The Impact of Innovation in Multinational Firms

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Abstract

What is the private return to innovation? When firms operate production sites in multiple countries, improvements developed at one site may be shared across others for efficiency gain. We develop a dynamic model that explicitly accounts for such transfer within the firm, and apply it to measure innovation returns for a comprehensive panel of U.S. multinationals during 1989–2009. We find that the data, which include detailed measures of affiliate production and innovation, are consistent with innovation generating returns at firm locations beyond the innovating site. Accounting for cross-plant effects of innovation, our estimates indicate the average firm realizes between 10 and 30 percent of the return to its U.S. parent R&D abroad, suggesting single-plant estimates may understate firms’ gain from innovation.

*The statistical analysis of firm-level data on U.S. multinational companies was conducted at the Bureau of Economic Analysis, U.S. Department of Commerce under arrangements that maintain legal confidentiality requirements. The views expressed are those of the author and do not reflect official positions of the U.S. Department of Commerce. The Bureau of Economic Analysis has reviewed this paper prior to release to ensure that data confidentiality is not unintentionally compromised. We thank seminar audiences at Duke University, George Washington University, University of Michigan, University of Minnesota, Princeton University, and Vanderbilt University for very helpful comments. Bilir thanks the Princeton International Economics Section for support. All errors are our own. E-mail: kbilir@ssc.wisc.edu, ecmorale@princeton.edu.
1 Introduction

Multinationals account for the substantial majority of R&D investment in the United States and other advanced economies, and are among the most innovation-intensive firms.¹ As in most firms, this investment is directed toward product and process innovation with the eventual aim of enhancing productivity. But, unlike other firms, multinationals operate production and innovation sites in multiple countries, raising the well-known possibility that improvements developed at one site may be shared across others for efficiency gain.²

Consider firms in the hard-disk drive industry. Offshore subsidiaries in this industry perform process innovation to improve efficiency, but are also influenced by innovation investment of the parent firm. First, parent innovation impacts the quality of a crucial input component that the parent manufactures and ships to its offshore subsidiaries for processing and assembly.³ High levels of parent innovation reduce the rate of input failure, thereby saving subsidiaries subsequent resource loss. Second, parent innovation impacts affiliate productivity through high-level product and process design, process monitoring, and assistance diagnosing and addressing process challenges.⁴

Such within-firm knowledge transfer forms an important feature of the multinational firm in theoretical models (Dunning 1981, Helpman 1984) and is also known to influence the global welfare effects of multinational production and shape patterns of multinational activity across countries.⁵ The idea that innovation may generate returns at firm locations beyond the innovating site also has clear theoretical implications both for understanding the firm-wide return to R&D investment and the global impact of government policies aimed at stimulating private innovation.⁶ However, as an empirical matter, the actual extent to which innovation investment by a firm in one country impacts its performance at sites abroad is not known.

This paper uses detailed information on parent and affiliate-level innovation and production to measure the private return to multinational firms’ innovation investment. We develop a dynamic model of firm innovation that explicitly accounts for intrafirm knowledge transfer across production sites. The model provides a detailed empirical framework which we then apply to estimate innovation returns within a comprehensive panel of U.S. multinationals during 1989–2009. We find that the data are consistent with innovation generating returns at firm locations beyond the innovating

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² Caves (2007).
³ Based on conversations with a former employee of the hard-disk drive firm Western Digital.
⁴ For further details on the industry and its production structure, see Igami (2014) and references therein.
site within five major manufacturing industries. Specifically, accounting for cross-plant effects of innovation, our estimates indicate the average firm realizes between 10 and 30 percent of the return to its U.S. parent R&D abroad.

In the model, the multinational firm makes a series of optimal production and innovation decisions for each production site based on the costs and expected gains from each activity. The firm determines both location-specific innovation and physical capital investments, as well as subsequent levels of static inputs including labor and materials to be used in production at each site. As in Aw, Roberts, and Xu (2011) and Doraszelski and Jaumandreu (2013), we assume affiliate-level productivity follows a Markov process that can be shifted by R&D expenditures. Importantly, however, innovation at one site may impact other sites within the same firm, and the impact of innovation on an affiliate may differ depending on whether investment is made by the affiliate, its U.S. parent, or another affiliate within the same firm. We further allow differences between parent and affiliate production and productivity evolution, capturing the possibility of vertically-linked multinationals, and provide for unobserved, systematic differences in affiliate productivity change across locations.

The model yields general expressions for the firm’s optimal input and investment decisions at each production location. Specifically, given an affiliate’s current revenue productivity, product quality, capital stock, local input prices and aggregate demand conditions, the firm’s input and investment decisions solve optimality conditions derived from a standard Bellman equation. We use these optimality conditions directly to estimate parameters of the affiliate production function corresponding to static labor inputs (Gandhi, Navarro, and Rivers 2013). However, to maintain flexibility regarding unknown cost functions for investment in physical capital and in knowledge through R&D, which may differ substantially across countries and the estimation of which is beyond the scope of this paper, we follow Doraszelski and Jaumandreu (2013) by taking an approach for which the precise form of these cost functions is not required.

To recover production and technology parameters determining the firm-wide return to innovation with the estimation strategy implied by our model, we use comprehensive panel data on U.S. multinationals’ global activity from the Bureau of Economic Analysis (BEA). Our data include detailed measures of production inputs, output, investment, and innovation for each firm-country pair during the period 1989–2008, and span multiple industries of which we focus our attention on five prominent manufacturing sectors.\(^7\)

These data reveal facts about firms’ organization of innovation activity across locations, which is rarely observable. First, almost all multinational firms and U.S. parent firms invest in R&D. Second, foreign affiliates participate in innovation investment in approximately half of firms, indicating that for a large share of firms, knowledge creation is an international endeavor. However, third, the average multinational firm reports R&D participation by only the minority of its foreign affiliates. And fourth, accordingly, the R&D intensity of the average U.S. parent operation is three to eight

\(^7\)The five industries we analyze are Industrial Machinery (SIC 35), Electronic and Other Electrical Equipment (SIC 36), Measuring and Analyzing Instruments (SIC 38), Chemicals and Allied Products (SIC 28), and Transportation Equipment (SIC 37).
times higher than that of its overall foreign-affiliate operations. That firms fragment innovation across countries to any extent suggests the presence of frictions limiting the communication of technical knowledge across countries (e.g. Arrow 1962, 1969), however, the sharp differences between observed parent and affiliate R&D participation is consistent with our estimates indicating firms' innovation activity may lead to intrafirm transfer of knowledge.

Specifically, our empirical analysis indicates innovation significantly impacts firm productivity dynamics within U.S. multinationals. Innovation investment by a U.S. parent firm has a positive and highly significant impact on the subsequent productivity change both of the parent and of its foreign affiliates. Our estimates reveal that the impact of parent innovation is long-lived, increasing affiliate productivity growth for up to five years after R&D expenditure. Moreover, the long-run effects of parent innovation are further compounded by persistence in affiliate-level productivity.

Accounting for both considerations, our estimates reveal that, on average, the immediate short-run elasticity of an affiliate’s value added with respect to the R&D investment of its U.S. parent in the previous period is highly significant and ranges between one and two percent; long-run effects are between three and eight percent depending on the industry. These estimates imply that the return to parent R&D—defined as the change in firm value resulting from a marginal increase in R&D investment—realized abroad is between five percent and 35 percent, on average.

Relative to the parent-level return to its own R&D investment, these estimates indicate that for the average firm, between ten and 30 percent of innovation gains are realized among affiliates abroad. This estimated impact share differs across the distribution of firms, and is influenced by the size of the parent and its foreign affiliates, the number of affiliates, and the R&D participation of each affiliate. Intuitively, returns to parent R&D realized abroad are minimal for multinationals with limited foreign operations. By contrast, our estimates imply that evaluating innovation returns based only on single-plant effects understates innovation returns for the majority of firms.

Finally, our results indicate that an affiliate’s productivity evolution is shaped by its own R&D expenditure, highlighting an aspect of firm activity not usually considered in theoretical models of the multinational firm. We find that affiliate innovation impacts subsequent productivity growth to an extent comparable to that found in Doraszelski and Jaumandreu (2013), and that innovating affiliates experience a faster rate of productivity obsolescence than non-innovating affiliates. However, in contrast to that of the U.S. parent, we do not find a robust effect of innovation by a foreign subsidiary on productivity at its U.S. parent or at other firm sites.

This paper contributes to a growing literature investigating the role of technology within the multinational firm. Our results are consistent with insights formalized in Helpman (1984), as well as recent empirical evidence indicating centrally-developed inputs and technology shape global patterns of production and sales within multinational firms (Arkolakis et al 2013; Irrazabal, Moxnes, 8

8This result is consistent with the idea that higher innovation levels increase the rate at which knowledge and technology obsolesce. Bilir (2014) similarly finds a negative correlation across industries between R&D intensity (R&D/sales) and the average length of product lifecycles, which reflect technology obsolescence rates of U.S. patents. Doraszelski and Jaumandreu (2013) also finds evidence of higher knowledge persistence among non-R&D performing plants than among R&D performers.
and Opromolla 2013; Keller and Yeaple 2013). In particular, our estimates complement Arkolakis et al (2013), which demonstrates that the within-firm correlation between parent and affiliate productivity is a determinant of the equilibrium gains from multinational production in the global economy. The productivity estimates we develop indicate that this correlation is influenced directly by a dynamic process featuring innovation investment and subsequent intrafirm knowledge transfer.

The model and estimation methods applied in this paper are related to prior empirical studies evaluating the link between R&D and productivity at the plant level. We estimate a dynamic model of endogenous R&D investment and our model is therefore related to Doraszelski and Jaumandreu (2013), Aw, Roberts, and Xu (2011) and Boler, Moxnes, and Ulltveit-Moe (2014). Like these papers, we build directly on insights in Griliches (1979), but focus on R&D expenditures as a proxy for the state of knowledge; we do not attempt to construct a stock of knowledge capital from the available history of R&D expenditures. This approach has the advantage that it does not place restrictions on features such as economies of scale in the accumulation of knowledge or the obsolescence rate of previously acquired knowledge. Our model is, however, distinct from Doraszelski and Jaumandreu (2013), and conceptually closer to Adams and Jaffe (1996), in that it considers the productivity consequences of R&D investment within a multiplant-firm, in which productivity gains from R&D investment may be shared within the firm across production locations.

The patterns we find regarding the intrafirm impact of innovation support models of the multinational firm featuring firm operations vertically linked by cross-plant intangible transfers, and thus complement results in Atalay, Hortacsu, and Syverson (2014). By measuring the influence of parent R&D on foreign-affiliate productivity growth, our results also contribute to research aimed at evaluating why affiliates of multinational firms are more productive and faster growing than unaffiliated firms in a given host country (Doms and Jensen 1998, Ramondo 2009, Guadalupe, Kozmina, and Thomas 2012, Branstetter and Drev 2014, National Science Board 2014). Specifically, our estimates suggest that the affiliate productivity and growth premium may be related, in part, to innovation investment by parent firms.

This latter observation implies a connection between our results and studies in which multinational activity influences the diffusion of ideas across countries (e.g. Branstter, Fisman, and Foley 2006, Branstetter 2006). Our estimates indicate building active agents and directed technology diffusion into models of international idea diffusion and growth (e.g. Eaton and Kortum 1996, 1999) may yield important insights regarding economic development and patterns of technological change across countries.

Finally, our focus on R&D investment and productivity change within large firms connects our work with research on innovation, firm size, and industry dynamics (Klepper and Graddy 1990, Cohen and Klepper 1992, 1996a,b, Klepper 1996, Klette and Kortum 2004), building on Schumpeter (1942). Our results confirm the positive relationship between R&D and productivity across firms emphasized by this literature. In addition, our estimates support the conjecture that a firm’s ability to share efficiency improvements across productive units increases its private return to
innovation investment (Nelson et al. 1967, Nordhaus 1969, Scherer 1970, Lunn 1982). In this, our estimates suggest that one explanation for multinationals’ nearly complete dominance of private R&D investment in the United States and other economies may be that innovation returns in such firms are, accordingly, substantially higher than those arising within single-plant firms.

The rest of the paper presents our theoretical and empirical analysis. We describe the data in Section 2, and develop a model of production and innovation investment within the multinational firm in Section 3. Section 4 derives our estimation framework from the model and describes how we apply it to evaluate the data. Sections 5, 6, and 7 describe the empirical results, and Section 8 concludes.

2 Data and Descriptive Statistics

Evaluating the link between innovation and productivity change in multinational firms requires measures of production inputs, output, and innovation for each location within the firm at different points in time. We describe these below.

2.1 U.S. Multinational Activity

We use confidential firm-level data on the operations of multinational firms from the Bureau of Economic Analysis (BEA) Survey of U.S. Direct Investment Abroad. These data provide detailed information on U.S. parent companies and each foreign affiliate on an annual basis. For our analysis, we assemble a new dataset combining both benchmark and annual survey responses covering firm operations in 84 countries for each year during 1989–2008. An important feature of the data for our analysis is its detailed information on production and innovation, including parent and affiliate-level R&D expenditures in each firm and year.

Because evaluating the impact of innovation on productivity requires estimating production functions, our empirical analysis proceeds at the industry level. We examine the activity of multi-

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10This survey is conducted by BEA for the purpose of producing publicly available aggregate statistics on the operations of U.S. multinational enterprises. Any U.S. person having direct or indirect ownership or control of 10 percent or more of the voting securities of an incorporated foreign business enterprise or an equivalent interest in an unincorporated foreign business enterprise at any time during the survey fiscal year in question is considered to have a foreign affiliate. However, for small affiliates that do not own another affiliate, parents report only a subset of items requested by the standard survey form. Foreign affiliates are required to report separately unless they are in the same firm, country, and three-digit industry. Each affiliate is considered to be incorporated where its physical assets are located.

11In benchmark years 1989, 1994, 1999, and 2004, the BEA’s data coverage is nearly complete: in a typical benchmark year, the survey accounts for over 99 percent of affiliate activity. In 1994, for example, participating affiliates accounted for an estimated 99.8 percent of total assets, 99.7 percent of total sales, and 99.9 percent of total U.S. FDI. This reflects the requirement of participation for every U.S. person having a foreign affiliate. Reporting requirements for the annual survey are less restrictive. In certain cases involving missing survey responses, the BEA data may instead report imputed values; these values are coded accordingly, and we exclude from our analysis all such observations. See Appendix A.5 for further details.

12R&D expenditure is not recorded for firms’ smallest, minority-owned foreign affiliates. Because our estimation below involves evaluating the impact of an affiliates’ own R&D on productivity change, in our baseline setting we restrict attention to majority-owned affiliates required to report R&D (Appendix A.5).
national firms separately in each of five major manufacturing industries: industrial machinery [SIC 35], electronics [SIC 36], instruments and devices [SIC 38], chemicals [SIC 28], and transportation equipment [SIC 37]. Each multinational firm is categorized based on the primary industry classification of its U.S. parent. Even within the same firm, productive tasks performed by foreign affiliates may differ from tasks performed by U.S. parent firms; in our estimation below we therefore follow an approach that flexibly allows for such differences between parent and affiliate operations.\textsuperscript{13}

The data include detailed affiliate-level information regarding production inputs, outputs, investment, innovation, trade within and outside the firm, and information regarding royalty payments and licensing fees; however, the data do not include a direct measure of material inputs. Table 1 provides a summary of value added, employment, physical capital, and innovation across the sample of firms, affiliates, countries, and industries used in our analysis.

\textit{Measuring Firm Innovation at the Affiliate Level}

We report statistics describing innovation expenditures within and across U.S. multinational firms in Tables 2 and 3.\textsuperscript{14} Our primary measure of parent and affiliate innovation is R&D investment, which is defined broadly by the survey, including expenditures on basic, applied, product, and process R&D; the measure excludes capital expenditures, routing testing and quality control, market research, and legal patent work, however, and is thus essentially a measure of expenditures on labor and materials used in innovation. While this rules out a model that explicitly distinguishes the efficiency impact of product innovation from that of process innovation as in Cohen and Klepper (1996b) and Dhingra (2013), we will adopt a model and estimation framework able to accommodate symmetrically both forms of innovation in sections 3 and 4 below.

It is important to note that, although the firm must report any research and development activity performed by each affiliate, this leaves open the possibility that an affiliate either a) performs R&D paid for by another firm or affiliate, or b) performs and pays for R&D on behalf of another firm or affiliate. Data from the benchmark-year surveys indicate neither a) nor b) is commonly observed. In 2004, for example, 96 percent of the R&D performed by affiliates was also paid for by the performing affiliate. Of the R&D performed by affiliates, 83 percent was for the performing affiliate’s own account, 14 percent was for another affiliate of the same firm, and only 3 percent was for an unaffiliated firm (U.S. Bureau of Economic Analysis 2008). Accordingly, the model in section 3 below considers the case in which each affiliate location in a firm performs and pays for its own R&D, while the technological knowledge resulting from R&D may be shared across locations.

\textsuperscript{13}At the affiliate level, in all specifications, we exclude from the sample imputed values and small or minority-owned affiliates for which only limited information is reported. We also exclude non-manufacturing affiliates in agriculture, mining, construction, transportation and public utilities, finance, insurance, and real estate, services, and health services for which the mechanism linking R&D investment and plant productivity is unclear. Additional details appear in Appendix A.5.

\textsuperscript{14}These statistics pertain to U.S. firms and their foreign affiliate operations in 1994. The 1994 benchmark-year survey is exceptionally comprehensive in its innovation measures, with all U.S. parent firms reporting R&D regardless of size, and all foreign affiliates above a low size threshold of $3 million reporting R&D; this period therefore provides an unusually complete representation of activity corresponding to the universe of U.S.-based multinational firms in 1994.
in the same firm.

2.2 Patterns of Innovation Within the Firm

Several strong patterns emerge from descriptive observation of the data corresponding to each industry. It is clear from Table 2 that almost all multinational firms invest in R&D, and also that nearly all firms' innovation investment involves expenditures by the U.S. parent operation. In the industrial machinery sector, for example, 90 percent of firms invest in innovation, and of these firms, over 99 percent innovate with the involvement of the U.S. parent (Table 2, column 1). However, foreign affiliates participate in innovation investment in only approximately half of firms; in the industrial machinery sector, 45 percent of firms report R&D investment by at least one foreign affiliate. Third, the average multinational firm reports R&D participation by only the minority of its foreign affiliates, with, for example, just 24 percent of affiliates in industrial machinery performing R&D. Accordingly, the R&D intensity (R&D/sales ratio) for the average U.S. parent operation is higher than that of its overall foreign-affiliate operations; in industrial machinery, the parent is on average 8.4 times as R&D intensive as foreign affiliates. This indicates innovation activity is substantially less dispersed across locations than production in multinational firms, with parents investing disproportionately in R&D.

Firms’ offshore R&D performance does, however, vary substantially across firms. On average, Table 3 indicates a firm’s foreign affiliates account for between 10 and 13 percent of its global R&D expenditures, but the standard deviation ranges between 19 and 21 percentage points, and the shape of the distribution is such that the 95th percentile firm locates the majority of its global R&D investment within offshore affiliates.

That firms fragment innovation across countries to any extent suggests the presence of frictions limiting the communication of technical knowledge across countries (e.g. Arrow 1962, 1969), however, the sharp differences between observed parent and affiliate R&D participation and the high degree of R&D concentration relative to production concentration is consistent with our estimates below indicating firms’ innovation decisions may involve intrafirm transfer of knowledge. Data on intrafirm royalty and license payments also strongly suggest parent firms are sharing technology with foreign affiliates, while affiliates share relatively less with parents: among manufacturing firms in 2004, aggregate royalty and license fees for the use of intangible intellectual property paid by foreign affiliates to U.S. parents within multinationals were nine to ten times higher than payments in the reverse direction (U.S. Bureau of Economic Analysis 2008).

Statistics reported in Table 3 further indicate U.S. multinationals concentrate a large share of foreign production and innovation in a relatively narrow set of countries. The United Kingdom and Mexico are among the top five locations for U.S. firms’ employment abroad in each of the industries considered here, followed closely by Canada and Germany; Brazil, France, Japan, and Malaysia also account for a large share of firms’ offshore employment. Germany and France are also the most important offshore R&D locations for U.S.-based firms, followed by the United Kingdom, Canada, and Japan; Belgium, Brazil, Ireland, and Singapore are also within the top-five R&D locations for
at least one industry.$^{15}$

3 Theory

We develop a simple model of endogenous R&D investment and productivity change within the multinational firm. For each production site, the firm makes optimal production and innovation decisions based on the costs and expected gains from each activity at that site. Innovation investment may influence the stochastic process governing productivity evolution both at the R&D site and other production sites within the innovating firm. Importantly, the model provides explicit estimating equations that enable us to recover technology parameters determining the firm-wide return to innovation in sections 4 and 5 below.

3.1 Setup

A multinational firm is composed of a parent operation and one or more affiliates located in other countries. Multinational firms are indexed by $i = 0, 1, \ldots, I$, and the affiliates of firm $i$ are indexed by $j = 0, 1, \ldots, J_i$ during period $t$; for each firm $i$, the index 0 corresponds to the parent, while $j = 1, \ldots, J_i$ correspond to its foreign affiliates. We assume that each affiliate of firm $i$ manufactures and sells its output in a single market, defined as a country-sector pair. Markets are indexed by $n = 1, \ldots, N$.

Each multinational firm $i$ makes parent- and affiliate-specific investment decisions in physical capital and in knowledge through R&D investment. The firm also determines the amount of labor to be used in production at each location. We assume these investment and production decisions are made in discrete time by the firm with the goal of maximizing the firm-wide expected net present value of future cash flows.

To flexibly capture differences between parent and subsidiary operations, in what follows we allow all structural parameters to differ between the parent and its affiliates abroad. This is consistent with models of the multinational firm in which parents and affiliates perform distinct production tasks (e.g. Helpman 1984). We assume for simplicity that all affiliates in the firm share identical structural parameters, but allow relevant input and output prices firms face to differ across markets.$^{16}$

$^{15}$A U.S. multinational’s decision to perform R&D in a foreign country may be influenced by investment conditions abroad including the corporate tax rate and opportunities for R&D tax incentives (see, for example, Hines 1994, 1995). In the data, we find a low correlation of between -4 and 4 percent across FDI host countries between affiliate R&D investment and the corporate tax rate incidence; nevertheless, our estimation framework below includes country-year fixed effects that capture local factors—including corporate tax rates and policy incentives—that may influence the productivity evolution of affiliates independently of the R&D decision.

$^{16}$The assumption that firm affiliates share structural parameters is appropriate among affiliates engaged in similar production tasks, and thus has implications for estimation and data construction that are discussed below in section 4.
3.2 Production

During period $t$, firm $i$’s affiliate $j$ combines inputs to create value added $Q_{ijt}$ according to the following production technology

$$ Q_{ijt} = H(L_{ijt}, K_{ijt}; \alpha)^{1-\alpha_m} M_{ijt}^{\alpha_m} \Omega_{ijt}, \quad (1) $$

where

$$ H(L_{ijt}, K_{ijt}) = \exp[h(l_{ijt}, k_{ijt}; \alpha)], $$

$$ h(l_{ijt}, k_{ijt}; \alpha) = \alpha l_{ijt} + \alpha k_{ijt} + \alpha l_{ijt}^2 + \alpha k_{ijt}^2 + \alpha l_{ijt} k_{ijt}. $$

In (1) above, $Q_{ijt}$ is total output, $L_{ijt}$ is the number of workers, $K_{ijt}$ is effective units of capital, $M_{ijt}$ is materials, and $\Omega_{ijt}$ denotes the physical productivity of firm $i$’s affiliate $j$ during period $t$.\(^{17}\) An advantage of the translog production function $H$ specified above is its flexibility: output elasticities may vary across sites and over time within a firm, even under identical production coefficients $\alpha$. This flexibility is important in our setting because the affiliates of a given multinational may operate across countries with different factor-market conditions, and may thus differ in the optimal relative usage of labor and capital in production.\(^{18}\)

We assume parent and affiliate operations face perfectly elastic supplies of labor and investment goods, independently of the respective markets $n$ in which they operate. Equilibrium input prices of labor $P_{nt}^l$ and capital $P_{nt}^k$ may differ across markets $n$ and time periods $t$. To keep the notation simple below, we omit the firm index $i$ and use lower-case letters to denote the logarithm of the corresponding upper-case variable.

3.3 Demand

Firm $i$’s affiliate $j$ faces the following demand function at period $t$

$$ q_{jt} = q_{nt} - \sigma p_{jt} + \sigma p_{nt} + (\sigma - 1) \xi_{jt}, \quad (2) $$

where $\sigma > 1$ is the elasticity of substitution across varieties, $n$ is the country-sector market in which affiliate $j$ is located, $p_{jt}$ is the log output price set by affiliate $j$ of firm $i$ at $t$, and $\xi_{jt}$ is a

\(^{17}\)As stated above, the parameter vector $\alpha$ corresponding to the parent firm ($j = 0$) may differ from that corresponding to its foreign affiliates ($j \neq 0$).

\(^{18}\)The assumption that the elasticity of substitution between materials and the joint output of labor and capital is equal to one is driven by data availability. Because affiliate materials use is not observed in the data, we cannot identify the parameters of a production function that is translog in labor, capital and materials. In Section 7, we use available data on consumption of materials supplied by the parent company and generalize the production function as $q_{jt} = (1 - \alpha_m)h(l_{jt}, k_{jt}, a_{jt}; \alpha) + \alpha_m m_{jt} + \omega_{jt}$, where $a_{jt}$ denotes consumption of materials supplied by the parent, $h(l_{jt}, k_{jt}, a_{jt})$ is translog in labor, capital, and materials supplied by the parent company and, abusing of notation, we use $m_{jt}$ exclusively to denote the log use of materials supplied by third-party firms.
demand shock that is unobserved to the econometrician but known to the firm when making its input and output choices at period $t$. Market-level variables $p_{nt}$ and $q_{nt}$ denote the log of the price index and total demand for firms operating in market $n$. Reliable data on aggregate consumption and average prices by sector-country for the large set of countries and years in our dataset is not available. Consequently, in our empirical exercise, we treat both $p_{nt}$ and $q_{nt}$ as variables observed to the firm but not to us.\footnote{In Section 7, we replicate our estimation using data on aggregate consumption and prices for a subset of host countries to proxy for $p_{nt}$ and $q_{nt}$ as an alternative to this approach.} We assume U.S. parent firms also face a demand function of the form in (2) above, allowing for differences in the demand elasticity $\sigma$ and market-specific parameters.

### 3.4 Revenue and Value Added

We use $Y_{jt}$ to denote the total revenue of affiliate $j$ during period $t$, $Y_{jt} = P_{jt}Q_{jt}$. Given the production and demand functions described in Sections 3.2 and 3.3, the revenue function is

$$y_{jt} = p_{nt} + q_{nt}/\sigma + \sigma^{-1}\left[(1 - \alpha_m)h(l_{jt}, k_{jt}; \alpha) + \alpha_m m_{jt} + \psi_{jt}\right].$$

where $\psi_{jt}$ is the sum of the productivity term and the demand shock, $\psi_{jt} = \omega_{jt} + \xi_{jt}$. As described in Section 2, we do not directly observe total usage of material inputs by firm affiliates in the data. However, assuming firms optimally determine the amount of materials used in production by each affiliate $j$ in every period $t$ by maximizing the static profits of $j$ at $t$, we can rewrite $y_{jt}$ as

$$y_{jt} = \kappa_{nt}^1 + h(l_{jt}, k_{jt}; \beta) + \kappa_{nt}^2 \psi_{jt},$$

(3)

where $\kappa_{nt}^1$ is a function of the parameters $\alpha_m$ and $\sigma$, the price of materials, the output price, and total expenditure in market $n$ at period $t$. In addition, $\beta = \alpha \kappa_2(1 - \alpha_m)$, and\footnote{Given that $\sigma > 1$ and $0 < \alpha_m < 1$, $0 < \kappa_2(1 - \alpha_m) < 1$ and, therefore, the parameters of the revenue function, $\beta$, are always smaller in absolute value that the parameters of the production function $\alpha$.} $\kappa_2 = (\sigma - 1)/(\sigma - \alpha_m(\sigma - 1))$.

The term $\kappa_{nt}^2 \psi_{jt}$ denotes affiliate $j$’s period-$t$ revenue productivity. Similarly, defining the value added function as $va_{jt} = y_{jt} - p_{nt}^m - m_{jt}^*$, where $m_{jt}^*$ denotes the optimal consumption of materials, we derive an expression for affiliate-level value added $va_{jt}$ as

$$va_{jt} = \kappa_{nt}^3 + h(l_{jt}, k_{jt}; \beta) + \kappa_{nt}^2 \psi_{jt},$$

(4)

where $\kappa_{nt}^3$ is defined in Appendix A.1.\footnote{See Appendix A.1 for additional details on how to derive the production and value-added functions.}

As we show in Section 6 below, in order to compute the returns to R&D, it is enough to know the revenue function parameter vector $\beta$. It is not necessary to know the production function parameter $\alpha$. As is immediate from equations (3) and (4), we may either use information on revenue or on
value added, together with information on labor and capital usage, to identify \( \beta \).

### 3.5 The Productivity Process

The revenue productivity \( \psi_{jt} \) of foreign affiliate \( j \) is assumed to evolve over time according to the following stochastic process

\[
\psi_{jt} = \psi_{jt-1}^e + \eta_{jt},
\]

with

\[
\psi_{jt-1}^e = (1 - d_{jt-1})(\mu_{1nt} + \rho_1\psi_{jt-1}) + d_{jt-1}(\mu_{2nt} + \rho_2\psi_{jt-1}) + g(r_{jt-1}, r_{0t-1}; \mu_r),
\]

where \( r_{jt-1} \) is the R&D expenditure of foreign affiliate \( j \), \( r_{0t-1} \) is the R&D expenditure of firm \( i \)'s parent \( j = 0 \), and \( r_{-jt-1} \) is the total R&D investment across firm-\( i \) foreign affiliates other than \( j \) at period \( t - 1 \). The dummy variable \( d_{jt-1} = 1 \{ R_{jt-1} > 0 \} \) takes the value 1 if firm \( i \)'s affiliate \( j \) performs a positive amount of R&D during period \( t - 1 \), and is zero otherwise. We estimate several variants of the model, but assume in our baseline setting that the function capturing the impact of R&D levels on productivity change \( g(\cdot) \) is defined as follows

\[
g(r_{jt-1}, r_{0t-1}; \mu_r) = \mu_a r_{jt-1} + \mu_p r_{0t-1}.\]

Notice that the specification in equation (5) is consistent with investment in R&D having both an *expected* impact on productivity, as captured by the \( \psi_{jt}^e \), and an *unexpected* impact that is accounted for by the term \( \eta_{jt} \), the productivity innovation. This productivity innovation captures exogenous temporary changes in the economic environment that affect the production process of a firm (e.g., weather conditions, strikes) as well as uncertainties inherent to the R&D process. We assume \( \eta_{jt} \) is mean independent of \( \psi_{jt-1} \), and is also mean independent of the R&D investment by both the parent and affiliate \( j \) at \( t - 1 \). However, we allow \( \eta_{jt} \) to be correlated both across affiliates \( j \) and between affiliates and the parent firm of the same firm \( i \).

Equation (6) incorporates a very flexible characterization of the expected impact of R&D on productivity. First, through the parameters \( \mu_{1nt} \) and \( \mu_{2nt} \), (6) accounts for the possibility that the impact of doing a positive amount of R&D on productivity, relative to those firms that adopt the corner solution of zero R&D, varies across sectors, countries and years. Given an amount of R&D investment, the expected impact of such investment on productivity might differ across countries (e.g., in certain countries, weak patent laws might allow the firm to only partially appropriate the returns to R&D investment; similarly, differences in the relative supply of skilled workers across countries may induce differences in variable R&D costs), sectors (e.g., differences in the cost of raising capital across sectors may translate into differences in the cost of R&D investment), and years. Second, through the parameters \( \rho_1 \) and \( \rho_2 \), equation (6) allows for a different evolution of productivity \( \psi_{jt} \) when affiliate \( j \) adopts the corner solution of zero R&D and when it chooses a
positive R&D level. This explicitly accounts for the possibility that innovative firms have productivity shocks that are more or less persistent than non-innovating firms.\footnote{According to the specification in equation (6), the effect of R&D investment on productivity exclusively depends on a binary variable capturing whether an affiliate does any investment in R&D at all. In Section 7, we generalize this specification and allow for interactions between lagged productivity and lagged R&D investment. Besides, we also allow the revenue productivity of an affiliate at \( t \) to depend on the lagged revenue productivity squared.} Third, the specification in equation (6) accounts for the possibility that affiliate \( j \)'s expected productivity change depends not only on its own R&D expenditure \( r_{jt-1} \), but also on the R&D investment \( r_{0t-1} \) of its parent firm. While (6) assumes the impact of parent R&D investment on affiliate productivity change is symmetric to that of the affiliate’s own innovation investment, the magnitude of these two effects may differ.\footnote{In Section 7 we generalize the relationship between affiliates’ productivity and their parents’ investment in R&D. Specifically, we allow affiliates’ productivity at some period \( t \) to depend not only on the R&D investment performed by the parent firm in period \( t-1 \) as posited in equation (6), but also on the aggregate R&D expenditure performed by the parent during the previous 3 or 5 years, and on the revenue productivity level of the parent, \( \psi_{0t} \).}

We assume that parents’ revenue productivity follow an stochastic process similar to that in equations (5) and (6):

\[
\psi_{0t} = \psi_{0t-1} + \eta_{0t},
\]  

(7)

with

\[
\psi_{0t-1} = \mu_{02t} + \rho_{02}e_{0t-1} + \mu_{0p}r_{0t-1}.
\]  

(8)

Note that we have introduced two asymmetries between parent and affiliates specification of the expected innovation in productivity \( \psi_{0}^{e} \). First, equation (8) assumes that parent firms perform a positive amount of R&D in every time period. Second, equation (6) allows innovation investment by the parent firm to potentially affect the evolution of foreign-affiliate productivity, while affiliate R&D does not impact the productivity of U.S. parent firms. Both characterizations are strongly consistent with the data, as our estimates based on alternative and more flexible forms of equations 5 through 8 indicate in Section 5 below.

### 3.6 Firm Optimization

For every period \( t \), each firm \( i \) determines its optimal levels of employment, physical capital investment, R&D investment, and material input use both for the parent company and its foreign affiliates \( j = 1, \ldots, J_{i} \). These decisions are taken after innovations to revenue productivity \( \eta_{jt} \) have been realized for every affiliate within the multinational firm \( i \). The Bellman equation associated
with firm $i$’s dynamic optimization problem is, accordingly,

$$V(S_{it}) = \max_{I_{it}, L_{it}, M_{it}, R_{it}} \sum_{j \in J_{it}} \left\{ \Pi(S_{jt}, I_{jt}, L_{jt}, M_{jt}) + \delta \mathbb{E}[V(S_{jt+1})|S_{jt}, I_{jt}, R_{it}] \right\}$$

(9)

where $\Pi(\cdot)$ is the profit function, $V(\cdot)$ is the value function, $\delta$ is the discount factor, and $S_{it}$ is the state vector for firm $i$. We define $S_{it} = (S_{0t}, S_{1t}, \ldots, S_{J_{it}t})$ with

$$S_{jt} = (\psi_{jt}, Q_{nt}, P_{nt}^l, P_{nt}^m, P_{nt}^k, K_{jt}),$$

for every $j = 0, \ldots, J_{it}$. The choice variables are investment in physical capital $I_{it}$, number of workers employed $L_{it}$, amount of material inputs $M_{it}$, and the level of R&D expenditure $R_{it}$.\(^{24}\)

The profit function of firm $i$’s affiliate $j$ at period $t$ in equation (9) above is

$$\Pi(s_{jt}) = Y_{jt} - P_{nt}^l L_{jt} - P_{nt}^m M_{jt} - C_k(P_{nt}^k, I_{jt}, K_{jt}) - C_r(R_{jt}),$$

(10)

where $C_k$ and $C_r$ are flexible cost functions of investment in physical capital and knowledge. Knowing the exact functional forms for $C_k$ and $C_r$ is important for determining the optimal capital and innovation investment for firm $i$’s affiliate $j$. These cost functions are, however, not observable in practice. An advantage of our estimation approach is therefore that it does not require explicit functional forms for $C_k$ or $C_r$, provided that there exist some functions $C_k$ and $C_r$ that rationalize firms’ observed investments in capital and R&D in the data.\(^{25}\)

We assume labor and materials are both fully flexible (static) inputs. Conversely, physical capital at period $t$ is determined by investment in physical capital in all periods previous to $t$ according to the following law of motion

$$K_{jt} = \delta K_{jt-1} + I_{jt}.$$  

### 4 Empirical Strategy

We apply the structure introduced in Section 3 to derive an estimating equation that depends exclusively on observed choice variables $(L_{it}, K_{it}, R_{it})$ and parameters of interest. In what follows, we present results using value added as our preferred measure of output.\(^{26}\)

Allowing for measurement error in the observed measure of value added, we can generalize the

\(^{24}\)In Section 7, we generalize our estimation procedure to account for the fact that multinational firms also optimally choose the set of affiliates $J_{jt}$ in every period $t$ as a function of the state vector $S_{jt}$.

\(^{25}\)For example, costs for each investment could simply be linear $C_k(P_{nt}^k, I_{jt}, K_{jt}) = P_{nt}^k I_{jt}$ and $C_r(R_{jt}) = R_{jt}$. However, in practice, the cost of buying $I_{jt}$ effective units of capital is likely to be heterogeneous across firms due to financial frictions (Midrigan and Xu 2012) or adjustments costs of capital. Similarly, the cost of investing a fixed amount of dollars into R&D is also likely to differ across firms due to grants, subsidized loans or tax credits.

\(^{26}\)In unreported results, we replicate our empirical analysis using affiliate-level sales revenues as an alternative measure of output.
ing equation (11) with equations (5) and (8), we obtain the following baseline estimating equation

\[ va_{jt} = \kappa_{nt}^3 + h(l_{jt}, k_{jt}; \beta) + \kappa^2 \psi_{jt} + \varepsilon_{jt}, \]  

(11)

where \( \varepsilon_{jt} \) captures measurement error, and we assume that \( \mathbb{E}[\varepsilon_{jt}|S_{js}, L_{js}] = 0 \), for any \( s \).\(^{27}\) Combining equation (11) with equations (5) and (8), we obtain the following baseline estimating equation

\[ va_{jt} = h(l_{jt}, k_{jt}; \beta) + (1 - d_{jt-1})[\gamma_{1nt} + \rho_1(va_{jt-1} - h[l_{jt-1}, k_{jt-1}; \beta])] + \\
\[ d_{jt-1}[\gamma_{2nt} + \rho_2(va_{jt-1} - h[l_{jt-1}, k_{jt-1}; \beta])] + \gamma_a r_{jt-1} + \gamma_p r_{0t-1} + u_{jt} \]  

(12)

where \( \gamma_a = \kappa^2 \mu_a, \gamma_p = \kappa^2 \mu_p, \gamma_{1nt} = \kappa^2 \mu_{1nt} + \kappa^3 \mu_{nt} - \rho_1 \kappa^3_{nt-1}, \gamma_{2nt} = \kappa^2 \mu_{2nt} + \kappa^3 \mu_{nt} - \rho_2 \kappa^3_{nt-1} \), and

\[ u_{jt} = \kappa^2 \eta_{jt} + \varepsilon_{jt} - \rho_1(1 - d_{jt-1})\varepsilon_{jt-1} - \rho_2 d_{jt-1}\varepsilon_{jt-1}. \]

The parameters \( \gamma_a \) and \( \gamma_p \) capture the elasticities of revenue productivity with respect to R&D investment by affiliate \( j \) and its parent, respectively. The market-year fixed effects \( \mu_{1nt} \) and \( \mu_{2nt} \) capture both the unobserved quantity and price indices (embedded in the terms \( \kappa^3_{nt} \) and \( \kappa^3_{nt-1} \)) as well as the market-year specific changes in revenue productivity, \( \mu_{1nt} \) and \( \mu_{2nt} \). Finally, the unobserved component \( u_{jt} \) captures both the shock to revenue productivity \( \kappa^2 \eta_{jt} \) as well as lagged and current values of the measurement error.

The complete parameter vector we estimate is \( (\beta, \rho_1, \rho_2, \gamma_r, \{\mu_{1nt}\}, \{\mu_{2nt}\}, \beta_{kk}, \beta_{lk}) \) captures parameters of the value added function, and, for \( x = 1, 2, \{\mu_{xnt}\} \) denotes the set of effects \( \mu_{xnt} \) for every \( nt \) pair in which there is at least one observation identifying such effect. Estimating this set of parameters using nonlinear least squares (NLS) in equation (12) will result in biased estimates unless we assume that labor is predetermined (i.e. \( l_{jt} \) is determined at period \( t - 1 \), before \( \eta_{jt} \) is realized) and value added is measured without error (i.e. \( \varepsilon_{jt-1} = 0 \)).\(^{28}\)

If the amount of labor hired by firm \( j \) at period \( t \) is at least partially determined after productivity innovations have been observed by firm \( i \), then \( l_{jt} \) will be correlated with \( \eta_{jt} \) and this will give rise to an endogeneity issue known as transmission bias (e.g., Griliches and Mairesse 1998). Similarly, if our measures of value added suffer from classical measurement error, \( va_{jt-1} \) will be correlated with \( \varepsilon_{jt-1} = 0 \) and this will generate the standard attenuation bias. In order to simultaneously address the potential problems of transmission bias and attenuation bias, we estimate the parameters of interest in two steps (see Gandhi, Navarro, and Rivers 2013). In the first step, we exploit information about the production function that is contained in the firms’ first order condition for labor. This allows us to recover consistent estimates of \( (\beta_l, \beta_{ll}, \beta_{lk}) \) and an structural proxy for \( \varepsilon_{jt} \) for every period \( t \). In the second step, conditional on these first stage estimates, we estimate \( (\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_r, \{\gamma_{1nt}\}, \{\gamma_{2nt}\}) \). Specifically, in this second step, we first apply the Frisch-Waugh-Lovell theorem to control for the fixed effects \( (\{\gamma_{1nt}\}, \{\gamma_{2nt}\}) \) and then use NLS to estimate \( (\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p) \). Additional estimation details appear in Appendix A.2.

\(^{27}\)In an abuse of notation, we use \( va_{jt} \) to denote both the theoretical and the observe (log of) value added of firm \( j \) at \( t \).

\(^{28}\)We impose these assumption in Section 7.
5 Estimation Results

5.1 Affiliate-Level Results

Tables 4 through 8 report estimates of the affiliate-level production function and the Markov process that determines productivity evolution for multinational affiliates in each of the five industries described in section 2; estimates corresponding to the productivity evolution of U.S. parent firms in each industry appear in Table 9. All estimates of equation (12) in Tables 4 through 9 result from the two-step procedure described in section 4 above.

Estimates corresponding to the industrial machinery sector appear in Table 4. The simplest specification, appearing in column 1, evaluates the impact of an affiliate’s own R&D expenditure on its productivity evolution without considering the potential effects of R&D performed elsewhere within the firm. Specifically, in column 1 we define the function capturing the impact of R&D investment on affiliate productivity change, \( g(r_{jt-1}, r_{0t-1}, r_{jt-1}; \gamma_r) \) in (12), as follows

\[
g(r_{jt-1}, r_{0t-1}; \gamma_r) = \gamma_a r_{jt-1}. \tag{13}
\]

The estimates in column 1 reveal two important effects of affiliate-level R&D. First, \( \gamma_a \) is positive and highly significant (\( \hat{\gamma}_a = 0.0122 \), standard error = 0.0030), indicating that an affiliate’s lagged R&D investment increases its productivity change, on average. Second, the persistence of an affiliate’s productivity level also depends on whether the affiliate performs R&D: the productivity of affiliates that perform any R&D \( (d_{jt-1} \equiv 1\{R_{jt-1} > 0\} = 1 \) in (15) above) decays over time significantly more rapidly than the productivity of affiliates not performing R&D \( (\hat{\rho}_2 = 0.7121 < 0.7666 = \hat{\rho}_1) \). This result is consistent with the idea that higher innovation levels increase the rate at which knowledge and technology obsolesce.\(^{29}\) The production function coefficients \( \beta \) also indicate the importance of both labor and capital inputs as determinants of affiliate output levels. Table 4 describes the input elasticities implied by \( \hat{\beta} \) given the sample distribution of labor and capital as described in Table 1; the estimated labor elasticity is 0.51, while estimates range between 0.15 and 0.17 for capital inputs.

Notice that all specifications in Table 4 include country-year fixed effects that absorb differences across locations and over time in affiliate productivity growth, as well as sector-year fixed effects that account for differences in productivity change across affiliates due to cross-affiliate differences in industrial composition within the parent-firm industry. Both sets of fixed effects are interacted with \( d_{jt} \equiv 1\{R_{jt} > 0\} \) as indicated in section 4. These fixed effects are important if, for example, some affiliates grow quickly due to unobserved local conditions such as institutions or other growth-enhancing amenities that are more likely to be present where affiliates tend to perform R&D (e.g. in highly-developed countries that have strong intellectual property protection and abundant skilled

\(^{29}\)For example, Bilir (2014) finds a negative correlation across industries between R&D intensity (the ratio of R&D to sales) and the average length of product lifecycles, which reflect technology obsolescence rates among U.S. patents. Doraszelski and Jaumandreu (2013) also finds evidence of higher knowledge persistence among non-R&D performing plants than among R&D performers.
labor); the interpretation of the R&D estimates \( \gamma_r \) would be unclear in the absence of these effects.

Columns 2 through 4 summarize estimation results for specifications evaluating the productivity impact of R&D performed not only by an affiliate \( j \), but also by its U.S. parent. The results in column 2 specify

\[
g(r_{jt-1}, r_{0t-1}; \gamma_r) = \gamma_a r_{jt-1} + \gamma_p r_{0t-1}
\]

and the estimates indicate that both affiliate R&D and U.S. parent R&D are important sources of productivity gains among its foreign affiliates (\( \hat{\gamma}_p = 0.0107 \), standard error = 0.0018). The estimated magnitudes \( \hat{\gamma}_p \) and \( \hat{\gamma}_a \) indicate that for the average affiliate, parent R&D generates gains per dollar of expenditure that comparable but slightly smaller than the productivity gain resulting from an affiliate’s own R&D investment. These estimates are consistent with the presence of knowledge frictions that limit firms’ ability to transmit parent knowledge to distant affiliates (e.g. Arrow 1962, 1969).

Because it is not obvious that the full impact of parent innovation occurs within a year, in columns 3 and 4 we consider an alternative timing assumption by allowing parent R&D investment summed over the previous five years to influence affiliate productivity evolution,

\[
g(r_{jt-1}, r_{0t-1-5}; \gamma_r) = \gamma_a r_{jt-1} + \gamma_p r_{0t-1-5},
\]

where \( r_{0t-1-5} = \log(\sum_{s=t-5}^{t-1} R_{0s}) \). This approach is conceptually related to Griliches (1979), but our aim is not to build a stock of knowledge capital, but rather to allow for the possibility that the impact of R&D may be realized multiple years after it is performed. The estimates in column 3 indicates that long-term parent innovation is not only statistically important, but also has a larger impact on affiliate productivity than last-period R&D considered in column 2 (\( \hat{\gamma}_{p5} = 0.0183 \), standard error = 0.0024). Putting the two into one specification in column 4, we find, moreover, that last-period parent R&D investment \( r_{0t-1} \) is statistically negligible while the five-year total \( r_{0t-1-5} \) is highly significant.

Affiliates may also benefit from the R&D investment by other foreign affiliates. Column 5 therefore evaluates the following specification

\[
g(r_{jt-1}, r_{0t-1-5}; \gamma_r) = \gamma_a r_{jt-1} + \gamma_p r_{0t-1-5} + \gamma_o r_{-jt-1}
\]

where \( r_{-jt-1} \) reflects the sum of R&D performed by all foreign affiliates other than \( j \) in the same multinational firm as \( j \). These estimates reveal that affiliate productivity is not on average significantly influenced by other subsidiaries’ innovation (\( \hat{\gamma}_o = -0.0007 \), standard error = 0.0010). Nevertheless, the impact of an affiliate’s own innovation on its productivity change remains stable and significant across each specification.

Table 5 presents analogous estimates to those presented in Table 4 for the electronics industry. The estimates in columns 1 through 5 again reveal several qualitatively and quantitatively important effects of R&D on affiliate-level productivity change. First, the marginal contribution of an affiliate’s own R&D, as captured by \( \gamma_a \), is positive and highly significant across all specifications (\( \hat{\gamma}_a = 0.0083 \),
standard error = 0.0029 in column 1, for example) but is only about two-thirds as large as the output elasticity among industrial machinery firms. However, as in the industrial machinery sector, an affiliate’s productivity persistence depends on whether the affiliate performs R&D: the productivity of affiliates that perform any R&D \( d_{jt} = 1 \{ R_{jt} > 0 \} = 1 \) in (15) above decays over time more rapidly than the productivity of affiliates not performing R&D \( (\hat{\rho}_2 = 0.752 < 0.728 = \hat{\rho}_1) \). The production function coefficients \( \beta \) again indicate the importance of both labor and capital inputs as determinants of affiliate output levels; the input elasticities implied by \( \hat{\beta} \) given the sample distribution of labor and capital as described in Table 1 are 0.49 for labor and between 0.20 and 0.22 for capital inputs.

The estimates in columns 2 through 4 also indicate the importance of parent R&D investment. As in Table 4, the estimates suggest parent innovation pays off over multiple years: in column 4, the estimated impact of innovation investment over the past five years is large and statistically significant \( (\hat{\gamma}_{p5} = 0.0191, \text{ standard error} = 0.0044) \), dominating the impact of last-period parent innovation. By contrast, column 4 indicates that when parent and other-affiliate R&D are both included in the complete specification, only parent R&D is important; the estimated impact of other-affiliate R&D \( \hat{\gamma}_o \) is not distinguishable from zero. Notice also that, in contrast to the industrial machinery sector estimates in Table 4, the marginal impact of an affiliate’s own R&D in the previous period is slightly smaller than that of its parent’s last-period R&D investment.

Qualitatively, these results are confirmed in Tables 6, 7, and 8, which consider the productivity evolution of foreign-affiliates in the chemical, instruments and devices, and transportation equipment industries, respectively. In each of these three industries, \( \hat{\gamma}_a \) coefficients across all columns indicate a highly significant impact of an affiliate’s R&D investment on its own productivity change. The estimated elasticity is substantially higher in the chemical industry \( (\hat{\gamma}_a = 0.026) \) than in transportation equipment or instruments and devices \( (\hat{\gamma}_a = 0.007) \). An affiliate’s R&D investment also has a significant impact on productivity persistence \( (\hat{\rho}_2 < \hat{\rho}_1) \). The estimates in columns 2 through 4 further indicate that, on average, an affiliate’s U.S. parent R&D investment is an important determinant of its productivity change; with the exception of the chemical industry, parent R&D has a durable impact on affiliate productivity change \( (\hat{\gamma}_{p5} > \hat{\gamma}_p) \). By contrast, investment in R&D by other affiliates in the same firm does not have a significant impact on affiliate-level productivity evolution, with the exception of the chemical sector (Table 7, column 5).

Taken together, Tables 4 through 8 provide evidence that, across this set of five major manufacturing industries, there exists a systematic positive relationship between R&D investment and affiliate-level productivity change. For a given affiliate \( j \), innovation investments by affiliate \( j \) and its U.S. parent significantly increase affiliate \( j \)’s productivity growth. As has been hypothesized by a wide existing literature on the multinational firm (e.g. Helpman 1984), these results are strongly consistent with a multinational firm model in which centrally-developed knowledge is shared with distant production affiliates. This has implications for evaluating the firm-wide returns to innovation that we describe below. In addition, our estimates further reveal the importance of affiliates’ own R&D investment, which has not been emphasized by this literature.
5.2 U.S. Parent-Level Results

Table 9 evaluates the impact of R&D investment on U.S. parent productivity for firms corresponding to the foreign affiliates evaluated in Tables 4 through 8. We evaluate parent-level analogues of (12), in which innovation investment impacts parent productivity change through the following function

\[ g(r_{0t-1}, r_{Jt-1}; \gamma_0^p) = \gamma_0^p r_{0t-1} + \gamma_0^a r_{Jt-1}, \]  

(17)

as indicated in equations (7) and (8), where \( r_{0t-1} \) is the parent’s own R&D investment and \( r_{Jt-1} \) captures the sum of R&D expenditures across all foreign affiliates of the parent. Columns 1 and 2 consider the industrial machinery sector. Column 1, which includes only parent R&D, indicates that a parent’s R&D investment has a positive and highly significant impact on its own productivity evolution (\( \hat{\gamma}_p^0 = .0340 \), standard error = .0030). This elasticity of value added with respect to R&D is approximately three times larger than that observed for the impact of R&D — parent or affiliate — on foreign-affiliate level productivity change in the chemical industry (Table 4, column 2). However, column 2 indicates that foreign affiliate R&D does not contribute significantly to the evolution of U.S. parent productivity. This qualitative pattern regarding R&D and parent productivity is upheld across all industries in Table 9 columns 3 through 10. As in Tables 4 through 8 above, these results indicate innovation has a larger impact at the performing site than at other sites within the same firm, consistent with communication frictions or firms in which parents and affiliates perform distinct innovation and production tasks.

6 The Firm-Level Return to Innovation

In this section, we compute the estimated return to R&D investment by U.S. parent firms and foreign affiliates using two approaches. First, in Section 6.1 we determine the elasticity of parent and affiliate productivity with respect to a marginal increase in R&D investment. Second, in Section 6.2 we complement this approach by evaluating the impact of a marginal increase in R&D investment on firm-wide value, the expected discounted sum of future cash flows. The results appear in Section 6.3.

6.1 The Productivity Impact of R&D

Parent firms in our estimation dataset perform R&D in every period. Accordingly, we compute the impact of an infinitesimal increase in parent R&D investment on parents’ expected revenue productivity under the assumption that parents are always innovating. Given the evolution of revenue productivity as described in equations (7) and (8), the effect of a marginal increase in R&D investment in the parent firm at period \( t - 1 \) on the expected revenue productivity of the
parent in year \( t + s \), for \( s \geq 0 \), is

\[
\frac{\partial E[\tilde{\psi}_{0t+s}|S_{it-1}]}{\partial r_{0t-1}} = \gamma_0 \rho_0^s,
\]

where, for every \( t \) and \( s \), \( \tilde{\psi}_{0t+s} = \kappa_2 \psi_{0t+s} \). The cumulative effect over infinite periods (conditional on \( |\rho_0| < 1 \)) is therefore

\[
\sum_{s=1}^{\infty} \frac{\partial E[\tilde{\psi}_{0t+s}|S_{it-1}]}{\partial r_{0t-1}} = \frac{\gamma_0}{1 - \rho_0}.
\] (18)

The cumulative effect of an infinitesimal increase in parent R&D investment during period \( t \) on affiliate \( j \)'s revenue productivity depends on the number of periods subsequent to year \( t \) during which affiliate \( j \) performs R&D. Let’s denote \( D_{jt}^{t+s} \) as the number of periods between \( t \) and \( t + s \), this last period not included, during which affiliate \( j \) has performed a positive amount of R&D. In this case,

\[
\frac{\partial E[\tilde{\psi}_{jt+s}|S_{it-1}]}{\partial r_{0t}} = \gamma_p \mathbb{E}[(\rho_1)^{s-D_{jt}^{t+s}}(\rho_2)^{D_{jt}^{t+s}}|S_{it-1}],
\]

where, for every \( t \) and \( s \), \( \tilde{\psi}_{jt+s} = \kappa_2 \psi_{jt+s} \), and the expectation is over \( D_{jt}^{t+s} \). Therefore, in the long run, the cumulative effect of an infinitesimal increase in R&D investment performed by the parent is:

\[
\sum_{s=0}^{\infty} \frac{\partial E[\tilde{\psi}_{jt+s}|S_{it-1}]}{\partial r_{0t-1}} = \sum_{s=0}^{\infty} \left\{ \gamma_p \mathbb{E}[(\rho_1)^{s-D_{jt}^{t+s}}(\rho_2)^{D_{jt}^{t+s}}|S_{it-1}] \right\}.
\] (19)

Similarly, the cumulative impact of affiliate-\( j \) R&D investment on affiliate-\( j \) revenue productivity is

\[
\sum_{s=0}^{\infty} \frac{\partial E[\tilde{\psi}_{jt+s}|S_{it-1}]}{\partial r_{jt-1}} = \sum_{s=0}^{\infty} \left\{ \gamma_a \mathbb{E}[(\rho_1)^{s-D_{jt}^{t+s}}(\rho_2)^{D_{jt}^{t+s}}|S_{it-1}] \right\},
\]

where notice that the future impact of innovation is again conditioned by the affiliate rate of productivity obsolescence.

As equations (18) and (19) show, computing the elasticity of both parent and each affiliate’s cumulative long-run productivity to parents’ R&D investment at period \( t - 1 \) depends on subsequent R&D decisions taken by affiliates. We only observe such decisions during our sample period. Accordingly, returns to R&D are computed using data from the 2004 survey (the most recent benchmark survey available that contains information on all firm affiliates) and assume that the observed distribution of affiliates and of R&D investments across these affiliates is held constant at 2004 values. Therefore, the cumulative long-run percentage change on the sum of all affiliates’ productivities of an infinitesimal percentage change in the parent’s R&D investment is then computed
where \( J_{i2004,d=0} \) denotes the number of firm-\( i \) affiliates not performing R&D in 2004, and \( J_{i2004,d=1} \) is the number of firm-\( i \) affiliates performing R&D. Combining (20) with (18) above evaluated at the estimated parameter vector yields an estimate of the overall firm-wide return to R&D investment by the U.S. parent of firm \( i \).

### 6.2 The Value Impact of R&D

An alternative way to define the private return to innovation investment for firm \( i \) is as the increase in the total firm-\( i \) value that results from an infinitesimal increase in R&D expenditure:

\[
\frac{\partial V(S_{it})}{\partial R_{0t-1}} = \frac{\partial}{\partial R_{0t-1}} \left\{ \sum_{s=0}^{\infty} \sum_{j \in J_{it+s}} \delta^{t+s} \mathbb{E}[\Pi(S_{jt+s})|S_{it-1}] \right\}
\]

where \( \Pi(S_{jt}) \) is defined in equation (10). Using the envelope theorem, we can write, for any time period \( t + s \) such that \( s \geq 0 \) and for any affiliate \( j = 1, \ldots, J_{it+s} \),

\[
\frac{\partial \Pi(S_{jt+s})}{\partial R_{0t-1}} = \frac{\partial \Pi(S_{jt+s})}{\partial \tilde{\psi}_{jt+s}} \frac{\partial \tilde{\psi}_{jt+s}}{\partial R_{0t-1}}.
\]

Given that \( Y_{jt} = \exp(k_{it} + h(l_{jt}, k_{jt}; \beta) + \tilde{\psi}_{jt}) \), the first term in equation (21) is equal to

\[
\frac{\partial \Pi(S_{jt+s})}{\partial \tilde{\psi}_{jt+s}} = Y_{jt+s},
\]

and, from the results in Section 6.1, we know that

\[
\frac{\partial \tilde{\psi}_{jt+s}}{\partial R_{0t-1}} = \gamma_p (\rho_1)^{s-D_{jt}^{t+s}} (\rho_2)^{D_{jt}^{t+s}} \frac{1}{R_{0t-1}}.
\]

Therefore, the derivative of firm-\( i \) value with respect to its parent R&D expenditure is

\[
\sum_{s=0}^{\infty} \delta^{t+s} \frac{1}{R_{0t-1}} \mathbb{E} \left\{ \sum_{j \in J_{it+s}} \left\{ \rho_2 \gamma_p Y_{0t+s} + (\rho_1)^{s-D_{jt}^{t+s}} (\rho_2)^{D_{jt}^{t+s}} \gamma_p Y_{jt+s} \right\} | S_{it-1} \right\}.
\]

As equation (22) shows, the effect of an increase in the R&D of the parent on firm \( i \)'s value depends on the expectation of the values taken in subsequent periods by: (a) number of affiliates; (b) sales revenue of both parent firm and all affiliates; (c) R&D decisions of affiliates. Given that our dataset
only allows us to observe these values during our sample period, we evaluate equation (22) under the assumption above that the most recent benchmark year observed in our sample is a steady-state. Under this assumption,

\[
\frac{\partial V(S_{it})}{\partial R_{0t-1}} = \frac{Y_{2004}}{R_{2004}} \left( 1 - \delta p_0 \right) + \mu_p \left( J_{i2004,d=0} \frac{1}{1 - \delta p_1} \frac{Y_{2004,d=0}}{R_{2004}} + J_{i2004,d=1} \frac{1}{1 - \delta p_2} \frac{Y_{2004,d=1}}{R_{2004}} \right),
\]

(23)

where \(\bar{Y}_{2004,d=0}\) denotes the average sales revenue in 2004 among the affiliates of firm \(i\) that perform no R&D in 2004, and analogously for \(\bar{Y}_{2004,d=1}\) for those firms performing a positive amount of R&D.

6.3 Results

Table 10 uses estimates from Tables 4 through 9 and moments of the data to evaluate the return to parent and affiliate R&D within multinational firms. Specifically for each multinational firm \(i\), we use equation (23) to evaluate the parent-level return to parent R&D, the affiliate-level return to parent R&D, the share of affiliate R&D returns in firm-wide returns to parent R&D, and the affiliate-level return to affiliate R&D. For simplicity, we assume no time discounting \(\delta = 1\) in constructing our estimates. Columns 1 through 5 correspond to estimates for the five industries considered by our analysis.

Comparing the estimates of parent-level returns to parent innovation in row 1 against affiliate-level returns to affiliate innovation in row 2 reveals that both forms of innovation impact productivity to a large degree. However, parent firms experience a larger productivity impact from parent R&D investment than foreign affiliates experience from their own innovation investment in all industries except for the chemical sector; foreign affiliates in the chemical industry have a higher long-run impact of innovation (0.81) than U.S. parent firms (0.62).

The estimates in Table 10 indicate that parent innovation generates returns in foreign countries. The share of parent-innovation returns earned abroad varies substantially across firms. For the average firm, between 10 and 30 percent of the return to parent R&D are realized within foreign affiliates. The distribution exhibits skewness in that, for the median firm, between 5 and 10 percent of parent R&D returns are realized abroad, and at the 90th percentile, returns are near 40 percent in four of five industries. Particularly for this upper range of firms, taking into account the returns to parent R&D realized abroad may be an important step toward evaluating the true return to innovation, and toward explaining the overwhelmingly high levels of R&D investment by U.S. multinationals relative to other U.S. firms (National Science Board 2014).

7 Robustness

7.1 Nonlinear Autoregressive Process for Productivity

In this section, we relax two of the assumptions imposed in equation (6): (a) the elasticity of current revenue productivity with respect to its lagged value depends on R&D investments only through
the dummy variable \( d_{it-1} \) capturing whether such investment is zero or positive; (b) conditional on the lagged R&D investment, the elasticity of current revenue productivity with respect to its lagged value is constant. Specifically, we substitute the specification in (6) for the more general expression

\[
\psi_{jt-1}^e = (1 - d_{jt-1})(\mu_{1nt} + \rho_1 \psi_{jt-1}) + d_{jt-1}(\mu_{2nt} + \rho_2 \psi_{jt-1} + \rho_3 \psi_{jt-1} r_{jt-1}) + \rho_4 \psi_{jt-1}^2,
\]

and the specification in equation (8) for

\[
\psi_{0t-1}^e = \mu_{02t} + \rho_02 \psi_{0t-1} + \rho_{03} \psi_{0t-1} r_{0t-1} + \rho_{04} \psi_{0t-1}^2 + \mu_{0p} r_{0t-1}.
\]

As Appendix A.3 shows, if we allow for market-year specific price and quantity indices (so that \( \kappa_{nt}^3 \) is possibly different from \( \kappa_{nt'}^3 \), for \( n \neq n' \) or \( t \neq t' \)) and apply the Frisch-Waugh-Lovell theorem to control for this very large set of fixed effects, then we cannot identify the level of the parameters \( \rho_1 \) and \( \rho_2 \) (only their difference is identified). As Section 6 makes it clear, even in the case in which we impose the simple specification in equation (6), identifying the value of \( \rho_1 \) and \( \rho_2 \) is key to correctly identify the returns to R&D investment. Therefore, we perform the estimation under the assumption that \( \kappa_{nt}^3 = \kappa^3 \), for all markets \( n \) and time periods \( t \). Under this assumption, we structurally estimate the parameter vector \( (\kappa^3, \beta_k, \beta_{kk}, \rho_1, \rho_2, \rho_3, \gamma_4, \gamma_a, \gamma_p) \), where \( \gamma_4 = \rho_4 / \kappa^3 \) and all the remaining parameters are as defined in Section 4.

As Appendix A.3.2 shows, the elasticity of parent cumulative revenue productivity over infinite periods with respect to parent R&D is, in this case,

\[
\frac{\gamma_0 p}{1 - \rho_02 - \rho_{03} r_{2004} - 2 \gamma_4 \psi_{2004}}.
\]

Similarly, the elasticity with respect to parent R&D investment of the sum across affiliates of the cumulative revenue productivity over infinite periods becomes

\[
\sum_{j=1}^{J_{2004}} \gamma_p \left( \frac{1 - d_{j2004}}{1 - \rho_1 - 2 \gamma_4 \psi_{j2004}} + \frac{d_{j2004}}{1 - \rho_2 - \rho_3 r_{j2004} - 2 \gamma_4 \psi_{j2004}} \right);
\]

and the elasticity of firm value with respect to parent R&D investment is

\[
\frac{Y_{2004}}{R_{2004}} \frac{\gamma_0 p}{1 - \rho_02 - \rho_{03} r_{2004} - 2 \gamma_4 \psi_{2004}} + \mu_p \frac{Y_{j2004}}{R_{j2004}} \sum_{j=1}^{J_{2004}} \left( \frac{1 - d_{j2004}}{1 - \rho_1 - 2 \gamma_4 \psi_{j2004}} + \frac{d_{j2004}}{1 - \rho_2 - \rho_3 r_{j2004} - 2 \gamma_4 \psi_{j2004}} \right).
\]

Equations (26) and (27) generalize (18) and (20), respectively.

We evaluate two alternative specifications in turn based on the extensions above, and present the resulting estimates in Tables 11 and 12. Table 11 first introduces the possibility that affiliate
innovation and productivity levels interact in determining affiliate productivity change, and we thus include the additional term $\psi_{jt-1}r_{jt-1}$ in each column. The results regarding affiliate productivity persistence and the impact of parent R&D on affiliate productivity change are robust to this alternative specification. Moreover, the impact of this interaction effect is significant across all columns. This impact is not, however, consistent in its sign: the influence of affiliate innovation on productivity change is higher for relatively productive affiliates in the industrial machinery, electronics, and instruments & devices sectors, while the opposite is true for affiliates in chemicals and transportation equipment.

Table 12 provides an analogous set of estimates in which the second form of non-linearity is introduced through a squared lagged-productivity term $\phi^2_{jt-1}$ in the affiliate-level Markov productivity process. These estimates reveal at least two interesting results. First, the squared productivity term is statistically important and negative, suggesting that a form of mean-reversion in productivity evolution may be present among foreign affiliates. Second, while parent R&D investment continues to have a positive and highly significant impact on affiliate productivity change, this magnitude of this impact is smaller in this alternative specification.

7.2 Dependency on Parent’s Productivity

The specification in equation (6) assumes that affiliates’ productivity in any year $t$ exclusively depends on the expenditure in R&D in year $t-1$. In Section 5, we generalize this specification and present results that allow affiliate’s productivity to depend on the flow of innovation performed at the parent firm for the previous five years. In this section, we allow affiliate productivity at any period $t$ to depend on the stock of knowledge employed by the parent firm in its production process, as measured by the parent’s revenue productivity $\tilde{\psi}_0t$. Specifically, we replace specification (6) with the following expression

$$\psi_{jt-1} = (1 - d_{jt-1})(\gamma_1nt + \rho_1\psi_{jt-1}) + d_{jt-1}(\gamma_2nt + \rho_2\psi_{jt-1}) + \gamma_a r_{jt-1} + \gamma_{pp} \tilde{\psi}_0t. \quad (29)$$

The economic phenomenon captured by the coefficient $\gamma_{pp}$ on the term $\tilde{\psi}_0t$ differs from that captured by the coefficient $\mu_p$ corresponding to the term $r_{0t-1}$ in three dimensions. Specifically, the parameter $\mu_{pp}$ captures the effect on affiliates’ productivity of 1) the weighted average of parent R&D expenditure in any year previous to $t$, with more weight assigned to more recent years; 2) parent R&D investment that is subsequently reflected by the parent’s productivity level; 3) technological innovations that occur within the parent firm and have consequences for affiliate productivity change, but that might not be reflected by R&D expenditure (e.g. organizational changes).

As Appendix A.4.2 shows, the elasticity of parent cumulative revenue productivity over infinite periods with respect to parent R&D is, in this case, identical to the expression in equation (18). The elasticity of the sum across affiliates of the cumulative revenue productivity over infinite periods
thus becomes

$$\gamma_{pp\gamma_{0p}} \left( J_{i1994,d=0} \frac{\rho_1}{(1-\rho_1)(1-\rho_{02})} + J_{i1994,d=1} \frac{\rho_2}{(1-\rho_2)(1-\rho_{02})} \right),$$

(30)

and the elasticity of firm value with respect to parent productivity is

$$\frac{\partial V(S_{it})}{\partial R_{0t-1}} = \frac{Y_{01994}}{R_{01994}} \frac{\gamma_{0p}}{1 - \delta \rho_{02}} + \gamma_{pp\gamma_{0p}} \left( J_{i1994,d=0} \frac{\delta \rho_1}{(1 - \delta \rho_1)(1 - \delta \rho_{02})} \frac{\bar{Y}_{1994,d=0}}{R_{01994}} + J_{i1994,d=1} \frac{\delta \rho_2}{(1 - \delta \rho_2)(1 - \delta \rho_{02})} \frac{\bar{Y}_{1994,d=1}}{R_{01994}} \right).$$

(31)

Results corresponding to this alternative specification appear in Table 13, which presents estimates for all five industries. The results indicate that, regardless of the industry, the current productivity level of the U.S. parent (instrumented by its one-period lag) is an important determinant of affiliate productivity change. Comparing the estimate for each industry against the elasticities with respect to parent R&D reported in Tables 4 through 9 reveals that for most sectors, the magnitude of the parent productivity impact lies between that of lagged parent R&D $r_{0t-1}$ and cumulative five-year lagged parent R&D $r_{0t-1,t-5}$. However, the impact of parent productivity in transportation equipment is mildly lower than the impact of lagged R&D, and is substantially smaller in the chemical industry. Taken together, the estimates in Table 13 demonstrate that this alternative mechanism through which parent R&D may enter and influence affiliate productivity change reinforces the qualitative, and for the most part, quantitative effects identified in Sections 4 and 5.

8 Conclusion

This paper uses detailed information on parent and affiliate-level innovation and production to measure the private return to multinational firms’ innovation investment. We develop a dynamic model of firm innovation that explicitly accounts for intrafirm knowledge transfer across production sites. The model provides a detailed empirical framework which we then apply to estimate innovation returns within a comprehensive panel of U.S. multinationals during 1989–2009. We find that the data are consistent with innovation generating returns at firm locations beyond the innovating site within five major manufacturing industries. Specifically, accounting for cross-plant effects of innovation, our estimates indicate the average firm realizes between 10 and 30 percent of the return to its U.S. parent R&D abroad, suggesting single-plant estimates may understate firms’ gain from innovation.

Government industrial policy—including innovation and production incentives—is likely to be a key force shaping multinationals’ activity across countries (Hines 1994, 1995). Many countries including the United States subsidize private R&D to encourage local innovation and growth. Our results indicate that local policies aimed at stimulating innovation may indirectly contribute to productivity gains abroad. Evaluating the implications of this effect for policies including the R&D tax credit and intellectual property reform is an important area for future research.
Finally, our estimates are connected to a literature that has examined the equilibrium relationship between international technology diffusion and economic growth across countries. The results presented here reveal that multinational activity systematically influences the diffusion of ideas across countries through a within-firm channel. Our estimates thus indicate the potential importance of future research aimed at building active agents and directed technology diffusion into models of international idea diffusion and growth.
REFERENCES


Table 1: Regression Summary Statistics by Industry, 1989-2008

<table>
<thead>
<tr>
<th>Industry</th>
<th>Industrial Machinery</th>
<th>Electronics</th>
<th>Instruments and Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
</tr>
</thead>
</table>

### Affiliate-Level Variables

- **Log value added, mean**: 10.43, 10.45, 10.37, 10.47, 10.57
- **Standard deviation**: 1.23, 1.18, 1.11, 1.18, 1.29
- **Log labor (number of employees), mean**: 5.94, 6.12, 5.81, 5.74, 6.25
- **Standard deviation**: 1.31, 1.35, 1.29, 1.25, 1.43
- **Log capital, mean**: 9.74, 9.96, 9.79, 10.06, 10.17
- **Standard deviation**: 1.78, 1.82, 1.78, 1.81, 1.81
- **Log R&D expenditure, mean**: 7.21, 7.60, 7.53, 7.24, 7.70
- **Standard deviation**: 1.97, 2.01, 1.90, 1.97, 2.02

### U.S. Parent-Level Variables

- **Log value added, mean**: 14.26, 14.20, 13.82, 14.52, 14.97
- **Standard deviation**: 1.55, 1.55, 1.62, 1.44, 1.70
- **Log labor (number of employees), mean**: 9.63, 9.62, 9.21, 9.53, 10.47
- **Standard deviation**: 1.42, 1.46, 1.53, 1.28, 1.47
- **Log capital, mean**: 15.78, 15.46, 15.18, 16.37, 16.56
- **Standard deviation**: 2.93, 2.84, 2.96, 2.64, 3.28
- **Log R&D expenditure, mean**: 12.08, 12.18, 12.04, 12.43, 12.90
- **Standard deviation**: 1.96, 1.90, 1.76, 1.83, 2.18

**Number of Observations, Affiliate-Year level**: 6,323, 6,505, 3,944, 11,016, 5,566

Notes: This table summarizes multinational activity within our regression data for five industries during 1989 through 2008. All variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Labor is the number of employees. Values are in log thousands of U.S. dollars in 2004.
### Table 2: Descriptive Evidence, Innovation in Multinational Firms

<table>
<thead>
<tr>
<th>Industry-Level Variables</th>
<th>Industrial Machinery</th>
<th>Electronics</th>
<th>Instruments and Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of firms with total R&amp;D &gt; 0</td>
<td>0.9091</td>
<td>0.8896</td>
<td>0.9251</td>
<td>0.9325</td>
<td>0.9167</td>
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<tr>
<td>Fraction of firms with parent R&amp;D &gt; 0</td>
<td>0.8864</td>
<td>0.8734</td>
<td>0.9031</td>
<td>0.9241</td>
<td>0.9091</td>
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<tr>
<td>Fraction of firms with total affiliate R&amp;D &gt; 0</td>
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<td>0.5065</td>
<td>0.5507</td>
<td>0.5654</td>
<td>0.5227</td>
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</table>

<table>
<thead>
<tr>
<th>Firm-Level Variables</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>R&amp;D Intensity (R&amp;D / Sales)</td>
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<tr>
<td>Firm, mean</td>
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<td>0.0443</td>
<td>0.0607</td>
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<td>0.0314</td>
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<td>Standard deviation</td>
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<td>0.0506</td>
<td>0.0540</td>
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<td>Parent, mean</td>
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<td>Standard deviation</td>
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<td>Affiliates, mean</td>
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<td>0.0128</td>
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<td>0.0095</td>
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<td>Standard deviation</td>
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<td>Share of affiliates with R&amp;D &gt; 0, mean</td>
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<td>Standard deviation</td>
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<td>Affiliate share in firm R&amp;D expenditure, mean</td>
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<td>0.1030</td>
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<td>0.1186</td>
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<td>Standard deviation</td>
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<td>0.1983</td>
<td>0.2186</td>
<td>0.1933</td>
<td>0.1989</td>
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Notes: This table summarizes multinational activity within the BEA data for five industries in 1994. All variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Values are expressed in thousands of U.S. dollars in 2004.
<table>
<thead>
<tr>
<th>Industry</th>
<th>Industrial Machinery</th>
<th>Electronics</th>
<th>Instruments and Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
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<tbody>
<tr>
<td>Number of affiliates</td>
<td>7.83</td>
<td>7.52</td>
<td>7.82</td>
<td>14.62</td>
<td>11.38</td>
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<td>Number of affiliates with R&amp;D &gt; 0</td>
<td>1.81</td>
<td>1.91</td>
<td>1.91</td>
<td>4.95</td>
<td>3.07</td>
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<tr>
<td>Total R&amp;D expenditure</td>
<td>$69.1 million</td>
<td>$86.7 million</td>
<td>$69.2 million</td>
<td>$121 million</td>
<td>$309 million</td>
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<tr>
<td>Affiliate share of total R&amp;D</td>
<td>10.56%</td>
<td>10.30%</td>
<td>12.26%</td>
<td>11.85%</td>
<td>11.08%</td>
</tr>
</tbody>
</table>

Top affiliate locations, by employment:
- United Kingdom
- Mexico
- Japan
- France
- Germany

Top affiliate locations, by R&D:
- Germany
- France
- Ireland
- Japan
- Singapore

Notes: This table summarizes average characteristics of the firm within the BEA data for five industries during 1994. All values are computed using data from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment. Number of affiliates, Number of affiliates with R&D > 0, Total R&D expenditure, and Affiliate share of total R&D are unweighted averages across firms in the regression sample. Top affiliate locations, by employment, lists the five countries with the highest number of affiliate employees in our regression sample, ranked from first to fifth. Top affiliate locations, by R&D, is analogous but based on total affiliate R&D expenditures in the industry and country.
Table 4: R&D Investment and Foreign-Affiliate Productivity Change, Baseline Estimates

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<tr>
<td>$\phi_{jt-1} \times (1-d_{jt-1})$</td>
<td>0.7666</td>
<td>0.7558</td>
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<tr>
<td>$\phi_{jt-1} \times d_{jt-1}$</td>
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<td>$r_{jt-1}$</td>
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<td>Y</td>
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<tr>
<td>Country-Year FE x $d_{jt-1}$</td>
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<td>Y</td>
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<tr>
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<td>Y</td>
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<tr>
<td>Country-Year FE x $d_{jt-1}$</td>
<td>Y</td>
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<td>Y</td>
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</tr>
<tr>
<td>N</td>
<td>6323</td>
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<tr>
<td>R-squared</td>
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</table>

Notes: ** p < 0.05, *** p < 0.01. This table provides estimates of equation (12) for industrial machinery firms (SIC 35) during 1989 through 2008. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Robust standard errors appear below each point estimate.
Table 5: R&D Investment and Affiliate-Level Productivity Change, Baseline Estimates

<table>
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<tbody>
<tr>
<td>( \phi_{jt-1} \times (1-d_{jt-1}) )</td>
<td>0.7524</td>
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<tr>
<td>( \phi_{jt-1} \times d_{jt-1} )</td>
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<td>0.0131***</td>
<td>0.013***</td>
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<td>( r_{jt-1} )</td>
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Input elasticities

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<td>0.4888</td>
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Country-Year FE

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Country-Year FE x \( d_{jt-1} \)

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Sector-Year FE

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Country-Year FE x \( d_{jt-1} \)

<table>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

N 6505 6505 6505 6505 6505
R-squared 0.8825 0.8834 0.8837 0.8837 0.8834

Notes: ** p < 0.05, *** p < 0.01. This table provides estimates of equation (12) for electronics firms (SIC 36) during 1989 through 2008. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Robust standard errors appear below each point estimate.
Table 6: R&D Investment and Affiliate-Level Productivity Change, Baseline Estimates

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi_{jt-1} \times (1-d_{jt-1}) )</td>
<td>0.7046</td>
<td>0.6935</td>
<td>0.6827</td>
<td>0.6839</td>
<td>0.6924</td>
</tr>
<tr>
<td></td>
<td>0.014***</td>
<td>0.014***</td>
<td>0.0141***</td>
<td>0.0142***</td>
<td>0.014***</td>
</tr>
<tr>
<td>( \phi_{jt-1} \times d_{jt-1} )</td>
<td>0.7185</td>
<td>0.7014</td>
<td>0.6896</td>
<td>0.6902</td>
<td>0.7013</td>
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<td>0.0164***</td>
<td>0.0166***</td>
<td>0.0166***</td>
<td>0.0164***</td>
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<tr>
<td>( r_{jt-1} )</td>
<td>0.0071</td>
<td>0.0077</td>
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<td>0.0077</td>
<td>0.0076</td>
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<tr>
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<td>0.0034**</td>
<td>0.0034**</td>
<td>0.0034**</td>
<td>0.0034**</td>
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<tr>
<td>( r_{0t-1} )</td>
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<td>0.0055</td>
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<tr>
<td></td>
<td>0.002***</td>
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<td>0.003*</td>
<td></td>
<td>0.0022***</td>
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<tr>
<td>( r_{0t-1t-5} )</td>
<td>0.0241</td>
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<td>0.0181</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>0.0031***</td>
<td>0.0045***</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>( r_{jt-1} )</td>
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<td></td>
<td></td>
<td>0.0013</td>
<td>0.0011</td>
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<tr>
<td>( e_l )</td>
<td>0.5032</td>
<td>0.5032</td>
<td>0.5032</td>
<td>0.5032</td>
<td>0.5032</td>
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<tr>
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<td>0.2052</td>
<td>0.1977</td>
<td>0.1943</td>
<td>0.1946</td>
<td>0.1974</td>
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</table>

Country-Year FE: Y Y Y Y Y
Country-Year FE \( x d_{jt-1} \): Y Y Y Y Y
Sector-Year FE: Y Y Y Y Y
Country-Year FE \( x d_{jt-1} \): Y Y Y Y Y

N: 3944 3944 3944 3944 3944
R-squared: 0.9153 0.9163 0.9166 0.9167 0.9164

Notes: ** p < 0.05, *** p < 0.01. This table provides estimates of equation (12) for firms in the instruments and devices sector (SIC 38) during 1989 through 2008. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Robust standard errors appear below each point estimate.
Table 7: R&D Investment and Affiliate-Level Productivity Change, Baseline Estimates

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
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<th>(3)</th>
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<tbody>
<tr>
<td></td>
<td>Chemicals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi_{jt-1} \times (1 - d_{jt-1})$</td>
<td>0.7803</td>
<td>0.776</td>
<td>0.7742</td>
<td>0.7749</td>
<td>0.7744</td>
</tr>
<tr>
<td></td>
<td>0.0090***</td>
<td>0.0090***</td>
<td>0.0090***</td>
<td>0.0090***</td>
<td>0.0090***</td>
</tr>
<tr>
<td>$\phi_{jt-1} \times d_{jt-1}$</td>
<td>0.6955</td>
<td>0.6906</td>
<td>0.6845</td>
<td>0.6836</td>
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<td>0.0089***</td>
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</tr>
<tr>
<td>$r_{jt-1}$</td>
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<td>0.0263</td>
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<td></td>
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<td>0.0021***</td>
<td>0.0021***</td>
<td>0.0021***</td>
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<tr>
<td>$r_{0t-1}$</td>
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<td>0.0043</td>
<td>0.0012***</td>
<td>0.0021**</td>
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<tr>
<td>$r_{0t-1t-5}$</td>
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<td>0.0189</td>
<td>0.0017***</td>
<td>0.0030***</td>
<td>0.0026</td>
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<tr>
<td>$r_{jt-1}$</td>
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<td>0.0009***</td>
<td>0.0009***</td>
<td>0.0009***</td>
<td>0.0009***</td>
</tr>
</tbody>
</table>

Input elasticities

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<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_l$</td>
<td>0.4203</td>
<td>0.4203</td>
<td>0.4203</td>
<td>0.4203</td>
<td>0.4203</td>
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<tr>
<td>$e_k$</td>
<td>0.0976</td>
<td>0.0966</td>
<td>0.0947</td>
<td>0.0955</td>
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</tbody>
</table>

Country-Year FE

|                          | Y       | Y       | Y       | Y       | Y       |
| Country-Year FE x $d_{jt-1}$ | Y       | Y       | Y       | Y       | Y       |
| Sector-Year FE            | Y       | Y       | Y       | Y       | Y       |
| Country-Year FE x $d_{jt-1}$ | Y       | Y       | Y       | Y       | Y       |

N 11016 11016 11016 11016 11016
R-squared 0.6828 0.6836 0.6846 0.6847 0.6838

Notes: ** p < 0.05, *** p < 0.01. This table provides estimates of equation (12) for firms in the chemical industry (SIC 28) during 1989 through 2008. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Robust standard errors appear below each point estimate.
Table 8: R&D Investment and Affiliate-Level Productivity Change, Baseline Estimates

<table>
<thead>
<tr>
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<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Transportation Equipment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$\phi_{jt-1} \times (1-d_{jt-1})$</td>
<td>0.7344</td>
<td>0.7231</td>
<td>0.7217</td>
<td>0.7218</td>
<td>0.7225</td>
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<tr>
<td></td>
<td>0.012***</td>
<td>0.0121***</td>
<td>0.0121***</td>
<td>0.0121***</td>
<td>0.0121***</td>
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<tr>
<td>$\phi_{jt-1} \times d_{jt-1}$</td>
<td>0.566</td>
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<td>0.0136***</td>
<td>0.0136***</td>
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<td>0.0018</td>
<td>0.0018</td>
<td>0.0018</td>
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<td>0.0137</td>
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<tr>
<td>$e_l$</td>
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<td>0.4888</td>
<td>0.4888</td>
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<tr>
<td>$e_k$</td>
<td>0.2111</td>
<td>0.2082</td>
<td>0.2069</td>
<td>0.2069</td>
<td>0.2084</td>
</tr>
</tbody>
</table>

Country-Year FE | Y  | Y  | Y  | Y  | Y  |
Country-Year FE x $d_{jt-1}$ | Y  | Y  | Y  | Y  | Y  |
Sector-Year FE | Y  | Y  | Y  | Y  | Y  |
Country-Year FE x $d_{jt-1}$ | Y  | Y  | Y  | Y  | Y  |

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<tr>
<td>R-squared</td>
<td>0.6878</td>
<td>0.6899</td>
<td>0.6899</td>
<td>0.6900</td>
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Notes: ** p < 0.05, *** p < 0.01. This table provides estimates of equation (12) for transportation equipment firms (SIC 37) during 1989 through 2008. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Robust standard errors appear below each point estimate.
### Table 9: R&D Investment and U.S. Parent-Level Productivity Change

<table>
<thead>
<tr>
<th>Industry</th>
<th>Industrial Machinery</th>
<th>Electronics</th>
<th>Instruments and Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>$\phi_{0t-1}$</td>
<td>0.8055</td>
<td>0.8042</td>
<td>0.8107</td>
<td>0.8107</td>
<td>0.7474</td>
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<tr>
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<td>0.0106***</td>
<td>0.0107***</td>
<td>0.0106***</td>
<td>0.0106***</td>
<td>0.0150***</td>
</tr>
<tr>
<td>$r_{0t-1}$</td>
<td>0.0340</td>
<td>0.0328</td>
<td>0.0274</td>
<td>0.0275</td>
<td>0.0417</td>
</tr>
<tr>
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<td>0.0030***</td>
<td>0.0031***</td>
<td>0.0031***</td>
<td>0.0032***</td>
<td>0.0044***</td>
</tr>
<tr>
<td>$r_{jt-1}$</td>
<td>0.0017</td>
<td>-0.0001</td>
<td>0.0025</td>
<td></td>
<td>0.0007</td>
</tr>
<tr>
<td></td>
<td>0.0012</td>
<td>0.0011</td>
<td>0.0014</td>
<td></td>
<td>0.0015</td>
</tr>
</tbody>
</table>

**Input elasticities**

| $e_l$ | 0.6128 | 0.6128 | 0.5814 | 0.5814 | 0.5438 | 0.5438 | 0.3985 | 0.3985 | 0.5538 | 0.5538 |
| $e_k$ | 0.2084 | 0.2004 | 0.2575 | 0.2574 | 0.2694 | 0.2639 | 0.4665 | 0.4645 | 0.2609 | 0.2604 |

**Year FE**

| Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |

**N**

| 2904 | 2904 | 2986 | 2986 | 2015 | 2015 | 2232 | 2232 | 1437 | 1437 |

**R-squared**

| 0.9556 | 0.9556 | 0.9755 | 0.9755 | 0.9717 | 0.9717 | 0.9887 | 0.9888 | 0.9801 | 0.9801 |

Notes: ** p < 0.05, *** p < 0.01. This table provides estimates of equation (12) for parent firms in five industries (as indicated above) during 1989 through 2008. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. parent operations corresponding to the foreign affiliate observations in Tables 4 through 8. Robust standard errors appear below each estimate.
### Table 10: Estimated Innovation Return and Distribution Across Parent and Multinational Affiliates

<table>
<thead>
<tr>
<th>Industry</th>
<th>Industrial Machinery</th>
<th>Electronics</th>
<th>Instruments and Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent Return to Parent R&amp;D</td>
<td>0.932</td>
<td>0.746</td>
<td>0.882</td>
<td>0.619</td>
<td>0.658</td>
</tr>
<tr>
<td>Affiliate Return to Own-Affiliate R&amp;D</td>
<td>0.506</td>
<td>0.236</td>
<td>0.272</td>
<td>0.810</td>
<td>0.135</td>
</tr>
</tbody>
</table>

**Affiliate Return to Parent R&D / Firm Return to Parent R&D**

**Distribution across firms**

- **Mean**: 0.149, 0.177, 0.266, 0.108, 0.138
- **Standard Deviation**: 0.177, 0.554, 1.523, 0.634, 0.194
- **25th percentile**: 0.032, 0.028, 0.032, 0.009, 0.021
- **50th percentile**: 0.095, 0.088, 0.088, 0.040, 0.094
- **75th percentile**: 0.222, 0.229, 0.200, 0.087, 0.254
- **90th percentile**: 0.353, 0.363, 0.353, 0.147, 0.353

**Notes:** This table evaluates the return to R&D investment within U.S. multinational firms in 2004 using equations (18), (19), and (20) and section 6.2 for five industries. Parent Return to Parent R&D and Affiliate Return to Own-Affiliate R&D are computed based on characteristics of the average firm. Affiliate Return to Parent R&D / Firm Return to Parent R&D is computed for each firm, and various moments of the resulting distribution across firms are reported here.
Table 11: R&D Investment and Affiliate-Level Productivity Change, Estimates with Nonlinearity I

<table>
<thead>
<tr>
<th></th>
<th>Industrial Machinery</th>
<th>Electronics</th>
<th>Instruments &amp; Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi_{jt-1} \times (I-d_{jt-1}) )</td>
<td>0.7852</td>
<td>0.7775</td>
<td>0.7161</td>
<td>0.7904</td>
<td>0.7458</td>
</tr>
<tr>
<td></td>
<td>0.0087***</td>
<td>0.0094***</td>
<td>0.0131***</td>
<td>0.0086***</td>
<td>0.0114***</td>
</tr>
<tr>
<td>( \phi_{jt-1} \times d_{jt-1} )</td>
<td>0.6461</td>
<td>0.4533</td>
<td>0.5199</td>
<td>0.7724</td>
<td>0.6884</td>
</tr>
<tr>
<td></td>
<td>0.0110***</td>
<td>0.0099***</td>
<td>0.0103***</td>
<td>0.0098***</td>
<td>0.0119***</td>
</tr>
<tr>
<td>( \phi_{jt-1} \times r_{jt-1} )</td>
<td>0.0129</td>
<td>0.0367</td>
<td>0.0263</td>
<td>-0.0141</td>
<td>-0.017</td>
</tr>
<tr>
<td></td>
<td>0.0054**</td>
<td>0.0054**</td>
<td>0.0090***</td>
<td>0.0042***</td>
<td>0.0081**</td>
</tr>
<tr>
<td>( r_{0t-1} )</td>
<td>0.0128</td>
<td>0.0118</td>
<td>0.0110</td>
<td>0.0035</td>
<td>0.0115</td>
</tr>
<tr>
<td></td>
<td>0.0018***</td>
<td>0.0018***</td>
<td>0.0021***</td>
<td>0.0012***</td>
<td>0.0022***</td>
</tr>
</tbody>
</table>

Input elasticities

| \( e_l \)    | 0.5113 | 0.4971 | 0.4864 | 0.4203 | 0.5141 |
| \( e_k \)    | 0.1364 | 0.1783 | 0.1878 | 0.0952 | 0.1353 |

Country-Year FE: Y, Country-Year FE x \( d_{jt-1} \): Y, Sector-Year FE: Y, Country-Year FE x \( d_{jt-1} \): Y

N: 6323 6505 3944 11016 5566
R-squared: 0.8470 0.8520 0.9097 0.6411 0.6900

Notes: ** p < 0.05, *** p < 0.01. This table provides estimates of an alternative specification described in Section 7 that includes an interaction effect between affiliate R&D and affiliate productivity. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Robust standard errors appear below each point estimate.
<table>
<thead>
<tr>
<th></th>
<th>Industrial Machinery</th>
<th>Electronics</th>
<th>Instruments &amp; Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi_{jt-1} \times (1-d_{jt-1}) )</td>
<td>1.1055</td>
<td>1.0889</td>
<td>1.1163</td>
<td>1.0786</td>
<td>1.0864</td>
</tr>
<tr>
<td></td>
<td>0.0104***</td>
<td>0.0096***</td>
<td>0.0148***</td>
<td>0.0073***</td>
<td>0.0104***</td>
</tr>
<tr>
<td>( \phi_{jt-1} \times d_{jt-1} )</td>
<td>1.0769</td>
<td>1.0701</td>
<td>1.1096</td>
<td>0.9506</td>
<td>0.9779</td>
</tr>
<tr>
<td></td>
<td>0.0106***</td>
<td>0.0104***</td>
<td>0.0146***</td>
<td>0.0094***</td>
<td>0.0120***</td>
</tr>
<tr>
<td>((\phi_{jt-1})^2)</td>
<td>-0.0164</td>
<td>-0.0141</td>
<td>-0.0247</td>
<td>-0.0097</td>
<td>-0.0098</td>
</tr>
<tr>
<td></td>
<td>0.0011***</td>
<td>0.0012***</td>
<td>0.0023***</td>
<td>0.0008**</td>
<td>0.0011***</td>
</tr>
<tr>
<td>( r_{jt-1} )</td>
<td>0.0100</td>
<td>0.0063</td>
<td>0.0045</td>
<td>0.0285</td>
<td>0.0163</td>
</tr>
<tr>
<td></td>
<td>0.0030***</td>
<td>0.0029***</td>
<td>0.0034***</td>
<td>0.0022***</td>
<td>0.0033***</td>
</tr>
<tr>
<td>( r_{0t-1} )</td>
<td>0.0070</td>
<td>0.0076</td>
<td>0.0068</td>
<td>0.0039</td>
<td>0.0039</td>
</tr>
<tr>
<td></td>
<td>0.0018***</td>
<td>0.0019***</td>
<td>0.0021***</td>
<td>0.0012***</td>
<td>0.1071***</td>
</tr>
</tbody>
</table>

Input elasticities

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( e_l )</td>
<td>0.5113</td>
<td>0.4971</td>
<td>0.4864</td>
<td>0.4203</td>
<td>0.5141</td>
</tr>
<tr>
<td>( e_k )</td>
<td>0.1033</td>
<td>0.1321</td>
<td>0.1687</td>
<td>0.0673</td>
<td>0.0718</td>
</tr>
</tbody>
</table>

Country-Year FE | Y | Y | Y | Y | Y |
Country-Year FE \( \times d_{jt-1} \) | Y | Y | Y | Y | Y |
Sector-Year FE | Y | Y | Y | Y | Y |
Country-Year FE \( \times d_{jt-1} \) | Y | Y | Y | Y | Y |

N | 6323 | 6505 | 3944 | 11016 | 5566 |
R-squared | 0.9989 | 0.9989 | 0.9992 | 0.9990 | 0.9988 |

Notes: ** \( p < 0.05 \), *** \( p < 0.01 \). This table provides estimates of an alternative specification described in Section 7 that includes a squared productivity term. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. Robust standard errors appear below each point estimate.
Table 13: R&D Investment and Affiliate-Level Productivity Change, Parent Productivity

<table>
<thead>
<tr>
<th></th>
<th>Industry Machinery</th>
<th>Electronics</th>
<th>Instruments &amp; Devices</th>
<th>Chemicals</th>
<th>Transportation Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>$\phi_{jt-1} \times (1-d_{jt-1})$</td>
<td>0.7892</td>
<td>0.7252</td>
<td>0.6848</td>
<td>0.7818</td>
<td>0.7153</td>
</tr>
<tr>
<td></td>
<td>0.0152***</td>
<td>0.0207***</td>
<td>0.0304***</td>
<td>0.0194***</td>
<td>0.0247***</td>
</tr>
<tr>
<td>$\phi_{jt-1} \times d_{jt-1}$</td>
<td>0.6960</td>
<td>0.6809</td>
<td>0.6359</td>
<td>0.6674</td>
<td>0.5846</td>
</tr>
<tr>
<td></td>
<td>0.0348***</td>
<td>0.0358***</td>
<td>0.0417***</td>
<td>0.0640***</td>
<td>0.0766***</td>
</tr>
<tr>
<td>$r_{jt-1}$</td>
<td>0.0116</td>
<td>0.0097</td>
<td>0.0128</td>
<td>0.0273</td>
<td>0.0077</td>
</tr>
<tr>
<td></td>
<td>0.0032***</td>
<td>0.0033***</td>
<td>0.0036***</td>
<td>0.0062***</td>
<td>0.0043**</td>
</tr>
<tr>
<td>$\phi_0 t$</td>
<td>0.0139</td>
<td>0.0142</td>
<td>0.0156</td>
<td>0.0052</td>
<td>0.0110</td>
</tr>
<tr>
<td></td>
<td>0.0021***</td>
<td>0.0020***</td>
<td>0.0025***</td>
<td>0.0011***</td>
<td>0.0019***</td>
</tr>
</tbody>
</table>

Input elasticities

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_l$</td>
<td>0.5130</td>
<td>0.4970</td>
<td>0.4814</td>
<td>0.4226</td>
<td>0.5140</td>
</tr>
<tr>
<td>$e_k$</td>
<td>0.1513</td>
<td>0.2056</td>
<td>0.1944</td>
<td>0.0969</td>
<td>0.1327</td>
</tr>
</tbody>
</table>

Country-Year FE: Y
Country-Year FE $\times d_{jt-1}$: Y
Sector-Year FE: Y
Country-Year FE $\times d_{jt-1}$: Y

N: 6323 6505 3944 11016 5566

Notes: ** $p < 0.05$, *** $p < 0.01$. This table provides estimates of an alternative specification described in Section 7 that includes a proxy for parent productivity as the channel through which parent R&D impacts affiliate productivity change. All regression variables are from the Bureau of Economic Analysis Survey of U.S. Direct Investment Abroad, and pertain to U.S. outward foreign direct investment reported annually during this sample period. We report GMM estimates in which the endogenous regressor, parent productivity in the current period, is instrumented by its one-period lag. Robust standard errors appear below each point estimate.
Appendix

A.1 Deriving Revenue and Value-Added Functions

We can write the optimization problem that determines the optimal usage of materials by affiliate $j$ at period $t$ as:

$$\max_{M_{jt}} \frac{\alpha_m(\sigma-1)}{\sigma} \exp(-\sigma p_{nt} + \frac{1}{\sigma}q_{nt} + \frac{\sigma-1}{\sigma}((1-\alpha_m)h(l_{jt}, k_{jt}; \alpha) + \omega_{jt} + \xi_{jt})) - P_{nt}^m M_{jt}$$

From the first order condition, the optimal quantity of materials, $M_{jt}^*$, should satisfy the following equation

$$P_{nt}^m M_{jt}^* = \frac{\alpha_m(\sigma-1)}{\sigma} \frac{\alpha_m(\sigma-1)}{\sigma} \exp(-\sigma p_{nt} + \frac{1}{\sigma}q_{nt} + \frac{\sigma-1}{\sigma}((1-\alpha_m)h(l_{jt}, k_{jt}; \alpha) + \omega_{jt} + \xi_{jt}))$$

or, equivalently,

$$\frac{\alpha_m(\sigma-1)}{\sigma} m_{jt}^* = \frac{\alpha_m(\sigma-1)}{\sigma} \ln \left( \frac{\alpha_m(\sigma-1)}{\sigma} \right) - \frac{\alpha_m(\sigma-1)}{\sigma - \alpha_m(\sigma-1)} p_{nt}^m$$

or, equivalently in a more compact notation,

$$y_{jt} = \frac{\alpha_m(\sigma-1)}{\sigma - \alpha_m(\sigma-1)} \ln \left( \frac{\alpha_m(\sigma-1)}{\sigma} \right) - \frac{\alpha_m(\sigma-1)}{\sigma - \alpha_m(\sigma-1)} p_{nt}^m - \frac{\sigma^2}{\sigma - \alpha_m(\sigma-1)} p_{nt} + \frac{1}{\sigma - \alpha_m(\sigma-1)} q_{nt} + \frac{(1-\alpha_m)(\sigma-1)}{\sigma - \alpha_m(\sigma-1)} h(l_{jt}, k_{jt}; \alpha) + \frac{(\sigma-1)}{\sigma - \alpha_m(\sigma-1)} (\omega_{jt} + \xi_{jt})$$

Therefore, assuming that firms choose their consumption of materials optimally, we can rewrite the revenue function as

$$y_{jt} = \kappa_{nt}^1 + \kappa^2((1-\alpha_m)h(l_{jt}, k_{jt}; \alpha) + \psi_{jt})$$
where
\[
\kappa_{nt}^1 = \kappa^2 \left( \alpha_m \ln \left( \frac{\alpha_m (\sigma - 1)}{\sigma} \right) - \alpha_m p_m^m - \frac{\sigma^2}{\sigma - 1} p_n^m + \frac{1}{\sigma - 1} q_{nt}^m \right),
\]
\[
\kappa^2 = \frac{(\sigma - 1)}{\sigma - \alpha_m (\sigma - 1)},
\]
\[
\psi_{jt} = \omega_{jt} + \xi_{jt}.
\]

Given that the function \( h(l_{jt}, k_{jt}; \alpha) \) is linear in \( \alpha \), we can rewrite the revenue function as:
\[
y_{jt} = \kappa_{nt}^1 + h(l_{jt}, k_{jt}; \beta) + \kappa^2 \psi_{jt},
\]
where \( \beta = \alpha \kappa^2 (1 - \alpha_m) \).

Value added is defined as
\[
VA_{jt} = Y_{jt} - P_{nt}^m M_{jt}^*.
\]

From the first order condition for materials,
\[
P_{nt}^m M_{jt}^* = \left( \frac{\alpha_m (\sigma - 1)}{\sigma} \right) Y_{jt}
\]
and, therefore,
\[
VA_{jt} = \left( 1 - \frac{\alpha_m (\sigma - 1)}{\sigma} \right) Y_{jt},
\]
or, equivalently,
\[
va_{jt} = \kappa_{nt}^3 + h(l_{jt}, k_{jt}; \beta) + \kappa^2 \psi_{jt},
\]
where
\[
\kappa_{nt}^3 = \ln \left( 1 - \frac{\alpha_m (\sigma - 1)}{\sigma} \right) + \kappa_{nt}^1.
\]

A.2 Estimation: Details

A.2.1 First Step

Given the production function in equation (1) and the assumption that labor is a flexible input, the first order condition with respect to labor is
\[
\beta_l + \beta_l^2 l_{jt} + \beta_{lk} k_{jt} = \frac{W_{jt}^l L_{jt}}{V A_{jt}} \exp(\varepsilon_{jt}),
\]

where $W_{jt}^l$ is an observed measure of total payments to labor, $P_{nt}^l L_{jt}$. Given the assumption that $\mathbb{E}[\varepsilon_{jt}|S_{js}, L_{js}] = 0$, we can identify $(\beta_l, \beta_k, \beta_{lk})$ from the moment condition

$$\mathbb{E}[w_{jt}^l - va_{jt} - \log(\beta_l + \beta_{lk} l_{jt} + \beta_{lk} k_{jt})|l_{jt}, k_{jt}] = 0.$$  

Given this orthogonality condition, we estimate $(\beta_l, \beta_k, \beta_{lk})$ using NLS. Using the estimates $(\hat{\beta}_l, \hat{\beta}_k, \hat{\beta}_{lk})$, we can recover an estimate of $\varepsilon_{jt}$ for every firm $j$ and period $t$ as

$$\hat{\varepsilon}_{jt} = \log(\hat{\beta}_l + \hat{\beta}_k l_{jt} + \hat{\beta}_{lk} k_{jt}) + va_{jt} - w_{nt}$$  

(32)

### A.2.2 Second Step

Defining $\hat{va}_{jt} = va_{jt} - \hat{\beta}_l l_{jt} - \hat{\beta}_{lk} l_{jt} - \hat{\beta}_{lk} k_{jt} - \hat{\varepsilon}_{jt}$ and $h(k_{jt}; \beta_k, \beta_{kk}) = \beta_k k_{jt} + \beta_{kk} k_{jt}^2$, we can rewrite equation (12) as

$$\hat{va}_{jt} = h(k_{jt}; \beta_k, \beta_{kk}) + (1 - d_{jt-1})(\gamma_{1nt} + p_1(\hat{va}_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk}))) +$$

$$+ d_{jt-1}(\gamma_{2nt} + p_2(\hat{va}_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk}))) + \gamma_a r_{jt-1} + \gamma_p r_{0t-1} + \kappa^2 \eta_{jt}.  

(33)

In order to estimate the parameters $(\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p)$ from equation (33), we follow two different approaches.

In a first approach, we apply the Frisch-Waugh-Lovell theorem and project $\hat{va}_{jt}$, $k_{jt}$, $k_{jt}^2$, $(1 - d_{jt-1})\hat{va}_{jt-1}$, $d_{jt-1}\hat{va}_{jt-1}$, $(1 - d_{jt-1})k_{jt-1}$, $(1 - d_{jt-1})k_{jt-1}^2$, $d_{jt-1}k_{jt-1}$, $d_{jt-1}k_{jt-1}^2$, $r_{jt-1}$ and $r_{0t-1}$ on the vector of fixed effects $((1 - d_{jt-1})\gamma_{1nt}, d_{jt-1}\gamma_{2nt})$. Denoting the residuals from this regression with a prime, we estimate $(\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p)$ using NLS on the following estimating equation

$$\hat{va}'_{jt} = \beta_k k'_{jt} + \beta_{kk} (k_{jt}^2)',$$

$$+ p_1((1 - d_{jt-1})\hat{va}_{jt-1}') - \beta_k ((1 - d_{jt-1})k_{jt-1}') - \beta_{kk} ((1 - d_{jt-1})k_{jt-1}^2)',$$

$$+ p_2((d_{jt-1}\hat{va}_{jt-1}') - \beta_k (d_{jt-1}k_{jt-1}') - \beta_{kk} (d_{jt-1}k_{jt-1}^2)'),$$

$$+ \gamma_a r'_{jt-1} + \gamma_p r'_{0t-1} + \kappa^2 \eta'_{jt}.  

In a second approach, we simplify the set of fixed effects included in equation (33) and assume that $\gamma_{1nt} = \gamma_1$ and $\gamma_{2nt} = \gamma_2$. Once we impose this restriction, we use NLS to estimate $(\gamma_1, \gamma_2, \beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p)$ directly from equation (33).
A.3 Nonlinear Autoregressive Process for Productivity: Details

A.3.1 Estimation

From equations (11) and (24), we can derive the following estimating equation:

\[ va_{jt} = \kappa_{nt}^3 + h(l_{jt}, k_{jt}; \beta) + \varepsilon_{jt} \]
\[ + (1 - d_{jt-1})(\kappa_2\mu_{1nt} + \rho_1(va_{jt-1} - \kappa_{nt-1}^3 - h(l_{jt-1}, k_{jt-1}; \beta) - \varepsilon_{jt-1})) \]
\[ + d_{jt-1}(\kappa_2\mu_{2nt} + \rho_2(va_{jt-1} - \kappa_{nt-1}^3 - h(l_{jt-1}, k_{jt-1}; \beta) - \varepsilon_{jt-1}) \]
\[ + \rho_3(va_{jt-1} - \kappa_{nt-1}^3 - h(l_{jt-1}, k_{jt-1}; \beta) - \varepsilon_{jt-1})r_{jt-1} \]
\[ + (\rho_4/\kappa_2)(va_{jt-1} - \kappa_{nt-1}^3 - h(l_{jt-1}, k_{jt-1}; \beta) - \varepsilon_{jt-1})^2 \]
\[ + \kappa_2\mu_{a}r_{jt-1} + \kappa_2\mu_{p}r_{0t-1} + \kappa_2\eta_{jt}. \]

Estimating \((\beta_1, \beta_2, \beta_k)\) and \(\varepsilon_{jt}\) following the procedure in Appendix A.2.1, we are left with the estimating equation

\[ \hat{va}_{jt} = \kappa_{nt}^3 + h(k_{jt}; \beta_k, \beta_{kk}) \]
\[ + (1 - d_{jt-1})(\kappa_2\mu_{1nt} + \rho_1(\hat{va}_{jt-1} - \kappa_{nt-1}^3 - h(k_{jt-1}; \beta_k, \beta_{kk}))) \]
\[ + d_{jt-1}(\kappa_2\mu_{2nt} + \rho_2(\hat{va}_{jt-1} - \kappa_{nt-1}^3 - h(k_{jt-1}; \beta_k, \beta_{kk}))) \]
\[ + \rho_3(\hat{va}_{jt-1} - \kappa_{nt-1}^3 - h(k_{jt-1}; \beta_k, \beta_{kk}))r_{jt-1} \]
\[ + (\rho_4/\kappa_2)(\hat{va}_{jt-1} - \kappa_{nt-1}^3 - h(k_{jt-1}; \beta_k, \beta_{kk}))^2 \]
\[ + \kappa_2\mu_{a}r_{jt-1} + \kappa_2\mu_{p}r_{0t-1} + \kappa_2\eta_{jt}. \]

or, equivalently,

\[ \hat{va}_{jt} = h(k_{jt}; \beta_k, \beta_{kk}) \]
\[ + (1 - d_{jt-1})(\gamma_{int} + \rho_1(\hat{va}_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk}))) \]
\[ + d_{jt-1}(\gamma_{2nt} + \rho_2(\hat{va}_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk}))) \]
\[ + \rho_3(\hat{va}_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk}))r_{jt-1} \]
\[ + \gamma_4((\hat{va}_{jt-1})^2 + (h(k_{jt-1}; \beta_k, \beta_{kk}))^2 - 2\hat{va}_{jt-1}h(k_{jt-1}; \beta_k, \beta_{kk})) \]
\[ + \gamma_{3nt}(\hat{va}_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk})) \]
\[ + \gamma_{ar_{jt-1}} + \gamma_pr_{0t-1} + \kappa_2\eta_{jt}, \]

where \(\gamma_{int} = \kappa_2\mu_{1nt} + \kappa_{nt}^3 - \rho_1\kappa_{nt}^3 + (\rho_4/\kappa_2)(\kappa_{nt-1}^3)^2, \gamma_{2nt} = \kappa_2\mu_{2nt} + \kappa_{nt}^3 - \rho_2\kappa_{nt}^3 + (\rho_4/\kappa_2)(\kappa_{nt-1}^3)^2, \gamma_{3nt} = - (\rho_4/\kappa_2)2\kappa_{nt-1}^3, \gamma_4 = \rho_4/\kappa_2, \gamma_a = \kappa_2\mu_a, \) and \(\gamma_p = \kappa_2\mu_p.\) It is computationally infeasible to estimate the vectors of fixed effects \(\gamma_{int}, \gamma_{2nt},\) and \(\gamma_{3nt}\) jointly with the structural parameter vector \((\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p, \gamma_4).\) There are two approaches we might follow to estimate the parameter vector \((\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p, \gamma_4).\)

First, we apply the Frisch-Waugh-Lovell theorem and project \(\hat{va}_{jt}, k_{jt}, k_{jt}^2, \hat{va}_{jt-1}^2, k_{jt-1}^3, \)
\( k_{jt-1}^4, \hat{v}_a_{jt-1}k_{jt-1}, \hat{v}_a_{jt-1}k_{jt-1}^2, r_{jt-1} \) and \( r_{0t-1} \) on the set of covariates \((1 - d_{jt-1})\gamma_{1nt}, d_{jt-1}\gamma_{2nt}, \hat{v}_a_{jt-1}\gamma_{3nt}, k_{jt-1}^2\gamma_{3nt}, k_{jt-1}^2\gamma_{3nt})\). Denoting the residuals from this regression with a prime, we estimate \((\beta_k, \beta_{kk}, \rho_1, \rho_2, \rho_3, \gamma_4, \gamma_a, \gamma_p)\) using NLS on the following estimating equation

\[
\hat{v}_a'_{jt} = \beta_k k_{jt}^4 + \beta_{kk}(k_{jt}^2)'
\]

\[
+ \rho_1(((1 - d_{jt-1})\hat{v}_a_{jt-1})' - \beta_k((1 - d_{jt-1})k_{jt-1})' - \beta_{kk}((1 - d_{jt-1})k_{jt-1}^2)')
\]

\[
+ \rho_2((d_{jt-1}\hat{v}_a_{jt-1})' - \beta_k(d_{jt-1}k_{jt-1})' - \beta_{kk}(d_{jt-1}k_{jt-1}^2)')
\]

\[
+ \rho_3((r_{jt-1}\hat{v}_a_{jt-1})' - \beta_k(r_{jt-1}k_{jt-1})' - \beta_{kk}(r_{jt-1}k_{jt-1}^2)')
\]

\[
+ \gamma_4((\hat{v}_a_{jt-1})' + \beta_k^2(k_{jt-1})' + \beta_{kk}^2(k_{jt-1})' + 2\beta_k\beta_{kk}(k_{jt-1})' - 2\beta_k(\hat{v}_a_{jt-1}k_{jt-1})')
\]

\[
- 2\beta_{kk}(\hat{v}_a_{jt-1}k_{jt-1}^2)') + \gamma_a r_{jt-1} + \gamma_p r_{0t-1} + \kappa_2 \eta_{jt}'.
\]

(35)

Given that we have previously regressed on \((\hat{v}_a_{jt-1}\gamma_{3nt}, k_{jt-1}\gamma_{3nt}, k_{jt-1}^2\gamma_{3nt})\), this regression does not allow to separately identify \(\rho_1\) and \(\rho_2\) (we can only identify the difference between both of them). However, this approach will allow us to test whether \(\rho_3\) and \(\gamma_4\) are statistically different from zero.

A second approach relies on the assumption that \(\gamma_{3nt} = \gamma_3\). This implies assuming that \(\kappa_{3nt}^3 = \kappa^3\) (i.e. price and quantity indices are assumed constant across markets). Given this assumption, we may apply the Frisch-Waugh-Lovell theorem and project \(\hat{v}_a_{jt}, \hat{v}_a_{jt-1}, k_{jt}, k_{jt-1}, k_{jt-1}^2, \hat{v}_a_{jt-1}, k_{jt-1}^3, k_{jt}^k, \hat{v}_a_{jt-1}k_{jt-1}, \hat{v}_a_{jt-1}k_{jt-1}^2, r_{jt-1}\) and \(r_{0t-1}\) on the set of covariates \((1 - d_{jt-1})\gamma_{1nt}, d_{jt-1}\gamma_{2nt})\). Denoting the residuals from this regression with a prime, we estimate \((\beta_k, \beta_{kk}, \rho_1, \rho_2, \rho_3, \gamma_4, \gamma_a, \gamma_p)\) using NLS on the following estimating equation

\[
\hat{v}_a'_{jt} = \beta_k k_{jt}^4 + \beta_{kk}(k_{jt}^2)'
\]

\[
+ \rho_1(((1 - d_{jt-1})\hat{v}_a_{jt-1})' - \beta_k((1 - d_{jt-1})k_{jt-1})' - \beta_{kk}((1 - d_{jt-1})k_{jt-1}^2)')
\]

\[
+ \rho_2((d_{jt-1}\hat{v}_a_{jt-1})' - \beta_k(d_{jt-1}k_{jt-1})' - \beta_{kk}(d_{jt-1}k_{jt-1}^2)')
\]

\[
+ \rho_3((r_{jt-1}\hat{v}_a_{jt-1})' - \beta_k(r_{jt-1}k_{jt-1})' - \beta_{kk}(r_{jt-1}k_{jt-1}^2)')
\]

\[
+ \gamma_4((\hat{v}_a_{jt-1})' + \beta_k^2(k_{jt-1})' + \beta_{kk}^2(k_{jt-1})' + 2\beta_k\beta_{kk}(k_{jt-1})' - 2\beta_k(\hat{v}_a_{jt-1}k_{jt-1})')
\]

\[
- 2\beta_{kk}(\hat{v}_a_{jt-1}k_{jt-1}^2)') + \gamma_a r_{jt-1} + \gamma_p r_{0t-1} + \kappa_2 \eta_{jt}'.
\]

Note that this equation is identical to equation (35). The only difference is that its covariates are residuals of a projection that does not include \((\hat{v}_a_{jt-1}\gamma_{3nt}, k_{jt-1}\gamma_{3nt}, k_{jt-1}^2\gamma_{3nt})\). Therefore, both \(\rho_1\) and \(\rho_2\) are separately identified.

Finally, a third approach relies on assuming that \(\mu_{1nt} = \mu_1, \mu_{2nt} = \mu_2, \) and \(\kappa_{3nt}^3 = \kappa_{3nt-1}^3 = \kappa^3\). Once we impose this restriction, we use NLS to estimate \((\gamma_1, \gamma_2, \kappa_3, \beta_k, \beta_{kk}, \rho_1, \rho_2, \rho_3, \gamma_4, \gamma_a, \gamma_p)\) directly from equation (33), where \(\gamma_1 = \kappa_2 \mu_1, \gamma_2 = \kappa_2 \mu_2, \) and \(\gamma_4 = \rho_4/\kappa_2\).
A.3.2 Returns to R&D

Impact of R&D Investment on Revenue Productivity  The effect of a marginal increase in \( r_{0t-1} \) on both \( \tilde{\psi}_{jt} \) for \( j = 1, \ldots, J_t \) and \( \tilde{\psi}_{0t} \) is identical to that in the baseline specification and equal to \( \mu_p \) and \( \mu_{0p} \), respectively. However, the propagation of the change in productivity at period \( t \) to subsequent periods is affected by the non-linearities introduced in equations (24) and (25).

Specifically, this propagation depends on the value of the parameters \( \rho_1 \) and \( \rho_2 \). Therefore, in order to compute the impact of R&D investment on revenue productivity we use the estimates obtained either by the second or the third approach described in Section A.3.1

\[
\frac{\partial \tilde{\psi}_{jt+s}}{\partial r_{0t-1}} = (1 - d_{jt+s-1})\rho_1 + d_{jt+s-1}(\rho_2 + \rho_3 r_{jt-1}) + 2\rho_4 \tilde{\psi}_{jt+s-1},
\]

or, equivalently,

\[
\frac{\partial \tilde{\psi}_{jt+s}}{\partial \tilde{\psi}_{jt+s-1}} = (1 - d_{jt+s-1})\rho_1 + d_{jt+s-1}(\rho_2 + \rho_3 r_{jt+s-1}) + 2\gamma_{4}\tilde{\psi}_{jt+s-1},
\]

with \( \tilde{\psi}_{jt+s-1} = v a_{jt+s-1} - \kappa^3 - h(l_{jt+s-1}, k_{jt+s-1}; \beta) = \tilde{v}a_{jt+s-1} - \kappa^3 - h(k_{jt+s-1}; \beta_k, \beta_{kk}) \). Therefore, if \( s > 0 \),

\[
\frac{\partial E[\tilde{\psi}_{jt+s}|S_{it}]}{\partial r_{0t-1}} = E \left[ \frac{\partial \tilde{\psi}_{jt+s}}{\partial r_{0t-1}} \bigg| S_{it} \right] = E \left[ \frac{\partial \tilde{\psi}_{jt+s}}{\tilde{\psi}_{jt+s-1}} \frac{\partial \tilde{\psi}_{jt+s-1}}{\partial r_{0t-1}} \right] = \mu_p E \left[ \prod_{s'=0}^{s-1} \left( (1 - d_{jt+s'})\rho_1 + d_{jt+s'}(\rho_2 + \rho_3 r_{jt+s'}) + 2\gamma_{4}\tilde{\psi}_{jt+s'} \right) \bigg| S_{it-1} \right],
\]

and the cumulative effect over infinite periods ahead is

\[
\sum_{s=0}^{\infty} \frac{\partial E[\tilde{\psi}_{jt+s}|S_{it}]}{\partial r_{0t-1}} = \mu_p E \left[ \sum_{s=1}^{\infty} \prod_{s'=1}^{s} \left( (1 - d_{jt+s'-1})\rho_1 + d_{jt+s'-1}(\rho_2 + \rho_3 r_{jt+s'-1}) + 2\gamma_{4}\tilde{\psi}_{jt+s'-1} \right) \bigg| S_{it-1} \right],
\]
Taking the observed data in year 1994 as steady-state, we can simplify this expression as

\[ \sum_{s=0}^{\infty} \frac{\partial E[\tilde{\psi}_{jt+1}]}{\partial r_{0t-1}} \]

\[ = \mu_p \sum_{s=1}^{\infty} \prod_{j' = 1}^{s} (1 - d_j 1994) \rho_1 + d_j 1994 (\rho_2 + \rho_3 r_j 1994) + 2 \gamma_4 \tilde{\psi}_j 1994) \big|_{s1 1994} \]

\[ = \mu_p \sum_{s=1}^{\infty} \prod_{j' = 1}^{s} (1 - d_j 1994) \rho_1 + d_j 1994 (\rho_2 + \rho_3 r_j 1994) + 2 \gamma_4 \tilde{\psi}_j 1994) \]

\[ = \mu_p \sum_{s=1}^{\infty} \prod_{j' = 1}^{s} (1 - d_j 1994) (\rho_1 + 2 \gamma_4 \tilde{\psi}_j 1994) + d_j 1994 (\rho_2 + \rho_3 r_j 1994 + 2 \gamma_4 \tilde{\psi}_j 1994) \]

\[ = \mu_p \sum_{s=1}^{\infty} \bigg( (1 - d_j 1994) (\rho_1 + 2 \gamma_4 \tilde{\psi}_j 1994) s^{-1} + d_j 1994 (\rho_2 + \rho_3 r_j 1994 + 2 \gamma_4 \tilde{\psi}_j 1994) s^{-1} \bigg) \]

\[ = \mu_p \left( \frac{1 - d_j 1994}{1 - \rho_1 - 2 \gamma_4 \tilde{\psi}_j 1994} + \frac{d_j 1994}{1 - \rho_2 - \rho_3 r_j 1994 - 2 \gamma_4 \tilde{\psi}_j 1994} \right), \]

where \( \tilde{\psi}_j 1994 = \tilde{\omega}_a 1994 - \kappa^3 - h(k_j 1994; \beta_k, \beta_{kk}) \). Aggregating across all affiliates, the expression equivalent to that in equation (??) for the case described in Section 7.1 becomes

\[ \sum_{j=1}^{J_{1994}} \mu_p \left( \frac{1 - d_j 1994}{1 - \rho_1 - 2 \gamma_4 \tilde{\psi}_j 1994} + \frac{d_j 1994}{1 - \rho_2 - \rho_3 r_j 1994 - 2 \gamma_4 \tilde{\psi}_j 1994} \right), \]

where \( J_{1994} \) denotes the total number of affiliates in 1994.

For the case of the parent firm, the cumulative effect over infinite periods of an infinitesimal change in \( r_{01994} \) is

\[ \frac{\mu_{0p}}{1 - \rho_2 - \rho_0 r_{01994} - 2 \gamma_0 \tilde{\psi}_0 1994} \]

where \( \tilde{\psi}_0 1994 = \tilde{\omega}_a 01994 - \kappa^3 - h(k_0 1994; \beta_{0k}, \beta_{0kk}) \).

**Impact of R&D Investment on MNC’s Value** Using the expressions derived above and following the same steps as in Section 6.2, the equation equivalent to that in equation (??) is

\[ \frac{Y_{01994}}{R_{01994}} \frac{\mu_{0p}}{1 - \rho_2 - \rho_0 r_{01994} - 2 \gamma_0 \tilde{\psi}_0 1994} + \frac{Y_{j1994}}{R_{j1994}} \sum_{j=1}^{J_{1994}} \left( \frac{1 - d_j 1994}{1 - \rho_1 - 2 \gamma_4 \tilde{\psi}_j 1994} + \frac{d_j 1994}{1 - \rho_2 - \rho_3 r_j 1994 - 2 \gamma_4 \tilde{\psi}_j 1994} \right), \]

where the first line captures the impact on the parent and the second line the total impact on all affiliates.
A.4 Dependency on Parent’s Productivity: Details

A.4.1 Estimation

From equations (11) and (29), we derive an estimating equation identical to that in equation (12) except that the term \( \gamma_{pp} \tilde{\psi}_0 t \) substitutes the term \( \gamma_p r_{0t-1} \):

\[
va_{jt} = (36) 
\]

\[
h(l_{jt}, k_{jt}; \beta) + (1 - d_{jt-1})(\gamma_{1nt} + \rho_1(va_{jt-1} - h(l_{jt-1}, k_{jt-1}; \beta))) + \\
d_{jt-1}(\gamma_{2nt} + \rho_2(va_{jt-1} - h(l_{jt-1}, k_{jt-1}; \beta))) + \gamma_a r_{jt-1} + \gamma_{pp} \tilde{\psi}_0 t + u_{jt},
\]

Estimating \((\beta, \beta_k, \beta_{kk})\) and \(\varepsilon_{jt}\) following the procedure in Appendix A.2.1, we are left with an estimating equation that is identical to that in equation (33) except that the term \( \gamma_{pp} \tilde{\psi}_0 t \) substitutes the term \( \gamma_p r_{0t-1} \):

\[
\hat{va}_{jt} = (37) 
\]

\[
h(k_{jt}; \beta_k, \beta_{kk}) + (1 - d_{jt-1})(\gamma_{1nt} + \rho_1(\hat{v}a_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk}))) + \\
d_{jt-1}(\gamma_{2nt} + \rho_2(\hat{v}a_{jt-1} - h(k_{jt-1}; \beta_k, \beta_{kk}))) + \gamma_a r_{jt-1} + \gamma_{pp} \tilde{\psi}_0 t + \kappa^2 \eta_{jt}.
\]

In order to estimate the parameters \((\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p)\) from equation (37), we follow two approaches analogous to those described in Section A.2.2. The only two difference with the estimation method described Section A.2.2 is that we need to account for the possible endogeneity affecting the term \( \tilde{\psi}_0 t \). Specifically, as long as the unexpected innovation to productivity, \( \eta_{jt} \), are correlated across firms within the same MNC, the terms \( \tilde{\psi}_0 t \) and \( \eta_{jt} \) will be correlated. In order to obtain estimates of \((\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p)\) that are robust to within-MNC correlation in \( \eta_{jt} \), instead of using NLS to estimate this parameter vector (as described in Section A.2.2) we use a two-step GMM estimator using the lagged value of the parent’s productivity, \( \tilde{\psi}_{0t-1} \), and instrument for its current value, \( \tilde{\psi}_{0t} \).

In equations (36) and (37), we have treated the parent’s productivity term \( \tilde{\psi}_0 t \) as if it was observed. In practice, this term is not directly observed in the data. In order to estimate the parameters \((\beta_k, \beta_{kk}, \rho_1, \rho_2, \gamma_a, \gamma_p)\) estimate first the parent’s production function and define a proxy for \( \tilde{\psi}_0 t \) as \( \hat{\tilde{\psi}}_{0t} = \hat{\tilde{v}}a_{0t} - h(k_{0t}; \hat{\beta}_k, \hat{\beta}_{kk}) \). Note that \( \hat{\tilde{\psi}}_{0t} \) does not account for the year fixed effects \( \kappa^3_{0t} \). However, these are automatically accounted for in equation (36) by the market-year effects \( \gamma_{1nt} \) and \( \gamma_{2nt} \).

A.4.2 Returns to R&D

Impact of R&D Investment on Revenue Productivity

Given the specification of parents’ and affiliates’ productivities in equations (8) and (29), a marginal increase in parent R&D at period \( t - 1 \) will affect the revenue productivity of any affiliate \( j \) at any period \( t \), exclusively
through its impact on parent productivity:

\[
\frac{\partial \tilde{\psi}_{jt}}{\partial r_{0t-1}} = \frac{\partial \tilde{\psi}_{jt}}{\partial r_{0t-1}} = \frac{\partial \tilde{\psi}_{jt}}{\partial r_{0t-1}} = \gamma_{pp} \gamma_{0p}.
\]

The effect on revenue productivity in year \( t + 1 \) will happen through two different channels: through \( \tilde{\psi}_{jt} \) and through \( \tilde{\psi}_{0t+1} \).

\[
\frac{\partial \tilde{\psi}_{jt+1}}{\partial r_{0t-1}} = \left( \frac{\partial \tilde{\psi}_{jt+1}}{\partial \tilde{\psi}_{jt}} \frac{\partial \tilde{\psi}_{jt}}{\partial r_{0t-1}} + \frac{\partial \tilde{\psi}_{jt+1}}{\partial \tilde{\psi}_{0t+1}} \frac{\partial \tilde{\psi}_{0t+1}}{\partial r_{0t-1}} \right) \frac{\partial \tilde{\psi}_{0t}}{\partial r_{0t-1}}
\]

\[
= \left( (1 - d_{jt}) \rho_1 + d_{jt} \rho_2 \right) \left( (1 - d_{jt}) \rho_1 + d_{jt} \rho_2 + \rho_{02} \right) \gamma_{pp} \gamma_{0p} + \rho_{02}^2 \gamma_{pp} \gamma_{0p}
\]

\[
= \left( (1 - d_{jt+1}) \rho_1 + d_{jt+1} \rho_2 \right) \left( (1 - d_{jt+1}) \rho_1 + d_{jt+1} \rho_2 + \rho_{02} \right) \gamma_{pp} \gamma_{0p}.
\]

Generalizing this expression for a general \( \tilde{\psi}_{jt+s} \) and assuming that the values of all variables are kept constant at their observed 1994 values, we obtain that, for an affiliate performing R&D in year 1994,

\[
\frac{\partial \tilde{\psi}_{jt+s}}{\partial r_{0t-1}} = \gamma_{pp} \gamma_{0p} \left( \sum_{s' = 0}^{s} \rho_2^{s-s'} \rho_{02}^{s'} \right) = \gamma_{pp} \gamma_{0p} \rho_2^s \left( \sum_{s' = 0}^{s} \left( \rho_{02}/\rho_2 \right)^{s'} \right) = \gamma_{pp} \gamma_{0p} \rho_2^s \times \frac{1 - \left( \rho_{02}/\rho_2 \right)^s}{1 - \left( \rho_{02}/\rho_2 \right)^s}
\]

\[
= \frac{\gamma_{pp} \gamma_{0p} \rho_2^s}{1 - \left( \rho_{02}/\rho_2 \right)^s} - \frac{\gamma_{pp} \gamma_{0p} \rho_2^s}{1 - \left( \rho_{02}/\rho_2 \right)^s} = \frac{\gamma_{pp} \gamma_{0p} \rho_2^s \left( \rho_2^s - \rho_{02}^s \right)}{\rho_2^s - \rho_{02}^s},
\]

and, for an affiliate not performing R&D in steady state,

\[
\frac{\partial \tilde{\psi}_{jt+s}}{\partial r_{0t-1}} = \gamma_{pp} \gamma_{0p} \left( \sum_{s' = 0}^{s} \rho_1^{s-s'} \rho_{01}^{s'} \right) = \gamma_{pp} \gamma_{0p} \rho_1^s \left( \sum_{s' = 0}^{s} \left( \rho_{01}/\rho_1 \right)^{s'} \right) = \gamma_{pp} \gamma_{0p} \rho_1^s \times \frac{1 - \left( \rho_{01}/\rho_1 \right)^s}{1 - \left( \rho_{01}/\rho_1 \right)^s}
\]

\[
= \frac{\gamma_{pp} \gamma_{0p} \rho_1^s}{1 - \left( \rho_{01}/\rho_1 \right)^s} - \frac{\gamma_{pp} \gamma_{0p} \rho_1^s}{1 - \left( \rho_{01}/\rho_1 \right)^s} = \frac{\gamma_{pp} \gamma_{0p} \rho_1^s \left( \rho_1^s - \rho_{02}^s \right)}{\rho_1^s - \rho_{02}^s}.
\]
Therefore, the cumulative effect of an infinitesimal change in \( r_{0t-1} \) on the sum of value added productivity for all affiliates over any subsequent period (assuming that the number of affiliates stays constant at their 1994 level) is

\[
\gamma_{pp}\gamma_{0p}(J_{i1994,d=0} \frac{\rho_1}{\rho_1 - \rho_{02}} (\frac{1}{1 - \rho_1} - \frac{1}{1 - \rho_{02}}) + J_{i1994,d=1} \frac{\rho_2}{\rho_2 - \rho_{02}} (\frac{1}{1 - \rho_2} - \frac{1}{1 - \rho_{02}})),
\]

or, equivalently,

\[
\gamma_{pp}\gamma_{0p}(J_{i1994,d=0} \frac{\rho_1}{(1 - \rho_1)(1 - \rho_{02})} + J_{i1994,d=1} \frac{\rho_2}{(1 - \rho_2)(1 - \rho_{02})}),
\]

For the parent firm, the elasticity of the cumulative effect on parent productivity with respect to parent R&D is identical to that in the baseline case (see equation 18).

**Impact of R&D Investment on MNC’s Value**  Using the expressions derived above and following the same steps as in Section 6.2, the equation equivalent to that in equation (??) is

\[
\frac{\partial V(S_{it})}{\partial R_{0t-1}} = \frac{Y_{01994}}{R_{01994}} \frac{\gamma_{0p}}{1 - \delta \rho_{02}} + \gamma_{pp}\gamma_{0p}(J_{i1994,d=0} \frac{\delta \rho_1}{(1 - \delta \rho_1)(1 - \delta \rho_{02})} \frac{\bar{Y}_{1994,d=0}}{R_{01994}} + J_{i1994,d=1} \frac{\delta \rho_2}{(1 - \delta \rho_2)(1 - \delta \rho_{02})} \frac{\bar{Y}_{1994,d=1}}{R_{01994}}).
\]

**A.5 Data and Measurement**

**Multinational activity and data sample:** Confidential firm-level data on the activity abroad of U.S. multinational firms is provided by the Bureau of Economic Analysis through a sworn-status research arrangement. The data include detailed financial and operating information for each foreign affiliate owned (at least a 10% share) by a U.S. entity. The data variables used for this project were extracted from the BEA’s comprehensive data files for each year during 1989–2008, and then merged by parent and affiliate identification numbers to form a complete panel.

The estimation described in sections 4 and 5 proceeds at the industry level for each of five major manufacturing sectors: industrial machinery (SIC 35), electronics (SIC 36), instruments and devices (SIC 38), chemicals (SIC 28), and transportation equipment (SIC 37). We build separate datasets by industry that are each subject to a uniform cleaning procedure. Observations are excluded if a) values are carried over or imputed based on previous survey responses; b) the affiliate is minority-owned or small and therefore exempt from reporting R&D expenditures; or c) the observation is neither preceded nor succeeded by another observation corresponding to the same affiliate. Below, we evaluate the extent to which the final dataset and the raw data capture overlapping information regarding the link between R&D and productivity.

The data-cleaning procedure impacts sample sizes across all tables. We therefore provide a detailed, step-by-step description of this procedure for the chemical industry (SIC 28) as a representative example. The complete dataset spanning all industries and 1989–2008 includes 612,196 affiliate-year level observations. Based on the primary industry reported for each affiliate, ap-
proximately one-third of these observations correspond to manufacturing affiliates in SIC 20–39 (36.84%), one-sixth correspond to retail affiliates in SIC 50–59 (18.92%), and the remaining half of affiliate observations correspond to other industries. The raw dataset for the chemical industry includes each parent firm reporting SIC 28 as its primary industry, and each of its foreign affiliates; this includes 226,076 observations.

The BEA requires only majority-owned and relatively large foreign affiliates of U.S. parent firms to report R&D expenditures, and we therefore restrict our analysis to these affiliates. The size threshold for affiliate participation in R&D reporting varies across years during the sample period; the highest such threshold in 1999 indicates an affiliate must report R&D only if its sales, assets, or net income exceed $50 million. To maintain a consistent sample, this cut-off is imposed uniformly across years in our baseline analysis; 80,191 affiliate-year observations remain in the sample after this cleaning step. While most affiliates are not continuously present in the data, the estimation in sections 4 and 5 requires only a minimum of two consecutive observations per affiliate; 3,718 observations are dropped to satisfy this restriction. An additional 10,543 imputed values are dropped, bringing the total number of observations to 65,930. These observations are collected to form three separate datasets: 1) 17,369 affiliate-year observations in the chemical industry (SIC 28); 2) 31,250 affiliate-year observations in manufacturing (SIC 20 through 39); 3) 39,945 affiliate-year observations in manufacturing and retail both (SIC 20 through 39, SIC 50 through 59). Finally, observations with missing or negative values for value added, lagged value added, capital, lagged capital, labor, lagged labor, or R&D expenditures are dropped to arrive at the following number of observations in each of the three datasets above: 1) 5,730; 2) 7,439 observations; and 3) 11,016 observations. An identical data cleaning process is applied to SIC 35, 36, 37, and 38.

Although all specifications in section 5 include country-year fixed effects so that our results are not sensitive to the following step, reported values in each year are nevertheless adjusted for inflation to U.S. dollars in 2004 using the the following consumer price index-based correction factors from the U.S. Bureau of Labor Statistics: 1989, 1.52; 1990, 1.45; 1991, 1.39; 1992, 1.35; 1993, 1.31; 1994, 1.27; 1995, 1.24; 1996, 1.20; 1997, 1.18; 1998, 1.16; 1999, 1.13; 2000, 1.10; 2001, 1.07; 2002, 1.05; 2003, 1.03; 2004, 1; 2005, 0.967; 2006, 0.937; 2007, 0.911; 2008, 0.877. In addition, during the sample period, the BEA switches from SIC to NAICS-based parent-firm and foreign-affiliate industry classifications. The U.S. Census Bureau concordance is applied to match NAICS-based observations to each of the five industries.

**Variable definitions in the dataset:** We define the main variables used in our analysis and document information regarding their construction. This information may be found in the instruction booklet for benchmark and annual surveys of U.S. direct investment abroad, Bureau of Economic Analysis, U.S. Department of Commerce. We provide condensed versions of the variable definitions here for clarity.

**U.S. parent:** The BEA requires a survey response from any U.S. person that had a foreign affiliate – that is, that had direct or indirect ownership or control of at least 10 percent of the voting stock of an incorporated foreign business enterprise, or an equivalent interest in an unincorporated
foreign business enterprise – at any time during the U.S. persons fiscal year corresponding to the survey year.

**Affiliate:** An affiliate is defined as a business enterprise located in one country which is directly or indirectly owned or controlled by a person of another country to the extent of 10 percent or more of its voting securities for an incorporated business enterprise or an equivalent interest for an unincorporated business enterprise, including a branch.

**Output:** The surveys collect both parent and affiliate-level sales revenues, which may be used as a measure of output. The BEA also constructs a parent and affiliate-level measure of value added using the following definition from Mataloni and Goldberg (1994). Specifically, the BEA measures value added for the U.S. parent or for a foreign affiliate from the factor-cost side as employee compensation (wages and salaries plus employee benefits), plus profit-type return (net income plus income taxes plus depreciation, less capital gains and losses, less income from equity investments), plus net interest paid (monetary interest paid plus imputed interest paid, less monetary interest received, less imputed interest received), plus indirect business taxes (taxes other than income and payroll taxes plus production royalty payments to governments, less subsidies received), plus capital consumption allowances (depreciation). Our analysis focuses on value added as the primary measure of output.

**R&D expenditure:** The BEA Survey of U.S. Direct Investment Abroad collects information on firms’ innovation expenditures at each production location, subject to reporting requirements documented above. Research and development expenditures includes basic and applied research in science and engineering, and the design and development of prototypes and processes, if the purpose of such activity is to: 1) Pursue a planned search for new knowledge whether or not the search has reference to a specific application; 2) Apply existing knowledge to the creation of a new product or process, including evaluation of use; or 3) Apply existing knowledge to the employment of a present product or process. R&D includes the activities described above, whether assigned to separate R&D organizational units of the company or conducted by company laboratories and technical groups that are not a part of a separate R&D organization. This variable includes all costs incurred to support R&D, including R&D depreciation and overhead. The variable excludes capital expenditures, routine product testing and quality control conducted during commercial production, geological and geophysical exploration, market research and surveys, and legal work pertaining to patents.

**Labor:** Labor is defined as number of employees of the U.S. parent or a foreign affiliate. Employees must be on the payroll at the end of the survey fiscal year, and include part-time employees, but exclude temporary and contract employees not included on your payroll records. The BEA allows this variable to be based on a count taken at some other date during the reporting period may be given provided it is a reasonable estimate of employees on the payroll at the end of the fiscal year of the survey. If the number of employees at the end of the survey fiscal year (or when the count was taken) was unusually high or low due to temporary factors (e.g., a strike), parent and affiliates are to enter the number of employees that reflects normal operations. If the number of employees fluctuates widely during the year due to seasonal business variations, firms are to
report the average number of employees on the payroll during the fiscal year. They are to base such an average on the number of employees on the payroll at the end of each pay period, month or quarter.

Capital: Capital is defined as the net (of depreciation) plant, property, and equipment of the U.S. parent or a foreign affiliate. Unlike assets, this measure thus captures physical capital and not inventories, other current assets, accumulated depreciation and depletion, equity investments in other foreign affiliates of which the reporter is a parent, or other noncurrent assets.

Ownership: Parent ownership of a foreign affiliate is determined based on the U.S. reporter’s direct and indirect ownership interest based on voting stock in an incorporated foreign affiliate, or an equivalent interest in the case of an unincorporated foreign affiliate.

Industry: The BEA surveys collect sales or gross operating revenues for both the U.S. parent and each foreign affiliate. These sales revenues are reported for five or more industries, ranked from largest sales to fifth-largest sales. The industry of an affiliate or U.S. parent is defined based on the industry for which it reports the highest sales revenues. In building the industry-level datasets, we define a parent firm to be in an industry based on whether it has reported top sales revenues in that industry in at least one period.

Affiliate country: The country of location for a foreign affiliate is the country in which the affiliate’s physical assets are located or where its primary activity is carried out.