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The spillover effects of foreign direct investment on the firms' productivity performances

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Abstract The study aims to examine foreign direct investment spillover effects on the firms' productivity performances and to examine the most important component of total factor productivity growth in explaining output growth. This study employs a time-varying stochastic frontier approach for firm level panel data of Indonesian manufacturing industry and performs a non-parametric test of the closeness of two distributions. The results demonstrate that foreign firms achieve higher productivity but less efficient than domestic firms. Increasing degrees of foreign ownership is negatively related to firms' productivity but positively related to firms' efficiency. There are positive horizontal spillover effects of foreign direct investment on the firms' productivity and efficiency. The backward spillovers have positive impact on firm's efficiency, and the forward spillovers have positive impact on firm's productivity. However, there are negative backward spillover effects on firms' productivity and negative forward spillover effects on firms' efficiency. Besides that, within the same market technology spillover from FDI are smaller with higher level of labour quality. In the upstream market, the degree of absorptive capacity of suppliers has a negative impact on firms' productivity but have a positive impact on reducing inefficiency. In the downstream markets, the greater ability of the buyers to identify, assimilate and exploit knowledge spillovers, the greater the impact on increasing productivity but the lesser the impact on reducing inefficiency. Finally, this study finds that all components of productivity; technological progress, technical efficiency change and scale efficiency change significantly contribute in explaining the TFP growth.

Keywords Foreign direct investment spillovers · Efficiency · Productivity · Manufacturing industry · Indonesia

JEL Classifications D24 · F23

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1 Introduction

There are many empirical studies that examine productivity gains from foreign direct investment (FDI) that focus solely on technological (or technical) change. They evaluate the FDI spillover effects on the conventional production function (Aitken and Harrison 1999; Blomström and Sjöholm 1999; Javorcik 2004; Blalock and Gertler 2008; Kohpaiboon 2009). However, theoretical arguments indicate that productivity gains from FDI can come from efficiency improvement. Superior technology may not only generate technology progress but also advanced managerial expertise and scale-production knowledge that contributes to technical efficiency improvement and scale efficiency enhancement (Kokko and Kravtsova 2008; Smeets 2008). Thus, the conventional approach of treating productivity gains from FDI as synonymous with technological change tends to understate the real spillover effects of FDI.

Given the fact that knowledge transfers from foreign firms are not only in the form of advanced technology but also managerial expertise and scale-production knowledge. Hence, a systematic analysis on FDI spillover effects should not only include technological gains but also technical and scale efficiencies. However, some previous studies have only focused on the effect of FDI spillover as a determinant of relative technical efficiency or distance from the frontier. They have investigated the effects of FDI spillover in explaining efficiency differences, either using stochastic frontier analysis (SFA) (Mastromarco and Ghosh 2009; Suyanto et al. 2009) or the related non-stochastic of data envelopment analysis (DEA) (Kravtsova 2008). And, very hardly to find any studies that have taken into account both efficiency improvement and technological progress as sources of productivity gains from FDI.

In order to capture the sources of productivity gains that channel through technical change and efficiency enhancement, we investigate the effects of FDI spillover in both respects. Therefore, the paper employs SFA for firm level panel data and includes a set of FDI spillover variables in determining the production frontier and in affecting deviations from frontier. Furthermore, the sources of productivity can be decomposed from stochastic frontier estimation into three components; technological change, technical efficiency change and scale efficiency change. The total factor productivity (TFP) growth is the summation of those three productivity components. Then, we examine the most important source of total factor productivity growth in explaining output growth using non-parametric test of the closeness of two distributions.

The organization of this paper proceeds as follows: Section 2 provides a literature review of sources of productivity gains from FDI. Section 3 discusses data sources and variable construction for panel data. It is continued by model specification and estimation techniques in Sect. 4. Section 5 presents the results for model selection and estimation, followed by an analysis of empirical results. The summary of findings and policy implications are given in the final section.

2 Literature review

The ability to attract FDI could bring immense benefits to a recipient country. Incoming multinational corporations (MNCs) provide both direct and indirect benefits to the host's economy. The direct benefits from foreign affiliates can take the form of new investments, productive capacity, labour demand, intermediate goods demand and sometimes exports that stimulate national income or economic growth, provide new opportunity, and increase tax revenue (Takii 2005; Suyanto 2010). In addition, the entry of foreign firms in host country has indirect effects on existing domestic firms. In the literature, these indirect effects are often called productivity spillovers from FDI (Blomström et al. 2000; Görg and Strobl 2004; Lipsey and Sjoholm 2005). The indirect benefits are in the form of knowledge externalities, which are generated through non-market mechanisms to a recipient economy and the domestic firms within the economy. Foreign firms increase competitive pressure, which motivates local firms to improve their productivity.

Theoretical arguments indicate that the externalities from inward FDI do not only generate productivity gains to domestic firms through technological progress but also efficiency improvement. The first form of incoming FDI indicates that the presence of foreign affiliates may support domestic firms implementing superior technology to imitate the advanced product which lead to move upward the technological frontier. And the second form imply that substantial inflows of FDI may stimulate domestic firms to catch-up with the best practice (firms which operate on the frontier) and to reach optimal production scale.

Productivity gains from foreign presence are often regarded synonymously with technological benefits. Firms in a developing country are often lack innovative capabilities and typically lag behind foreign affiliates. The introduction of advanced product from foreign firms may accelerate the diffusion of new technology in the host country. The presence of advanced products and technologies from foreign affiliates in local markets can inspire and stimulate local innovators to conduct research and development (R&D) activity. This will support the local firms for inventions. Hence, positive FDI spillovers to the productivity growth of domestic firms are reflected in the upward shift of the firms' production technology (Caves 1971; Glass and Saggi 1999). This argument is consistent within the standard practice of the production function, which assumes that establishments are operated at full efficiency and constant return to scale.

In addition to technological benefits, there is another source of productivity gain which leads productivity increases. Treating productivity gains from FDI similar with technological progress tends to devalue the real spillover effects of FDI. Advanced technology may not only create technology progress but also advanced managerial expertise and scale-production knowledge that contributes to technical efficiency improvement and scale efficiency enhancement. The advanced managerial knowledge from foreign firms provides domestic firms skills related to technical efficiency. A firm as the producer of output for given inputs then either operates within or on this frontier. The first outcome regards as a technically inefficient while the latter reflects on some level of technical efficiency. By observing MNCs behavior, local firms may find out the ways to produce more output with the certain combination of inputs, or

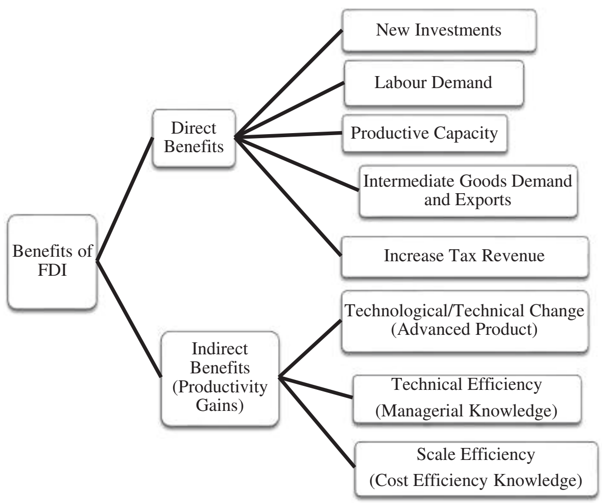

Fig. 1 Benefits of foreign direct investment

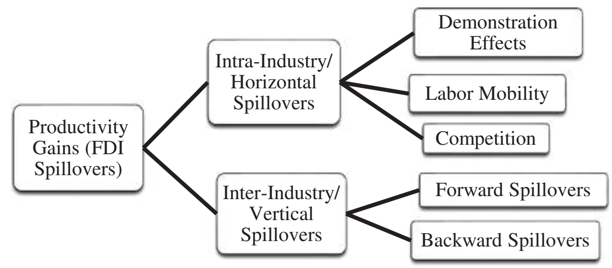

Fig. 2 The transmission of productivity gains from foreign direct investment

to produce a given amount of output using less input combinations. This technical efficiency therefore refers to the ability to avoid waste or slack by producing as much output as input usage allows (Kravtsova and Zelenyuk 2007). Moreover, cost efficiency knowledge is also an important factor for scale efficiency. The domestic firms learn ways to achieve optimal level of production scale, given with a certain existing resources. Some firms may operate under a variable return to scale, so by learn the behavior of foreign firms, domestic firms can increase in returns to scale or scale efficiency advancement (Girma and Görg 2007). The benefits from encouraging FDI that we discuss above are illustrated in Fig. 1.

Furthermore, the productivity gains from incoming FDI can be transmitted into two broad channels; intra-industry productivity spillovers and inter-industry productivity spillovers (Javorcik 2004; Girma et al. 2008; Lin et al. 2009; Keller 2009). If the presence of foreign firms generate productivity to domestic firms in the same industry, these spillovers are considered as intra-industry spillovers or horizontal spillovers. On the other hand, if incoming foreign firms increase productivity of domestic firms across industries, these spillovers are regarded as inter-industry spillovers or vertical spillovers. The intra-industry spillovers may occur through three channels of productivity spillovers transmission mechanisms. They are demonstration effect, labour mobility and competition. While, the inter-industry spillovers are channeled through vertical linkages. Vertical technology transfer can arise through both backward (from buyer to supplier) and forward (from supplier to buyer) linkages. Figure 2 outlines a schematic concept of productivity gains transmission from incoming FDI.

The presence of MNC subsidiaries in the domestic market can generate demonstration effects for domestic firms in two ways. First, the domestic firms can adopt directly from foreign firm's technologies through imitation or reverse engineering (Das 1987; Khalifah and Adam 2009). Local firms can learn how foreign firm affiliates procure, produce, sell, manage, and adapt technology. Obviously, the relevance of this effect increases with the similarity of the good produced by foreign firms. They can then imitate the behaviour of foreign firms. Second, the domestic firms are stimulated indirectly by new innovation and R&D (Cheung and Lin 2004). The presence of advanced products from foreign affiliates in host country can encourage and motivate local innovators to do R&D activity which leads to innovation and invention. Therefore, domestic firms can upgrade the level of their managerial skills and production technology, and may experience increases in productivity.

Another channel for FDI productivity spillovers is related to labour mobility. The MNCs play a more active role than domestic firms in educating and training local workers. Through this training, and subsequent work experiences, workers become familiar with foreign firms' technology and production techniques. The possibility of domestic firms hiring workers who, having previously worked for a foreign firm, know about the technology and are able to implement it in the domestic firm (Fosfuri et al. 2001; Glass and Saggi 2002), resulting in productivity spillovers when the trained workers move to domestic firms or establish their own business (De Mello 1997). Nevertheless, it is important to stress a possible negative impact arising through this channel, as MNCs may attract the best workers from domestic firms by offering higher wages. The influence of this labour mobility on the efficiency of local firms is difficult to evaluate as it involves tracking the workers in order to investigate their impact on the productivity of other workers (Saggi 2002). It is not surprising that there is a shortage of detailed studies in relation to this particular aspect.

Furthermore, the competition pressure from FDI is one potentially important determinant of spillovers. The entry of MNCs may lead to greater competition in domestic markets.

Foreign firms which enter into a market may increase competition and force local firms to become more efficient. As long as foreign firms serve host country markets as well as foreign and domestic products are substitutes, the presence of foreign firms in a domestic market may increase competition. Competition is an incentive for domestic firms to utilise existing resources efficiently or even to adopt new technologies. Domestic firms are then forced to defend their market share by increasing their productivity. However, competition may also restrict the market power of domestic firms. The efficiency of domestic firms may also be negatively affected through competition channel. When the profit effects are larger than the efficiency effects, the competition from foreign firms may result in negative spillovers to domestic firms. Markusen and Venables (1999) argue that the entry of foreign firms to domestic markets reduces domestic firms' sales, leads to the exit of some domestic firms, and restores sales of remaining firms to zero profit level. Aitken and Harrison (1999) present a similar argument but focus on the increasing of average costs in domestic firms as a factor for the negative spillover effects. The presence of MNCs may imply significant losses of their market shares, forcing them to operate on a less efficient scale, with a consequent increase in their average costs.

A channel of vertical spillovers will exist when the MNC subsidiaries are linked to upstream and downstream industries in host countries (Rodriguez-Clare 1996; Javorcik 2004; Blalock and Gertler 2008). The domestic firms in local markets with the MNCs as customers of intermediate inputs may result in backward linkages spillover effect. Meanwhile, MNCs acting as suppliers of intermediate inputs to domestic firms may result in forward linkages spillover effect.

The MNC subsidiaries demand intermediate inputs with a specific standard of quality, which is usually higher than the domestic standard. The MNCs might find it profitable to develop local supplier networks and to help improve the performances of these networks by providing information related to sophisticated technology, technical assistance, and other services to local suppliers. In some cases, MNC subsidiaries may also provide technical and managerial training to domestic suppliers to ensure the inputs meet their qualifications. This demand forces domestic suppliers to increase their efficiency and productivity improvement. This channel of productivity spillovers is commonly known as backward linkages.

The MNCs might supply services to local customers that purchase their products for use as inputs. As argued by Javorcik (2008), the entry of MNCs provides new and more suitable inputs for local producers. Access to a greater variety of inputs, especially those with a higher quality, is more likely to increase the efficiency and productivity of firms in downstream industries. Domestic buyers in downstream industries may also receive productivity spillovers from MNC subsidiaries. The relationship between MNC suppliers and domestic buyers are known as forward linkages.

These links create an opportunity for domestic suppliers or buyers to gain productivity spillovers. This forward spillover together with the backward spillover, sums up to a vertical spillover of FDI in the productivity of domestic suppliers and buyers. This vertical spillover can be seen as a development of an industry by MNC subsidiaries that lead to a development of other related industries.

3 Data sources and variables construction

The main data are taken from an annual survey of medium and large manufacturing establishments conducted by the Indonesian Central Board of Statistics (Badan Pusat Statistik or BPS). The survey relies on census and covers all establishments. It is carried out by sending a questionnaire to all large and medium establishments, those are recorded in the directory of establishments compiled by the BPS.[1] The medium and large industrial series data are designed to survey all manufacturing establishments employing at least 20 workers in every year. Large establishment is an establishment engaging with more than 99 employees, while medium establishment is an establishment engaging with 20–99 employees. This empirical analysis will use the data from 2003 to 2009.[2] The numbers of original observations during the periods of study are 169,366 establishments. These observations vary with the year of survey, with the minimum number of 20,324 manufacturing establishments in 2003 and the maximum number of 29,468 establishments in 2006 (Table 1).

The main variables used in the production frontier model consist of output and input variables. The output variable is proxy by total gross output. It refers to total value of output produced by a firm in a given year. Capital stock is measured by the replacement value of fixed assets. The values of fixed assets contain three asset types: lands and buildings, machinery and other capital goods, and vehicles. The labour input is measured by the number of employees. The number of employees is used instead of man hours due to the unavailability of the data. Material is the total cost of

[1] Some firms may have more than one factory and BPS delivers a different questionnaire to the head office of every firm with more than one factory.

[2] The BPS has conducted annual survey of manufacturing industry since 1975 and the recent available data are for the year 2009. However, this study uses only the period of data from 2003 to 2009. It is because the BPS changed the specific identification code to KIPN in the year 2001 without providing a concordance table to the previously used identification code (PSID).

Table 1 The number of foreign and domestic indonesian manufacturing establisments

Years	Number of plants			Number of plants			Number of plants		
	Before cleaning data			After cleaning data 1			After cleaning data 2		
	Foreign	Domestic	Total	Foreign	Domestic	Total	Foreign	Domestic	Total
2003	1777	18,547	20,324	1645	17,134	18,779	1558	16,448	18,006
2004	1698	18,987	20,685	1608	16,993	18,601	1540	16,365	17,905
2005	1695	19,034	20,729	1609	17,266	18,875	1532	16,635	18,167
2006	2175	27,293	29,468	1539	15,178	16,717	1427	14,525	15,952
2007	2200	25,798	27,998	2080	24,008	26,088	1971	23,189	25,160
2008	2237	23,457	25,694	2151	22,141	24,292	2092	21,482	23,574
2009	2240	22,228	24,468	2149	20,867	23,016	2054	20,191	22,245
2003–2009	14,022	155,344	169,366	12,781	133,587	146,368	12,174	128,835	141,009

A plant with any share of foreign assets is considered as foreign firm. Cleaning Data 1 is applying material input criteria 1. Cleaning Data 2 is applying material input criteria 2

domestic and imported raw material used in the production process. While energy is the total expenditure on gasoline, diesel fuel, kerosene, public gas, lubricant and electricity. The output and input material, energy and capital stock are valued in monetary terms and valued in thousand rupiah. Therefore, it is necessary to deflate the values output and inputs into real values. Gross output and inputs are deflated using a wholesale price index (WPI) published by the BPS at a constant price of 2005. The value of imported material is also controlled using the exchange rate index.

The supplementary data used in this study are input output (I–O) tables. It is used for calculating spillover variables for downstream and upstream industries (backward and forward linkages). The I–O table captures 175 economic sectors and divides manufacturing activity into 90 sectors. BPS provides concordance tables linking the I–O codes to 5-digit ISIC codes. BPS assumes that technology is constant every five year and that is why BPS only provides data of I–O table every 5 year. During the selected period of the study, it is assumed that technology is constant. Hence, all the vertical (backward and forward) linkages is estimated by applying an available data of I–O table which were published in year of 2005.[3]

An unbalanced panel dataset will be used for estimating stochastic production function with inefficiency effects.[4] There are several adjustment steps to set up an unbalanced panel data. A few observations are dropped when making consistency checks between industrial codes with international standard industrial classification (5-digit ISIC).[5] The data of fixed assets show relatively high variations from year to year. Many establishment report missing value or zero on those fixed assets. In order to reduce the volatility and impute these missing values, the capital series are regressed against the lagged values of real output to obtain predictions for capital at establishment level. These missing values are calculated following a methodology similar to Vial (2006), Ikhsan (2007) as well as Suyanto and Salim (2013). The capital series are regressed against once lagged values of real output to obtain predictions for capital at establishment level. The predictions are then imputed for establishments which report zero or missing values.[6]

The dataset are cleaned to minimize noise from non-reporting, misreporting and key-punch error, such as in inputs and foreign share. Some establishments in a given year reported missing values of some inputs, such as material, energy and labour cost. These missing values in these particular variables are eliminated from the observation.[7] Furthermore, there is obvious typing mistake of raw data in foreign share, for example, foreign share of a firm for the whole of the selected period is typed as a 100 %, except for a certain year being typed as 0 %, and then the 0 % share is adjusted to 100 %.[8] During the periods of the study, more than 2 % domestic firms changes to foreign

[3] Besides that, this study also considers the I–O table for the year 2000 for estimating backward and forward linkages for the years 2003 and 2004, while the remaining linkages is estimated using the I–O table for the year 2005.

[4] However, this study applies a balanced panel data for calculating output and input growth as well as for decomposing total factor productivity growth into three component sources of productivity. After constructing a balance panel data using observation with material input criteria 1, the numbers of observations in every year are removed to 10,093 firms. Meanwhile using criteria 2, the numbers of observations become 8705 firms in each year.

[5] For firms with same PSID, if they have different ISIC, the most dominant ISIC will replace the less dominant ISIC. However, if each firm with same PSID has a different ISIC in every year, it is dropped from observations. After this adjustment, the original observations are dropped around 0.13 %.

[6] The missing value of fixed assets are around 30.06 % from the original sample, and 70.46 % of them can be estimated.

[7] The missing values in material, energy and labour cost are about 0.07 %, 2.87 % and less than 0.01 % from the original sample.

[8] This interpolation applies to less than 1 % of the sample.

Table 2a A statistic summary of the main variables using material input criteria 1

Variables	Units		Years						
			2003	2004	2005	2006	2007	2008	2009
Output (Y)	Billion Rupiah	Mean	45.87	51.39	51.33	52.44	41.11	47.68	51.61
		Std. Dev.	341.22	394.55	391.87	408.60	345.90	581.39	713.76
Capital (K)	Billion Rupiah	Mean	80.25	26.27	54.36	4455.60	8.13	10.78	553.34
		Std. Dev.	5336.97	924.39	2982.62	263,000.00	140.18	156.73	74,700.00
Labour (L)	Workers	Mean	212.50	211.18	204.16	213.50	165.35	174.63	178.42
		Std. Dev.	747.62	790.50	788.70	768.72	628.75	683.48	668.09
Material (M)	Billion Rupiah	Mean	28.36	32.23	32.39	31.94	25.14	28.46	30.25
		Std. Dev.	194.04	250.56	251.40	249.03	222.15	291.75	379.20
Energy (E)	Billion Rupiah	Mean	2.87	3.57	3.52	2.43	2.17	2.87	2.16
		Std. Dev.	36.21	44.46	48.40	28.61	24.02	32.51	24.52
Number of observations			18,779	18,601	18,875	16,717	26,088	24,292	23,016

Mean = arithmetical average, Std. Dev. = standard deviation

firms and less than 1 % foreign firms becomes to a domestic firm. The numbers of domestic and foreign establishments in each year are reported in Table 1.

When the ratio of material input to gross output is too low or too high, and in some cases the ratio is more than one, which seems to be unreasonable. Hence, the observation is controlled from this implausible sense using material input over gross output criteria. The samples are considered to be excluded from the observations if the value of particular material input in relation to gross output is less than 5 % and higher than 95 %, and we call this material input criteria 1. After this adjustment process, the total observation during the periods of study is 146,368 establishments which are grouped into 34,896 identification code (PSID) and 344 industrial classifications (ISIC). Besides that, this study also accomodates the material input criteria of 10 and 90 %, which we call material input criteria 2 and the number observation reduces to 141,009 establishments which are classified into 34,578 PSID and 341 ISIC categories. Table 2a, b show the main data in each year using these criteria.

The exogenous variables included in the models can be divided into key variables and other exogenous variables. The key variables are set of FDI variables, such as the dummy variable of foreign firm (FOR), horizontal spillovers (*HSpill*), backward spillovers (*BSpill*) and forward spillovers (*FSpill*). While, the other variables are openness variables that can be measured by imported input material intensity (*Imp*) and export intensity (*Exp*), absorptive capacity variable (*Abs*), the degree of market competition (*HHI*) as well as firm size (*FSize*). All industrial sectors in this study are classified based on the 5-digit industrial code and all calculations of their values are based on the original observations.

There are some different definitions of foreign ownership. According to the different studies, the definition of foreign equity capital varies. Studies by Aswicahyono and Hill (1995), Blomström and Sjöholm (1999), Koirala and Koshal (1999), Ramstetter (1999), Narjoko and Hill (2007), readily accept any positive amount of foreign ownership, while Haddad and Harrison (1993) consider firms with at least 5 % equity owned by foreigners. The IMF (2004) and OECD (2009) definition of foreign firms is defined as an incorporated enterprise in which a foreign investor owns 10 % or more of their equity capital. The IMF and OECD definition is characterized an internationally standard threshold of foreign firm. Another study, like Djankov and Hoekman (2000) consider the relevant threshold to be 20 %.

This study accommodates several thresholds of foreign assets percentages. All joint-venture companies with 5, 10 and 20 % of foreign assets will be considered as foreign firms in the model. Variable of foreign ownership is measured by a dummy variable and it will be defined as:

$$\begin{aligned} FOR_{it} &= 1 \text{ if the share equity of foreign ownership } i \text{ at} \\ &\quad \text{time } t \text{ is greater than or equals the thresholds.} \\ &= 0 \text{ if otherwise} \end{aligned} \quad (1)$$

An extension, such as an interacting *FOR* dummy variable with foreign equity share (*FSh*FOR*) is also included in the model. This interacting variable captures the effect of higher percentages of foreign ownership on firms' productivity and efficiency.

The foreign share of gross output is chosen as a proxy of horizontal spillover from foreign firms. As in Javorcik (2004) and Blalock and Gertler (2008), the *HSpill* variable

Table 2b A statistic summary of the main variables using material input criteria 2

Variables	Units		Years						
			2003	2004	2005	2006	2007	2008	2009
Output (Y)	Billion Rupiah	Mean	44.25	49.43	47.75	49.48	40.50	47.35	51.35
		Std. Dev.	326.22	362.05	353.84	369.12	347.40	585.74	725.22
Capital (K)	Billion Rupiah	Mean	77.79	25.48	55.04	4,641.57	7.92	10.78	572.05
		Std. Dev.	5,410.00	938.91	3,039.39	268,744.90	140.61	158.53	76,026.51
Labour (L)	Workers	Mean	211.99	211.35	202.57	211.80	164.78	175.02	177.68
		Std. Dev.	756.27	798.82	789.15	779.64	633.00	687.24	667.27
Material (M)	Billion Rupiah	Mean	26.77	30.44	28.74	29.43	24.49	28.26	29.83
		Std. Dev.	164.05	210.19	188.38	204.27	224.32	295.33	384.81
Energy (E)	Billion Rupiah	Mean	2.79	3.50	3.36	2.31	2.14	2.91	2.20
		Std. Dev.	35.00	42.82	46.33	26.9	23.98	32.97	24.93
Number of observations			18,006	17,905	18,167	15,952	25,160	23,574	22,245

Mean = arithmetical average, Std. Dev. = standard deviation

is the horizontal spillover effects from FDI to domestic firms' productivity in the same market. It is calculated as follows:

$$HSpill_{jt} = \frac{\sum_{i \in j} FSh_{it} * Y_{it}}{\sum_{i \in j} Y_{it}}, \quad (2)$$

where *HSpill* denotes the horizontal spillover effects, *FSh* measures the share of firm's total equity owned by foreign investors. *Y* expresses output, subscript *i* denotes the *i*-th firm, *j* describes the *j*-th industry, $i \in j$ indicates a firm in a given industry and *t* represents time.

FDI can also generate vertical spillovers through the linkage channel. The backward and forward spillover variables here are established according to the I–O table, especially the Leontief inverse matrix which captures both direct and indirect (inter-sectoral) linkages. The measurement of vertical linkages in this study will follow Kohpaiboon's (2009) study. This is different from Javorcik (2004) and Blalock and Gertler (2008) whose vertical linkages proxy captures only the direct linkages.

To do so, inter-industry linkage is constructed based on the Leontief inter-industry accounting framework. Consider an input–output framework in which the import content of each transaction is excluded (non-competitive type):[9]

$$X = A^d X + Y^d + E, \qquad A^d = [a_{kl}], \qquad a_{kl} = X_{kl}/X_l \quad (3)$$

Solving Eq. (3) for *X*:

$$X = [I - A^d]^{-1}[Y^d + E], \qquad [I - A^d]^{-1} = [b_{kl}], \quad (4)$$

where *X* is column vector of total gross output. A^d is domestic input output coefficient matrix. $[a_{kl}]$ is element of domestic input-output coefficients matrix.[10] Y^d is column vector of domestic demand on domestically produced goods. *E* is column of export demand on domestically produced goods. $[b_{kl}]$ is the Leontief domestic inverse matrix which captures both direct and indirect (inter-sectoral) linkages in the measurement process. It shows the total units of output required, directly and indirectly, from all sectors when the demand for the industry's product rises by one unit.

The variable of backward spillover (*BSpill*) captures the foreign presence in the upstream industries that are supplied by industry j. The measurement is defined in the following way:

$$BSpill_{jt} = \sum_k b_{kl} * HSpill_{jt}, \quad (5)$$

where b_{kl} indicates amount of industry *k's* output demanded by an additional unit of industry *l's* output produced. The product between each element b_{kl} and its corresponding degree of foreign presence ($b_{kl} * HSpill_{jt}$) measures to a certain extent derived demand from foreign presence for industry *k's* output. Hence, the sum of that product indicates total derived demand from foreign firms for industry *k's* output. This indicates the backward linkages from foreign firms. In Eq. (5), inputs supplied within the industry are not included, because the effects are already captured by horizontal spillovers.

While the FDI effect on suppliers is measured by backward spillovers, the FDI effect on buyers is represented by forward spillovers. The forward spillover is calculated in a

[9] There is another type of I–O table in which the import transactions are not excluded from domestic transactions.

[10] This coefficients matrix (a_{kl}) used by Javorcik (2004) and Blalock and Gertler (2008) for calculating vertical linkages and captures only direct demand.

similar way as backward spillover and excluding outputs produced by foreign firms for export (Y_{it}−X_{it}). The purpose of this measure is to capture the potential spillovers from foreign firms to domestic buyers' productivities. The forward spillover is defined as:

$$FSpill_{jt} = \sum_{l} b_{kl} * \frac{\sum_{i \in j} FSh_{it} * (Y_{it} - X_{it})}{\sum_{i \in j} (Y_{it} - X_{it})}, \quad (6)$$

where b_{kl} indicates demand for industry $k's$ output to be used as inputs for producing a unit of industry $l's$ output. When multiplying each element b_{kl} with its corresponding foreign share, this multiplying indicates industry l purchases its intermediate inputs supplied by foreign plants located in industry k. For the same reason as before, inputs purchased within the industry are excluded. Hence, the sum of that product would reflect a proportion of total intermediate inputs used in industry l supplied by foreign firms, indicating forward linkage from foreign firms.

Having access to leading edge technologies through technology transfers may not itself lead to productivity improvements. An absorptive capacity is a critical factor in firms' ability to catch up with other firms at the technological frontier or to shift upward from the technological frontier. Spillovers may not materialize if the technology is not absorbed and utilized efficiently, and then there may be little scope for learning. Therefore, the spillovers effects from FDI do not guarantee to occur automatically, it depends with the capability of the human capital in a receipt country.

Human capital plays a crucial role on absorptive capacity of host industry in which the foreign firms operate. Mastromarco and Ghosh (2009) as well as Henry et al. (2009) found that the existing level of human capital is an important variable for greater technology absorption. The most appropriate indicator to assess human capital on the firms' productivity and efficiency is the quality of the workers. It represents the skills of workers that affect the productivity and efficiency of the firm. Unfortunately this, information is not available at firm level data that we use in this study. However, Le and Pomfret (2011) argue since the number of skilled workers are not available, labour costs (including wages and training costs) per worker can be used as a proxy for the human capital stock of the firm. This is based on the assumption that firms with higher average labour costs per worker employ higher skilled labour. Therefore, the labour cost per worker will be used as a proxy for absorptive capacity variable (Abs_{it}) in this study. To account for the absorptive capacity in determining the extent of technology spillovers, we interact absorptive capacity variable with the spillover variables. The absorptive capacity may facilitate FDI spillover effects in the Indonesian manufacturing industries. This interaction between technology spillovers from FDI with the absorptive capacity variable may represent rapid adoption of new technology in the manufacturing sectors.

Moreover, the openness variables can be determinants that affect the firm's productivity performance. Technology transfer from international trade provides greater importance for productivity growth for firms in developing countries which have little new technology. Technical progress could be embodied in new materials, intermediate manufactured products, capital equipment are traded on international markets thus allowing countries to import the R&D investments made by others. Keller (2009) suggests that import and export intensities can be a significant channel for transmitting technological knowledge. The importing or exporting plants might receive technology spillovers through their importing or exporting experiences. They might come into contact with foreign technology through their importing or exporting activities, and more likely that they get more access to technology. This raises the firm technological capacity, which in turn increases the firm productivity. Therefore, both will be included in the model, which import intensity (Imp_{it}) is measured by share of imported material and export intensity (Exp_{it}) is measured by ratio export to gross output of firm i at time t.

Broadly, firm's higher productivity performances can occur as a result of the lower or higher degree of market competition. There are two alternative hypotheses that have been put forward to explain correlation between productivity performance and competition. On the one hand, higher concentration can be the result of dynamic competition among firms of differential productivity that removes less productive firms from the industry as argued by Demsetz (1973), Peltzman (1977), Sidak and Teece (2009) as well as Teece (2011). On the other hand, higher concentration is an inverse measure of static competition that can protect less productive firms. This means that productivity improvement could be stimulated in the more competitive environment as introduced by Nickell et al. (1997) and Ahn (2002).

The dynamic competition is propelled by the change in external circumstances and the generation of new products, new processes, and new business models. Firms with better organization can manage of their resources efficienly. Some efficiency might be gained by a decline of this inefficiency fringe, any substantial change in market structure would likely involve a reallocation of output among the most efficiency firms. In addition, the most productive firms also have greater intensity of technological innovation of firms or have greater innovating effor to conduct R&D activities. The more productive firms will be more profitable and gain market share, consequently, the concentration of the market increases. And therefore, high concentration is likely to have rapid technological change which leads to higher productivity.

Table 3a A statistical summary of exogenous variables using material input criteria 1

Variables	Units		Years						
			2003	2004	2005	2006	2007	2008	2009
$FOR_{5\,\%}$	Binary dummy	Mean	0.09	0.09	0.08	0.09	0.08	0.09	0.09
		SD	0.28	0.28	0.28	0.29	0.27	0.28	0.29
$FOR_{10\,\%}$	Binary dummy	Mean	0.09	0.09	0.08	0.09	0.08	0.09	0.09
		SD	0.28	0.28	0.28	0.29	0.27	0.28	0.29
$FOR_{20\,\%}$	Binary dummy	Mean	0.09	0.09	0.08	0.09	0.08	0.09	0.09
		SD	0.28	0.28	0.28	0.29	0.27	0.28	0.29
FSh	Ratio	Mean	0.07	0.07	0.07	0.08	0.07	0.08	0.08
		SD	0.24	0.24	0.24	0.25	0.24	0.25	0.26
Imp	Ratio	Mean	0.08	0.05	0.05	0.04	0.04	0.04	0.04
		SD	0.20	0.13	0.13	0.12	0.12	0.12	0.12
Exp	Ratio	Mean	0.12	0.12	0.13	0.14	0.12	0.10	0.11
		SD	0.29	0.30	0.29	0.31	0.28	0.28	0.29
HSpill	Ratio	Mean	0.19	0.18	0.18	0.20	0.18	0.21	0.22
		SD	0.18	0.17	0.17	0.18	0.17	0.21	0.21
BSpill	Ratio	Mean	1.13	1.03	1.07	1.16	1.17	1.19	1.25
		SD	1.16	1.13	1.15	1.22	1.26	1.40	1.29
FSpill	Ratio	Mean	1.11	1.05	1.05	1.04	1.14	1.25	1.38
		SD	0.99	0.95	0.94	0.90	1.01	1.08	1.10
Abs	Million Rupiah	Mean	8 .80	9.07	9.90	12.60	11.04	13.06	14.00
		SD	17.55	14.46	10.65	10.94	8.71	21.04	23.21
HHI	Ratio	Mean	0.10	0.10	0.11	0.10	0.09	0.10	0.11
		SD	0.12	0.12	0.13	0.13	0.12	0.14	0.14
FSize	Ratio	Mean	0.02	0.02	0.02	0.01	0.01	0.01	0.01
		SD	0.07	0.07	0.06	0.06	0.05	0.06	0.06
Number of observations			18,779	18,601	18,875	16,717	26,088	24,292	23,016

Mean = arithmetical average, Std. Dev. = standard deviation. Explanations for the subscripts are provided in footnote 10

On the other hand, the degree of market competition can affect the level of managers' and workers' efforts. Monopoly rents to monopolistic firms can be captured by their managers and workers in the form of managerial slack or lack of efforts. Competitive pressure may reduce such slack by giving more incentives to their managers and workers for increasing their efforts and improving efficiency. It can be reasonably expect that product market competition would discipline firms into efficient operation. Beside that, competition can be also defined in terms of productivity growth through innovations. Productivity gains come from enhancing innovations which introduce new and better products, and successful innovations will eventually raise the level and growth rate of productivity.

In the sense of the degree of market competition, the *HHI* can be used as a measure of the degree of market competition. Higher values of *HHI* indicates greater concentration of sales among producers and thus less competition. The first argument suggests that higher value of *HHI* is associated with greater productivity, while the latter argument suggests that higher value of *HHI* is associated with lower productivity. The measure of market concentration of industry j at time t can be calculated as follows:

$$HHI_{jt} = \sum_{i=1}^{n} s_{it}^2, \qquad \text{where } i \in j, \tag{7}$$

where s_i^2 is market share of each firms.

The firm size variable (*FSize*) will also be included in the models. Based on a number of studies such as Moulton (1990) and Kohpaiboon (2009), the *FSize* in the models controls industry effects, especially when using a sample covering many industries and using aggregation. In this study, the $FSize_{it}$ is measured by output of the firm i divided by output of the industry j at time t. The summary statistics of exogenous variables discussed above using material input criteria 1 and 2 are presented in Table 3a and b.[11]

[11] The subscripts of 5, 10 and 20 % in the dummy *FOR* show the threshold of foreign equity share.

Table 3b A statistical summary of exogenous variables using material input criteria 2

Variables	Units		Years						
			2003	2004	2005	2006	2007	2008	2009
$FOR_{5\,\%}$	Binary dummy	Mean	0.09	0.09	0.08	0.09	0.08	0.09	0.16
		SD	0.28	0.28	0.28	0.28	0.27	0.28	0.36
$FOR_{10\,\%}$	Binary dummy	Mean	0.09	0.09	0.08	0.09	0.08	0.09	0.15
		SD	0.28	0.28	0.28	0.28	0.27	0.28	0.36
$FOR_{20\,\%}$	Binary dummy	Mean	0.09	0.08	0.08	0.09	0.08	0.09	0.14
		SD	0.28	0.28	0.28	0.28	0.27	0.28	0.35
FSh	Ratio	Mean	0.07	0.07	0.07	0.07	0.07	0.08	0.08
		SD	0.24	0.24	0.24	0.25	0.24	0.25	0.26
Imp	Ratio	Mean	0.08	0.04	0.05	0.04	0.04	0.04	0.04
		SD	0.20	0.13	0.13	0.11	0.12	0.12	0.12
Exp	Ratio	Mean	0.12	0.12	0.12	0.13	0.12	0.11	0.11
		SD	0.28	0.30	0.29	0.31	0.28	0.28	0.29
HSpill	Ratio	Mean	0.19	0.18	0.18	0.20	0.18	0.21	0.22
		SD	0.18	0.17	0.17	0.18	0.17	0.21	0.21
BSpill	Ratio	Mean	1.13	1.03	1.07	1.16	1.17	1.19	1.24
		SD	1.16	1.14	1.16	1.22	1.27	1.41	1.29
FSpill	Ratio	Mean	1.11	1.05	1.06	1.04	1.14	1.25	1.38
		SD	0.99	0.96	0.94	0.90	1.01	1.08	1.10
Abs	Million Rupiah	Mean	8.75	9.06	9.79	12.60	11.06	13.11	14.02
		SD	17.66	14.45	10.31	10.91	8.67	21.27	23.46
HHI	Ratio	Mean	0.10	0.10	0.11	0.10	0.09	0.10	0.11
		SD	0.12	0.12	0.13	0.13	0.12	0.14	0.14
FSize	Ratio	Mean	0.02	0.02	0.02	0.01	0.01	0.01	0.01
		SD	0.07	0.07	0.06	0.06	0.05	0.06	0.06
Number of observations			18,006	17,905	18,167	15,952	25,160	23,574	22,245

Mean = arithmetical average, Std. Dev. = standard deviation. Explanations for the subscripts are provided in footnote 10

4 Model specification and estimation technique

The productivity analysis literature can be divided into two main branches: parametric and non-parametric methods. And, there are two most popular estimation methods which deal with productivity measurement, data envelopment analysis (DEA) and stochastic frontier analysis (SFA). The DEA is representative of the non-parametric method involving a linear programming model. It was originally proposed by Charnes et al. (1978). DEA develops a non-parametric piece-wise surface or frontier which is determined by the most efficient producers over the dataset. It deals with many outputs in a consistent way. It is very flexible in the specification of technology with no particular production function assumption. However, DEA is a deterministic model, because efficiency is measured as the distance to this frontier without involving statistical noise. This makes sensitive to the extreme values or outliers and causes the effect of measurement error to be completely unpredictable (Van Biesebroeck 2007). Therefore, the estimated production frontier and efficiency measures will be bias.

Most nonparametric methods for measuring efficiency are based on envelopment techniques, such as DEA. Statistical inference based on these estimators is available but, by construction, they are very sensitive to the outliers. To overcome this problem, Cazals et al. (2002) provide a nonparametric estimator using free disposal hall (FDH), which is more robust to these outliers. Furthermore, Daraio and Simar (2005) develop ideas proposed by Cazals et al. (2002) allowing environmental factors in the model which may influence the production process but they are neither inputs nor outputs under the control of the producer. Another model, Bădin et al. (2012) show how to measure the impact of environmental factors in a nonparametric production model using conditional efficiency measures. And more recently, Mastromarco and Simar (2015) propose a nonparametric production frontier model with two-step dynamic approach. Their model aims to analyze the external factors that may affect the economic performance of production unit.

SFA, on the opposite, is a regression-based approach and assuming a production function and specific distributions for the error terms. The two pioneering papers of SFA were published by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). They independently introduced a stochastic parametric model, containing a common structure of two error components. The first error is associated with random statistical noise and the second error is intended to capture the technical inefficiency of firms' production. But, this method applies negative of an exponential and half-normal distribution for the second error. On the other hand, a more flexible distribution for unobserved inefficiency was developed by Stevenson (1980), namely a truncated normal distribution. Initial panel data models were developed on the time invariant inefficiency assumption. Then, this assumption was relaxed in a series of papers by Cornwell et al. (1990), Kumbhakar (1990) as well as Battese and Coelli (1992). It is distributed as truncated normal distribution which permitted time variant model and usually estimated with maximum likelihood method. Since the inefficiency varies across time and producers, it is likely to find determinants of inefficiency variation. In the early study, the efficiency are predicted in the first stage and then regressed against a vector of exogenous variables in second stage. In more recent studies, Kumbhakar et al. (1991), Huang and Liu (1994) as well as Battese and Coelli (1995) extend the model by allowing the impact of environment factors simultaneously in the model.

Due to numerical and statistical instability infinite samples, stochastic frontier models are difficult to estimate even in full parametric setting up. Even though parametric approach suffers of misspecification problems, this study still carries out a one-step stochastic frontier model proposed by Kumbhakar et al. (1991), Huang and Liu (1994) as well as Battese and Coelli (1995). Therefore, this model needs assumptions about specific parametric functional forms for the production. To select a proper stochastic production frontier, several alternative production functions will be estimated and an appropriate production function will be selected using the generalized log-likelihood test.

This study develops a time-varying stochastic frontier production function for panel data that focus on the effects of FDI variables. These variables may affect a firm's productivity performance. These variables are more related to the environment in which the production occurs. Furthermore, the theoretical arguments indicate that gains of FDI not only come from technological benefits but also from efficiency improvements. A way to incorporate these variables into the stochastic frontier approach is by including FDI variables in both the production function and inefficiency function. The stochastic frontier model for panel data with exogenous variables ($\mathrm{z_{it}}$) can be specified in a general form as follows:

$$y_{it} = \beta_0 + \boldsymbol{x_{it}}\beta + \boldsymbol{z_{it}}\tau + v_{it} - u_{it}, \tag{8a}$$

$$u_{it} = \delta_0 + \boldsymbol{z_{it}}\delta + \omega_{it}, \tag{8b}$$

where y_{it} is the logarithm of output. $\boldsymbol{x_{it}}$ is a vector of logarithm of inputs. $\boldsymbol{z_{it}}$ is a vector of exogenous variables affecting productivity and efficiency. Subscript i indicates the i-th firm, subscript t represents the t-th year for each firm. β_0 and δ_0 are intercepts. $\boldsymbol{\beta}$, $\boldsymbol{\tau}$ and $\boldsymbol{\delta}$ are vectors of parameter to be estimated. v_{it} is random variable assumed to be $iid.N(0, \sigma_v^2)$ and independetly of the u_{it} which is non-negative a random variable assumed to account for technical inefficiency and is assumed to be independently distributed as truncations at zero of the $N(\boldsymbol{z_{it}}\delta, \sigma_u^2)$ distribution. ω_{it} is a random variable, defined by the truncation of the normal distribution with zero mean and variance, σ^2, such that the point of truncation is $\boldsymbol{z_{it}\delta}$, i.e. $\omega_{it} \geq -\boldsymbol{z_{it}\delta}$.

The prediction of the technical efficiencies is based on its conditional expectation, given the model assumptions. Given the specifications in Eqs. (8a) and (b), the technical efficiency of production for the i-th firm at t-th year is defined as follows:

$$TE_{it} = \frac{y_{it}}{\hat{y}_{it}} = \frac{f(\boldsymbol{x_{it}}, \boldsymbol{z_{it}}; \beta, \tau).exp(v_{it} - u_{it})}{f(\boldsymbol{x_{it}}, \boldsymbol{z_{it}}; \beta, \tau).exp(v_{it})} \tag{9a}$$

$$= \exp(-u_{it}) = exp(-\boldsymbol{z_{it}}\delta - \omega_{it}) \tag{9b}$$

Equation (9a) shows that the TE_{it} is measured as a ratio of the realized output (y_{it}) over the potential maximum output ($\hat{y}_{it}$). Hence, the TE_{it} scores vary between 0 and 1. The most efficient firm (or the best-practice firm) has a TE_{it} score equal to 1 and inefficient firms have TE_{it} scores below 1.

The parameters of both the production frontier and inefficiency effect are estimated simultaneously using a maximum-likelihood method, under appropriate distributional assumptions for both error components (v_{it} and u_{it}). The likelihood function is expressed in terms of variance parameters, $\sigma_s^2 \equiv \sigma_v^2 + \sigma^2$ and $\gamma \equiv \sigma^2/\sigma_s^2$, which lies between 0 and 1. If γ equals zero, then the model reduces to a traditional mean response function in which z_{it} can be directly included into the production function. This indicates that the ordinary least square (OLS) is a better fitting of the data. On the other hand, if γ is closer to unity, then the frontier model is appropriate.

This study applies a flexible functional form, namely, a stochastic translog (transcendental logarithmic) production frontier to test the spillover hypothesis from FDI. This frontier is a more flexible functional form of production frontier. It is characterized by a non-fixed substitution elasticity and is therefore subject to fewer constraints than a general logarithm linear model (Christensen et al. 1973; Heathfield and Wibe 1987). In addition, the translog functional form provides more generalized estimates than other logarithm linear models as it imposes relatively fewer a priori restrictions on the structure of production (Kopp and Smith 1980). By adopting a flexible functional form, the risk of errors in the model specification can be reduced.

To control the industry specific factors other than the firm size, the model is augmented by industrial dummy variables.[12] Two industries may have reasonably similar structures in terms of relative firm sizes but be affected by different unobservable factors. Therefore, the industrial dummies variables are added to the translog stochastic frontier production function with inefficiency effects and it is specified as follows:

$$y_{it} = \beta_0 + \sum_{n=1}^{N} \beta_n xn_{it} + \tfrac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} xn_{it} xm_{it} + \beta_t t + \tfrac{1}{2}\beta_{tt} t^2 + \sum_{n=1}^{N} \beta_{nt} xn_{it} t_{lt} + \sum_{d=2}^{D} \beta_d Dd_{it} + \sum_{k=1}^{K} \beta_k Zk_{it} + v_{it} - u_{it} \tag{10a}$$

$$u_{it} = \delta_0 + \sum_{k=1}^{K} \delta_k Zk_{it} + \omega_{it}, \tag{10b}$$

where y is total gross output and xn is inputs, such as capital, labour, input material and energy. All output and inputs are in natural logarithm and all express in deviation from their geometric means.[13] t is time trend variable. Zk is a vector of exogenous variables, such as dummy variable of foreign ownership, interacting foreign ownership dummy variable with foreign equity share, horizontal spillover within industry, forward spillover, backward spillover, absorptive capacity, interacting absorptive variable with FDI spillover variables, import and export intensity, degree of market concentration and size of firm. All variables are more throughly described in Section 3 and Dd is industrial dummy variables and the control group is dummy $D1$. β_0 and δ_0 are intercepts of the production function and inefficiency function. $\beta's$ and $\delta's$ are parameters to be estimated. Subscript i indicates the i-th firm, subscript t represents the t-th year for each firm. v_{it} is the stochastic error term, u_{it} is the technical inefficiency and ω_{it} is an error term in inefficiency equation.

Various sub-models of the translog will be tested under a number of null hypotheses, given the specification of the translog model in Eq. (10a). A null hypothesis of the interacting parameters of input with time equal to zero ($\beta_{nt} = 0$) is for a Hicks-neutral technological progress. Similarly, a null hypothesis of time parameters equal to zero ($\beta_t = \beta_{tt} = \beta_{nt} = 0$) is for no technology progress in the frontier. A null hypothesis of the interacting parameters of time and input equal to zero ($\beta_{tt} = \beta_{nt} = \beta_{nm} = 0$) is to test whether Cobb-Douglas frontier production function is appropriate. A null hypothesis of the parameters of inefficiency function equal to zero ($\gamma = \delta_0 = \delta_k = 0$) are for a no-inefficiency effect. γ is a parameter associated with variance of inefficiency effect, u_{it}. If γ is zero, the model reduces to a traditional mean response function in which the exogenous variables in the inefficiency model can be directly only included into the production frontier.

The generalized log-likelihood test is performed to choose the correct stochastic production frontier. The translog production function model is used as a base form, and four alternative models are tested against the translog model. For performing tests of the relevant null hypotheses, the generalized likelihood ratio statistic $\lambda = -2[l(H_O) - l(H_1)]$ is employed, where $l(H_O)$ is the log-likelihood value of the restricted frontier model, and $l(H_1)$ is the log-likelihood value of the translog model. If the null hypothesis is true, the test statistic has approximately a χ^2 distribution with degrees of freedom equal to the number of parameters involved in the restrictions. The test statistic under the null hypothesis of no-inefficiency effects has approximately a mixed χ^2 distribution.

The estimated coefficients of the production functions in Eq. (10a) can not be directly interpreted economically, but we can retrieve for calculating output elasticity with respects to each input. It is calculated as follows:

$$\varepsilon_{nit} = \frac{\partial y_{it}}{\partial xn_{it}} = \beta_n + \frac{1}{2}\sum_{n=1}^{4}\sum_{m=1}^{4} \beta_{nm} xm_{it} + \beta_{nt} t \tag{11}$$

for each input at each data point. Further, the standard return to scale elasticity is calculated as follows:

$$\varepsilon_{Tit} = \sum_{n=1}^{N} \varepsilon_{nit} \tag{12}$$

This study also applies the Allen partial elasticity of substitution between two inputs in an n-factors production system which originally introduced by Allen and Hicks (1934). It is

[12] The classification of industrial dummy variables will be based on the Indonesian Investment Coordinating Board classifications and it is provided in the Appendix Table 11.

[13] For example, given the geometric mean of Y_{it} is $\overline{Y}$, the transformed data for output (y_{it}) for the firm i and time t is obtained as $y_{it} = ln(Y_{it}) - ln(\overline{Y})$.

formulated in the following way:

$$\sigma_{nm} = \frac{\sum_{n=1}^{N} x_n f_n}{x_n x_m} \frac{F_{nm}}{F}, \tag{13}$$

where f_n is first order partial derivative $(=(\partial y)/(\partial x_n))$. F is the determinant of the bordered Hessian matrix and F_{nm} is cofactor associated with f_{nm} in F.

For a quasi-concave production function in the two inputs case, the elasticity of substitution (σ_{nm}) has to be positive. This implies that two factors are always substitutes. Since the isoquant is convex, the ratio of inputs (x_n/x_m) decreases and then the diminishing marginal rate of technical substitution (the ratio of f_m/f_n) increases. Therefore, σ_{nm} is positive because the ratio of inputs and the marginal rate of technical substitution move in opposite direction.

On the other hand, the σ_{nm} in a multi-inputs case has received a great deal of attention. Hence, it is useful to discuss further its property. In Chambers (1988), the Eq. (13) can express as follows:

$$K_m \sigma_{nm} = \frac{f_m F_{nm}}{x_n F}, \quad \text{where} \quad K_m = \frac{x_m f_m}{\sum_{n=1}^{N} x_n f_n}, \tag{14}$$

$$\sum_{n=1}^{N} K_m \sigma_{nm} = \frac{1}{x_n F} \sum_{n=1}^{N} f_m F_{nm} = 0, \tag{15}$$

where Eq. (15) is extended from the first row (column) of the bordered Hessian consisting of marginal product by a set of Alien cofactors. Therefore,

$$K_n \sigma_{nn} = -\sum_{m \neq n} K_m \sigma_{nm} = \frac{f_n F_{nn}}{x_n F} \tag{16}$$

If the production function is concave, the principal minors of bordered Hessian will interchange in sign. This means that F_{nn}/F is negative. Since f_r is positive, σ_{nn} is negative. Thus, $\sum_{m \neq n} K_m \sigma_{nm} > 0$, this concludes that at least one σ_{nm} must be positive. An input cannot be a complement for all other inputs in terms of Allen measure. Therefore, the elasticity of substitution in the more than two inputs cases can be positive or negative. There will be complements if $\sigma_{nm} < 0$ and substitutes if $\sigma_{nm} > 0$.

Moreover, Orea (2002) and Coelli et al. (2003) note that total factor productivity (TFP) growth can be decomposed into three components: technological change (TC), technical efficiency change (TEC) and scale efficiency change (SEC). TC is technological change which the shift in the technology frontier between the two periods. TEC is movement to the technology frontier or getting closer to the frontier, as catch up. SEC is as a component of productivity change for capturing economies of scale. SEC is appropriate for producers under variable return to scale (VRS).

TC can be calculated directly from the estimated parameters in Eq. (10a). It is based on the coefficient of time, time squared, and the interactions of time with the inputs. However, this TC may vary for different input vectors if technological change is non-neutral. $TC_{it,t-1}$ measure requires calculating the partial derivative with respect to time at each data point. For firm i in period t this is:

$$\frac{\partial y_{it}}{\partial t} = \beta_t + \beta_{tt} t + \beta_{nt} x n_{it} \tag{17}$$

then, $TC_{it,t-1}$ can be defined by:

$$TC_{it,t-1} = 0.5 \left[\left(\frac{\partial y_{it-1}}{\partial t} \right) + \left(\frac{\partial y_{it}}{\partial t} \right) \right] \times 100 \tag{18}$$

Given the estimation in Eq. (9a), $TEC_{it,t-1}$ of firm i between time periods t and $t-1$ is then defined as:

$$TEC_{it,t-1} = ln \left(TE_{it}/TE_{it-1} \right) \times 100, \tag{19}$$

where $ln(TE_{it}/TE_{it-1})$ is the natural logarithm of technical efficiency of firm i at the period t over technical efficiency of the period $t-1$.

The last term required in calculating TFP growth is SEC. It requires the calculation of production elasticity for each input at each data point, such as Eqs. (11) and (12) and we can construct the scale factors as follows:

$$SF_{it} = (\varepsilon_{Tit} - 1)/\varepsilon_{Tit} \tag{20}$$

at each data point. $SEC_{it,t-1}$ between period t and $t-1$ is given by the summation of the average of the scale factor for the i-th firm between the two periods multiplied by the change in the respective input usage and it can be formulated as follows:

$$SEC_{it,t-1} = \frac{1}{2} \sum_{n=1}^{N} [(SF_{it} \varepsilon n_{it} + SF_{it-1} \varepsilon n_{it-1})(x n_{it} - x n_{it-1})] \times 100 \tag{21}$$

Finally, the TFP change or growth for each firm between any two time periods is the summation of $TEC_{it,t-1}$, $SEC_{it,t-1}$ and $TC_{it,t-1}$. Therefore, the TFP growth can be defined as follows:

$$TFPg_{it,t-1} = TEC_{it,t-1} + SEC_{it,t-1} + TC_{it,t-1}, \tag{22}$$

where $TFPg_{it,t-1}$ is the TFP growth between period t and $t-1$, for the i-th firm.

In order to know the most important component of total factor productivity growth in explaining output growth, a non parametric kernel density will be considered to estimate the distribution of the productivity component. We perform a non-parametric test of the closeness of two distributions based on Li (1996) and adapted to efficiency score as well as explore their performance in terms of the size and power of the test in various Monte Carlo experiments as suggested by Simar and Zelenyuk (2006).[14] It is important to adapt the

[14] We would like to thank to a reviewer #2 for this idea to perform a non-parametric test of the closeness of two distributions.

Li (1996) decomposition to the case of stochastic frontier estimation, meaning random errors must be in charge in the growth decomposition. To do so, we utilize SFA which allows disentangling inefficiency from random errors and identifying the driving factors which explain TFP growth.

To investigate the statistically relevant components in the output decomposition, we compare their relevant empirical distributions, smoothed out through a kernel estimator, and perform the non-parametric tests of closeness as developed by Aiello et al. (2011) for SFA. T-Statistic for testing the distribution of the productivity components is constructed in the following way:

$$T = \frac{N\sqrt{hI}}{\hat{\sigma}}, \tag{23}$$

where N is the number of sample, h is the smoothing parameter, I is the integrated square error metric which is the accepted measure of global closeness between the two distributions and $\hat{\sigma}$ is the estimated variance. This T-statistic test is asymptotically distributed as a standard normal $N=(0,1)$. And, the standard normal kernel distribution which is proposed by Fan and Ullah (1999) and Kumar and Russell (2002) as follows:

$$K(x) = \frac{1}{\sqrt{2\pi}} exp^{-\frac{x^2}{2}} \tag{24}$$

Let $f(x)$ and $g(x)$ be two unknown density which describe two different distributions. We are interested to test null hypothesis $H_0: f(x) = g(x)$ against the alternative $H_1: f(x) \neq g(x)$. And, I is defined as:

$$I = \int [f(x) - g(x)]^2 dx = \int [f^2(x) + g^2(x) - 2f(x)g(x)]dx$$

$$= \int f(x)dF(x) + g(x)dG(x) - 2g(x)dF(x) \tag{25}$$

The measure I has to fulfill the following properties for testing our null hypothesis: $I \geq 0$ and the equality holds if and only if $f(x) = g(x)$. And then, I and $\hat{\sigma}$ can be estimated as follows:

$$I = \frac{1}{N^2h}\sum_{i=1}^{N}\sum_{j=1,i\neq j}^{N}\left[K\left(\frac{x_i-x_j}{h}\right) + K\left(\frac{y_i-y_j}{h}\right) - K\left(\frac{x_i-y_j}{h}\right) - K\left(\frac{y_i-x_j}{h}\right)\right] \tag{26}$$

$$\hat{\sigma}^2 = \frac{1}{N^2h\sqrt{\pi}}\sum_{i=1}^{N}\sum_{j=1}^{N}\left[K\left(\frac{x_i-x_j}{h}\right) + K\left(\frac{y_i-y_j}{h}\right) - 2K\left(\frac{x_i-y_j}{h}\right)\right] \tag{27}$$

Moreover, the output growth rate (y_g) is decomposed into the contribution due to weighted input growth (x_g) and TFP growth (TFP_g), where input is the summation of capital, labour, material and energy $(x = k + l + m + e)$. By comparing of kernel distribution of output growth and input growth through testing the null hypothesis $H_0: f(y_g) = g(x_g)$, we could analyze whether output growth distribution can be explained by input growth. When the H_0 is rejected, then it could be concluded that total factor productivity variations significantly explain the variations of the output growth distribution. In addition, to evaluate the contribution of input growth on the variation of output growth, we test the null hypothesis $H_0: f(y_g) = g(TFP_g)$. When the H_0 is rejected, then it could be concluded that input growth can be significantly sources of the changes in output growth distribution. As mention before, TFP growth is decomposed into three components of productivity. To assess which the most important component in explaining the variations in the TFP growth distribution, we consider three hypotheses, such as $H_0: f(y_g) = g(TC)$, $H_0: f(y_g) = g(TEC)$ and $H_0: f(y_g) = g(SEC)$. When we reject the H_0, then the component of productivity has a significant role in explaining the TFP growth.

5 Empirical results

5.1 The FDI spillover effects on the firms' productivity performances

Based on the methodology that has been discussed in Sect. 3, we can construct six alternative models of the stochastic production frontier with inefficiency effects.[15] The accuracy of FDI spillover estimates requires an appropriate functional form of stochastic production frontier. To find an appropriate functional form that represents the data, various sub-models of the translog are tested against a translog model using generalized likelihood ratio (LR) statistic test. The results of null hypotheses tests of various sub-models of the translog against translog model are reported in Table 4.

The estimated results of the stochastic production frontier with inefficiency effects in Eq. (10a) and (b) could be divided into three parts; the estimated coefficients of inputs on the production function, the estimated coefficients of FDI spillover on production function and inefficiency function. Moreover, the particular interest of this study is on the estimated FDI coefficients of the production function and inefficiency function. Hence, we analyze initialy the FDI spillover effects on the firms' productivity and efficiency, then we analyze the coefficients of the production function through evaluating the output elasticity with respect to each input as well as elasticity of substitution between capital and labour. The results of FDI spillover

[15] Model 1 to Model 3 are estimated using material input criteria 1, while Model 4 to Model 6 are estimated using material input criteria 2.

Table 4 Hypotheses testing of various models of translog

Various models of translog	Hick-neutral (df = 4)	No Tech. progress (df = 6)	Cobb-Douglas (df = 15)	No-inefficiency effect (df = 13)	Conclusions
H_0	$\beta_{nt} = 0$		$\beta_t = \beta_{tt} = \beta_{nt} = 0$	$\beta_{tt} = \beta_{nt} = \beta_{nm} = 0$	$\gamma = \delta_0 = \delta_k = 0$
Model 1	−44.57	2029.83	29,361.75	2133.02	Hick-Neutral
Model 2	−1395.00	45.01	30,461.40	4419.76	Hick-Neutral
Model 3	3372.95	−109,973.52	31,368.55	4386.15	No tech. progress
Model 4	151.66	232.87	23,169.77	3870.57	Translog
Model 5[a]	−198.11	−118.35	23,264.79	3818.71	Hick-Neutral/ No Tech. progress
Model 6	90.04	696.85	23,039.07	3827.96	Translog
Critical value of χ^2 at α = 1 %	13.28	16.81	30.58	27.03[b]	

[a] For Model 5, we further conduct testing for hick-neutral against no-technological progress. (Since the LR statistic test (=79.76) is greater than the critical value of χ^2 at $\alpha = 1$ % (=9.21), we conclude that hick-neutral is used for estimating Model 5.)

[b] Using critical values of Mix χ^2 at $\alpha = 1$ %. (This critical value is taken from Table 1 of Kodde and Palm (1986))

effects on the firms' productivity are reported in Table 5 and on the firms' efficiency are presented in Table 6. And, the results of the estimated coefficients of inputs on production functions are provided in Appendix Table 12.

We start by focusing on all the dummies *FOR* in production functions (in Table 5). They carry rather large, statistically significant coeffcients, suggesting that foreign establishments have comparable high levels of productivity. However, the coefficients of the dummy *FOR* in the inefficiency functions (in Table 6) are positive and statistically significant. Those positive signs indicates that foreign firms are less efficient than domestic firms, keeping other variables constant.

By evaluating the interacting foreign share with the dummy *FOR* in production functions, the degree of foreign ownership in establishments seem to have negative and significant effect on productivity, except for Model 1 and 4. These results show that increases the degree of foreign ownership negatively affect firms' productivity. This negative spillover, such as market stealing effect causes foreign firms forcing local firms to cut their production. On the other hand, the estimated interacting dummy variables with foreign equity in the inefficiency functions have negative signs and statistically significant, except for Model 4. This describes that increasing share of foreign equity associated with reducing inefficiency.

More important for the purpose of this study, the presence of intra-industry and inter-industry spillovers are addressed. The positive and significant coefficient on the *HSpill* in Table 5 suggests that firm's output increases when the share of output of foreign firm within the same market rises. This study finds evidence of horizontal spillovers from foreign firms to domestic firms, which is consistent with our previous empirical studies on the Indonesian manufacturing sector which use a conventional approach of production function (Blalock and Gertler 2008; Sjöholm 1999). The negative signs of *HSpill* and statistically different from zero appear in all models in Table 6. These indicate that the competitive effects of foreign firms do reduce the inefficiency of domestic firms through the same market. Indigenous establishments may be able to reduce innovation costs by observing and imitating the foreign invested companies.

To examine vertical spillovers on the firms' productivity performance, we deliberate on all the models in Table 5 as well as Table 6. The coefficients of *BSpill* and *FSpill* in all models in Tables 5 and 6 have the similiar signs and significancies, except a *BSpill* coefficient in Model 1 in Table 6.[16] The negative and statistically significant *BSpill* coefficients seem to appear in all models of production functions (see Table 5). The negative productivity spillovers in the upstream markets may appear if the intermediate inputs produced by local suppliers are not used intensively by foreign affiliates. They may import their intermediate inputs. Therefore, the negative backward productivity spillovers arise in the upstream markets. In addition, the negative backward spillovers could arise when foreign companies have greater bargaining power than local companies. This condition may lead to unfavouring contractual agreements towards local enterprises and may squeeze their profit. Hence, the productivity of local suppliers will decrease. But, the coefficients of *BSpill* in inefficiency functions, except a coefficient in Model 1 (see Table 6a) have negative signs and statistically diffrent from zero. These may indicate that the presence of foreign firms

[16] As mention in footnote 3, this study consider using I–O table of year 2000 instead of year 2005 for calculating inter-industry linkages for year of 2003 and year of 2004 and the estimated coefficients of *BSpill, FSpill* and their interact with absorptive capacity are almost similar with the results using I–O table of year 2005. Unfortunately, we do not report these results in Tables 5 and 6.

Table 5 The estimated coefficients on production functions

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$FOR_{5\,\%}$	0.068*			1.711*		
	(0.011)			(0.061)		
$FSh*FOR_{5\,\%}$	0.017			8.242*		
	(0.012)			(0.209)		
$FOR_{10\,\%}$		1.247*			1.388*	
		(0.216)			(0.011)	
$FSh*FOR_{10\,\%}$		−1.142*			−1.282*	
		(0.219)			(0.009)	
$FOR_{20\,\%}$			3.137*			2.041*
			(0.130)			(0.060)
$FSh*FOR_{20\,\%}$			−3.044*			−1.937*
			(0.127)			(0.062)
HSpill	0.072*	0.062*	0.062*	0.051*	0.063*	0.065*
	(0.006)	(0.008)	(0.007)	(0.007)	(0.006)	(0.007)
BSpill	−0.011*	−0.024*	−0.026*	−0.022*	−0.021*	−0.022*
	(0.002)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
FSpill	0.037*	0.043*	0.044*	0.039*	0.038*	0.039*
	(0.002	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Abs	0.255*	0.282*	0.281*	0.274*	0.268*	0.270*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
*Abs*HSpill*	0.025*	−0.003	−0.013***	−0.009	−0.006*	−0.008
	(0.006)	(0.009)	(0.007)	(0.006)	(0.002)	(0.006)
*Abs*BSpill*	−0.077*	−0.038*	−0.039*	−0.023*	−0.030*	−0.026*
	(0.003)	(0.003)	(0.003)	(0.002)	(0.001)	(0.003)
*Abs*FSpill*	0.056*	0.040*	0.043*	0.020*	0.030*	0.025*
	(0.003)	(0.004)	(0.003)	(0.003)	(0.002)	(0.003)
Imp	0.044*	0.059*	0.044*	0.063*	0.057*	0.072*
	(0.011)	(0.020)	(0.011)	(0.012)	(0.011)	(0.011)
Exp	0.004	0.023*	0.023*	0.026*	0.021*	0.021*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
HHI	0.119*	0.074*	0.062*	0.080*	0.076*	0.079*
	(0.009)	(0.011)	(0.009)	(0.010)	(0.010)	(0.009)
FSize	5.337*	22.441*	26.295*	14.488*	15.884*	14.997*
	(0.118)	(1.525)	(0.679)	(0.362)	(0.036)	(0.392)
Number of Observations	146,368	146,368	146,368	141,009	141,009	141,009

Standard errors are in parentheses. The estimated coefficients in Model 1 to Model 3 are using material input criteria 1 and in Model 4 to Model 6 are using material input criteria 2

* denotes significance at 1 %, ** denotes significance at 5 %, *** denotes significance at 10 %

generate positive spillovers on firm's technical efficiency in the upstream industries.

On the other hand, the coefficients of *FSpill* in production and inefficiency functions are positive and statistically different from zero (see Table 5a and b). These finding indicate that the linkages of foreign firms to downstream industries provide technological gains to domestic buyers. Sales of these inputs by MNCs may be accompanied by provision of complementary services that may not be available in connection with imports. Foreign firms have incentives to improve domestic firm's productivity through input cost reduction and quality improvement in return, which then lead to productivity benefits. However, the positive sign in inefficiency functions indicate that the presences of foreign firms generate negative spillovers on firm's technical efficiency in the downstream industries.

Even though the inter-industry spillovers do not entirely enhance firms' productivity performance, the presence of

Table 6 The estimated coefficients on inefficiency functions

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Const	−0.147*	−0.145*	−0.134*	−0.142*	−0.143*	−0.149*
	(0.005)	(0.007)	(0.005)	(0.006)	(0.005)	(0.005)
$FOR_{5\,\%}$	0.136*			1.762*		
	(0.013)			(0.062)		
$FSh{*}FOR_{5\,\%}$	−0.103*			8.187*		
	(0.013)			(0.209)		
$FOR_{10\,\%}$		1.317*			1.456*	
		(0.216)			(0.046)	
$FSh{*}FOR_{10\,\%}$		−1.260*			−1.386*	
		(0.222)			(0.013)	
$FOR_{20\,\%}$			3.213*			2.121*
			(0.129)			(0.062)
$FSh{*}FOR_{20\,\%}$			−3.173*			−2.052*
			(0.126)			(0.065)
HSpill	−0.069*	−0.154*	−0.145*	−0.128*	−0.125*	−0.111*
	(0.007)	(0.014)	(0.012)	(0.013)	(0.010)	(0.013)
BSpill	0.001*	−0.010	−0.020*	−0.024*	−0.015*	−0.021*
	(0.004)	(0.007)	(0.004)	(0.005)	(0.003)	(0.005)
FSpill	0.031*	0.023*	0.031*	0.045*	0.031*	0.039*
	(0.005)	(0.008)	(0.005)	(0.006)	(0.001)	(0.007)
Abs	0.073*	0.134*	0.125*	0.155*	0.139*	0.147*
	(0.002)	(0.004)	(0.002)	(0.003)	(0.007)	(0.002)
*Abs*HSpill*	0.118*	0.080*	0.070*	0.043*	0.066*	0.052*
	(0.003)	(0.007)	(0.004)	(0.005)	(0.011)	(0.007)
$Abs{*}BSpill_{05}$	−0.102*	−0.048*	−0.043*	−0.014*	−0.036*	−0.024*
	(0.003)	(0.003)	(0.002)	(0.002)	(0.004)	(0.004)
$Abs{*}FSpill_{05}$	0.050*	0.047*	0.044*	−0.002*	0.031*	0.015*
	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)	(0.005)
Imp	0.301*	0.293*	0.263*	0.264*	0.265*	0.286*
	(0.013)	(0.027)	(0.014)	(0.016)	(0.016)	(0.015)
Exp	0.040*	0.072*	0.069*	0.072*	0.065*	0.066*
	(0.006)	(0.007)	(0.007)	(0.008)	(0.007)	(0.007)
HHI	0.219*	0.177*	0.149*	0.178*	0.182*	0.185*
	(0.011)	(0.017)	(0.013)	(0.016)	(0.015)	(0.014)
FSize	5.157*	22.229*	26.074*	14.318*	15.715*	14.830*
	(0.115)	(1.523)	(0.678)	(0.361)	(0.028)	(0.391)
Sigma − squared	0.089*	0.093*	0.091*	0.081*	0.081*	0.081*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Gamma	0.039*	0.138*	0.119*	0.147*	0.139*	0.142*
	(0.001)	(0.005)	(0.002)	(0.003)	(0.005)	(0.002)
Log likelihood function	−28,506	−27,363	−27,408	−16,605	−16,676	−16,626
LR test of the one-side error	2133	4420	4386	3871	3819	3828
Number of Observation	146,368	146,368	146,368	141,009	141,009	141,009

Standard errors are in parentheses. The estimated coefficients in Model 1 to Model 3 are using material input criteria 1 and in Model 4 to Model 6 are using material input criteria 2

* denotes significance at 1 %, *** denotes significance at 10 %

foreign affiliate is still a potential to source inputs from local suppliers and to serve the domestic demands. In general, these findings might not provide straightforward support for policies promoting FDI in the Indonesian manufacturing industry. Policy makers might at least need to consider whether the incoming FDI is intended to benefit the local suppliers or to serve the local buyers. In cases where there is potential for multinationals to steal market from domestic firms, policy makers should at least, at the minimum, ensure that the negative FDI spillovers on domestic firms do not outweigh the overall benefits of the FDI.

The *abs* coefficients have positive signs and statistically different from zero in production and inefficiency funcions. This suggets that a larger share of skilled workers increases firms' productivity, but decreases firms' efficiency. The coefficients of interacting *abs*HSpill* variables in production functions are negative and statistically significant, except in Model 1 and Model. And in inefficiency functions, they are positive and statistically significant. These finding show that technology spillover from FDI in the same markets are smaller with higher level of labour quality. All coefficients of interacting *abs*BSpill* variables in the production functions have negative signs and statistically different from zero. This means the degree of absorptive capacity of suppliers have negative impact on firms' productivity. However, the negative and statistically significant coefficients in inefficiency functions show that the degree of absorptive capacity of the suppliers have positive impact on reducing inefficiency. Moreover, the interacting coefficients of *abs*FSpill* in productions have positive signs and statistically different from zero. This shows the greater ability of the buyers to identify, assimilate and exploit knowledge spillovers is the greater impact on increasing productivity. However in the inefficiency functions, the estimated coefficients of *abs*FSpill* have positive and statistically different from zero, except in Model 4. This indicates that the greater degree of absortive capacity of the buyer have less impact on reducing inefficiency.

Examining the remaining regressors, the openness coefficients seem to be positive and statistically significant both in production and inefficiency functions. The positive signs in production functions show that the greater import and export activities associated with greater effect on increasing productivity. Higher import and export activities may be a significant channel for receiving technology spillover which rises firms' productivity. However, the positive signs in inefficiency functions indicate that higher import and export activities lead to bigger inefficiency. The coefficient of *HHI* are positive and statistically significant in production and inefficiency functions. In the production function, the high concentration among firms in the Indonesian manufacturing industry increases the firm's productivity. It may be through technological progress and scale efficiency. A higher value of *HHI* indicates greater concentration of sales among producers. Even though higher concentration of the firms increases the productivity, it is associated with greater inefficiency. This is shown by the positive sign and statistically significant coefficient of *HHI* in the inefficiency function. The coefficient of *FSize* is also positive and statistically significant both in production and inefficiency functions. This finding may not be a surprise; bigger firms are likely to possess modern technology and capital equipment compared to smaller firms due to technology diffusion. However, the positive coefficient of controlling variable in the inefficiency function indicates that bigger firms do not have higher efficiency.

Further, the estimated coefficients of inputs on the production functions in Eq. (10a) are reported in Appendix Table 12. They can not be directly interpreted economically, but we can retrieve them for calculating output elasticity with respect to each input. Based on the discussion above, we choose only Model 6 for calculating the output elasticity with respect to each input. It examines how much output will increase when the level of input increases. These measures are computed at the mean value of the entire sample and each industry classification over the observation period 2003–2009 and displayed in Table 7. By comparing the elasticity of output with respect to capital (e_k), labour (e_l), material (e_m) and energy (e_m) across industry, it is noted that output is driven more by material than by capital, labour or energy. Studies on productivity in Indonesian manufacturing industries by Ikhsan (2007) and Suyanto (2010) also show that the output elasticity of material inputs has the highest elasticity coefficient. The total elasticity (e_T) across industry shows around one, exhibiting constant returns to scale. For more detail results, we also distinguish those elastisities across industries in three sub-periods of time using box plots are provided in Appendix Figs. 3a–h. The results also describe that all outputs are driven more by material than the other inputs.

As mentioned before that the elasticity of substitution between capital and labour in this study is measured by Allen partial elasticity of substitution. It measures the response of derived input demand to a price change of another input, holding output and all other input prices constant. The larger the magnitude of the substitution elasticity, the higher the degree of substitutability (if $\sigma_{kl} > 0$) or complementarily (if $\sigma_{kl} < 0$) between the two inputs. The result of substitution elasticity between capital and labour is displayed in Table 7. We find that D2, D3, D6, D7, D9, D10 and D11 have substitution elasticity between capital and labour greater than zero ($\sigma_{kl} > 0$), meaning that capital is a substitute for labour. On the other hand, D1, D4, D5 and D8 have substitution elasticity between capital and labour less than zero ($\sigma_{kl} < 0$), showing that capital is a complementarily with labour. And, the elasticity of substitution

Table 7 Elasticity of output and elasticity of substitution during periods of 2003–2009

Industry classification	Elasticity of capital (ε_k)	Elasticity of labour (ε_l)	Elasticity of material (ε_m)	Elasticity of energy(ε_e)	Total elasticity (ε_T)	Elasticity of substitution (σ_{kl})
D1	0.007	0.226	0.752	0.015	1.000	−0.209
D2	0.009	0.255	0.713	0.023	0.999	2.341
D3	0.008	0.236	0.738	0.018	1.000	0.440
D4	0.008	0.244	0.725	0.021	0.999	−1.113
D5	0.007	0.206	0.772	0.014	0.999	−0.763
D6	0.006	0.168	0.821	0.005	1.000	0.236
D7	0.008	0.209	0.768	0.015	0.999	0.170
D8	0.011	0.289	0.666	0.032	0.998	−0.301
D9	0.007	0.208	0.772	0.013	1.000	0.386
D10	0.008	0.230	0.744	0.018	1.000	0.059
D11	0.007	0.189	0.795	0.010	1.000	0.243
D12	0.006	0.219	0.757	0.016	0.999	−0.112
All firms	0.008	0.231	0.743	0.018	0.999	−29.123

σ_{kl} is elasticity of substitution between capital and labour

between capital and labour for all firms on average is less than zero or −29.123.

5.2 The total factor productivity (TFP) growth and its component

We initially test the relative important component of TFP growth in affecting the output growth by examining the distribution of output growth against input and TFP growth as well as against the components of TFP growth. And then, we investigate the average TFP growth and its components between foreign and domestic firms across industry and in the three periods of time.

The results of null hypotheses tests of compering the kernel distribution of output growth against input growth as well as TFP growth and its components are reported in Table 8. We compare the T-statistic and the critical value of T for foreign and local firms, since T-statistic value is greater than its critical value, we can reject the null hypothesis. All null hypotheses of output growth distribution $f(y_g)$ against input growth $f(x_g)$ are rejected. These conclude that TFP variations of foreign and domestic firms significantly contribute for explaining output growth variations. All null hypotheses of $f(y_g) = f(TFP_g)$ are also rejected. These are possible to infer that input growth of foreign and local firms can significantly influence the changes in output growth distribution.

Furthermore, the importance of TEC, SEC and TC in explaining the variations in the TFP growth distribution is evaluated by testing whether the output growth distribution is equal to the distribution of the component of productivity growth. As the results show, the T-statistic of null hypotheses of $f(y_g) = f(TEC)$, $f(y_g) = f(SEC)$ and $f(y_g) = f(TC)$ for both multinational and domestic firms are higher than their critical values, meaning all null hypotheses can clearly be rejected. This indicates that all components of productivity have a significant role in explaining TFP growth for our sample of all manufacturing firms.

The average output and input growth as well as TFP growth and its components are reported in Tables 9 and 10. In the period 2004–2005, D11 for foreign firms had highest

Table 8 Hypotheses testing of output growth

Null hypotheses	T-Statistic	
	Foreign firms	Domestic firms
$f(y_g) = g(x_g)$	2413	20,344
$f(y_g) = g(TFP_g)$	568	7107
$f(y_g) = g(TEC)$	567	7108
$f(y_g) = g(SEC)$	1015	8057
$f(y_g) = g(TC)$	1015	8056
Number of Observations	47,379	4851
Critical Value of T at $\alpha = 1$ %	2.39	2.35

Critical Value of T is calculated using a bootstrap procedure. (We apply a bootstrap procedure to approximate the statistic distribution under the null hypotesis of f(x) = g(x). 10,000 repetitions of two standard normally distributed random variables are generated with sample size: 20, 50, 100, 250, 500, 4851 and 47,379. We evaluate performance for the following confident interval of 90, 95, 97.5 and 99 %. The simulation results show with the increase in the sample size, the difference between the simulated results and the standard normal distribution diminish. This confirms that using a bootstrap procedure is appropriate.)

Table 9 The average of output and input growth

Industry classification		Year 2004–2005		Year 2006–2007		Year 2008–2009	
		yg	*xg*	*yg*	*xg*	*yg*	*xg*
Foreign firms	D1	−8.96	8.35	9.65	−26.88	7.22	−32.07
	D2	−7.20	12.97	15.68	28.45	2.79	−51.71
	D3	19.12	39.73	3.11	10.53	3.05	−40.73
	D4	−8.92	−4.10	−0.03	−19.88	−17.63	−63.34
	D5	10.58	6.67	2.20	−29.20	6.25	2.88
	D6	2.55	−14.13	17.45	67.65	−10.50	−88.77
	D7	12.60	47.67	7.98	1.94	−0.35	−55.20
	D8	−4.59	−1.31	9.29	−9.10	−19.23	−52.18
	D9	8.65	15.21	24.07	67.34	2.72	−54.63
	D10	−9.10	−44.61	60.09	177.95	−49.39	−114.84
	D11	21.90	69.67	12.36	5.21	4.39	−43.96
	D12	–	–	–	–	–	–
All foreign firms		3.01	15.96	14.38	24.63	−1.33	−53.29
Domestic firms	D1	1.89	3.75	10.68	50.78	−5.88	−1.59
	D2	−2.77	−0.39	7.89	32.29	0.49	6.42
	D3	−1.22	0.48	0.09	18.40	3.76	−0.03
	D4	−4.74	1.34	1.07	25.80	−13.45	−26.29
	D5	12.88	31.59	1.05	32.60	1.41	−19.59
	D6	10.40	24.51	12.20	51.74	−9.82	−38.07
	D7	8.36	23.86	5.88	42.79	−2.97	−9.75
	D8	−0.93	−7.24	5.84	37.01	−12.52	5.41
	D9	0.13	3.25	22.80	80.35	−7.40	−26.91
	D10	−4.20	−16.95	11.67	78.56	−6.56	−40.12
	D11	0.48	1.20	27.78	85.67	2.95	−12.86
	D12	15.35	28.27	24.34	82.45	17.55	40.11
All domestic firms		1.54	6.16	9.73	46.25	−5.17	−9.01

y_g and x_g is arithmetic average of annual rate in percentage

output growth (21.90 %) and input growth (69.67 %) than other industries, while D10 for foreign firms had highest negative output growth (−9.10 %) and input growth (−44.61 %) than other industry. On average, the output of both foreign and domestic industries grew at average rate of 3.01 and 1.54 % and input grew at average rate of 15.96 and 6.16 %. In the period 2006–2007, all industries had positive output growth rate, except D4 for foreign firms, and all local industries had positive input growth. D10 for foreign firms had highest output and input growth, attaining 60.09 and 177.95 respectively, however D4 was the only industry that had a negative output growth (−4.10 %). On average output and input grew at 14.38 and 24.63 % for foreign firms and at 9.73 and 46.25 % for local firms. In period 2008–2009, many industries declined into negative values of output and input growth. The output growth rate ranged from −49.39 to 17.55 %, while the input growth rate ranged from −114.84 to 40.11 %. On average for both foreign and local industry had negative output and input growth. For foreign establishments, the average output and input growth was −1.33 and −53.29 % and for local firms was −5.17 and −9.01 %.

In Table 10 in the first and second periods of observation, most of the TFP of domestic industries grow positively. On the contrary, in the third periodof study all foreign industries have negative TFP growth, except for D10. In period 2004–2005, on average TFP of foreign firms did not grow (0.00 %) and domestic firms grew negatively (−0.01 %). And in the period 2006–2007, on average the TFP growth of domestic firms show a higher value than the foreign firms. The TFP growth for domestic firms increased to 1.43 % but for foreign firms decreased into a negative value (−0.12 %). In the period 2008–2009, the TFP growth of most manufacturing industries deteriorated into negative values, on average the TFP growth of domestic firms decreased to −1.21 % and for foreign companies sharply declined to −9.08 %. Moreover, on average TFP growth of domestic firms was still greater than foreign firms. It can be

Table 10 The average of total factor productivity growth (TFPg) and its components

Industry classification		Year 2004–2005				Year 2006–2007				Year 2008–2009			
		TC	TEC	SEC	TFPg	TC	TEC	SEC	TFPg	TC	TEC	SEC	TFPg
Foreign firms	D1	0.34	−7.73	0.03	−7.36	−0.15	−10.11	0.04	−10.23	−0.52	−4.40	0.04	−4.88
	D2	0.55	3.85	−0.03	4.37	0.15	−0.51	0.07	−0.29	−0.36	−6.85	0.00	−7.20
	D3	0.68	−9.48	0.03	−8.79	0.30	−3.61	0.03	−3.28	−0.22	−20.29	0.04	−20.46
	D4	0.45	0.96	0.01	1.42	0.17	3.37	0.01	3.55	−0.47	−6.53	−0.03	−7.02
	D5	0.12	−13.27	−0.01	−13.16	−0.02	2.83	0.06	2.88	−0.64	−11.70	0.02	−12.32
	D6	0.06	1.58	0.01	1.64	−0.41	−2.15	0.02	−2.53	−0.97	−7.53	0.04	−8.47
	D7	0.26	−2.34	0.01	−2.06	−0.09	1.94	−0.01	1.84	−0.66	−4.48	0.04	−5.10
	D8	0.39	21.93	0.05	22.37	0.12	−5.17	0.01	−5.04	−0.45	−5.97	−0.08	−6.50
	D9	0.30	0.23	0.00	0.53	−0.07	5.02	0.06	5.02	−0.61	−13.81	0.00	−14.42
	D10	0.40	75.03	−0.06	75.36	−0.19	−105.01	0.20	−105.00	−0.67	31.44	−0.22	30.51
	D11	0.15	−1.44	−0.02	−1.30	−0.08	6.96	0.06	6.93	−0.67	−6.50	0.01	−7.17
	D12	–	–	–	–	–	–	–	–	–	–	–	–
All foreign firms	0.33	0.62	0.00	0.95	−0.04	−0.12	0.04	−0.12	−0.57	−8.25	0.01	−9.08	
Domestic firms	D1	0.34	0.49	−0.01	0.82	−0.23	1.01	0.01	0.79	−0.71	−0.41	−0.01	−1.12
	D2	0.39	0.19	−0.01	0.57	−0.17	1.67	0.01	1.51	−0.67	−0.21	−0.01	−0.88
	D3	0.32	1.08	0.00	1.40	−0.16	3.43	0.00	3.26	−0.70	1.62	−0.01	0.91
	D4	0.39	−0.35	0.00	0.05	−0.07	0.34	0.01	0.28	−0.63	0.01	−0.03	−0.65
	D5	0.20	2.58	−0.05	2.74	−0.26	1.98	0.02	1.73	−0.84	0.78	0.01	−0.05
	D6	0.17	1.43	−0.04	1.56	−0.29	6.74	0.01	6.47	−0.86	−1.64	−0.02	−2.51
	D7	0.28	0.87	−0.02	1.13	−0.20	0.55	0.02	0.37	−0.78	−0.71	0.01	−1.49
	D8	0.40	1.05	0.01	1.46	−0.14	0.74	−0.01	0.59	−0.64	0.06	−0.01	−0.59
	D9	0.26	1.69	−0.01	1.94	−0.22	1.98	−0.01	1.75	−0.80	−2.41	−0.01	−3.21
	D10	0.28	−15.16	0.01	−14.87	−0.11	24.46	0.01	24.36	−0.79	−12.60	−0.02	−13.41
	D11	0.22	−2.14	0.01	−1.92	−0.20	1.98	−0.01	1.77	−0.83	1.80	0.00	0.97
	D12	0.25	−0.25	−0.09	−0.09	−0.21	−0.54	0.01	−0.75	−0.83	−4.95	−0.02	−5.82
All domestic firms		0.32	0.63	−0.01	0.94	−0.19	1.62	0.01	1.43	−0.73	−0.48	−0.01	−1.21

Note TEC, TC, SEC, TFPg are arithmetic average of annual rate in percentage

said that over the period of the study, even though from the result of a non-parametric test of the closeness of two distributions both input and TFP growth significantly influence the changes in output grow th, the contribution of TFP growth to the output growth rate seems to be lower than input growth.

Looking at each of the component of TFP growth, in the period 2004–2005, the average TEC of foreign and local firms was almost similar, slightly more than 0.6 %. The average SEC shows that foreign establishments did not change much during that period, while the domestic firm had a negative magnitude (−0.01 %). The average TC for both foreign and local firms was around 0.3 % and for all industries indicate had positive small change in TC. This indicates that all industries experience technological progress. In the period 2006–2007, the average value of TEC for multinational firms decreased into a negative value (−0.12 %), but for local firms still had a positive value (1.62 %). The averages SEC for both foreign and local firms slightly increased to 0.04 and 0.01 % respectively. However, the averages TC for both foreign and local firms had negative magnitudes (−0.04 and −0.19 %) and all domestic industries seem to have technological regress. The negative magnitude of average TEC for multinational companies still emerged over the last period of the study, even larger reaching −8.52 %. For domestic companies, the average TEC also turns to a negative value (−0.48 %). The average SEC for foreign firms increased to 0.01 %, while domestic establishments turned to a negative value (−0.01 %). Furthermore, the negative magnitudes of TC do not only appear on all local industries but also on all foreign affiliates. This reveals that all manufacturing industries experience technological regress. The average TC for foreign firms was −0.57 % and for local firms was −0.73 %.

The result through investigating TC in Table 10 shows that since the second period of observation, technological regress seems to appear in all indigenous industries. And in the last period of the study, all foreign industries also experience technological regress. One reason why there is technological regress is most of manufacturing firms in Indonesia use old machine for their production processes and unfortunately they do not upgrade their machinery regularly. Cost to handle their old machines are cheaper than if they have to buy or import the new ones and with this condition operating their production are still profitable.

Another reason to understanding this technological regress is to recognize how the process of knowledge is transmitted to the next generation in developed and developing countries. Technological knowledge in a modern world is conceived as a stock which may stagnate but never shrinks. And, it is also characterized by a lot of R&D activities. Giving incentives to invest in the R&D will affect the technological knowledge. Hence, old techniques are always rediscovered and new techniques are also invented in a developed country. However, it seems to be different in a developing country such as Indonesia which commonly has little domestic sources of new technology and few group undertake little R&D. The technological knowledge in this economy mostly embodies in human beings and dynamically transmitted across generations in order to be preserved in society. When there is an imperfect transfer of knowledge to next generation, it will stimulate the neglect of techniques which rendered are temporarily unbeneficial. Then, these techniques could not be transmitted to next generations and would be lost. This seems reasonable to assert that the knowledge lost outweighed the knowledge gained, so the average technological stock declined over period. The stock of technology would not instantly return to its former size. Therefore, this opens an opportunity of technological regress.

Furthermore, investments in R&D activities in Indonesian have always been very small. According to the Word Development Indicators, since 2000 to 2014, total R&D expenditure to GDP has never exceeded 0.1 percent. Most of R&D activities have been done by a major government agency; Indonesian Institute of Sciences (LIPI). Local firms have never conducted any significant commitment to invest in R&D activities. Moreover, MNCs do not regard that the country is suitable to do R&D activities, because of the limited protection of intellectual property rights and the absence of any significant public support for R&D activities. To avoid further technological regress, the Indonesian government has to prioritize by choosing which economic policy is to strengthen technological progress. In the short run, the government can provide a soft credit for enterprises that purchase new machinery, regularly facilitate machinery upgrading by replacing old machinery with newer machinery that would be more productive or give import duty exemption for the import of capital goods. In the long run, the government should increase the ratio of R&D expenditure to GDP, provide intellectual property rights and public support for R&D activities.

6 Conclusion

This paper examines the FDI variables in Indonesian manufacturing, using firm level panel data over the period 2003–2009 and investigates the most important component of total factor productivity growth in explaining output growth. The empirical results demonstrate that foreign firms achieve higher productivity but less efficient than domestic firms. The higher degree of foreign ownership leads to increase firms' efficiency but decrease firms' productivity. There may be a market stealing effect which causes multinational firms to force local firms to cut their production.

The positive horizontal spillover effects on the firms' productivity and efficiency indicate that intra-industry spillovers effects from FDI are present in the Indonesian manufacturing sectors. The backward spillovers have positive impact on firm's efficiency, while the forward spillovers have positive impact on the firm's productivity. However, there is negative backward spillover effects on the firms' productivity and negative forward spillover effects on the firms' efficiency. Hence, it can be said that the inter-industry spillover do not totally improve firms' productivity performance in the upstream and downstream industry.

The policy implications of these results might not support totally for policies promoting FDI in Indonesian manufacturing industry. Policy makers should consider whether the incoming MNCs benefits local firms. In this circumstance where there is potential loss and gains from the FDI spillovers, policy makers should at least ensure that the negative FDI spillovers on domestic firms do not outweigh the overall benefits of the FDI. In contrast, when there are potential benefits from multinational companies for domestic firms, policy makers should offer incentives to encourage FDI.

More skilled labour in the work place increases firms' productivity but decrease firmrs' efficiency. The technology spillover from FDI in the intra-industry market is smaller with higher level of labour quality. In the inter-industry market, the degree of absorptive capacity of suppliers has a negative impact on firms' productivity but have a positive impact on reducing inefficiency. On the other hand, the degree of absorptive capacity of buyers has a positive impact on firms' productivity but have a negative impact on reducing inefficiency.

The results from examining the remaining regressors show that greater import and export activities are associated with greater effect on increasing productivity, but lead to bigger inefficiency. The higher concentration of the firm increases firms' productivity but decreases the technical efficiency of firms. The bigger firms are likely to possess modern technology and capital equipment compared to smaller firms due to technology diffusion. However, the positive coefficient of controlling variable in the inefficiency function indicates that bigger firms do not have higher efficiency.

The finding of hypotheses tests of output growth distributions conclude that both input and TFP growth significantly contribute for explaining in output growth variations. And, all components of productivity; TEC, TC and SEC have a significant role in explaining TFP growth for our sample of all manufacturing firms. When look at the each component of TC, this study finds that technological regress seems to take place in all indigenous industries since the second period of the study and in all foreign industries in the last period of the study. This finding suggests a policy for strengthening the technological progress through investing capital formation. Indonesian government can provide soft loans for manufacturing firms that acquire new machinery, periodically assist to upgrade their machinery to be more productive or offer import duty exemption for the import of capital goods, increase the proportion of R&D expenditure to GDP, provide intellectual property rights and public facility for R&D activity.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Appendix

See Tables 11 and 12.
See Figs. 3a–h.

Table 11 The industrial manufacturing classification

Classification	Types of industries
*D*1	Food industry
*D*2	Textile industry
*D*3	Leather goods and Footwear industry
*D*4	Wood industry
*D*5	Paper and printing industry
*D*6	Chemical and pharmaceutical industry
*D*7	Rubber and plastic industry
*D*8	Non metallic mineral industry
*D*9	Metal, machinery and electronic industry
*D*10	Medical precision and Optical instruments, watches and clock industry
*D*11	Motor vehicles and other transport equipment industry
*D*12	Other industry

Table 12 The estimated coefficient of inputs on production functions

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Const	−0.140*	−0.129*	−0.139*	−0.108*	−0.114*	−0.113*
	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)
k	0.008*	0.008*	0.008*	0.008*	0.007*	0.008*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
l	0.252*	0.247*	0.247*	0.229*	0.230*	0.229*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
m	0.725*	0.721*	0.720*	0.745*	0.744*	0.745*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
e	0.023*	0.020*	0.020*	0.017*	0.017*	0.017*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
k^2	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
l^2	0.073*	0.071*	0.071*	0.059*	0.060*	0.060*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
m^2	0.107*	0.107*	0.107*	0.095*	0.096*	0.096*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
e^2	0.007*	0.007*	0.007*	0.006*	0.006*	0.006*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
kl	0.004*	0.004*	0.004*	0.002*	0.002*	0.003*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
km	−0.007*	−0.006*	−0.006*	−0.004*	−0.004*	−0.005*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ke	0.002*	0.002*	0.002*	0.002*	0.002*	0.002*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lm	−0.083*	−0.081*	−0.081*	−0.070*	−0.071*	−0.071*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
le	0.014*	0.013*	0.013*	0.010*	0.011*	0.010*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
me	−0.023*	−0.022*	−0.021*	−0.019*	−0.019*	−0.019*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
t	−0.003*	−0.002*		−0.002*	−0.002*	−0.002*
	(0.000)	(0.000)		(0.000)	(0.000)	(0.000)
t^2	−0.002*	−0.002*		−0.003*	−0.003*	−0.003*
	(0.000)	(0.001)		(0.000)	(0.000)	(0.000)
kt				−0.002*		−0.002*
				(0.000)		(0.000)
lt				0.003*		0.003*
				(0.000)		(0.000)
mt				−0.001**		−0.001**
				(0.000)		(0.000)
et				0.000		0.000
				(0.000)		(0.000)
*D*2	0.016*	0.023*	0.026*	0.020*	0.019*	0.019*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
*D*3	−0.016*	−0.019*	−0.018*	−0.011**	−0.013*	−0.012**
	(0.005)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
*D*4	−0.015*	−0.017*	−0.017*	−0.018*	−0.017*	−0.017*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)

Table 12 continued

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
*D*5	0.046*	0.056*	0.054*	0.047*	0.047*	0.047*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
*D*6	0.070*	0.071*	0.071*	0.066*	0.065*	0.065*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
*D*7	−0.013*	−0.009**	−0.007***	−0.010*	−0.010*	−0.010*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
*D*8	−0.032*	−0.047*	−0.047*	−0.029*	−0.031*	−0.030*
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
*D*9	0.023*	0.017*	0.019*	0.024*	0.024*	0.024*
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
*D*10	−0.066*	−0.089*	−0.088*	−0.051*	−0.056*	−0.055*
	(0.017)	(0.019)	(0.017)	(0.016)	(0.015)	(0.016)
*D*11	0.104*	0.108*	0.109*	0.099*	0.101*	0.100*
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
*D*12	−0.011	−0.012	−0.013	−0.015	−0.017	−0.016
	(0.011)	(0.012	(0.012)	(0.011)	(0.011)	(0.011)
Number of observations	146,368	146,368	146,368	141,009	141,009	141,009

Standard errors are in parentheses

* denotes significance at 1 %, ** denotes significance at 5 %, *** denotes significance at 10 %

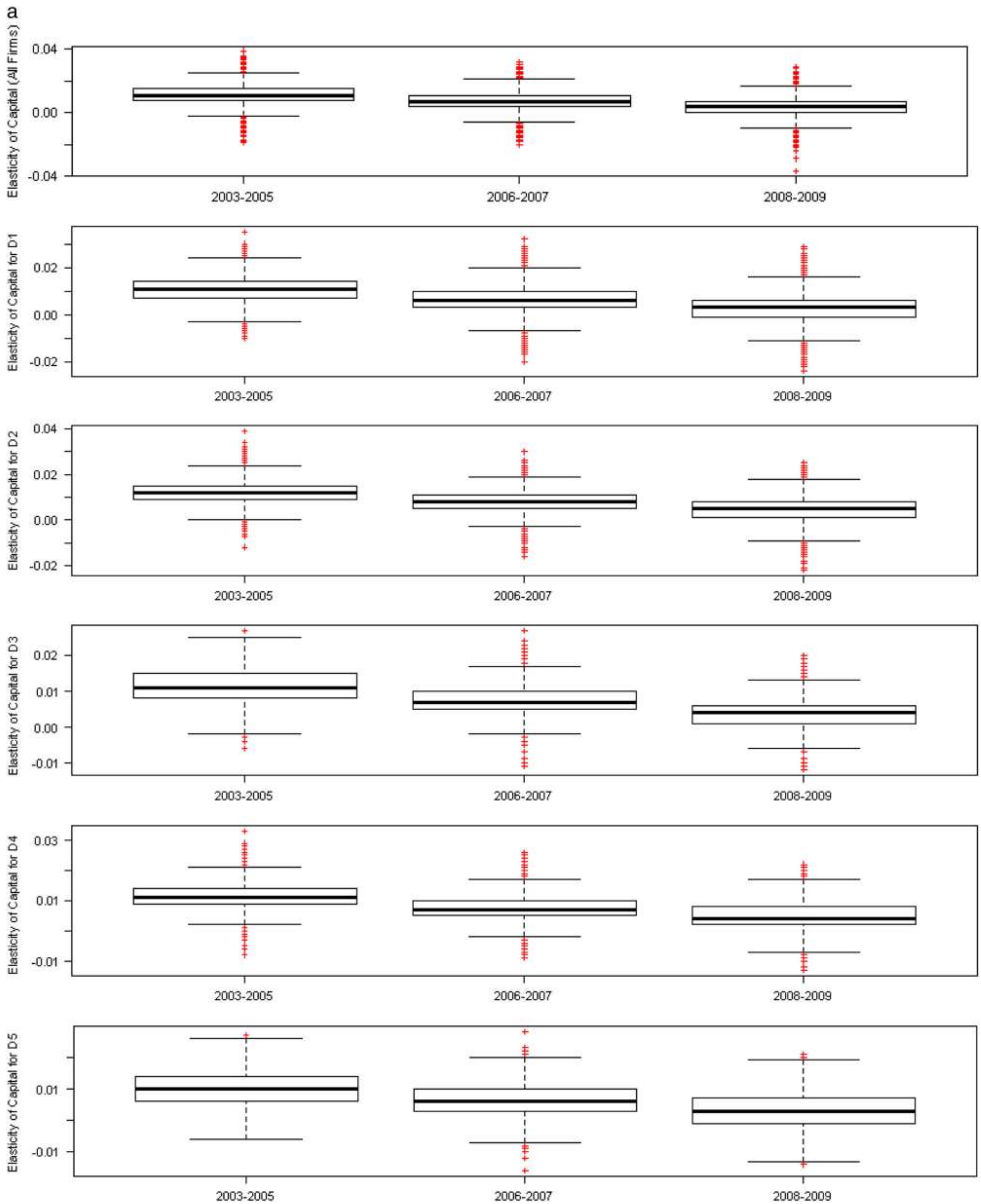
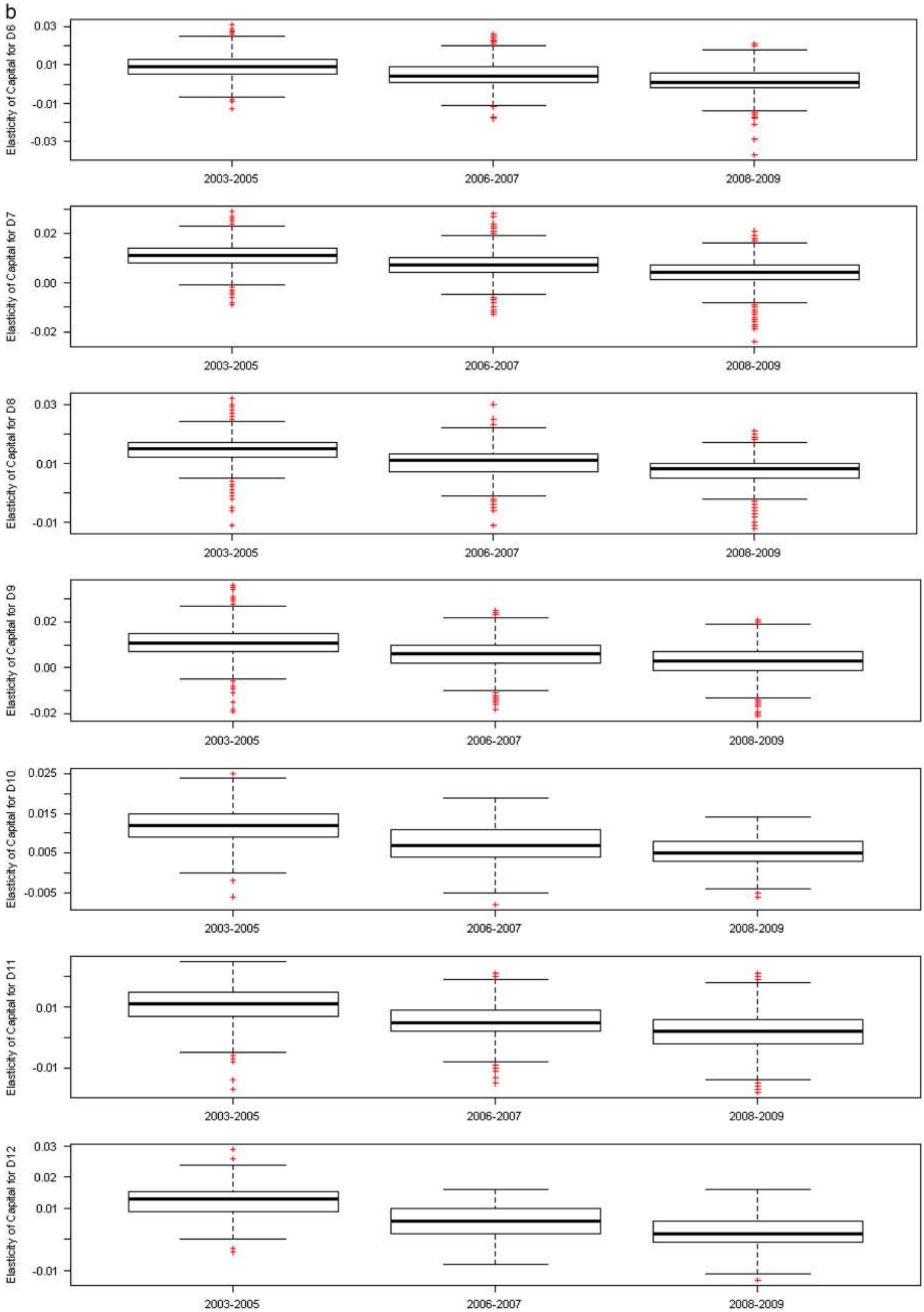


Fig. 3 **a** Output elasticity of capital for all firms and D1–D5. **b** Output elasticity of capital for D6–D12. **c** Output elasticity of labour for all firms and D1–D5. **d** Output elasticity of labour for D6–D12. **e** Output elasticity of material for all firms and D1–D5. **f** Output elasticity of material for D6 to D12. **g** Output elasticity of energy for all firms and D1 to D5. **h** Output elasticity of energy for D6 to D12. The *box* indicates the 75, 50 and 25 percentiles, and the *two whiskers* describe the minimum and maximum values



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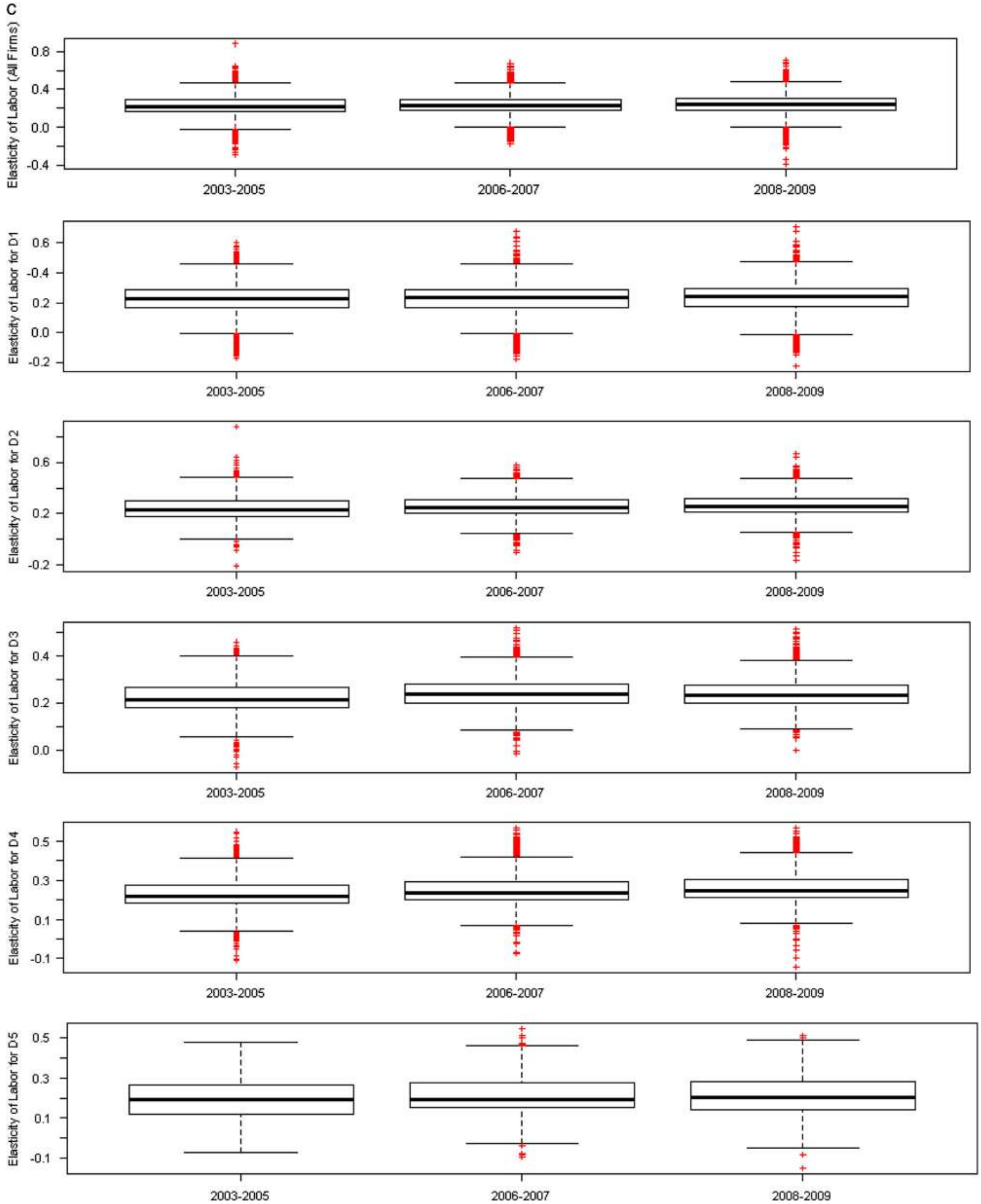

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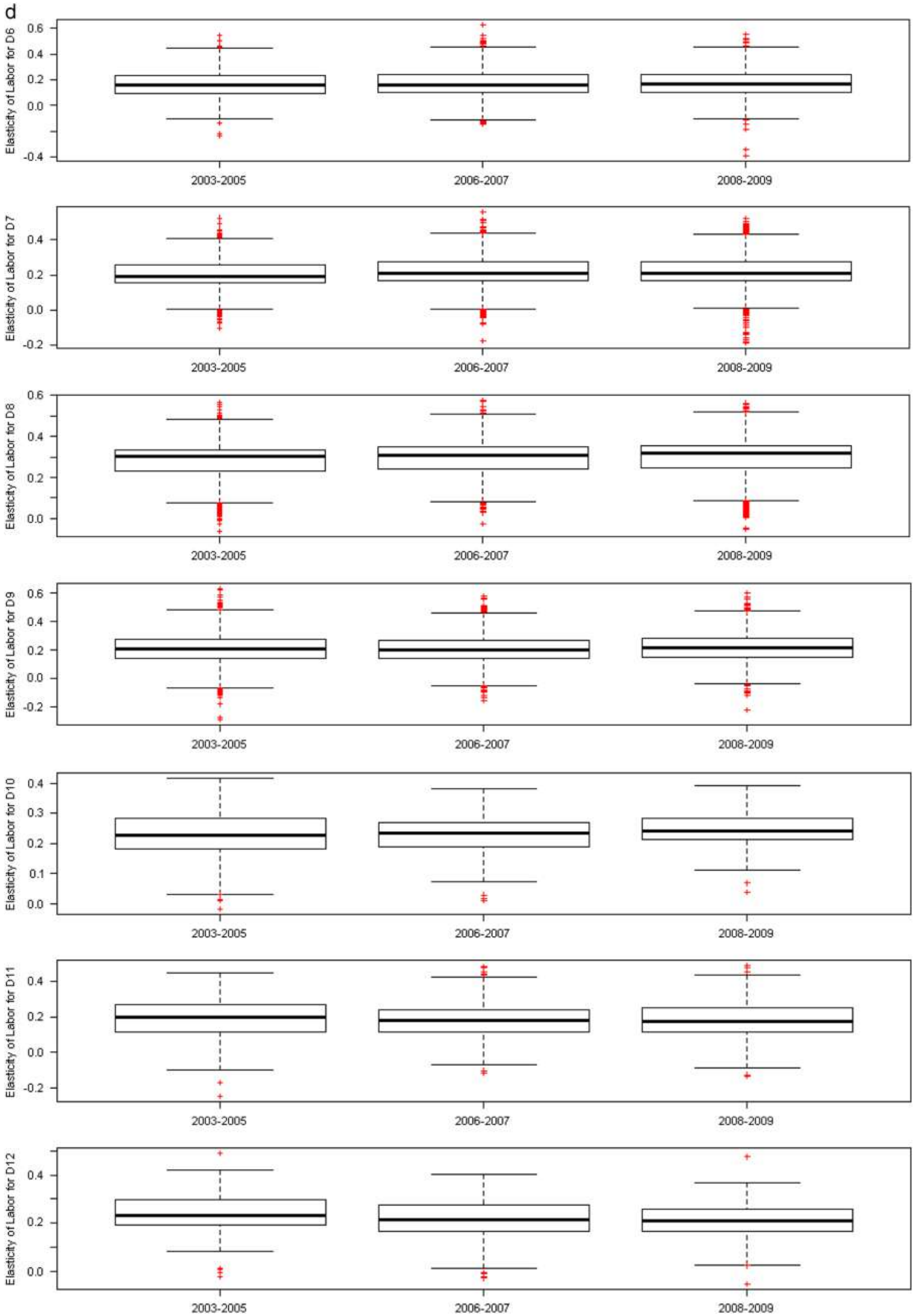

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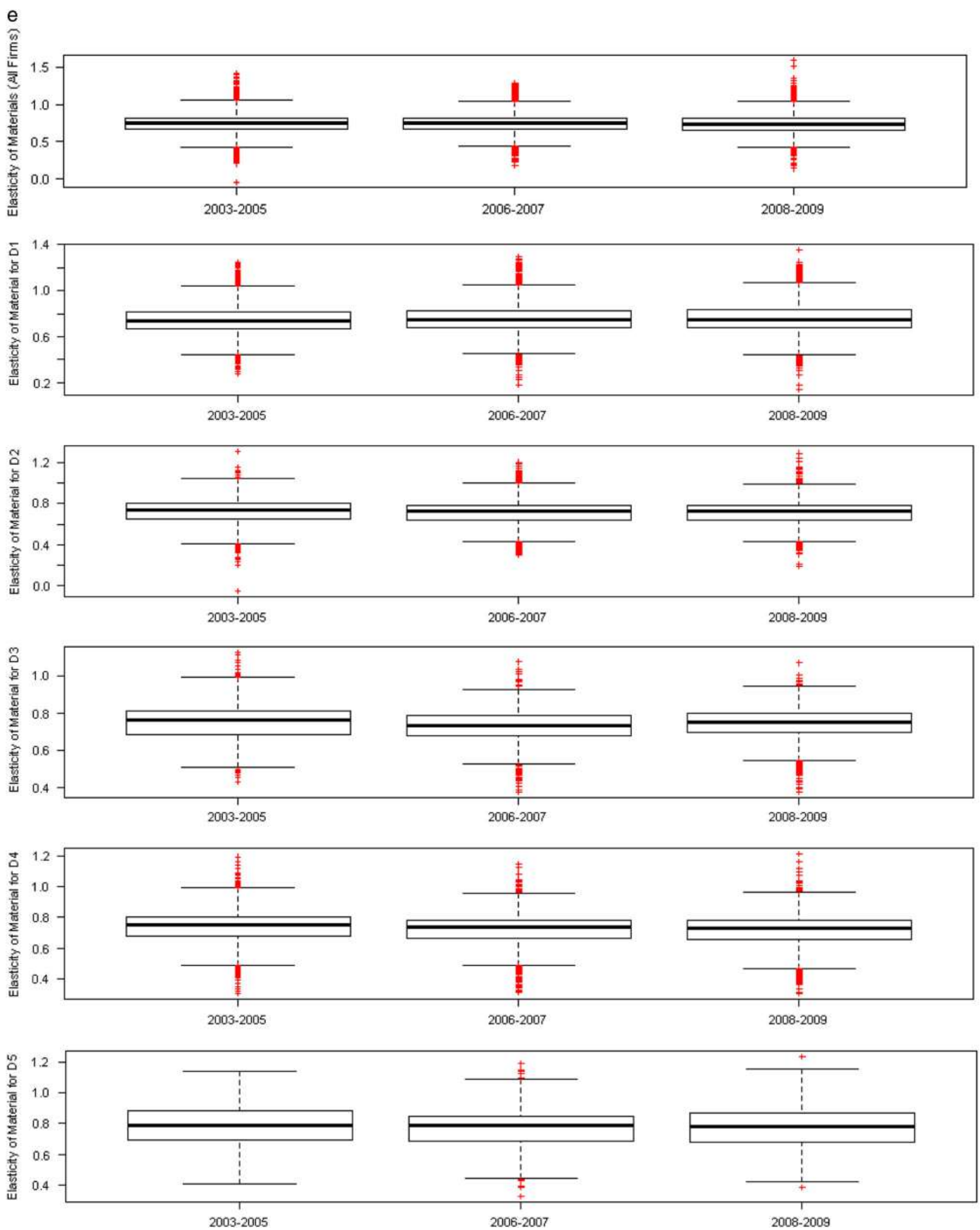

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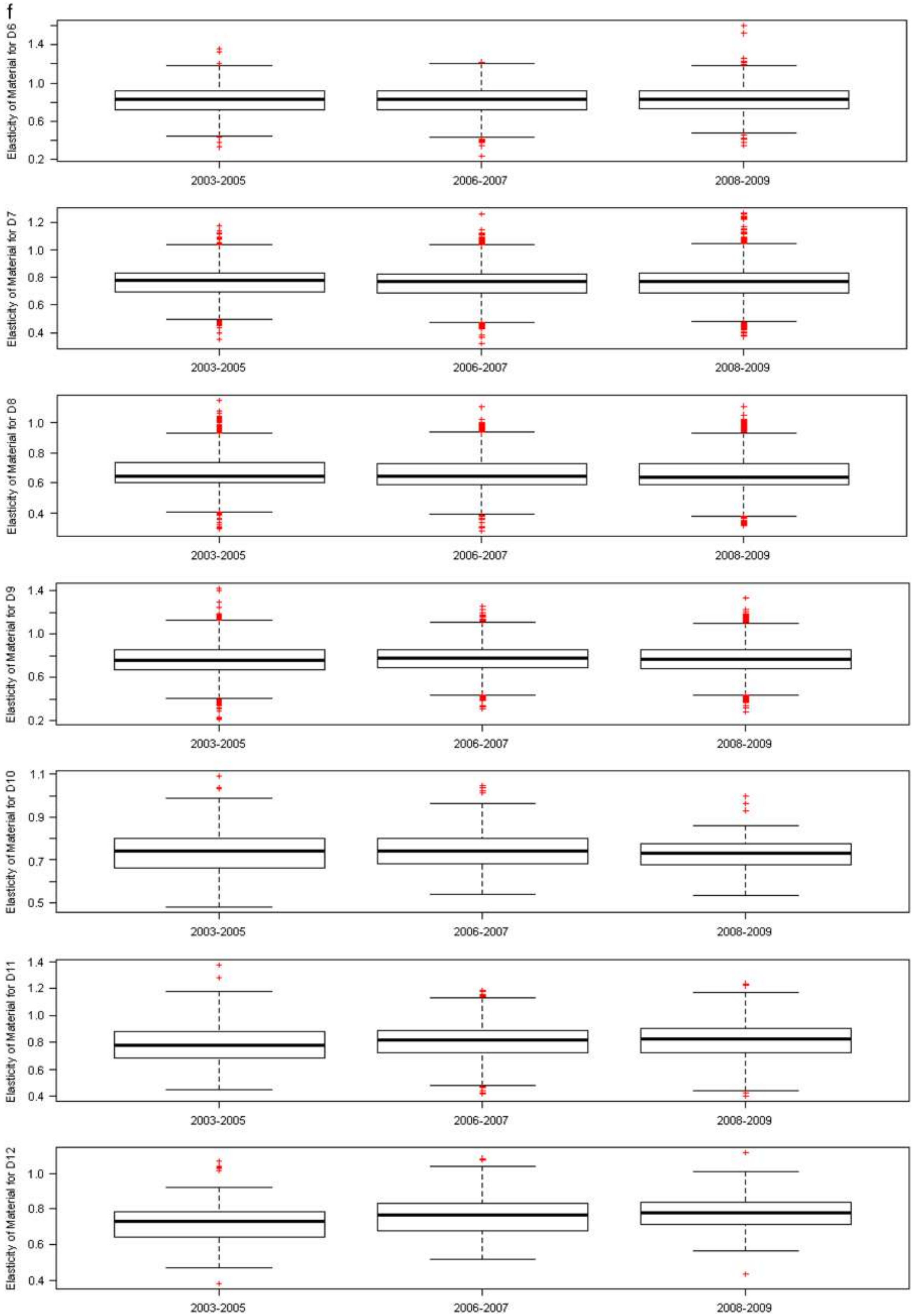

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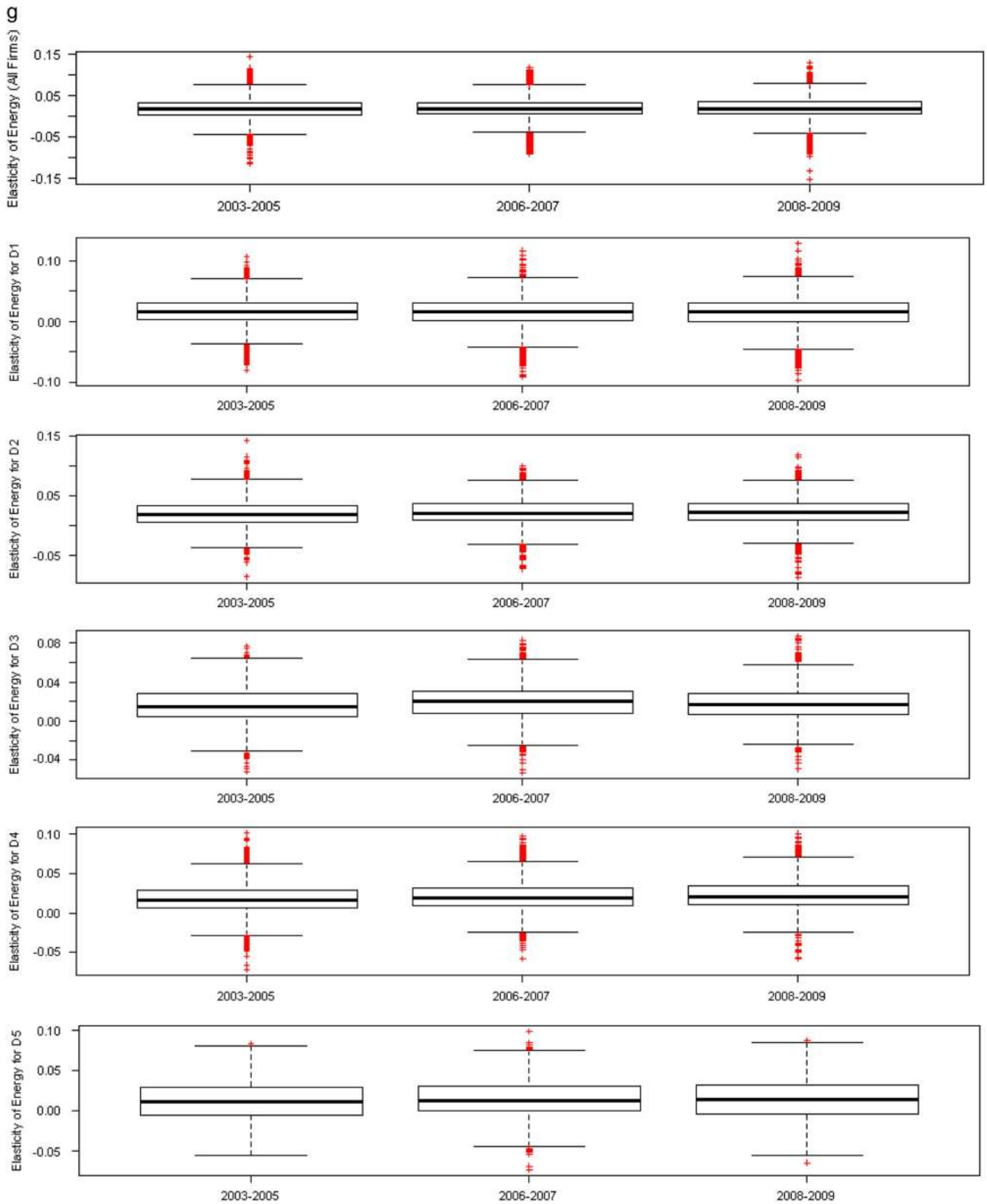

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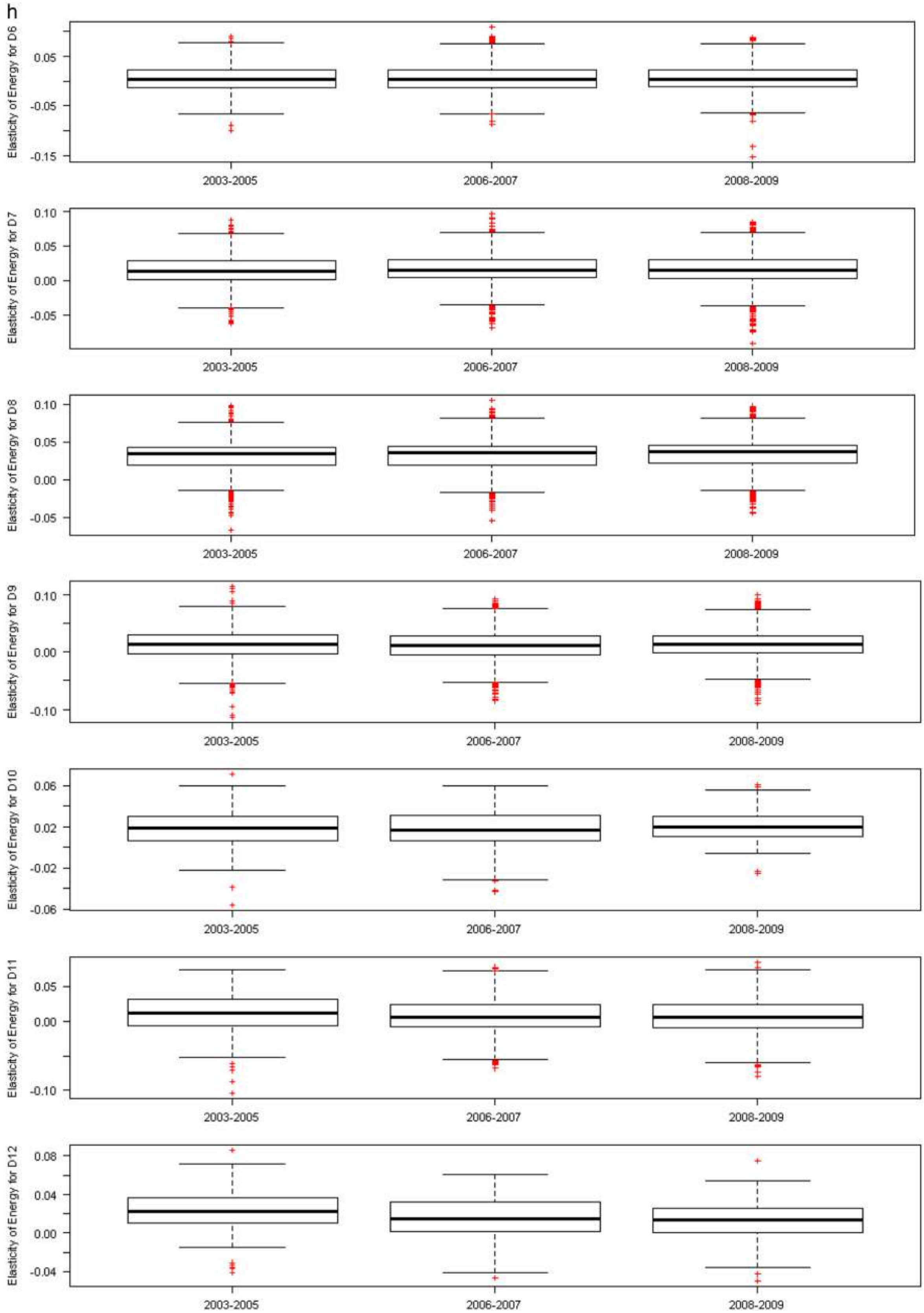

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