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Towards more complete capture of spillover effects

By: Bruno Merlevede and Koen Schoors

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Bruno Merlevede*
Ghent University

Koen Schoors†
WDI and Ghent University

Abstract

We analyze productivity spillovers of FDI on domestic companies, both within and across industries. In the identification of intraindustry spillovers, we separate out labor market effects from other effects. Interindustry spillovers are identified through upstream, downstream, and supply-backward linkage effects. Dynamic input output tables are used to construct the linkages. For a panel of Romanian firms, we find evidence that labor market effects differ from other intraindustry effects. Spillovers across industries dominate those within industries. The supply-backward effect behaves as predicted by theory. Firm-specific level of technology, firm size, and ownership structure are all found to affect spillovers.

JEL Classification: F2
Keywords: FDI, spillovers, absorptive capability, firm size, ownership structure

*Corresponding author: Postdoctoral Fellow of the Fund for Scientific Research - Flanders (Belgium) (F.W.O.-Vlaanderen), Department of Economics and CERISE (Centre for Russian International Socio-Political and Economic Studies), Ghent University, Tweekerkenstraat 2, B-9000 Ghent, Belgium, email: Bruno.Merlevede@UGent.be

†Department of Economics and CERISE, Ghent University, Tweekerkenstraat 2, B-9000 Ghent, Belgium, Koen.Schoors@UGent.be

1 Introduction

When a firm invests in a foreign country, it often brings with it proprietary technology to compete successfully with indigenous firms (James R. Markusen, 1995). Believing that this transferred technology will be adopted by domestic firms, host country policymakers may try to implement policies to attract foreign direct investment (FDI). Unfortunately, such faith in the positive spillover effects of FDI contrasts starkly with the empirical evidence (Dani Rodrik, 1999). The literature surveys of Holger Görg and David Greenaway (2004) and Beata Smarzynska Javorcik (2004) conclude that there is no clear evidence of aggregate positive spillovers from FDI.

Looking at the literature more closely, however, we see a distinction between spillovers to firms in the same industries (intraindustry or horizontal spillovers) and spillovers to firms in linked industries (interindustry or vertical spillovers). Horizontal spillovers have received widespread attention, while the vertical spillover discussion launched by Dermot McAleese and Donogh McDonald (1978) and Sanjaya Lall (1980) languished for two decades until its recent revival by Koen Schoors and Bartoldus van der Tol (2002) and Smarzynska Javorcik. Schoors and van der Tol and Smarzynska Javorcik distinguish vertical spillovers that occur through contacts between foreign firms and their local suppliers in upstream industries (backward spillovers) from those that occur through contacts between foreign firms and their downstream customers (forward spillovers). Both studies suggest that spillovers between industries dominate spillovers within industries.

To this mix, we add another type of interindustry spillover effect – the supply-backward spillover. Markusen and Anthony J. Venables (1999) theorize that "FDI may also create demands for local output and these 'backward linkages' may strengthen supply industries, this in turn feeding (via forward linkages) to other local firms" (Markusen and Venables, pp. 336-37). In a two-sector model, they show how foreign investment may fuel demand for locally produced intermediate products, encouraging local suppliers to produce inputs conforming to higher foreign quality standards and eventually making local producers in downstream industries more productive through the availability of better inputs.

We analyze productivity spillovers of FDI in a sample of domestic Romanian companies. Our analysis extends the literature in five ways. *i)* We test for the presence of supply-backward spillovers. *ii*) We better identify horizontal spillovers by separating out labor market effects from other effects. *iii)* Although the literature suggests different conditionalities for spillovers, it analyzes them in isolation. We combine firm-specific level of technology, degree of foreign ownership, and firm size and allow for possible non-linearities. *iv)* The few papers that consider vertical spillovers use static input-output tables and a panel of firms.

This creates an implicit assumption that the structure of the economy does not change over time. We use instead a series of input-output tables. v) Rather than limiting our scope to manufacturing industries, we consider all industries. A considerable amount of foreign investment now goes to service industries such as transport, communication services, financial services, business services, and trade. These industries are important suppliers to the rest of the economy and their improved productivity may have effects on linked industries. Failure to acknowledge the role of these industries in the production chain creates a strong possibility of bias.

Our results indicate that horizontal spillovers via the labor market differ from other horizontal spillovers and that vertical spillovers are economically more important than horizontal spillovers. The presence of a supply-backward spillover is strongly supported by the data. Additionally, the dependence of spillovers on the degree of foreign ownership, firm size, and the firm's level of technology is non-linear. Ignoring non-manufacturing industries and changes in the economic structure is shown to bias results.

This paper continues as follows. In section 1, we provide a short overview of the spillover literature. Section 2 focuses on the interactions of firm-specific conditionalities: level of technology, degree of foreign ownership, and firm size. Section 3 lays out the data and the estimation strategy. Results and interpretation are provided in section 4. Section 5 concludes.

2 Spillovers of foreign investment to local firm productivity

The literature has identified several channels through which FDI may affect productivity of firms in the host country. Here, we consider horizontal and vertical spillovers. Figure 1 illustrates how the spillovers considered in this paper run through the host economy's production chain.

Horizontal spillovers run from a foreign firm to a host country firm in the same industry. David J. Teece (1977) suggests two main channels for horizontal spillovers: mobility of workers trained by foreign firms (see Andrea Fosfuri *et al.*, 2001, and Görg and Eric Strobl, 2005) and technology imitation (the demonstration effect). Foreign entry may also fuel competition in the domestic market. Fiercer competition urges host country firms to either use existing technologies and resources more efficiently or adopt new technologies and organizational practices, which provides another important channel of horizontal spillover (see Brian J. Aitken and Ann E. Harrison, 1999, and Amy Jocelyn Glass and Kamal Saggi,

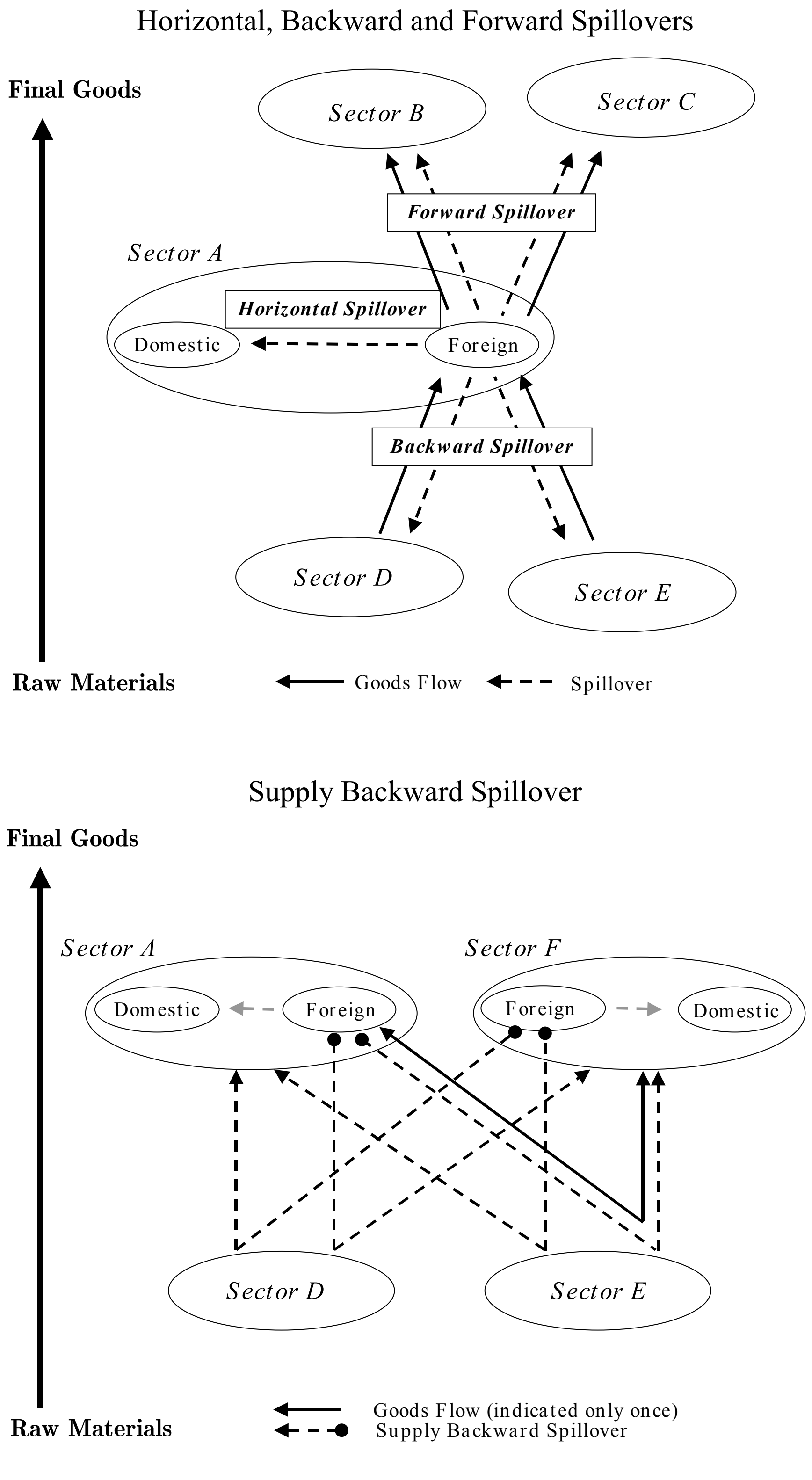

Figure 1: Spillover schemes

2002). None of these effects is necessarily positive, however. Labor market dynamics may entail negative spillovers such as a brain drain of local talent to foreign firms to the detriment of local firm productivity (Garrick Blalock and Paul J. Gertler, 2004) or an overall increase in wages irrespective of productivity improvements caused by foreign firms paying higher wages (Aitken *et al.*, 1996). Where foreign technology is easily copied, the foreign investor may choose to avoid leakage costs on state-of-the-art technology by restricting its technology transfer to technology that is only marginally superior to technology found in the host country (see Glass and Saggi, 1998). Such policies obviously limit the scope for horizontal spillovers via demonstration effects. The higher productivity of foreign affiliates may also lead to lower prices or less demand for the products of domestic competitors. If domestic firms fail to respond to the increased competition and raise productivity, they will be pushed up their average cost curves. Ultimately, domestic producers may not merely fall behind, but fall by the wayside, driven out of business by the shock of foreign entry (see Aitken and Harrison on this market-stealing effect). These partial effects are hard to disentangle empirically. We identify labor market spillovers by including a measure that accounts for labor market effects next to a measure that incorporates the net effect of all other spillovers.

As seen from the top panel in Figure 1, backward spillovers go from the foreign firm to its upstream local suppliers. Thus, even if foreign firms attempt to minimize their technology leakage to direct competitors (horizontal effect), they may still want to assist their local suppliers in providing inputs of sufficient quality in order to realize the full benefits of their investment. In other words, they want the inputs from the host country to be lower cost yet similar in quality to inputs in the home country.[1] If the foreign firm decides to source locally, it may transfer technology to more than one domestic supplier and encourage upstream technology diffusion to circumvent a hold-up problem. Andres Rodriguez-Clare (1996) shows that the backward linkage effect is more likely to be favorable when the good produced by the foreign firm uses intermediate goods intensively and when the home and host countries are similar in terms of the variety of intermediate goods produced. Under reversed conditions, the backward linkage effect could even damage the host country's economy.

Figure 1 also suggests how a forward spillover goes from the foreign firm to its downstream local buyer of inputs. The availability of better inputs due to foreign investment enhances the productivity of firms that use these inputs. However, there is also a danger that inputs produced locally by foreign firms are more expensive and less adapted to local requirements. In this case there would be a negative forward spillover.

[1] This incentive is qualified, of course. First, when transportation costs between the home and host country are low enough, MNCs can source inputs in their home country rather than in the host country. Second, MNCs can put pressure on uncooperative local suppliers by inducing suppliers from their home country to invest in the host country, creating an isolated enclave of mutually linked foreign firms.

Finally, we note the supply-backward spillover mentioned in the bottom panel of Figure 1, which goes from the foreign firm through its local suppliers to the local customers of these suppliers. Markusen and Venables suggest a trade-off between increased product market competition, which they claim had an adverse effect on productivity, and interindustry linkage effects, which are said to be positive. When vertical linkage effects are strong enough, foreign investors can stimulate demand for locally produced intermediate products. This demand stimulus encourages local suppliers to invest and produce inputs conforming to higher quality standards (see also Magnus Blomström and Ari Kokko, 1998). This may not only exert a positive effect on the productivity of local intermediate good producers, but may also stimulate the productivity of their local customers.[2]

3 Conditionalities

The existence, direction, and magnitude of spillovers may depend on firm-specific characteristics. We consider how three characteristics – level of technology, degree of foreign ownership, and firm size – interact to affect FDI spillovers.

Ronald Findlay (1978) constructs a dynamic model of technology transfer through FDI from developed to developing countries. He argues that there is a positive connection between the distance to the world's technological frontier and economic growth. Findlay's model implies that productivity spillovers are an increasing function of the technology gap between foreign and domestic firms. Measures of the level of technology, however, are commonly used as a measure of absorptive capability. This notion refers to the ability of firms to assimilate outside knowledge and technology. Blomström (1986) finds that foreign firms are more likely to eliminate the local competition when the initial level of technology is low and human capital is poor, i.e. if the absorptive capability is low. Kokko *et al.* (1996) find that horizontal spillovers are positive and significant only for plants with small or moderate technology gaps relative to foreign firms. Fredrik Sjöholm (1999) notes that high technology differences give rise to large spillovers, although results are sensitive to the choice of technology measure. Examining a sample of Russian firms, Ksenia Yudaeva *et al.* (2003) observe that the stock of human capital in regions where foreign firms operate is a factor in determining the extent to which domestic firms benefit from the entry of foreign firms. However, there is no theoretical ground for the assumption that technology affects FDI spillovers linearly. Findlay suggests that spillovers are a negative function of the level of technology, while the absorptive capability interpretation suggests a positive relation.

[2] Because Markusen and Venables consider a two-sector model, local customers are always in the same industry as foreign firms. We extend their idea to all local customers.

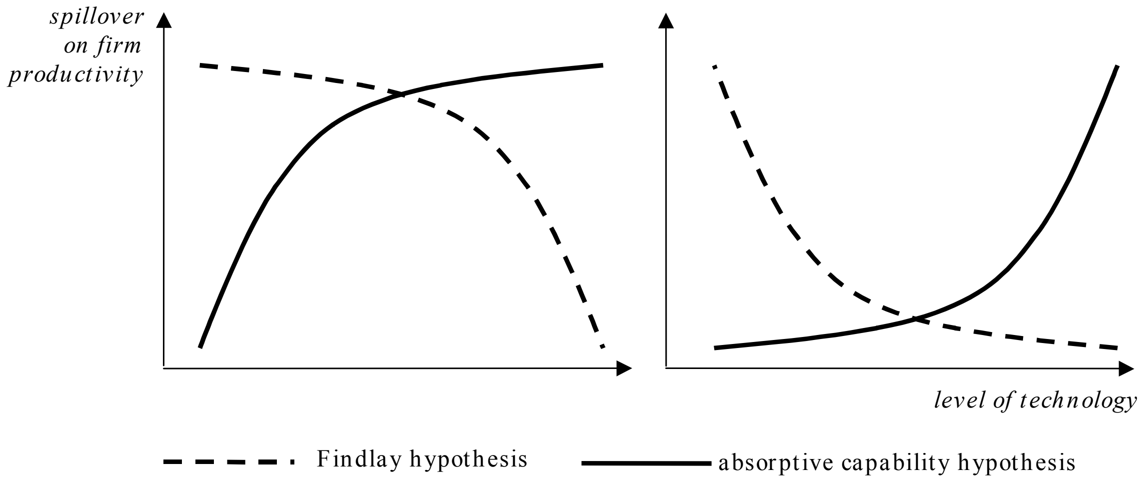

Figure 2: Spillovers as a non-linear function of the level of technology

Figure 2 suggests roughly how these competing hypotheses might give rise to non-linear relationships. Sourafel Girma and Görg (2005) offer a U-shaped relationship between productivity growth and their horizontal spillover variable interacted with the level of technology. Girma (2005) observes that horizontal spillovers increase with absorptive capability up to a threshold level, beyond which the increase is much less pronounced.

The degree of foreign ownership also appears to play a role. Blomström and Sjöholm (1999) suggest that productivity spillovers increase with local participation in the foreign firm because it facilitates access to foreign technology. This creates a tension, however, as foreign firms with extensive local participation have less control over their proprietary knowledge, which may make them reluctant to bring in state-of-the-art technology when they seek to reduce technology leakage. In a cross-section analysis of Indian firms, Blomström and Sjöholm find that establishments with minority and majority foreign ownership differ in the degree of FDI spillovers. Smarzynska Javorcik and Mariana Spatareanu (2003) perform the same test in a panel of Romanian firms. They find that positive horizontal spillovers originate from majority foreign-owned firms, because they bring more advanced technology with them, while minority foreign-owned firms are associated with negative horizontal spillovers. With respect to backward spillovers, the direction of the effect switches. Minority foreign-owned firms give rise to positive backward spillovers, while majority foreign-owned firms give rise to negative backward spillovers. This is probably explained by the fact that firms with higher local participation are more likely to buy their inputs locally. Smarzynska Javorcik's own findings for Lithuania support this explanation.

Thirdly, firm size may be important. If larger firms have greater resources with which to exploit innovative opportunities, they should be able to benefit more from foreign technology. On the other hand, small and medium-sized firms are often important sources of innovation. Small firms make important contributions to innovation because they are less bureaucratic and exploit innovations that might otherwise appear insignificant to large firms (Evis Sinani and Klaus E. Meyer, 2004). This appears to be the case in Romania, where large enterprises (typically former state enterprises) remain clumsy at adopting new technologies or adapting to market changes.

4 Empirical approach, data and variables

4.1 Empirical approach

We use a two-step procedure. The first step consists in the estimation of a standard production function. The second step relates the estimated total factor productivity to measures of FDI spillovers and several control variables.

Our initial problem is that firms react to firm-specific productivity shocks that are not observed by the researcher. For example, a firm confronted with a large positive productivity shock might respond by using more inputs. Zvi Griliches and Jacques Mairesse (1995) provide a detailed account of this problem and make the case that inputs should be treated as endogenous variables since they are chosen on the basis of the firm's unobservable assessment of its productivity. OLS estimates of production functions therefore yield biased estimates of factor shares and biased estimates of productivity.[3] We thus employ the semi-parametric approach suggested by Steven G. Olley and Ariel Pakes (1996) and subsequently modified by James Levinsohn and Amil Petrin (2003). While details on the methodology appear in Appendix A, it is sufficient here to note that it allows for firm-specific productivity differences that exhibit idiosyncratic changes over time. We estimate domestic industry production functions for each industry j in the period 1998–2001, excluding foreign firms from the estimation. A measure of total factor productivity tfp_{it} is obtained as the difference between value added and capital and labor inputs, multiplied by their estimated coefficients:

$$\forall j : tfp_{it} = va_{it} - \widehat{\beta}_l l_{it} - \widehat{\beta}_k k_{it} \tag{1}$$

In the second step, we relate tfp_{ijrt} to a vector of spillover variables, **FDI**, a concentration index, H, and industry, region, and time dummies (α_j, α_r, and α_t). Note that we pool industries for the estimation of (2), whereas (1) is an industry-specific estimation.

[3] Specifically, the coefficient of labor is biased upwards, while the capital coefficient is biased downwards.

$$tfp_{ijrt} = \alpha_i + \Psi_1 f\left(\mathbf{FDI}_{jt}, T_{ijrt}\right)' + \alpha_2 H_{jt} + \alpha_j + \alpha_r + \alpha_t + \varepsilon_{ijrt} \tag{2}$$

Concentration (H_{jt}) is measured by the Herfindahl concentration index. The theoretical literature is inconclusive as to the impact of competition on productivity. Stephen J. Nickell (1996) finds a positive impact of competition on firm performance, which suggests a negative sign for α_2. The vector of spillover variables ($\mathbf{FDI}_{jt}$) covers different transformations of the horizontal and vertical spillovers. We first look at the spillover variables traditionally considered in the literature. Next, we add the horizontal labor market spillover and the supply-backward spillover. We then interact the spillover variables with the firm-specific level of technology (T_{ijrt}) in a non-linear way. Finally, we consider whether the degree of foreign ownership and firm size play a role. Specification (2) is first differenced and estimated as a fixed effects model:

$$\Delta tfp_{ijrt} = \beta_i + \Omega_1 \Delta f\left(\mathbf{FDI}_{jt}, T_{ijrt}\right)' + \beta_2 H_{jt} + \beta_t + \varepsilon_{ijrt} \tag{3}$$

The fixed effects control for all time-invariant firm-specific unobservables driving productivity growth, including region and industry effects. The first-differenced time dummies still control for the business cycle. Because $\mathbf{FDI}_{jt}$ and H_{jt} are defined at the industry level, while estimations are performed at the firm level, standard errors need to be adjusted (see Brent R. Moulton, 1990). Standard errors are clustered for all observations in the same industry and year.

4.2 Data description and variable definitions

Romanian firm-level data for 1996–2001 are drawn from the Amadeus database published on DVD and CD by Bureau Van Dijk. The entire Amadeus series is used to construct a database of time-specific foreign entry in local Romanian firms.[4] The sample is unbalanced due to firms entering in later years, both because of increased coverage and new start-ups. There is no exit. Industry price level data at Nace 2-digit level[5] are taken from the Industrial Database for Eastern Europe from the Vienna Institute for International Economic Studies and from the Statistical Yearbook of the Romanian National Statistical Office (RNSO). Our industry classification follows the classification used in the Romanian input-output (IO)

[4] Amadeus DVDs are released each year. They provide a pan-European database of financial information on public and private companies. Specific entries, however, only indicate the most recent ownership information. Since ownership information is gathered at irregular intervals, we do not have ownership information for all years and firms. Ownership changes tend to show up *ex post* in the database. Therefore, if a given firm has any gaps in its ownership series, we fill the gaps with the information from the following year.

[5] *Nomenclature générale des activités économiques dans les Communautés européennes.*

tables. This classification is then linked to the Nace classification scheme. IO tables for the period 1995–2001 were obtained from the RNSO.

The matrix **FDI** in (3) contains measures of foreign presence to capture the different spillovers described above. We classify a firm as foreign ($Foreign = 1$) when foreign participation exceeds 10%.[6] The horizontal spillover variable $Horizontal_{jt}^{X}$ captures the degree of foreign presence in sector j at time t and is measured as:

$$Horizontal_{jt}^{X} = \frac{\sum_{i \in j} Foreign_{it} * X_{it}}{\sum_{i \in j} X_{it}} \tag{4}$$

where X_{it} refers to either employment L_{it} for the horizontal labor market spillover, and real output Y_{it} for the net other horizontal spillover. $Horizontal_{kt}^{Y(L)}$ is industry k's share of output (labor) produced (employed) by foreign-owned firms.

For the measurement of the backward spillover variable $Backward_{jt}$, one possibility might be to employ the share of firm output sold to foreign firms. However, this information is unavailable from our dataset. Moreover, the share of firm output sold to foreign-owned firms may cause endogeneity problems if the latter prefer to buy inputs from more productive domestic firms. We thus measure $Backward_{jt}$ as:

$$Backward_{jt} = \sum_{k \ if \ k \neq j} \gamma_{jkt} * Horizontal_{kt}^{Y} \tag{5}$$

where γ_{jkt} is the proportion of industry j's output supplied to sourcing industry k at time t. The γs are calculated from the time-varying IO tables for intermediate consumption. In the calculation of γ, we explicitly exclude inputs sold within the firm's industry ($k \neq j$) because this is captured by $Horizontal_{jt}^{Y}$.[7] Since firms cannot easily switch between industries for their inputs, we avoid the problem of endogeneity by using the share of industry output sold to downstream domestic markets k with some level of foreign presence $Horizontal_{kt}^{Y}$. In the same spirit, we define the forward spillover variable $Forward_{jt}$ as:

$$Forward_{jt} = \sum_{l \ if \ l \neq j} \delta_{jlt} * Horizontal_{lt}^{Y} \tag{6}$$

where the IO tables reveal the proportion δ_{jlt} of industry j's inputs purchased from upstream

[6] This threshold level is commonly applied (e.g. by the OECD) in FDI definitions.

[7] To clarify, we offer the following example. Consider three sectors: j, k_1, and k_2. Suppose that half of the output of j is purchased by k_1 and the other half by k_2. Further suppose that no foreign firms are active in k_1, but half of the output of k_2 is produced by foreign firms. The backward variable for sector j would be $(0.5 * 0.0) + (0.5 * 0.5) = 0.25$. From this, it can be easily seen that the value of *Backward* increases with foreign presence in the sectors k that source inputs from j and with the share of output of sector j supplied to industries with foreign presence.

industries l. Inputs purchased within the industry ($l \neq j$) are again excluded, since this is already captured by $Horizontal$.[8]

The variable $SupplyBackward_{jt}$, which captures the hypothesis of Markusen and Venables, is constructed as:

$$SupplyBackward_{jt} = \sum_{l \; if \; l \neq j} \delta_{jlt} * Backward_{lt} \qquad (7)$$

where δ_{jlt} reveals again the proportion of industry j's inputs purchased from upstream industries l that in turn supply the downstream industries of foreign firms as measured by $Backward_{lt}$. Identification is possible as long as the share of industry a's output supplied to its downstream industry b, i.e. γ_{ab}, is sufficiently different from the share of industry b's inputs purchased from upstream industry a, i.e. δ_{ba}. This is the case for our IO tables.

The above definitions are based on a dummy-variable version of $Foreign$. This approach excludes any possible relation between spillover effects and the level of foreign participation. The Amadeus database contains the exact share in total equity owned by foreign investors at the firm level. Using the exact share, however, implicitly assumes a linear relation between the degree of foreign ownership and the spillover. Thus, we also employ an alternative classification based on relevant thresholds of foreign ownership – minority, majority or full foreign ownership – which gives rise to three separate measures of $Foreign$ and three versions of each spillover variable.

A measure of the level of technology needs to reflect the relative technical capabilities of a domestic firm vis-à-vis the foreign firms in the same industry. In constructing measure T_{it}, we apply the Levinsohn-Petrin technique on earlier years of the full sample of both domestic and foreign firms to avoid endogeneity. The estimated relation is then used to derive total factor productivity measures φ_{it} for all firms. T_{it} is defined in (8) as the distance between firm i's lagged productivity level, φ_{it-1}, and the lagged "foreign frontier" in its industry. The latter is defined as the mean productive efficiency of the 25% most productive foreign firms in industry j ($\overline{\varphi}_{jt-1,FOR}$). More productive firms have higher values of T.

$$T_{it} = \frac{\varphi_{it-1}}{\overline{\varphi}_{jt-1,FOR}} \qquad (8)$$

We integrate the level of technology in the analysis by considering the interaction of T

[8] Consider three sectors: j, l_1, and l_2. Suppose j buys 75% of its inputs with l_1 and the remaining 25% with l_2. Further suppose that 10% of l_1's output is produced by foreign firms, and half of the output of l_2 is produced by foreign firms. The backward variable for sector j would be $(0.75 * 0.10) + (0.25 * 0.50) = 0.20$.

	full sample (n=215516)		domestic sample (n=192851)	
	mean	st. dev.	mean	st. dev.
ln real value added	8.308	2.052	8.149	1.989
ln real capital	7.366	2.460	7.185	2.407
ln labor	1.823	1.457	1.737	1.407
ln TFP	5.338	1.201	5.284	1.176
level of technology	0.171	0.190	0.160	0.179
Herfindahl	0.025	0.046	0.024	0.044
$Horizontal^Y$	0.256	0.156	0.248	0.153
$Horizontal^L$	0.190	0.149	0.183	0.145
$Backward$	0.257	0.074	0.256	0.076
$Forward$	0.303	0.073	0.303	0.073
$SupplyBackward$	0.266	0.039	0.265	0.039

Table 1: Summary statistics for the full and domestic sample

with $Horizontal$, $Backward$, $Forward$, and $SupplyBackward$. Since the above discussion suggests possible non-linearities, we consider interactions with the squared level of technology (T^2). Table 1 gives summary statistics for the variables described here.

5 Results

5.1 Dynamic economic structure

In Table 2, we show a baseline version of (3) to verify whether changes in economic structure matter for FDI spillovers. The estimates in the first column are based on spillover variables calculated with the correct time-varying IO tables. Vertical spillovers are economically and statistically more significant than horizontal spillovers. Backward spillovers carry a negative sign, while forward spillovers are positive. In the following columns, we recalculate the spillover variables using the IO table for a specific year. This is the current practice in much of the literature, mostly because of data limitations. As can be seen, the results are fairly murky and depend on the year of choice for the IO table. We conclude that the time varying character of Romania's economic structure is important in understanding the reaction of Romanian firms to FDI. Failure to take this into account may bias results.

	IO-98/01	IO-96	IO-98	IO-99	IO-00	IO-01
$\Delta Horizontal^Y$	0.221	0.100	0.002	-0.144	-0.145	-0.143
	[0.41]	[0.18]	[0.00]	[0.26]	[0.26]	[0.25]
$\Delta Backward$	-0.567	0.020	-2.021	-0.183	-1.679	-0.793
	[2.17]**	[0.01]	[1.08]	[0.16]	[1.03]	[0.39]
$\Delta Forward$	1.412	1.708	1.620	-0.257	-0.145	-0.227
	[2.34]**	[2.18]**	[1.77]*	[0.28]	[0.17]	[0.32]
N	150626	150626	150626	150626	150626	150626
# firms	68233	68233	68233	68233	68233	68233
R^2	0.01	0.01	0.01	0.01	0.01	0.01

Second-step fixed effect estimates for domestic firms; the dependent variable is firm-level TFP growth based on first-step production function estimates. Column headings refer to the year of the IOtable.

Robust t-statistics in brackets; */**/*** significant at 10%/5%/1%.

Table 2: Impact of dynamic input output tables on estimated spillover effects

5.2 Labor market and supply-backward spillover

In Table 3, we introduce the horizontal labor market spillover and the supply-backward spillover. Panel A reports the results for all industries. We report different combinations of the variables. In contrast to Jozef Konings (2001), we find that local firm productivity is enhanced by horizontal labor market spillovers. This finding is robust throughout and confirms the findings of Görg and Strobl. Other horizontal spillovers exert no positive effect on local firm productivity. Inspection of the coefficients of the vertical spillover variables reveals that the supply-backward spillover is economically much more important than horizontal spillovers. The estimated coefficient for the supply-backward spillover is consistently positive and is inclined to be statistically significant. This lends support to the hypothesis of Markusen and Venables. Forward linkages to foreign firms are found to fuel total factor productivity of domestic firms, while backward linkages to foreign firms appear detrimental to total factor productivity. In panel B, we repeat our estimations for manufacturing industries only. We employ reduced IO tables for manufacturing to recalculate the spillover variables. The results change drastically. Most spillovers are no longer statistically different from zero. Only the backward spillover retains its statistical significance. The economic conclusion is now in line with earlier findings: backward links of local manufacturing firms to foreign firms are now beneficial to total factor productivity. This should not come as a surprise. According to Romania's National Trade Register Office,[9] 4% of all foreign affiliates in Romania were located in the primary sector, 19% in the secondary sector, and 77% in the tertiary sector at the end of 2002. Limiting the analysis to manufacturing ignores the lion's

[9]Data reported in the World Investment Report 2005, UNCTAD.

Panel A - Results for all industries					
	(1)	(2)	(3)	(4)	(5)
$\Delta Horizontal^Y$	-0.020	-0.142	-0.041	-0.389	-0.334
	[0.04]	[0.25]	[0.07]	[0.66]	[0.57]
$\Delta Horizontal^L$		0.749	0.799	0.761	0.690
		[2.30]**	[2.41]**	[2.23]**	[2.16]**
$\Delta Backward$	-0.701	-0.676	-0.619		-0.562
	[2.56]**	[2.81]***	[2.52]**		[2.28]**
$\Delta Forward$	1.183	1.325	1.489	1.196	
	[2.02]**	[2.22]**	[2.60]***	[1.99]**	
$\Delta Supply\text{-}Backward$	2.767	2.073		1.695	3.027
	[2.16]**	[1.64]		[1.37]	[2.59]***
N	150626	150626	150626	150626	150626
# firms	68233	68233	68233	68233	68233
R^2	0.02	0.02	0.02	0.02	0.02

Panel B - Results for manufacturing industries					
	(1)	(2)	(3)	(4)	(5)
$\Delta Horizontal^Y$	-0.106	-0.076	-0.069	-0.041	-0.078
	[1.11]	[0.81]	[0.77]	[0.42]	[0.85]
$\Delta Horizontal^L$		-0.208	-0.218	-0.192	-0.214
		[1.19]	[1.25]	[1.10]	[1.14]
$\Delta Backward$	0.501	0.523	0.530		0.533
	[2.20]**	[2.32]**	[2.38]**		[2.33]**
$\Delta Forward$	0.103	0.038	0.034	0.140	
	[0.46]	[0.20]	[0.17]	[0.70]	
$\Delta Supply\text{-}Backward$	0.361	0.266		0.325	0.262
	[0.68]	[0.51]		[0.61]	[0.51]
N	55629	55629	55629	55629	55629
# firms	25096	25096	25096	25096	25096
R^2	0.01	0.01	0.01	0.01	0.01

Second-step fixed effect estimates for domestic firms; the dependent variable is firm-level TFP growth based on first-step production function estimates. Robust t-statistics in brackets;*/**/*** significant at 10%/5%/1%.

Table 3: Effect of introducing of the horizontal labor market spillover and the supply-backward spillover variables

share of foreign affiliates operating in Romania. Many are upstream service industries, and neglecting the effect of their improved productivity on the rest of the economy could well lead to inappropriate conclusions.

5.3 Level of technology

In Table 4, we allow non-linear interactions of the spillover variables with the level of technology.[10] The first column gives the results for all firms, while further columns give results for three split samples: small, medium-sized, and large firms. The implied non-linear relation between the spillovers and the level of technology is shown in Figure 5 in Appendix B. The interaction between spillover variables and the level of technology cannot be rejected. Even the output-based horizontal spillover exhibits a significant interaction with the level of technology for small and medium-sized firms. The interaction with the level of technology turns out to be non-linear, except for supply-backward spillovers to medium-sized and large firms.

Firm size plays an important role. Generally, spillover effects seem to be larger for small and medium-sized firms than for large firms in both directions. On one hand, smaller firms may more easily adapt to newer and better inputs and find it easier to adjust their production processes, which allows larger positive spillovers. On the other hand, they may be less resilient to potential negative spillovers as they face harder budget constraints. This could be specifically true for Romania. Most large enterprises are former state enterprises that, while poor at adopting new technologies, are well connected to the sources of soft finance.

The horizontal labor market spillover seems to be very positive, although the relation is not highly stable across size classes. F-tests reject zero labor market effects. The non-linear interaction with the level of technology (small firms excluded) is not rejected. This lends support to the absorptive capability hypothesis. Access to higher skilled labor through foreign presence in the industry is positive for all domestic firms, though most of the benefits go to firms that were already more productive. The backward spillover is found to be mainly negative, but the interaction with the level of technology is not very stable across size classes. For every size class, F-tests reject that the forward spillover is not present. The forward spillover also exhibits a very significant and stable non-linear interaction with the level of technology across size classes. The results reveal a U-shape relation between the level of technology and the contribution of forward spillovers to total factor productivity. This lends support to the conjecture that both the Findlay and the absorptive capability

[10] The results for manufacturing only are available on request.

	All firms	L<5	5<=L<50	L>=50
$\Delta Horizontal^Y$	-0.293	-0.503	0.129	-1.054
	[0.50]	[0.79]	[0.25]	[2.29]**
$\Delta\left(T * Horizontal^Y\right)$	1.086	4.538	0.758	1.023
	[1.17]	[3.38]***	[0.82]	[1.36]
$\Delta\left(T^2 * Horizontal^Y\right)$	-0.515	-2.446	-0.851	-0.626
	[1.32]	[3.82]***	[2.23]**	[1.38]
$\Delta Horizontal^L$	0.960	1.166	0.686	0.175
	[2.54]**	[3.17]***	[2.18]**	[0.57]
$\Delta\left(T * Horizontal^L\right)$	-1.153	-1.542	-0.950	-1.032
	[1.61]	[1.59]	[1.28]	[1.30]
$\Delta\left(T^2 * Horizontal^L\right)$	0.756	0.606	1.227	1.054
	[2.10]**	[0.82]	[2.48]**	[2.23]**
$\Delta Backward$	-0.893	-0.989	-0.785	-0.507
	[3.68]***	[3.70]***	[3.59]***	[1.88]*
$\Delta\left(T * Backward\right)$	1.442	1.106	0.928	1.424
	[2.07]**	[0.94]	[1.26]	[1.33]
$\Delta\left(T^2 * Backward\right)$	-1.524	-1.444	-1.354	-0.835
	[3.47]***	[1.55]	[2.56]**	[1.22]
$\Delta Forward$	2.328	2.337	1.953	1.728
	[3.64]***	[3.67]***	[3.11]***	[3.78]***
$\Delta\left(T * Forward\right)$	-4.139	-3.132	-2.973	-4.025
	[2.60]***	[1.69]*	[1.50]	[3.56]***
$\Delta\left(T^2 * Forward\right)$	3.029	3.390	3.258	2.412
	[3.38]***	[3.19]***	[2.96]***	[4.78]***
$\Delta Supply\text{-}Backward$	1.959	2.530	2.801	-0.484
	[1.74]*	[1.87]*	[2.67]***	[0.50]
$\Delta\left(T * Supply - Backward\right)$	-4.309	-12.737	-4.369	-0.914
	[2.04]**	[4.41]***	[1.84]*	[0.50]
$\Delta\left(T^2 * Supply - Backward\right)$	0.381	4.465	-0.072	-1.061
	[0.30]	[2.75]***	[0.05]	[1.11]
N	120317	56095	53348	10874
# firms	55097	30866	26351	4993
R^2	0.09	0.12	0.11	0.13

Second-step fixed effect estimates for domestic firms; the dependent variable is firm-level TFP growth based on the first-step production function estimates. Columns 2-4 are split-samples according to the domestic firm's number of employees (L). Robust t-statistics in brackets; */**/*** significant at 10%/5%/1%.

Table 4: Impact of the interaction of spillover variables with the level of technology (T) and sample splits based on firm size (L) - Results for all industries

	All firms	L<5	5<=L<50	L>=50
F-tests				
No *T-Horizontal*^{L}	2.32*	1.50	4.36**	3.32**
No *Horizontal*^{L}	3.94***	3.35**	5.32***	2.23*
No *T-Horizontal*^{Y}	0.87	7.29***	4.10**	1.02
No *Horizontal*^{Y}	0.59	5.11***	2.83**	2.26*
No *T-Backward*	6.61***	1.37	4.12**	0.89
No *Backward*	7.78***	5.35***	6.53***	1.27
No *T-Forward*	6.26***	6.81***	7.50***	11.62***
No *Forward*	6.81***	7.69***	6.64***	9.17***
No *T-SupplyBackward*	6.38***	11.71***	6.61***	4.97***
No *SupplyBackward*	4.56***	8.36***	6.34***	4.09***

T-'Spillover' tests the joint significance of the T and T^2 interactions, 'Spillover' the joint significance of the T and T^2 interactions and the level of Spillover.Columns 2-4 are split-samples according to the domestic firm's number of employees (L). */**/*** rejection at 10%/5%/1%.

Table 5: Impact of the interaction of spillover variables with the level of technology (T) and sample splits based on firm size (L) - Results for all industries - F-tests

hypothesis are at work. Nevertheless, the exact shape of the relation suggests that the access to better inputs because of foreign direct investment mainly benefits the more productive domestic firms. The supply-backward spillover is strongly detected for small firms, and less convincingly for medium-sized and large firms. Better inputs through foreign presence in not directly related industries mainly benefits small firms, provided that their level of technology is high enough to absorb these better inputs.

5.4 Degree of foreign ownership

In our third step, we verify whether spillovers depend on the ownership structure of foreign-owned firms. We create separate variables for spillovers from fully foreign-owned firms (more than 95%), majority foreign-owned firms (more than 50%, but less than 95%), and minority foreign-owned firms (less than 50%), and repeat the specification of Table 4 with a full, a majority and a minority foreign-ownership version of each spillover variable. The results and joint significance tests for the various spillovers and their interactions with the level of technology are reported in Appendix C.[11]

In figures 3 and 4, we show the implied non-linear relationships between the level of technology and the spillovers for different size classes and different degrees of foreign own-

[11] The results for manufacturing only are available on request. They consider split majority (>50%) versus minority (<50%) ownership, as well as split full (>95%) versus partial (<95%) ownership.

ership.[12] In each subfigure, the bold solid line represents the estimated relationship for all firms, the fine solid line refers to small firms, the dotted line to medium-sized firms, and the broken line to large firms. The level of technology is shown on the horizontal axis, while the effect of the spillover on total factor productivity is on the vertical axis. Horizontal labor market spillovers exhibit a clear U-shaped relationship with the level of technology for fully and majority foreign-owned firms. Horizontal labor market spillovers are especially beneficial where the labor comes from fully-owned foreign firms, less so for labor from majority foreign-owned firms, and not significantly different from zero (not reported here) for labor from minority foreign-owned firms. Other net horizontal spillovers are only significant for firms that compete with fully foreign-owned firms, where there is a positive effect on productivity unless the absorptive capability is very low (as shown in Figure 3). Hence, the market-stealing effect only applies to the least productive local firms facing competition from fully foreign-owned firms. Comparison of the size of the effect on total factor productivity in the various panels of figures 3 and 4 reveals that horizontal spillovers are economically less significant than vertical spillovers.

F-tests in Appendix C indicate that the joint significance of backward spillovers and their non-linear interactions with the level of technology can almost never be rejected. Domestic firms that supply intermediates to industries with many full or majority foreign-owned affiliates experience relatively negative backward spillovers. For a given level of technology, the backward spillover is generally more likely to be positive for large local firms than for medium-sized or small local firms. This is not true for minority foreign-owned affiliates. Since minority foreign-owned affiliates are dominated by local partners that are well connected to the local market, they are more likely to source their inputs with relatively smaller local firms. It is not surprising therefore that small firms upstream of minority foreign-owned affiliates tend to enjoy large positive backward spillovers when the local firm's absorptive capability is sufficiently high. In the previous section, we found that forward spillovers were U-shaped. Introducing the degree of foreign ownership reveals that the significance of this result mainly depends on majority foreign-owned affiliates. In this case, we find a clear positive forward spillover is consistently present across size classes. Inspection of the implied relation in Figure 4 does not allow us to reject this earlier finding of a U-shaped relationship.

We find very strong support for the presence of a supply-backward spillover. Across size classes, its joint significance is never rejected and the joint significance of the interaction with the level of technology only once. A domestic firm's total factor productivity is

[12] To describe the contribution of a spillover to total factor productivity growth as a function of the level of technology, we first construct a weighted average of the spillover variable concerned (weights are the number of firms in an industry). Multiplying the weighted average with the estimated coefficients gives the parameters of this function.

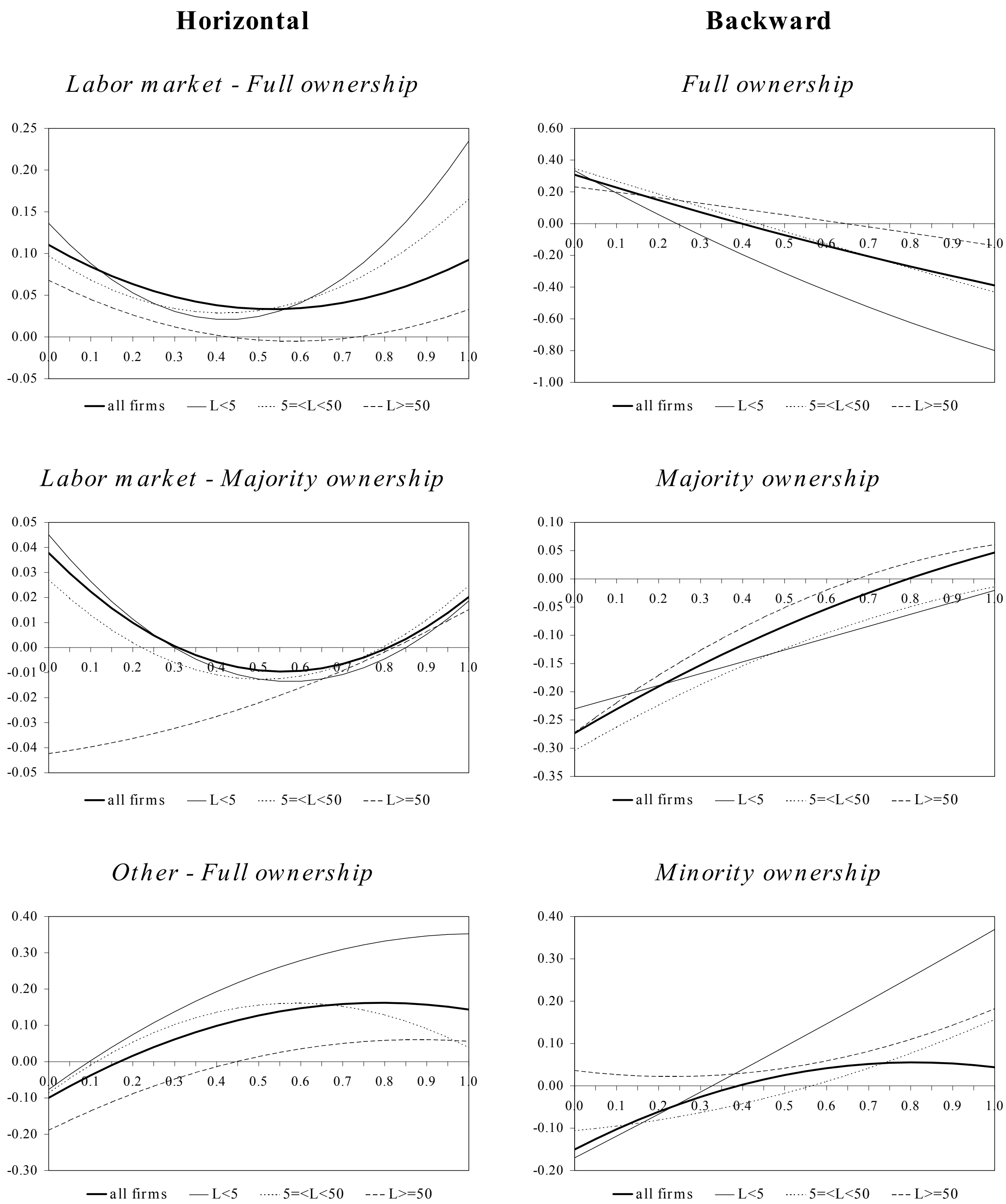

Figure 3: Horizontal and backward spillover effects on firm-level TFP (vertical axis) as a function the level of technology (T, horizontal axis) for different classes of foreign ownership and firm size (L denotes the number of employees)

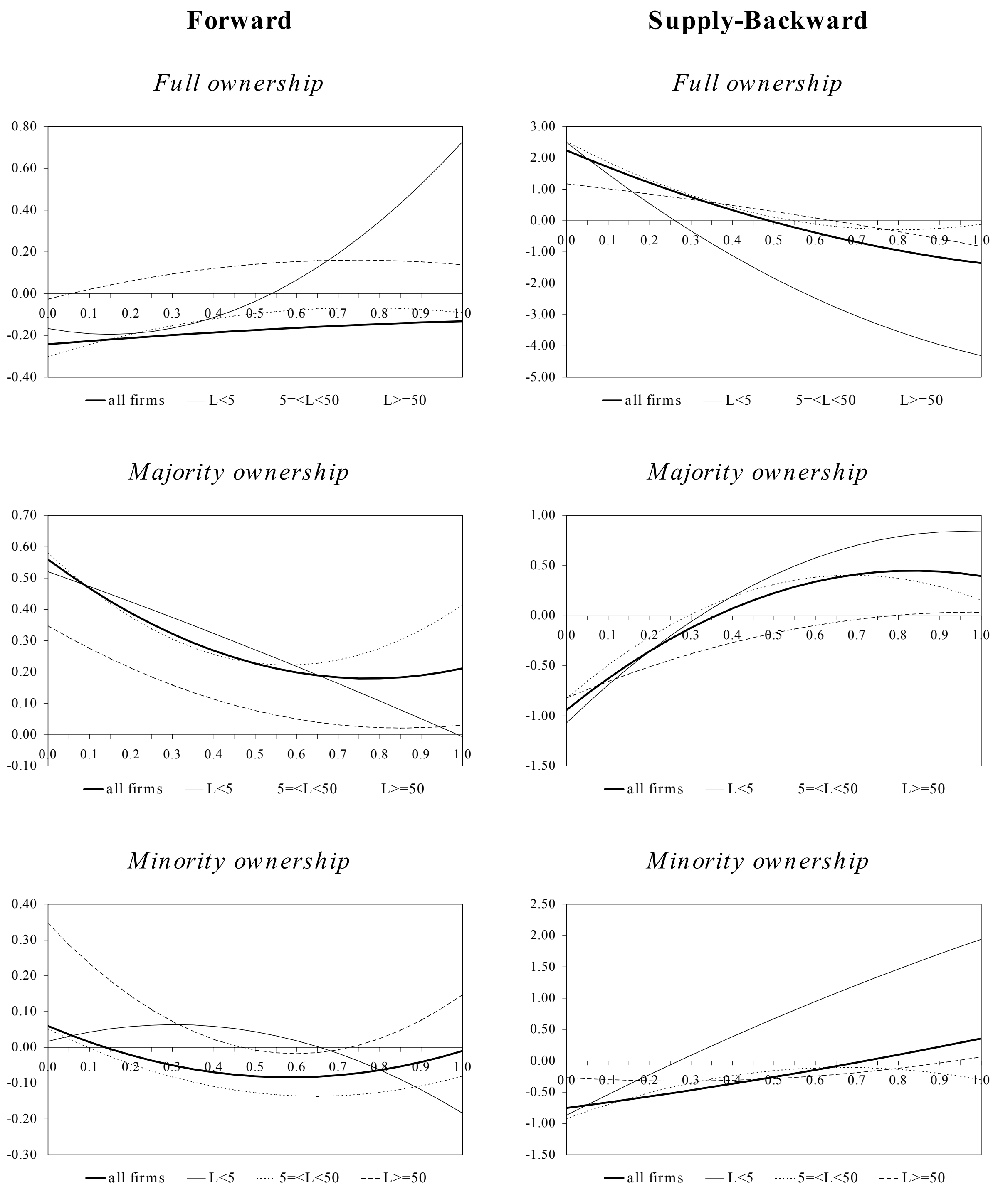

Figure 4: Forward and supply-backward spillover effects on firm-level TFP (vertical axis) as a function the level of technology (T, horizontal axis) for different classes of foreign ownership and firm size (L denotes the number of employees)

strongly affected by buying inputs from firms that also supply to foreign-owned affiliates. Economically, this effect dominates other spillovers. Although we note no supply-backward spillovers for large firms in Table 4, the interaction with the degree of foreign ownership reveals important supply-backward effects from fully and majority foreign-owned firms. The effects for small firms are large and strongly depend on the degree of foreign ownership and the level of technology. Small firms suffer negative supply-backward spillovers from fully foreign-owned firms, except where they are technologically backward (Findlay hypothesis). On the other hand, small firms with supply-backward linkages to less than fully foreign-owned firms enjoy large positive productivity spillovers, provided their absorptive capability exceeds a minimal threshold. This may reflect the fact that foreign firms that are not fully foreign-owned develop closer relationships with domestic suppliers. It follows that domestic suppliers will have greater incentives to tailor their production standards to the needs of such firms. Domestic firms that buy intermediates from these suppliers will find it difficult to use these more specific inputs in their own production when their absorptive capability is insufficient. Domestic firms with higher absorptive capability, on the other hand, are able to use higher quality inputs to improve their own productivity.

5.5 Actual spillover effects

Finally, we use the results of Table 7 in Appendix C to calculate the net effect of foreign presence on domestic firms. For each firm we predict firm level spillovers by multiplying the estimated coefficients with the actual values of the variables concerned. Table 6 shows the spillovers' contribution to total factor productivity growth during the period 1998–2001, averaged over firms for different ranges of the initial level of technology. The breakdown in technology ranges is based on the 1998 level of technology percentiles.

Results in table 6 reveal that the average Romanian firm enjoys positive total net spillovers at any initial level of technology. The effect is distinctively positive for firms with the highest level of technology, which indicates that absorption is important. The supply-backward spillover has contributed most to the productivity growth of Romanian firms. It accounts for more than 50 percent of total net spillovers and is especially important for small and medium-sized firms. The forward spillover, in contrast, is highly positive for large firms, while the effect is smaller, but still positive, for small and medium-sized firms. Apparently, better inputs explain the lion's share of FDI-fueled productivity growth. Backward spillovers are positive for large firms, but often detrimental to small and medium-sized firms. Large firms draw apparently more benefits from their linkages to foreign clients. It unclear as why foreign clients seem less eager to transfer technology to small local firms; perhaps it is a

	$Horizontal^Y$	$Horizontal^L$	$Backward$	$Forward$	$SupplyBack$	$Total$
All	-0.0159	0.0414	-0.0039	0.0287	0.2473	0.2975
p1<IT<p10	-0.0073	0.0369	0.0311	0.0176	0.2529	0.3311
p10<IT<p25	-0.0086	0.0312	0.0182	-0.0001	0.2527	0.2934
p25<IT<p50	-0.0095	0.0290	-0.0022	-0.0095	0.2422	0.2500
p50<IT<p75	-0.0126	0.0416	-0.0134	0.0235	0.2280	0.2672
p75<IT<p90	-0.0269	0.0591	-0.0193	0.0736	0.2446	0.3310
p90<IT<p99	-0.0365	0.0550	-0.0065	0.1073	0.3076	0.4268
L<5	-0.0110	0.0487	-0.0094	0.0346	0.2629	0.3258
p1<IT<p10	0.0151	0.0488	0.0057	0.0549	0.2380	0.3625
p10<IT<p25	0.0105	0.0402	0.0008	0.0297	0.2423	0.3235
p25<IT<p50	0.0086	0.0306	-0.0256	0.0037	0.2262	0.2436
p50<IT<p75	-0.0063	0.0431	-0.0232	0.0174	0.2442	0.2752
p75<IT<p90	-0.0380	0.0745	-0.0012	0.0664	0.2898	0.3915
p90<IT<p99	-0.0891	0.0852	0.0338	0.1081	0.4272	0.5652
5<L<50	0.0072	0.0323	0.0072	0.0278	0.2856	0.3601
p1<IT<p10	0.0188	0.0193	0.0273	0.0098	0.2542	0.3294
p10<IT<p25	0.0167	0.0212	0.0216	0.0049	0.2633	0.3277
p25<IT<p50	0.0117	0.0266	-0.0006	0.0104	0.2622	0.3102
p50<IT<p75	0.0002	0.0407	-0.0021	0.0259	0.2806	0.3454
p75<IT<p90	-0.0108	0.0523	0.0042	0.0709	0.3028	0.4194
p90<IT<p99	0.0208	0.0189	0.0211	0.0635	0.4066	0.5310
L>50	-0.0364	0.0148	0.0158	0.1215	0.1955	0.3112
p1<IT<p10	-0.0197	0.0225	0.0254	0.1342	0.2052	0.3676
p10<IT<p25	-0.0204	0.0092	0.0135	0.0778	0.2127	0.2928
p25<IT<p50	-0.0208	0.0099	0.0107	0.0624	0.1938	0.2560
p50<IT<p75	-0.0309	0.0159	0.0161	0.1172	0.1840	0.3022
p75<IT<p90	-0.0582	0.0211	0.0201	0.1718	0.1870	0.3419
p90<IT<p99	-0.0536	0.0084	0.0159	0.1841	0.2214	0.3761

Table entries are averaged firm-level predictions of the spillover's (the column headings) contribution to TFP growth during the period 1998–2001 for different ranges of the 1998 level of technology (IT). pX refers to the Xth percentile of the distribution of IT. Predictions are obtained by multiplying the appropriate estimated coefficients with the actual values of the spillover variables concerned. Size classes are based on the number of employees L. The first line for each size class lists the average over all firms.

Table 6: Actual domestic firm TFP-increase during 1998-2001 due to spillover effects for different categories of firm size (L) and the initial level of technology in 1998 (IT)

lack of awareness or perhaps there is greater worry over technology leakage. Interestingly, horizontal labor market spillovers are always positive and dominate the other net horizontal spillovers. Labor market spillovers are especially beneficial to small firms, and nearly zero for large firms, confirming the F-tests above. The other horizontal spillovers are not only smaller than labor market spillovers, but also often negative, certainly for large firms. Again, large firms appear to have suffered most from market-stealing.

6 Conclusions

This study analyzed horizontal and vertical productivity spillovers of foreign direct investment on domestic Romanian companies from 1998 to 2001, a period when the Romanian economy experienced substantial structural changes. We therefore employed a series of input-output tables for the calculation of vertical spillovers to overcome possible bias in the results. Since the lion's share of foreign affiliates operate in the services sector, we study spillover effects for all industries, not just manufacturing. Indeed, we found indications that restricting the analysis to manufacturing industries biases results, particularly with respect to backward spillovers. We therefore strongly recommend that further studies neglect neither changes in economic structure nor the tertiary sector.

We distinguished among five forms of spillover: two horizontal and three vertical. The presence of foreign affiliates in the same or linked industries affects local firm total factor productivity in a non-linear way. Specifically, the level of technology, the degree of foreign ownership, and local firm size were found to play important roles in this relation.

Horizontal labor market spillovers from fully and majority foreign-owned firms tended to be positive and exhibit a clear U-shaped relationship with the level of technology. Horizontal labor market spillovers were especially beneficial when the labor came from fully foreign-owned firms. Other net horizontal spillovers tended to be insignificant, with the exception of a market-stealing effect for large firms and the least productive domestic firms facing competition from fully foreign-owned firms.

Vertical spillovers were found to be more important economically than horizontal spillovers. This is distinctly the case for the supply-backward spillover: buying goods from firms that also supply to foreign firms in a different industry was found to enhance total factor productivity greatly, lending support to the theory of Markusen and Venables. Forward spillovers were generally positive and exhibited a U-shaped relation with the level of technology across size classes, although this relation is mostly driven by majority foreign-owned firms. This lends support to the conjecture that both the Findlay and the absorptive capability hypothesis are at work. Backward spillovers are generally positive for large firms, but often detrimental to small firms, unless these sell to industries with a large share of minority foreign-owned affiliates. In the latter case, small firms tend to enjoy very positive backward spillovers, provided their absorptive capability is sufficiently high. This may be due to the fact that foreign firms are unlikely to buy their inputs from small local firms unless they are dominated by local partners.

So what was the net welfare effect on the Romanian economy? When all spillover effects are accounted for, has foreign direct investment been beneficial or detrimental to the total factor productivity of local firms? We find that the average Romanian firm enjoys positive total net spillovers at any initial level of technology. The effect is distinctly positive for firms with the highest level of technology.

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APPENDIX A: Production function estimation

We estimate the following production function sector by sector to derive sector-specific labor and capital intensities.

$$\forall j : \ln VA_{irt} = \beta_0 + \beta_l \ln L_{irt} + \beta_k \ln K_{irt} + \omega_t + \eta_t \tag{9}$$

where subscripts irt stand for firm i and region r at time t, and j stands for sector j. VA stands for real value added of the firm, L is the freely variable input labor and K is the state variable capital. The error has two components, the transmitted productivity component given as ω, and η, an error term that is uncorrelated with input choices. The key difference between ω and η is that the former is a state variable and hence impacts the firm's decision rules. ω is not observed by the econometrician; instead the firm immediately adjusts its freely variable input L in response. We focus on value added rather than sales because it is a better measure of firm performance. Consider the following version where small cases refer to variables in logs and firm and region subscripts have been dropped.

$$va_t = \beta_0 + \beta_l l_t + \beta_k k_t + \omega_t + \eta_t \tag{10}$$

Levinsohn and Petrin (2003) start by assuming that the demand for the intermediate input, materials m_t, depends on the firm's state variables k_t and ω_t:

$$m_t = m_t (k_t, \omega_t) \tag{11}$$

Making mild assumptions about the firm's production technology, it can be shown that the demand function is monotonically increasing in ω_t. This allows inversion of the intermediate demand function, so ω_t can be written as a function of k_t and m_t.[13]

$$\omega_t = \omega_t (k_t, m_t) \tag{12}$$

The unobservable productivity term is now expressed solely as a function of two observed inputs. Following Olley and Pakes (1996), Levinsohn and Petrin (2003) make a final identifi-

[13] Due to possible correlation with labor and capital, direct FDI participation in the firm may distort the estimation. We focus here solely on domestic firms. What about the spillovers? Since we estimate a production function for each sector separately and because the spillover variables are sector-specific, there is only variation in the time dimension. The correlation between spillover variables on one hand, and labor and capital on the other, is fairly low (below 0.2 for almost all spillovers in all sectors). Furthermore, the possible correlation will to some extent be accounted for in the analysis. If ω_t is a function of foreign presence, this will be reflected in material input choice as $m_t = m_t (k_t, \omega_t (foreign))$. The inverted function would read $\omega_t = \omega_t (k_t, m_t (foreign))$.

cation restriction by assuming that productivity is governed by a first-order Markov process:

$$\omega_t = E\left[\omega_t | \omega_{t-1}\right] + \xi_t \tag{13}$$

where ξ_t is an innovation to productivity that is uncorrelated with k_t (but not necessarily with l_t; this is part of the source of the simultaneity problem). The estimation routine itself starts with transforming (10).

$$\begin{aligned} va_t &= \beta_0 + \beta_l l_t + \beta_k k_t + \omega_t + \eta_t \\ &= \beta_l l_t + \phi_t\left(k_t, m_t\right) + \eta_t \end{aligned} \tag{14}$$

where

$$\phi_t\left(k_t, m_t\right) = \beta_0 + \beta_k k_t + \omega_t\left(k_t, m_t\right) \tag{15}$$

By substituting a third-order polynomial approximation in k_t and m_t for $\phi_t\left(k_t, m_t\right)$, it is possible to consistently estimate parameters as

$$va_t = \delta_0 + \beta_l l_t + \sum_{g=0}^{3} \sum_{h=0}^{3-h} \delta_{gh} k_t^g m_t^h + \eta_t \tag{16}$$

where β_0 is not separately identified from the intercept of $\phi_t\left(k_t, m_t\right)$. This completes the first stage of the estimation routine from Levinsohn and Petrin (2003), from which an estimate of β_l and an estimate of ϕ_t (up to the intercept) are available. The second stage of the estimation procedure begins by computing the estimated value for ϕ_t using

$$\widehat{\phi}_t = \widehat{va}_t - \widehat{\beta}_l l_t \tag{17}$$

$$= \widehat{\delta}_0 + \sum_{i=0}^{3} \sum_{j=0}^{3-i} \widehat{\delta_{ij}} k_t^i m_t^j \tag{18}$$

For any candidate values β_k^* , one can compute (up to a scalar constant) a prediction for ω_t for all periods t using

$$\widehat{\omega}_t = \widehat{\phi}_t - \beta_k^* k_t \tag{19}$$

Taking the $\widehat{\omega}_t$'s for all t, a consistent (non-parametric) approximation to $E\left[\omega_t | \omega_{t-1}\right]$, say $E\left[\omega_t \widehat{| \omega_{t-1}}\right]$, is given by the predicted values from the regression

$$\widehat{\omega}_t = \gamma_0 + \gamma_1 \widehat{\omega}_{t-1} + \gamma_2 \widehat{\omega}_{t-1}^2 + \gamma_3 \widehat{\omega}_{t-1}^3 + \varepsilon_t \tag{20}$$

Given $\widehat{\beta}_l$, β_k^*, and $E\left[\omega_t \widehat{| \omega_{t-1}}\right]$ the sample residual of the production function can be written as

$$\widehat{\eta_t + \xi_t} = va_t - \widehat{\beta}_l l_t - \beta_k^* k_t - E\left[\omega_t | \widehat{\omega_{t-1}}\right] \tag{21}$$

The estimate $\widehat{\beta}_k$ of β_k can then be defined as the solution to[14]

$$\min_{\beta_k^*} \sum_t \left(va_t - \widehat{\beta}_l l_t - \beta_k^* k_t - E\left[\omega_t | \widehat{\omega_{t-1}}\right] \right)^2 \tag{22}$$

Since each of the two main stages of estimation involves a number of preliminary estimators, the covariance matrix of the final parameters must account for the sampling variation introduced by all of the estimators used in the two stages. Although deriving an analytic covariance matrix may be feasible, this calculation is not trivial. Instead, Levinsohn and Petrin (2003) substitute computational power for analytic difficulties, employing the bootstrap method to estimate standard errors.[15]

For the estimation the data are taken from the Amadeus database, described in the main text. Value added is calculated as real output Y, measured as sales deflated by producer price indices of the appropriate Nace industry minus real material input M, measured as material costs deflated by a weighted intermediate input deflator where the industry-specific weighting scheme is drawn from the IO tables. Labor L is expressed as the number of employees. Real capital K is measured as fixed assets, deflated by the average of the deflators for the following five Nace industries: machinery and equipment (29); office machinery and computing (30); electrical machinery and apparatus (31); motor vehicles, trailers, and semi-trailers (34); and other transport equipment (35). This approach follows Smarzynska Javorcik (2004).

[14] A golden-section search algorithm is used to minimize (22).

[15] Given the use of panel data, sampling occurs with replacement from firms, using the entire time series of observations for that firm in the bootstrapped sample when the firm's ID-number is randomly drawn. A bootstrapped sample is complete when the number of firm-year observations (closely) equals the number of firm-year observations in the original sample. The variation in the point estimates across the bootstrapped samples provides an estimate for the standard errors of the original point estimates (see Petrin *et al.*, 2004).

APPENDIX B: Relation between spillover and technology gap implied by results in Table 4

In each subfigure, the bold solid line represents the estimated relationship for all firms, the fine solid line refers to small firms, the dotted line to medium firms, and the broken line to large firms. The level of technology (T) is shown on the horizontal axis, while the vertical axis is the spillover effect on total factor productivity.

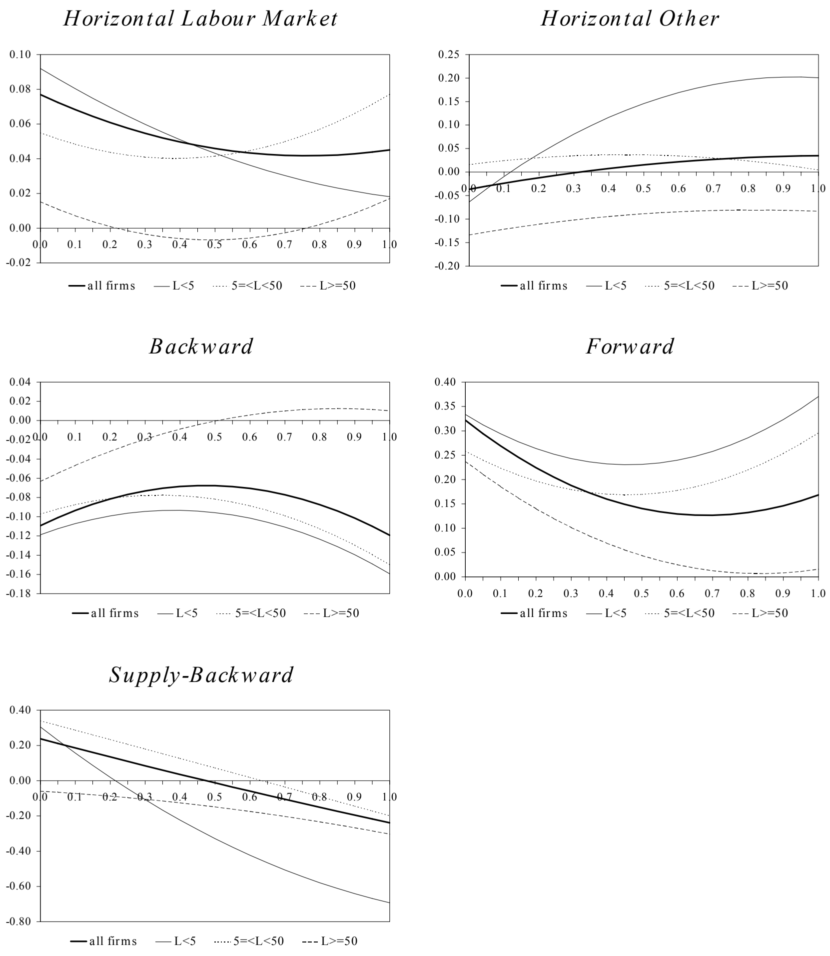

Figure 5: Spillovers to firm productivity (vertical axis) as a function of the level of technology (horizontal axis) for different classes of firm size

APPENDIX C: The effect of the degree of foreign ownership

	All firms	L<5	5<=L<50	L>=50
$Horizontal^{L}_{full}$	1.377	1.726	1.216	0.783
	[2.64]***	[3.08]***	[2.13]**	[1.09]
$T*Horizontal^{L}_{full}$	-3.609	-6.908	-4.133	-2.895
	[1.89]*	[2.09]**	[1.93]*	[1.42]
$T^2*Horizontal^{L}_{full}$	3.387	8.157	4.981	2.490
	[3.37]***	[3.82]***	[3.69]***	[1.90]*
$Horizontal^{L}_{maj}$	0.601	0.754	0.420	-0.589
	[2.50]**	[3.04]***	[1.53]	[1.49]
$T*Horizontal^{L}_{maj}$	-2.701	-3.415	-2.429	0.326
	[3.26]***	[2.42]**	[2.45]**	[0.35]
$T^2*Horizontal^{L}_{maj}$	2.421	2.973	2.393	0.475
	[4.51]***	[2.12]**	[3.17]***	[0.74]
$Horizontal^{L}_{min}$	-0.353	-0.093	-0.226	0.450
	[1.83]*	[0.35]	[1.09]	[1.23]
$T*Horizontal^{L}_{min}$	1.961	0.457	0.068	-0.386
	[2.81]***	[0.30]	[0.07]	[0.38]
$T^2*Horizontal^{L}_{min}$	-0.854	1.362	1.528	-0.082
	[2.46]**	[1.19]	[2.19]**	[0.14]
$Horizontal^{Y}_{full}$	-0.797	-0.609	-0.699	-1.489
	[0.98]	[0.73]	[0.81]	[2.56]**
$T*Horizontal^{Y}_{full}$	5.303	6.642	6.840	4.469
	[3.78]***	[3.12]***	[4.57]***	[3.16]***
$T^2*Horizontal^{Y}_{full}$	-3.360	-3.240	-5.827	-2.538
	[4.49]***	[2.87]***	[6.43]***	[2.40]**
$Horizontal^{Y}_{maj}$	0.187	-0.095	0.251	0.201
	[0.34]	[0.15]	[0.52]	[0.41]
$T*Horizontal^{Y}_{maj}$	-1.918	3.032	-1.126	-1.653
	[1.49]	[1.31]	[0.79]	[1.43]
$T^2*Horizontal^{Y}_{maj}$	1.488	-2.134	-0.148	0.383
	[1.97]**	[1.08]	[0.15]	[0.47]
$Horizontal^{Y}_{min}$	-0.485	-0.854	0.296	-0.951
	[0.71]	[1.25]	[0.40]	[1.16]
$T*Horizontal^{Y}_{min}$	1.907	6.469	-2.423	-0.094
	[0.89]	[1.80]*	[1.16]	[0.04]
$T^2*Horizontal^{Y}_{min}$	-2.478	-11.122	1.117	0.955
	[1.99]**	[4.54]***	[0.90]	[0.53]
$Backward_{full}$	2.516	2.783	2.801	1.857
	[3.24]***	[3.25]***	[3.26]***	[2.79]***

	All firms	L<5	5<=L<50	L>=50
$T * Backward_{full}$	-6.740	-12.078	-6.533	-2.695
	[3.34]***	[3.58]***	[2.67]***	[1.64]
$T^2 * Backward_{full}$	1.045	2.636	0.246	-0.278
	[1.36]	[1.61]	[0.27]	[0.30]
$Backward_{maj}$	-3.285	-2.866	-3.548	-3.181
	[5.35]***	[4.15]***	[5.35]***	[4.81]***
$T * Backward_{maj}$	5.258	2.575	5.035	6.454
	[3.27]***	[0.93]	[2.82]***	[3.72]***
$T^2 * Backward_{maj}$	-1.412	0.038	-1.648	-2.563
	[2.20]**	[0.03]	[2.46]**	[2.54]**
$Backward_{min}$	-3.861	-4.455	-2.675	0.915
	[1.84]*	[1.90]*	[1.16]	[0.54]
$T * Backward_{min}$	13.070	13.354	2.282	-3.139
	[2.21]**	[1.26]	[0.33]	[0.62]
$T^2 * Backward_{min}$	-8.079	0.786	4.370	6.813
	[2.58]**	[0.12]	[1.35]	[1.99]**
$Forward_{full}$	-1.749	-1.168	-2.272	-0.190
	[1.66]*	[1.06]	[1.96]*	[0.19]
$T * Forward_{full}$	1.163	-2.626	4.629	3.666
	[0.40]	[0.48]	[1.40]	[1.53]
$T^2 * Forward_{full}$	-0.365	8.892	-3.042	-2.470
	[0.22]	[2.48]**	[1.50]	[1.82]*
$Forward_{maj}$	5.205	4.877	5.382	3.203
	[8.49]***	[7.33]***	[7.73]***	[5.74]***
$T * Forward_{maj}$	-9.134	-4.410	-11.503	-7.050
	[4.84]***	[1.14]	[5.23]***	[3.70]***
$T^2 * Forward_{maj}$	5.899	-0.532	9.962	4.130
	[4.77]***	[0.17]	[6.95]***	[3.34]***
$Forward_{min}$	1.403	0.393	1.233	8.025
	[1.02]	[0.25]	[0.82]	[4.56]***
$T * Forward_{min}$	-11.563	7.151	-13.896	-28.214
	[1.69]*	[0.58]	[1.91]*	[4.62]***
$T^2 * Forward_{min}$	9.931	-11.816	10.749	23.609
	[2.04]**	[1.51]	[2.03]**	[4.96]***
$SupplyBackward_{full}$	18.448	20.681	20.798	9.536
	[6.61]***	[6.62]***	[6.97]***	[3.47]***
$T * SupplyBackward_{full}$	-45.625	-87.280	-57.790	-12.508
	[5.30]***	[4.64]***	[6.93]***	[1.66]*
$T^2 * SupplyBackward_{full}$	15.982	30.865	36.017	-3.712
	[3.00]***	[2.27]**	[6.38]***	[0.57]
$SupplyBackward_{maj}$	-10.255	-11.858	-8.892	-8.807

	All firms	L<5	5<=L<50	L>=50
	[4.43]***	[4.49]***	[4.06]***	[4.60]***
$T * SupplyBackward_{maj}$	36.283	44.258	38.467	18.565
	[6.19]***	[4.04]***	[7.05]***	[3.39]***
$T^2 * SupplyBackward_{maj}$	-21.720	-23.112	-27.912	-9.371
	[7.11]***	[2.99]***	[9.03]***	[2.10]**
$SupplyBackward_{min}$	-19.213	-22.351	-23.508	-6.741
	[3.21]***	[3.05]***	[3.54]***	[1.31]
$T * SupplyBackward_{min}$	22.238	86.343	62.254	-9.967
	[0.92]	[1.90]*	[2.41]**	[0.44]
$T^2 * SupplyBackward_{min}$	6.072	-14.038	-46.450	18.299
	[0.45]	[0.52]	[3.17]***	[1.10]
N	120317	56095	53348	10874
#firms	55097	30866	26351	4993
R^2	0.14	0.16	0.17	0.18

Robust t statistics in brackets; */**/*** significant at 10%/5%/1%

Table 7: Effect of degree of foreign ownership, firm size and the interaction of spillover variables with the level of technology - Results for all industries

	All firms	L<5	5<=L<50	L>=50
F-tests				
No $T - Horizontal^{Y}_{full}$	10.16***	5.00***	23.02***	5.22***
No $Horizontal^{Y}_{full}$	6.78***	3.34**	15.49***	3.97***
No $T - Horizontal^{Y}_{maj}$	2.15	0.86	1.76	2.57*
No $Horizontal^{Y}_{maj}$	1.55	0.90	1.17	2.46*
No $T - Horizontal^{Y}_{min}$	2.88*	19.33***	0.67	0.69
No $Horizontal^{Y}_{min}$	2.19*	14.36***	0.51	1.27
No $T - Horizontal^{L}_{full}$	8.65***	9.56***	13.06***	1.86
No $Horizontal^{L}_{full}$	6.87***	8.28***	9.76***	1.28
No $T - Horizontal^{L}_{maj}$	11.48***	2.94*	6.04***	2.49*
No $Horizontal^{L}_{maj}$	7.96***	3.32**	4.04***	2.10*
No $T - Horizontal^{L}_{min}$	3.96**	6.34***	19.81***	0.92
No $Horizontal^{L}_{min}$	2.83**	5.36***	13.84***	1.83
No $T - Backward_{full}$	11.03***	11.08***	16.52***	6.68***
No $Backward_{full}$	7.46***	7.40***	11.42***	4.95***
No $T - Backward_{maj}$	6.21***	1.65	4.00**	11.94***
No $Backward_{maj}$	9.60***	6.74***	10.55***	8.83***
No $T - Backward_{min}$	3.33**	4.49**	5.07***	6.19***
No $Backward_{min}$	2.41*	3.64**	3.38**	4.84***
No $T - Forward_{full}$	0.12	10.40***	1.14	1.66
No $Forward_{full}$	1.10	7.55***	1.49	1.32
No $T - Forward_{maj}$	12.56***	3.74**	27.03***	6.91***
No $Forward_{maj}$	28.70***	27.79***	34.78***	11.47***
No $T - Forward_{min}$	2.10	2.82*	2.09	12.42***
No $Forward_{min}$	1.40	2.19*	1.45	9.51***
No $T - Supply\text{-}Backward_{full}$	19.83***	19.73***	24.13***	7.68***
No $Supply\text{-}Backward_{full}$	16.89***	18.76***	18.95***	6.84***
No $T - Supply\text{-}Backward_{maj}$	25.35***	9.17***	42.08***	8.15***
No $Supply\text{-}Backward_{maj}$	17.01***	8.05***	28.34***	7.15***
No $T - Supply\text{-}Backward_{min}$	3.92**	5.66***	5.62***	1.14
No $Supply\text{-}Backward_{min}$	5.92***	5.41***	7.14***	2.99**

T-'Spillover' tests the joint significance of the T and T^2 interactions, 'Spillover' the joint significance of the T and T^2 interactions and the level of Spillover.Columns 2-4 are split-samples according to the domestic firm's number of employees (L). */**/*** rejection at 10%/5%/1%.

Table 8: Effect of degree of foreign ownership, firm size and the interaction of spillover variables with the level of technology - Results for all industries - F-tests

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