputs. In this paper we identify and quantify transfers of intangible inputs, and how they determine both the production technology and productivity evolution of the firm.

We use a carefully constructed European panel of majority owned parent-affiliate groups with full balance sheet information on both sides for the period 2004-2015 and extend a typical production function estimation procedure. Due to the data restrictions on intangible inputs, we devise an empirical method that allows us to characterise the full set of intangibles transferred between parent and affiliates.

We identify, at the firm level, the importance of productivity transfers within ownership structures and confirm the theoretically based argument that firm boundaries exist to facilitate the transfer of intangibles. We flexible account for transfers of intangible technology within

the boundaries of the firm that are both significant inputs in the firm's production technology and potential determinants of its productivity evolution. Exploiting the richness of the data, we find that firms with foreign ownership-links experience larger transfers of intangible technology from their linked firm, while foreign-owned affiliates benefit more from productivity increases induced by learning mechanisms compared to domestically owned affiliates, consistent with theories of optimal knowledge within multinationals.

The results presented in this paper are particularly poignant due to inherent difficulties in measuring intangible assets. Therefore, they are particularly relevant to policymakers and institutions which can use them as a strong reference point for shaping future policies on intangible assets.

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Appendices

A Additional Figures and Tables

Table 8: List of NACE Rev.2 2-digit industries in the manufacturing sector.

Division	Description
10	Manufacture of food products
11	Manufacture of beverages
12	Manufacture of tobacco products
13	Manufacture of textiles
14	Manufacture of wearing apparel
15	Manufacture of leather and related products
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
17	Manufacture of paper and paper products
18	Printing and reproduction of recorded media
19	Manufacture of coke and refined petroleum products
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery & equip.
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment n.e.c.
29	Manufacture of motor vehicles, trailers and semi-trailers
30	Manufacture of other transport equipment
31	Manufacture of furniture
32	Other manufacturing
33	Repair and installation of machinery and equipment

Table 9: Data Representativeness

	foreign affiliates in country				*country's affiliates abroad*			
	# affiliates		*employment*		*# affiliates*		*employment*	
	n	share	*n*	share	*n*	share	*n*	share
AT	367	0.88	37,996	0.63	819	0.63	120,519	0.59
BE	344	1.13	55,566	0.72	652	0.58	48,866	0.54
BG	93	0.24	42,089	0.65	6	0.08	167	0.00
CZ	1,142	0.49	258,709	0.90	77	1.08	4,039	0.33
DE	1,184	0.53	152,578	0.29	2,589	0.38	422,789	0.39
EE	267	0.93	18,974	0.62	29	0.53	1,992	0.51
ES	742	0.46	121,756	0.45	577	0.64	66,609	1.10
FI	214	0.85	31,361	0.96	371	0.52	38,912	0.39
FR	771	0.41	49,492	0.21	1,181	0.51	227,717	0.42
HR	128	0.41	14,904	0.58	13	-	377	-
HU	263	0.21	81,542	0.57	33	0.33	4,927	0.62
IT	904	0.81	144,301	0.98	1,119	0.54	105,083	0.39
NO	160	0.44	12,187	0.39	208	0.45	22,748	0.43
PL	1,637	0.98	143,913	0.53	57	0.55	9,781	0.44
PT	292	0.46	39,533	0.48	72	0.49	7,617	0.56
RO	912	0.39	179,599	0.65	5	0.16	47	0.04
SE	239	0.36	37,774	0.44	770	0.66	78,734	0.48
SI	109	0.44	15,862	0.51	46	0.89	5,388	0.76
SK	303	0.45	77,714	0.59	56	0.36	5,033	0.32
Total	10,904	0.57	1,578,614	0.55	10,904	0.57	1,578,614	0.55

Notes: Number of firms and employees covered by our dataset both in levels (n) and as a share (share) of inward Foreign Affiliates Statistics (FATS) provided by Eurostat for the year 2012 (affiliates in manufacturing and parents in all industries - FATS does not provide parent industry).

Table 10: Sumary Statistics for Domestic Ownership

Affiliates' ...	Obs.	Mean	St.Dev.	p25	p50	p75
$Output^{\dagger}$	57082	27	244	1.7	5.3	16
$Capital^{\dagger}$	57082	5.5	36	.15	.86	3.6
$Material^{\dagger}$	57082	17	190	.69	2.5	8.9
$Labour$	57082	89	406	12	30	79
$Wages$	56976	41908	44841	27737	37656	47896
Parents' ...						
$Output^{\dagger}$	44845	141	1258	6.7	20	64
$Capital^{\dagger}$	44845	24	152	.91	3.6	13
$Material^{\dagger}$	44845	91	960	3	10	35
$Labour$	44845	361	2182	35	89	250
$Wages$	44800	47503	586429	30800	41282	52114
$Affiliates$	44845	1.3	.78	1	1	1

Notes: † monetary variables in million Euro. BvDEP database for manufacturing firms in 19 EU countries for the period 2004 to 2015.

Table 11: Sumary Statistics for Foreign Ownership

Affiliates' ...	Obs.	Mean	St.Dev.	p25	p50	p75
$Output^{\dagger}$	15178	57	331	3.8	12	33
$Capital^{\dagger}$	15178	15	320	.44	2.2	7.3
$Material^{\dagger}$	15178	39	241	2	6.5	20
$Labour$	15178	201	592	29	75	184
$Wages$	15164	34455	65290	12017	27120	48073
Parents' ...						
$Output^{\dagger}$	12771	298	2011	22	56	148
$Capital^{\dagger}$	12771	43	220	2.3	8.2	24
$Material^{\dagger}$	12771	199	1526	11	29	82
$Labour$	12771	711	3672	91	224	551
$Wages$	12752	51529	40454	38394	48057	59535
$Affiliates$	12771	1.2	.55	1	1	1

Notes: † monetary variables in million Euro. BvDEP database for manufacturing firms in 19 EU countries for the period 2004 to 2015.